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# EXTRACTION, PROPERTIES AND USES OF ESSENTIAL OILS IN THE FOOD INDUSTRY: A REVIEW

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**Abstract:** Essential oils or volatile oils are a mixture of substances of variable composition that give the characteristic aroma to different plant tissues. The composition of the oils can vary greatly depending on the extraction methods used to obtain them. In this review we will discuss in more detail distillation methods, cold expression, extraction with solvents, supercritical fluids and microwave-assisted extraction. In turn, they have a variety of uses to give flavor to foods and beverages. They stand out for their antioxidant and antimicrobial functional properties, which has increased the interest of researchers in studying their functional properties and the potential uses of essential oils in terms of food preservation, whose composition has shown to have inhibitory effects on the development of pathogenic microorganisms, however, their use as food preservatives requires a case-by-case analysis in relation to the food matrix, the type and dose of essential oil, in such a way that the preservative capacity is compatible without negatively affecting the organoleptic characteristics of the product.

**Keywords:** essential oils, extraction, food industry, antioxidant, antimicrobial.

## INTRODUCTION

Safer food saves lives. With every mouthful eaten, one is potentially exposed to diseases of microbiological origin or chemical contamination, so billions of people are at risk, and millions become ill each year; many die as a result of consuming unsafe food (WHO, 2015).

The microbial safety of food is a significant concern for consumers, regulatory agencies, and the food industry. At the same time, there is a growing trend among Western consumers to prefer products with a 'green' image, i.e., fewer synthetic additives, more natural foods, and foods with a lower environmental impact (Sendra, 2016; Tuley de Silva, 1996). Thus, among the alternatives, essential oils are considered one of the most effective methods to prevent food spoilage due to their solid and natural antibacterial properties. The literature has reported that more than 1340 plants contain specific antimicrobial compounds, and more than 30,000 phenolic compounds were isolated from volatile oils for use in the food industry (Wu et al., 2019).

Humans have been extracting essential oils from aromatic plants since the dawn of humanity, and their applications include diverse purposes, not only their use in cooking to enhance the flavor and health benefits of food but also their application in the manufacture of perfumes, cosmetics, and medicines. In fact, throughout history, numerous civilizations have used essential oils and fragrances for various purposes, including for religious ceremonies, in producing perfumes, or as therapeutic agents against infectious diseases.

The ancient Egyptians used essential oils in medicine and perfumery to use in mummification techniques. The Phoenicians, Jews, Greeks, Romans, and other cultures around the Mediterranean basin also used these aromatic substances. At the same time, the Mayans and Aztecs in the Americas possessed a culture of highly refined fragrances.

In ancient Asia, the Vedas codified the use of aromas and perfumes for both liturgy and therapeutic purposes (Sonwa, 2000). While the Chinese, from 2000 BC, used incense in their burials and religious ceremonies, they perfected the art of stick incense known as sticks and considered that fragrances could have medicinal use (Flores, 2010).

After the fall of the Roman Empire and with the rise of the Christian and Muslim civilizations, the art and science of fragrances was taken to the Arab world, where it reached a high level of sophistication through stills. In the Middle Ages, this knowledge of fragrances

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was brought back to Europe by the Crusaders returning from the Holy Land and was further developed by alchemists and monasteries. The alchemists sought to create the 'elixir of life' to live indefinitely. At the same time, the monasteries used essential oils to obtain various medicines to cure different diseases or to make aromatic derivatives such as soap and perfume. During the Renaissance, essential oils in perfumery and cosmetics spread worldwide (Sonwa, 2000).

The term 'essential oil' is believed to have been derived from 'Quinta esencia,' the name coined in the 16th century by Paracelsus von Hohenheim for the practical component of a drug (Burt, 2004). These volatile oils, essential oils, or simply essences, are the natural aromatic substances responsible for plant fragrances, which are synthesized and secreted by specific specialized histological structures, often located on or near the plant's surface. They may also be deposited in specific tissues, e.g., in the pericarp of citrus fruits, in the petals of roses, and in the bark, stems, and leaves of cinnamon (Lopez, 2004). They are usually complex mixtures of up to more than 100 components that can be low molecular weight aliphatic compounds (alkanes, alcohols, aldehydes, ketones, esters, and acids), monoterpenes, sesquiterpenes and phenylpropanes (Martinez, 2003).

Aromatic plants have been used to improve the flavor of different foods. In addition, the use of these plants and spices in phytotherapy is mainly related to the different functional properties of their essential oils, such as antimicrobial, spasmolytic, carminative, hepatoprotective, antiviral, anticancer, insecticidal, and antioxidant properties. In particular, the antimicrobial and antioxidant activity has formed the basis for many applications, including preserving processed foods, pharmaceuticals, medicine, and food additives.

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On the other hand, there is a wealth of scientific literature on essential oils' antioxidant and antimicrobial properties in vitro. Recent developments in the use of essential oils in food point to the interaction between these substances and food matrices; some examples are the development of edible films with essential oils, encapsulation of the oils, and their incorporation in active packaging (Sendra, 2016).

The objectives of this work were to update knowledge regarding essential oils and their applications in the food industry. Additionally, to describe the composition of essential oils used in the industry, gather information on technologies for the extraction of essential oils, and review the potential use as a functional ingredient in food preservation.

## ESSENTIAL OILS

Essential oils are the volatile liquid fractions, generally distillable by steam distillation. These volatile substances are responsible for the characteristic aroma of plants, are formed in the cytoplasm and are usually present in the form of tiny droplets between the cells. From a chemical point of view, essential oils are mixtures of fragrant substances or mixtures of fragrant and odorless substances. In general, these oils accumulate in modified epidermal cells, although depending on the family or genus, they can also accumulate in other structures such as stems, roots, flowers and fruits. In turn, they are known as volatile oils as opposed to vegetable, animal and mineral oils. Indeed, a drop of essential oil on a cloth or paper evaporates in a few minutes or days, depending on the temperature, which is not the case with fatty oils (Sonwa, 2000; Martínez, 2003; Flores, 2010).

The International Organization for Standardization (ISO) has defined essential oils as "a product obtained from a natural raw material of vegetable origin, by steam distillation, by mechanical processes of the epicarp of citrus fruits, or by dry distillation, after separation of the aqueous phase, if any, by physical processes without affecting the quality of the product, such as filtration, decantation or centrifugation".

## GENERAL CHARACTERISTICS

Essential oils, in general, constitute 0.1 to 1% of the dry weight of the plant. As defined above, essential oils are complex mixtures, generally made up of numerous constituents, usually liquids, but sometimes solids. They are poorly soluble in water, soluble in alcohols and organic solvents including ethanol and diethyl ether, and mix well with vegetable oils, fats and waxes because of their lipophilic character. In addition, most essential oils have a density lower than that of water, except for some oils such as bitter almond, mustard, cinnamon, parsley or clove.

When fresh, at room temperature, they are colorless to slightly yellowish with an aromatic odor, very clean to the touch and easily absorbed by the skin. They are sensitive to oxidation and therefore resinify taking a dark yellowish color, this phenomenon is prevented by storing them in dark jars completely filled and sealed, to protect them from light and oxygen in the air (López, 2004; Ortuño, 2006; Ríos, 2016).

On the other hand, according to the U.S. Food and Drug Administration (FDA), there is a wide range of plants whose essential oils, oleoresins (without solvents) and natural extracts (including distillates) are generally recognized as safe for use.

## CHEMICAL COMPOSITION OF ESSENTIAL OILS

Plants produce a wide variety of organic compounds from secondary metabolism. These substances have no role in primary processes such as photosynthesis, respiration, nutrient assimilation, differentiation, or the formation of carbohydrates, proteins and lipids. They are characterized by a restricted distribution in the plant kingdom (Taiz and Zeiger, 2002).

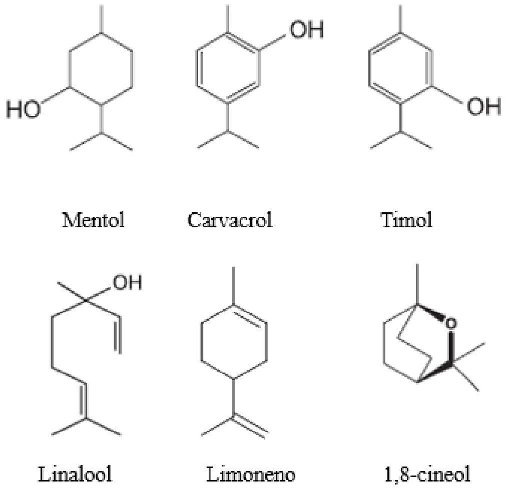
Secondary plant metabolites (including oleoresins and essential oils) can be divided according to chemical structure into three groups: terpenes or terpenoids, phenols and their derivatives and nitrogenous compounds or alkaloids, whose formation and concentration, accumulated in the cells of the different plant tissues is variable, depending on multiple factors; among them, the functionality of these compounds for the plant, the edaphoclimatic conditions in which the crop was developed and the genetic characteristics of the species or variety (Bruneton, 2001; Taiz and Zeiger, 2002; Hussain et al., 2008).

As mentioned above, essential oils are complex mixtures of volatile substances whose composition involves a proportion of hydrocarbons of the polymethylene series of the terpenes group that respond to the formula $(C_5H_8)_n$ along with other compounds, almost always oxygenated, including alcohols, esters, ethers, aldehydes and phenolic compounds (Flores, 2010).

Considering an essential oil as a product with a characteristic aroma, when classifying its composition based on this property, it is possible to state that there are majority components usually responsible for the overall aroma, while other minority components in concentration have the characteristic of "rounding" the aroma or aromatic profile (Ortuño, 2006). Thus, some oils are almost monomolecular, since they possess almost exclusively a single component, others are rich in 2-3 molecules. But most are polymolecular, since they contain 3-4 majority molecules, a certain number of minority molecules and, sometimes, hundreds of different molecules that are present only in traces (López, 2004).

The components of essential oils generally belong, almost exclusively, to two groups characterized by distinct biogenetic origins: the terpenoid group on the one hand and, to a lesser extent, the group of aromatic compounds derived from phenylpropane. In essential oils, terpenic compounds are made up of isoprene units (5 carbons), which can be monoterpenes (10 carbons) and sesquiterpenes (15 carbons). These monoterpenes and sesquiterpenes can be acyclic, monocyclic and bicyclic, as well as oxygenated and non-oxygenated (Fig. 1) (Bruneton, 2001).

Examples of essential oils whose majority components correspond to the monoterpenes group are peppermint oil (*Mentha piperita* L.) with menthol; lemon (*Citrus limon* L.) with limonene; coriander (*Coriandrum sativum* L.) and basil (*Ocimum basilicum* L.) with linalool; in the case of thyme (*Thymus vulgaris L.*) and oregano (*Origanum vulgare* L.) both with carvacrol and thymol, which have different proportions of carvacrol and thymol.) with linalool; in the case of thyme (*Thymus vulgaris* L.) and oregano (*Origanum vulgare* L.) both with carvacrol and thymol which, in different proportions and together with other minority components, produce the differences in sensory perception between these species (Bozin *et al.*,2006Belitz *et al.*, 2009).

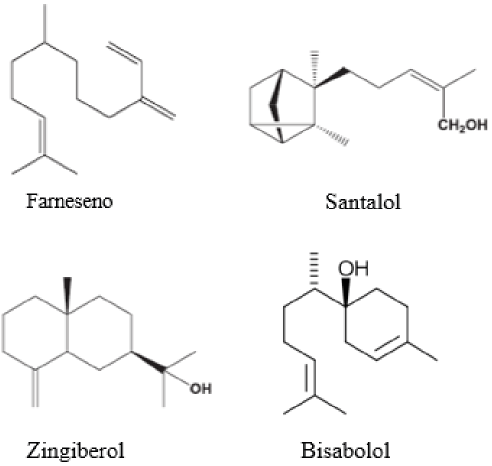


Mentol Carvacrol Timol

Linalool Limoneno 1,8-cineol

Figure 1: Examples of aliphatic, mono- and bicyclic, oxygenated and non-oxygenated monoterpenes (Own elaboration).

There are also sesquiterpene-rich oils including sandalwood (*Santalum album*) with santalol, German chamomile (*Matricaria recutita*) with bisabolol and ginger (*Zingiber officinale*) with zingiberol (Fig.2) (Rios, 2016).



Farneseno Santalol

Zingiberol Bisabolol

Figure 2: Examples of aliphatic, mono- and bicyclic, oxygenated and non-oxygenated sesquiterpenes (Own elaboration).

Aromatic compounds derived from phenylpropane are much less frequent than terpenoids. They are generally allyl- and propenyl-phenols, aldehydes, some characteristic of essential oils of the Apiaceae family, anise and fennel with anethole, anisaldehyde; parsley and celery with apiol, methyl-chavicol (=stragol) among others; they are also found in cloves, nutmeg, basil, cinnamon (eugenol, safrole, asaronas, cinnamaldehyde) (Fig.3) (Flores, 2010).

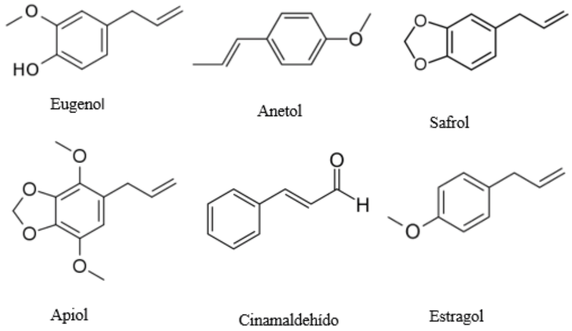


Figure 3: Examples of phenylpropane-derived compounds (Own elaboration).

Other volatile compounds may also be present in essential oils. In the special case of those obtained by processes other than distillation, solvent extraction or pressing, non-volatile compounds may be present. In many cases, these are precursors of known derivatives, such as sesquiterpene lactones or glycosides, which in some cases are hydrolyzed or transformed into volatile compounds during the distillation process, while others may also be present in their original form in the extract.

Other compounds that can be found in essential oils include coumarins which, although present in small amounts can be detected in some relevant aromatic plants or species, such as lavender and lavandin (*Lavandula* spp.) which can contain up to 0.3% coumarin (Ríos, 2016). Most coumarins are found in fruits and vegetables of the Rutaceae and Umbelliferae families and include celery, carrots and parsnips, as well as citrus species, especially in the peel (Tiwari and Cummins, 2013). An example is the furanocoumarins in the essential oil of bergamot (Citrus bergamia), which often contains bergaptene (Rios, 2016).

Nitrogenous or sulfur compounds, characteristic of roasted or roasted products, are rather rare in essential oils: butenetioate pyrazines from galbanum *(Ferula* spp.), 2-acetyl-4-isopropenylpyridine and other pyridines from the essential oil of *Mentha spicata* L. (Bruneton, 2001).

On the other hand, organosulfur compounds are characteristic of the genus *Allium* e.g. diallyl sulfide, allyl methyl sulfide, S-allylcysteine. *Allium* (onions, garlic, among others) contain mainly cysteine sulfoxides, and when the tissues are cut, the enzyme allinase is released, which converts the cysteine sulfoxides into thiosulfinates. These compounds are reactive, volatile, produce characteristic odors and are lachrymatory (Benkeblia, 2004).

The nitrogenous compounds produced in fruits of peppers and chili peppers, which cause a burning sensation, are called capsaicinoids. Capsaicin (trans-8-N-vanillyl-6-nonenamide) is a volatile, acidic alkaloid responsible for the burning sensation (Campos-Vega and Oomah, 2013).

Other compounds that can be part of essential oils are glucosinolates, such as synalboside from white mustard (*Brassica alba*); salicylates from wintergreen (*Gaultheria procumbens*); and amygdalin from bitter almond (*Prunus communis var. amara*), which releases benzaldehyde and hydrogen cyanide (Ríos, 2016).

## EXTRACTION METHODS

It is evident that essential oils have a complex and variable composition, made up of numerous constituents where even trace components are important, since they give the oil its characteristic aroma. Various methods can be used to separate the aromatic substances from plant tissues. The composition of the oil can vary greatly depending on the extraction method used, so it is important that the natural proportion of the constituents is maintained during the extraction of essential oils (Anitescu *et al*., 1997).

Essential oils are isolated by several methods, such as hydrodistillation, steam distillation, organic solvent extraction, microwave-assisted hydrodistillation, supercritical $CO_2$ extraction, and solvent-free microwave extraction, among others (Fadel *et al*., 2011). Steam distillation is the most commonly used method to produce essential oils on a commercial basis; carbon dioxide extraction produces a higher natural organoleptic profile, but has a higher cost (Burt, 2004).

## DISTILLATION

### Hydrodistillation

Hydrodistillation has become the standard method of essential oil extraction and is often used to isolate non-water soluble natural products with high boiling point. This process involves complete immersion of the plant material in water, followed by boiling. This method protects the extracted oils to some extent, as the surrounding water acts as a barrier to prevent overheating. Subsequently the vapors emitted, both water vapor and essential oils condense into an aqueous fraction and are easily separable (Tongnuanchan and Benjakul, 2014).

It is important to consider:

- The vegetable must always be in contact with water.
- The water in the distiller must be sufficient and permanent for the whole process, in order to avoid overheating and carbonization at the bottom of the vessel.
- The plant material must be kept in constant agitation in order to avoid agglomeration and sedimentation at the bottom of the container (Flores, 2010).

Although the extraction of an essential oil by distillation seems to be a simple process, it has many drawbacks. Because the raw material is exposed to boiling water for long periods of time, differences in the composition of the volatile oils being extracted can occur, either because of the high temperature or the acidity of the water. During distillation, if hydrolysis of esters to alcohols and acids occurs, this can have serious implications for oils with high concentrations of esters. In addition, some essential oils require rectification. This process involves redistillation of the oil to remove undesirable impurities (e.g., waxes) as well as components that may impart an unacceptable odor (Stratakos and Koidis, 2016).

### Vapor entrainment

The steam distillation process, also called steam distillation, is the most widely used method with 93% of essential oils extracted by this method and the remaining 7% can be extracted by other methods (Tongnuanchan and Benjakul, 2014). Unlike hydrodistillation it consists of a vessel containing only the plant material, water vapor is injected and penetrates the tissues, consequently the oil evaporates. The emerging mixture of vaporized water and oil moves through a coil, usually cooled with a stream of water, where the steam condenses. The condensed water and essential oil mixture is collected and separated by decantation or, in rare cases, by centrifugation (Sonwa, 2000).

In steam distillation by entrained distillation, the volatile component of a mixture formed by this and other “non-volatile” components is selectively vaporized. This is achieved by injecting water vapor directly into the mixture, which is called “entrained steam”, although in reality its function is not to “drag” the volatile component, but to condense forming another immiscible phase that will yield its latent heat to the mixture to be distilled to achieve its evaporation. In this case, two immiscible phases will be present throughout the distillation (organic and aqueous), therefore, each liquid will behave as if the other were not present. That is, each will exert its own vapor pressure and will correspond to that of the pure liquid at a reference temperature. Furthermore, in steam distillation the distillate obtained will be pure in relation to the non-volatile component (waxes) since the “non-volatile” component will never be present in the steam while the volatile component is being distilled, something that does not happen in hydrodistillation, in which the distillate continues to present both components, although more enriched in one of them. Steam distillation is a simple and low-cost method, but its disadvantage is that it requires long periods of time and has low yields compared to other methods (Peredo *et al.*, 2009).

Boutekedjiret *et al.* (2003) compared essential oils extracted by hydrodistillation and steam distillation of rosemary (*Rosmarinus officinalis* L.), finding differences in both yields and chemical composition; the oil obtained by steam distillation has a higher yield and a higher proportion of monoterpene hydrocarbons and ether, while that obtained by hydrodistillation is characterized by a high content of ketones, alcohol and esters. Monoterpenes are found in small proportions in the hydrodistilled oil, due to hydrolysis reactions of these components into alcoholic monoterpenes. The steam entrainment method, besides obtaining higher yields and better oils, allows extraction in less time than water distillation.

## Aroma recovery

Fruit flavors are recovered during the production of fruit juice concentrates. Generally speaking, in aroma recovery technology, an aroma concentrate is a stream in which the aroma compounds are concentrated at least 100 times (*100-fold*) above the concentration of the raw material stream. To obtain this concentrate, the aroma recovery process involves two basic stages: the separation of the aromas from the juice and a subsequent concentration or rectification of the aqueous stream containing the diluted aromas (Diban, 2008).

Industrially, in the first stage, the juice is heated to boiling under reduced pressure in order to evaporate 20 to 25% of the water. The steam that is given off contains most of the substances responsible for the aroma. This vapor condenses in the lower zone of a column containing theoretical plates, where a fractional distillation takes place to recover and concentrate the aromas[1] . A theoretical plate is a physical barrier of different materials built into the column. Each plate corresponds to a partial vaporization-condensation cycle (simple distillation).

As in any distillation process with rectification, the highly volatile components are enriched in the vapor phase and the low volatile ones are enriched in the liquid phase. Thus, different concentrations of compounds can be found along the distillation column and therefore different aroma fractions can be obtained from each plate of the column. The lighter aromas are obtained from the plates at the head of the column, aromas of medium volatility are found in the middle zone of the column, while the heaviest fraction of

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[1] Schwartz, M. 2020, Oct. Scent recovery. [Personal interview]. Department of Agroindustry and Oenology, Faculty of Agronomic Sciences, University of Chile.

aromas is removed from the lower part of the column (from the first plate). A high reflux fraction is used to enrich the aromas. When a concentration of about 100-200 *folds* is reached, the reflux is regulated so that 1 L of aroma concentrate is collected for every 100 L of fresh juice introduced into the system (Diban, 2008).

For the elimination of terpenes, sesquiterpenes and kerosenes, fractional distillation or rectification is used, taking advantage of the difference in the boiling points of these substances: terpenes: 150-180 C, sesquiterpenes: 240-280 °C, kerosenes: 180-240 °C. This operation is carried out under vacuum (3-5 mmHg) so as not to alter the original aroma of the essences. However, suffice it to say that the boiling point of substances with oxygen atoms (aldehydes, ketones, esters, etc.) is 90-110 °C at l mmHg, and at these temperatures, the original perfume of the essential oil is altered (Ortuño, 2006).

Fractional distillation is also used to enrich or isolate a single aromatic compound. Many essential oils, such as those from citrus fruits, contain terpenic hydrocarbons that contribute little to aroma, but readily autooxidize and polymerize ("resin formation"). These undesirable oil constituents (e.g. limonene from orange oil) can be removed by fractional distillation (Belitz *et al.*, 2009).

## COLD EXPRESSION

Expression or cold pressing is the oldest extraction method and is used almost exclusively for the production of citrus essential oil. This method refers to any physical process in which the essential oil secreting glands present in the flavedo of the fruit are ruptured and the oil is released. This process results in an aqueous emulsion, which is subsequently centrifuged to separate the essential oil (Stratakos and Koidis, 2016).

At the industrial level, essential oils are obtained from citrus fruits as a by-product of juice production. The most widely used machines in the world are the Brown oil extractor and the JBT FoodTech in-line extractor from John Bean Technologies Corp. Oil extraction can be prior to juice extraction in *pellatrici* style, as in the Brown International Corp. oil extractors or the Indelicato and Speciale *pellatrici* where the fruits pass through a series of lacerating rollers that oscillate and after passing through the fruit remove the peel, which in turn is immersed in water to avoid loss of volatiles to the atmosphere and subsequently separate the emulsion (Arce and Soto, 2008).

In other equipment, oil recovery can be simultaneous with juice extraction, as in JBT FoodTech's whole citrus juice extractor, this equipment consists of two opposing cups, one above the other, each divided into fingers that fit together as they come together. In the center of each cup is a circular cutter that penetrates the fruit while the upper cup is stationary and as the upper cup continues to descend, the juice, pulp and seeds of the fruit pass through the lower cutter into an outlet tube through which the juice is separated, while the essential oils released by the compression of the peel, are filtered between the fingers of the cups and washed by water to facilitate their recovery, so that juice and oils are extracted by separate zones. It is important to mention that fruit sorting by size is crucial, since the difference in size between the cup and the fruit can result in undesirable forms of damage to the peel resulting in the mixing of juice and oil (Arce and Soto, 2008).

Cold pressing is the most commonly used procedure for citrus essential oils due to the thermal instability of terpene hydrocarbons, in particular d-limonene (Mahato *et al.*, 2019).

## SOLVENT EXTRACTION

This method is commonly used to extract thermolabile essential oils, for example, from flowers (Stratakos and Koidis, 2016). It can be by maceration, which consists of soaking the plant material in a liquid, which is usually an organic solvent, at room temperature. The solution can be stirred to increase the rate of extraction of phytochemicals from the plant material. Once the extraction is complete, it is filtered to separate the plant debris. This plant material can then undergo another extraction step by adding fresh solvent to the material and allowing it to soak, a process that can be repeated several times to ensure complete extraction (Harbourne *et al*., 2013).

After extraction of the liquid mixture containing the essential oil (along with other compounds), the solvent can be separated by evaporation. The product obtained is a concentrate which can be a resin (resinoid) or concretes (a combination of wax, fats and essential oil). The concentrate is then mixed with alcohol to extract the oil and is distilled at low temperatures, then the alcohol absorbs the fragrance and when the alcohol evaporates, the aromatic oil, known as absolute, remains. However, this method is a relatively slow process and this coupled with the use of solvents, makes the oils more expensive than other methods (Tongnuanchan and Benjakul, 2014).

The solvents commonly used for extraction are acetone, hexane, ethanol, petroleum ether and methanol. The main advantage of extraction over distillation is that a lower temperature is used during the process, thus reducing the risk of changes due to high temperatures. The oil obtained will contain a small amount of solvent as a residue and therefore is not suitable for food application, however, if the solvent used is ethanol, it is safe for consumption and is considered "food grade" (Stratakos and Koidis, 2016).

Soxhlet extraction is a well-established solvent extraction technique. It is a standard technique and the main reference for evaluating the performance of other solid-liquid extraction methods. During extraction, the solvent is usually recovered by evaporation. Extraction and evaporation temperatures have a significant effect on the final quality of the products. Among its advantages, it has many industrial applications, good reproducibility and efficiency (Velasco *et al*., 2007).

In a Soxhlet system extraction the plant material is placed in a container, which has perforated sides and bottom, to allow liquid flow. There is a collection flask below the container and a reflux condenser above it. Heat is applied to the flask containing the solvent; the solvent evaporates and travels to the condenser. The condensed solvent then falls over the sample container, when it reaches a certain level it is discharged back into the solvent flask. The solute is separated from the solvent by distillation, as the solute is left in the flask and the solvent passes into the plant material. This procedure is repeated until the extraction is complete (Harbourne *et al*., 2013).

One of the most important natural extracts marketed in the world is vanilla extract (*Vanilla planifolia* Jacks. ex Andrews) which is conventionally obtained by percolation of an aqueous solution of ethanol at 30-40% by volume, likewise, there are other products derived from vanilla that are highly demanded such as vanilla oil (Salas *et al.,* 2017).

## SUPERCRITICAL FLUID EXTRACTION

In general, conventional extraction methods such as steam distillation and solvent extraction have traditionally been used; however, these have disadvantages such as low yield, loss of volatile compounds, long extraction times and toxic solvent residues. This led to the development of other extraction techniques that can overcome these problems. One alternative is supercritical fluid extraction; this procedure can be performed in batch, semi-batch and continuous (Stratakos and Koidis, 2016).

A supercritical fluid is any substance that is subjected to pressure and temperature conditions above its critical point, thus possessing properties intermediate between gas and liquid. The density of a supercritical fluid is similar to that of liquid and its viscosity is similar to that of gas and it has a higher diffusion coefficient than liquid. These characteristics favor its penetration into different matrices and solubilization of solutes, so that supercritical fluids can diffuse through solids like a gas and dissolve materials like a liquid. Selective extraction of components is possible with small variations in pressure and temperature close to the critical point, causing large changes in their density, which can enhance extraction (Anzueto, 2018).

It is a separation process that can be considered both a form of distillation (in which the separation of solutes is based on their vapor pressure differences) at high pressure, and a form of extraction with conventional liquid solvents (the separation is based on solute/solvent interactions). Supercritical fluids can selectively dissolve some constituents of mixtures, depending on their chemical structure (Del Valle and Aguilera, 1999).

One of the most widely used supercritical fluids in the extraction of compounds is carbon dioxide ($CO_2$ ), due to its comparative advantages, such as low cost, easy to obtain and low critical properties (7.38 MPa, 31.06 ºC) (Esquivel and Aguilar, 2007).

Supercritical $CO_2$ is a very flexible solvent due to the large variations in its properties, even though it is not a universal solvent. As pressure increases, supercritical $CO_2$ is able to separate less volatile, higher molecular weight, and/or higher polarity compounds within those non-polar such as, (in order of decreasing extraction capacity): essential oils, heavier terpenes and esters, free fatty acids, oils, waxes, resins and pigments (chlorophyll, carotenes). Proteins, starches, sugars and mineral salts are insoluble (Del Valle and Aguilera, 1999).

Thus, extraction with supercritical $CO_2$ has been used to extract oleoresins and essential oils (mixtures of substances), also for the fractional separation of bioactive compounds such as antioxidants and pigments; in turn, the food industry has used this technique in the decaffeination of tea and coffee, obtaining hop extract for brewing beer, recovery of aromas from fruit juices, among others (Del Valle and Aguilera, 1999, Belitz *et al*., 2009).

The essential oil obtained by supercritical fluids presents a richer chemical composition, both in the number of components and in their proportion; according to Reverchon and Senatore (1992) the rosemary extract obtained by supercritical $CO_2$ has an aroma characteristic of fresh material and more intense compared to the essential oil obtained by hydrodistillation, which is modified by the extraction process; this effect was reported by Anitescu *et al.*(1997) for coriander essential oil, which had a superior aroma compared to a commercial oil obtained by hydrodistillation.

### MICROWAVE ASSISTED EXTRACTION

In the search for lower cost and environmentally friendly methods, microwave-assisted extraction techniques have been developed. These techniques have been described with a unique heating mechanism (friction-based), reasonable cost and good performance in atmospheric conditions, all leading to higher extraction yields, shorter operation times and higher selectivity compared to conventional methods (Stratakos and Koidis, 2016). In turn, it is considered a "green" method due to its low energy consumption and reduced CO footprint$_2$ (Elyemni *et al.,* 2019).

This technology operates with the application of electromagnetic energy to promote the generation of heat within the plant material to improve the rate of extraction of volatile compounds from plant matrices. It is known that a frequency of 2.45 GHz has a significant effect on the speed of various processes in the chemical and food industry. Some of the techniques that stand out are microwave-assisted hydrodistillation, solvent-free microwave extraction or "dry" distillation, gravity-assisted hydrodiffusion and microwave, among others (Kokolakis and Golfinopoulos, 2013).

The equipment to carry out this technique can be adapted by modifying a conventional microwave oven, making a hole in the upper part that connects a flat-bottomed flask with a refrigeration apparatus (a condenser connected to a gravity separation tube, through which a stream of cold water passes), sealing the connection with the oven to avoid microwave leakage. Similarly, for assisted hydrodistillation, a distillation apparatus is adapted to a microwave oven, with the difference that the sample is accompanied by water (Peredo *et al.,* 2009).

In solvent-free microwave extraction, also called "dry" microwave distillation, it is necessary to place fresh vegetables in a microwave reactor. The internal heating of the *in situ* water within the plant material distends and bursts the glands and oil receptacles, releasing the essential oil which is then carried away by the *in situ* water from the plant material by distillation. The vapor then passes through a condenser outside the microwave cavity, where it condenses and is recovered (Ferhat *et al.*, 2007; Abroomand *et al.*, 2011).

Comparative studies between conventional hydrodistillation and microwave-assisted hydrodistillation indicate that the latter stands out for higher yields, this added to a higher proportion of monoterpenes and oxygenated compounds present in the essential oil; on the other hand, the extraction time is significantly shorter, 20 to 25 minutes compared to 3 hours for hydrodistillation (Moradalizadeh *et al.*, 2013; Elyemni *et al.*, 2019).

The microwave extraction process is simple and can be performed on a large scale with microwave reactors to extract large quantities of oil; these reactors are suitable for the extraction of 10, 20 or 100 kg of fresh plant material per batch. However, high levels of safety are required for all persons using this equipment (Bousbia *et al.*, 2009).

## FUNCTIONAL PROPERTIES

### ANTIOXIDANT ACTIVITY

Free radicals are unavoidable by-products of cellular oxygen metabolism, which in addition to having certain functions as regulatory or signaling molecules, can alter the structure of cellular macromolecules such as lipids, proteins and DNA, and contribute to the pathogenesis of a number of human degenerative diseases. In turn, oxidation of biomolecules by free radicals limits the shelf life of raw and processed foods.

The adverse effects of free radicals can be reduced with natural or synthetic antioxidants. When present in foods or in the body at low concentrations compared to those of the oxidizable substrate, they retard or prevent oxidation of the substrate. Antioxidants have been used to prevent deterioration of product quality and maintain their nutritional value (Slamenova and Horvathova, 2013; Alvines, 2019).

In foods, the most commonly used antioxidants are of synthetic origin, such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), propylgallate (PG) and tert-butylhydroquinone (TBHQ), which are suspected of causing or promoting negative health effects. For this reason there is a growing interest in studies of natural additives as potential antioxidants (Kulisic *et al*., 2004).

In essential oils there are several compounds that perform antioxidant functions; this is characterized by yielding hydrogen from the phenolic groups, thus interrupting the propagation of oxidation through the chain of free radicals. Also, the mechanism of action of an antioxidant, which is actually a reducing agent, is explained by the session of electrons that it can make to another substance (oxidant), i.e., there are atoms that experience an increase in their oxidation state. In this way stable compounds are formed that cannot initiate or propagate lipid oxidation or other oxidizable substance[2] (Cervato et al., 2000).

Essential oils and their components have been shown to be effective in delaying the lipid oxidation process. When evaluating the chemical and sensory changes during storage of roasted sunflower seeds with essential oils of oregano (*Origanum vulgare* L.) and pennyroyal (*Lippia turbinata* Griseb.), both showed a protective effect against oxidative deterioration of lipids and sensory quality of the seeds; however, oregano essential oil showed greater antioxidant activity. Similarly, consumers had a positive acceptability of these products. On the other hand, essential oils are a rich source of polyphenols, which are recognized as stronger antioxidants than tocopherols. For that reason, they are gaining more attention due to their wide consumer acceptance as they are considered safe. Oils with components such as eugenol, thymol or carvacrol have shown remarkable antioxidant activity, because these compounds have a phenolic base (Quiroga, 2013).

Several essential oils have shown some antioxidant activity, however, those with a higher activity are those rich in oxygenated monoterpenes in their composition as some representatives of the *Lamiaceae* family such as thyme, oregano, rosemary, lavender, sage, among others. In some studies, thyme and oregano oils have shown higher antioxidant activity than BHT (Sacchetti *et al*., 2005; Bozin *et al.,* 2006; Hussain *et al*., 2011). In turn, clove, cinnamon and ginger oil presented equal or higher antioxidant capacity than BHT (Ghadermazi *et al*., 2017, El-Baroty et al., 2010).

## ANTIMICROBIAL ACTIVITY

The main cause of food spoilage is the appearance of different types of microorganisms (bacteria, yeasts and molds). Various essential oils and their components have demonstrated antibacterial and antifungal activity against pathogenic microorganisms that can be found in food (Laranjo *et al*., 2017).

The antibacterial action of essential oils can be attributed to the lipophilic nature of the volatile compounds and their ability to penetrate through the cell membrane and into the cell interior, increasing permeability and as a result leakage of metabolites and cellular components (Slamenova and Horvathova, 2013).

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[2] Schwartz, M. 2020, Oct. Antioxidant activity. [Personal interview]. Department of Agroindustry and Oenology, Faculty of Agronomic Sciences, University of Chile.

The phenolic nature of volatile oils elicits an inhibitory response to the growth of pathogenic bacteria likely to be found in foods. Phenolic compounds can rupture the cell membrane disrupting cell functions, and eventually cause leakage of cell contents (Bajpai *et al.*, 2012). The mechanisms of action may relate to the ability of phenolic compounds to alter the permeability of microbial cells damage cytoplasmic membranes, interfere with the cellular energy generation system (ATP) and affect ion reflux (Burt, 2004; Bajpai *et al.*, 2012). Cell membrane rupture causes disruption of several vital processes, such as nutrient processing, synthesis of structural macromolecules and growth regulators, finally the disrupted permeability of the cytoplasmic membrane can lead to cell death.

Thus the interaction of essential oils with cell membranes results in the inhibition of the growth of some Gram-positive and Gram-negative bacteria. In general, it is believed that essential oils are more effective against Gram-positive bacteria due to the interaction of the cell membrane with hydrophobic components of the oils. In contrast, Gram-negative bacteria should be more resistant to volatile compounds since they possess a hydrophilic cell wall, thus Gram-positive bacteria such as *Staphylococcus aureus, Listeria monocytogenes and Bacillus cereus* are more susceptible than Gram-negative bacteria such as *Escherichia coli and Salmonella Enteritidis* (Rivera *et al.*, 2015).

According to Bozin *et al.* (2006) although Gram-positive bacteria were more sensitive to essential oils, a remarkable susceptibility of pathogenic Gram-negative bacteria, including strains of *Pseudomonas aeruginosa, Escherichia coli, Salmonella enteritidis, Salmonella typhi and Shigella*, including some multi-resistant strains, were particularly sensitive to the oils of *O. Vulgare* and *T. Vulgaris,* especially the essential oil of *O. Vulgare* is of particular interest.

This antibacterial effect of essential oil components such as thymol, menthol and linalyl acetate is due to a disruption of the lipid fraction of bacterial plasma membranes, while carvacrol changes the fatty acid composition, disintegrating the outer wall of Gram-negative bacteria, releasing lipopolysaccharides and increasing the permeability of the cytoplasmic membrane (Laranjo *et al.*, 2017).

Those volatile oils containing aldehydes or phenols, such as cinnamaldehyde, citral, carvacrol, eugenol or thymol as major components showed the highest antibacterial activity, followed by others containing terpenic alcohols. Other essential oils containing ketones or esters, such as β-myrcene, α-tuyone or geranyl acetate had much weaker activity. While volatile oils containing more terpenic hydrocarbons tended to be inactive (Bassolé and Juliani, 2012).

On the other hand, the essential oils of certain spices, such as clove, thyme, black pepper, oregano, pepper, garlic, onion and cinnamon, have been shown to be effective in inhibiting spore germination and growth of *Clostridium botulinum* at high concentrations (150 - 200 ppm), however, at low concentrations (10 ppm), cinnamon, oregano and clove oils proved to be the most effective (Ismaiel and Pierson, 1990).

The antifungal action is similar to the antibacterial mechanisms by direct contact, but also have antifungal activity in vapor phase, this effect is mainly for molds. By direct contact the essential oils penetrate and alter the permeability of the fungal cell wall and cytoplasmic membranes, in turn, disintegrating the mitochondrial membranes. In contrast, the vapor phase generated by volatile compounds attacks the life cycle of some molds at the germination stage, affecting hyphal growth and sporulation. The inactivation of conidia produced by essential oils is a key inhibition process, because conidia are stable to heat, light and chemical compounds, being difficult to eliminate (Laranjo *et al.*, 2017).

According to Nazzaro *et al*. (2017) volatile oils can affect fungi by disrupting the cell membrane or cell wall, or by inhibiting the formation of the cell wall, in turn they have an effect at the intracellular level affecting the functionality of mitochondria and inhibiting efflux pumps in the cell membrane thus affecting ATP levels and pH inside the cell. Inhibition of $H^+$ -ATPase leads to intracellular acidification and death.

According to Benkeblia (2004) essential oils of garlic and onion have demonstrated antifungal activity on *A. niger, P. cyclopium and F. oxysporum* in *in vitro* studies, which proved to have a more noticeable effect at high concentrations. Another example is citrus essential oils that have also been studied by several authors demonstrating significant antifungal activity in both *in vitro* studies and in *vivo* analyses (Mahato *et al.,* 2019).

## APPLICATIONS IN THE FOOD INDUSTRY

### FLAVORING / FOOD FLAVORING

Seasoning food with herbs and spices to make it more appetizing is an ancient practice.

According to the RSA (Food Sanitary Regulations, 2019) those aromatic substances or mixtures thereof obtained by physical or chemical processes of isolation or synthesis of natural, natural-identical and artificial type accepted by FAO/WHO, European Union, Food and Drug Administration and F.E.M.A. (Flavor and Extractive Manufacturing Assoc.) are allowed to be used as flavoring/aromatizing agents.

As context shall be understood by:

Natural flavoring/aromatizing agent: a pure product of defined chemical structure or a flavoring preparation of undefined chemical structure, whether concentrated or not, that has saporiferous characteristics and is obtained by a physical, microbiological or enzymatic process from products of vegetable or animal origin;

Flavoring/aromatizing identical to natural: is that product obtained by physical, microbiological, enzymatic, chemical synthesis or isolation processes by chemical processes, whose formulation includes components identical to those existing in nature;

Artificial flavor/aromatizing agent: a product whose formulation includes, in any proportion, components that are not naturally found in animal or vegetable products and are obtained by chemical synthesis.

Traditionally, spices are used to flavor foods, which are marketed unground or coarsely or finely ground powders. After grinding, the shelf life of spices is limited. Favorable storage conditions are the absence of air, a relative humidity of less than 60% and a temperature of less than 20 °C. Crushed spices quickly lose their aroma and can absorb aromas from other sources. Herbal spices are dried before grinding and the loss of aroma substances depends on the spice and drying conditions (Belitz *et al*., 2009).

Spice extracts are used in food preparation on an industrial scale, as they are easier to handle than spice powders and are free of microorganisms (Belitz *et al*., 2009). Aromatic concentrates, essences, extracts and individual compounds are used for this purpose. Aromatic compounds can be of natural or artificial origin, of which approximately 75% of the flavors used are of vegetable origin in the form of essential oils, extracts and distillates (Diban, 2008).

### In the Beverage Industry

In the soft drink industry, essential oils are used for the preparation of concentrated syrups of the different flavors that can be found in the market, for example, cola, orange and lemon-lime flavors. Orange or lemon-lime flavored drinks generally have oils of all citrus fruits (lemon, orange, lime, neroli) in different proportions for each particular flavor. In the case of cola-flavored drinks, the syrups are made with a complex blend of essential oils and plant extracts including coca extract, citrus essential oils, nutmeg, cinnamon, vanilla, and kola nut extract (Ameh and Obodozie-Ofoegbu, 2016).

Spirits or alcoholic beverages are products for human consumption and represent an important outlet for agribusiness worldwide. Various national and international legal decrees, standards and specifications establish rules on the definition, description and presentation of the different types of spirits, which can be separated into two categories, distillates and liqueurs (Christoph and Bauer-Christoph, 2007).

Distillates have alcoholic strength between 30 and 50° GL. and are produced by distillation from fermented agricultural products containing carbohydrates; their flavor is characterized by aromatic compounds coming from the raw material and the alcoholic fermentation, in addition to the distillation, storage and aging processes, such as wine distillates like brandy, whose aroma is given by the type of fruit (grapes or other fruits like cherry or plum brandy), the distillation process, the type of wood used for aging, added to the aging time, extract aromatic compounds from the wood, and the product undergoes a series of chemical reactions that characterize its organoleptic quality (Christoph and Bauer--Christoph, 2007); Belitz *et al.*, 2009)

Liqueurs are spirits corresponding to mixtures of alcohols with water, with a minimum ethanol content of 15°GL and a minimum sugar content of 100 g/L, depending on the legislation, for Chile a minimum of 16°GL is considered; they are produced by flavoring ethanol of agricultural origin, distillates of agricultural origin or one or more spirits with natural vegetable materials such as herbs, fruits, fruit juices, cream, chocolate, steam distilled essential oils, distilled spirits or natural or artificial flavoring extracts. Examples are bitter, herbal or spice liqueurs such as aniseed, caraway, curacao, mint, ginger, bitter liqueurs and angostura, fruit flavored liqueurs are made with natural fruit essences, distillates or fruit extracts (Law No. 18455, Christoph and Bauer--Christoph, 2007; Belitz *et al.*, 2009).

An example is the ancient manufacture of vodka, whose principle of preparation based on the use of a purified alcohol in combination with herbal components; Subsequently, in Russia finally invented and popularized aromatic vodkas, tinctures, liqueurs and ratafias derived from macerations with spices, herbs or fruits, which then became popular all over the world (Biragov and Tinikashvili, 2018).

Another case in flavored alcoholic beverages is gin. Regular gin is made from distillates of juniper (*Juniperus communis*) and various spices, contains at least 38 °GL, while dry gin has an alcohol content of at least 40° GL (Belitz *et al.*, 2009).

## ENCAPSULATION OF ESSENTIAL OILS

Ingredients in food systems slowly oxidize and degrade, losing their activity and becoming unsafe. Prolonged storage also results in reactions between ingredients, which may limit their bioavailability, or may change the physical properties (color and flavor) of the food. Most of these limitations can be overcome with encapsulation techniques (Gupta et al., 2016).

Encapsulation is a process by which certain biologically active substances (flavors, vitamins or essential oils) and other substances are introduced into a biopolymer matrix in order to prevent their loss, protect them from the environment and prevent them from undergoing degradation reactions due to light or the presence of oxygen.

Microencapsulated substances have the advantage of being gradually released from the matrix or wall that has trapped them. And of course, pharmacological and food products with better sensory and nutritional characteristics are obtained. There are biopolymeric substances that serve as coating materials, such as alginates, carbohydrates, gums, proteins, etc. The most commonly used technique is spray drying, in which emulsions are first prepared to stabilize the compounds of interest, then atomization of the mixture and subsequent drying of the particles forms the encapsulation (Castañeta *et al*., 2011).

There are many techniques to perform microencapsulations, including coacervation, centrifugal suspension separation, fluidized bed coating, freeze-drying, liposome encapsulation, spray drying, spray cooling, among others (Gupta *et al*., 2016).

Encapsulation could provide many advantages, such as the protection of essential oils from degradation. Indeed, high temperatures, ultraviolet light and oxidation could compromise the biological activity of fragile components through volatilization or degradation of the active ingredients. Formulation of essential oils as microcapsules or microspheres could also be used to control the release of encapsulated oils (El Asbahani *et al*., 2015).

The physical, structural and chemical characterizations of encapsulated essential oil formulations are fundamental to evaluate the variables that affect the optimization process and the functionality of the product. To determine the efficiency of an encapsulation as a preservative, it is necessary to know the release kinetics, which can be sudden, in which the active compound is released rapidly at the beginning, delayed, where the release of the active compound occurs after a period of delay, and sustained, in which the active compound is released steadily for a given time (Matiacevich and Sáez, 2017).

Encapsulation allows increasing the efficacy of essential oils and decreasing their sensory impact on food. Encapsulation of rosemary essential oil has shown more effective antimicrobial activity than rosemary oil alone against *L. monocytogenes* in pork liver sausage (Pandit and Shelef, 1994; Nazzaro et al., 2012). Encapsulated cinnamon oil demonstrated long-lasting antibacterial activity against *Staphylococcus aureus, Escherichia coli, Pseudomonas fragi and Shewanella putrefaciens* (sh2) during the 10-day storage period (Yang *et al*., 2020).

## FOOD PRESERVATION

Food preservation seeks to prolong the shelf life of food products. Shelf life or useful life has been defined as the period of time during which the food product will remain safe; it ensures the maintenance of sensory qualities, chemical, physical, microbiological and functional characteristics; in turn, shelf life should be declared on the nutritional label, when stored under the recommended conditions. Therefore, it can be said that any additive that can extend or maintain the shelf life of a food product can be described as a preservative, in this case essential oils can be considered as an additive (Adelakun *et al*., 2016).

It is well known that essential oils act as food additives, antimicrobial agents or antioxidants, among others. Their activities vary depending on the plant source, chemical composition, extraction methods, etc. Due to the unique odor associated with volatiles, this may limit the use of essential oil in some foods, as it may alter the typical odor/flavor of foods (Tongnuanchan and Benjakul, 2014).

### Animal products

Meats are very susceptible to spoilage due to their chemical composition, endogenous enzyme activity, storage temperature, humidity, atmospheric oxygen, light and microorganisms that influence the freshness and shelf life of fresh meat, lipid peroxidation being the main cause of loss of quality in meats and meat products. Apart from refrigeration, one of the main current technologies for meat preservation is the use of synthetic chemical products as preservatives. Increased consumer health awareness has increased negative perceptions about synthetic food additives. Thus, the use of essential oils as preservatives for meat and meat products has been evaluated (Chivandi *et al*., 2016).

According to Al-Hijazeen *et al.* (2016), adding concentrations higher than 100 ppm of oregano essential oil improved the color stability of raw chicken meat and decreased the malodorous volatiles in cooked meat. However, the effects of oregano essential oil on lipid and protein oxidation and on volatiles in cooked meat were more significant than in raw meat and could replace a synthetic antioxidant (e.g., BHA) to prevent deterioration of raw and cooked meat quality during storage. On the other hand, the essential oil of Mendoza thyme (*Acantholippia seriphioides*) showed good antioxidant capacity in beef patties, vacuum-packed under modified atmosphere and stored at 4 ± 0.5 °C (Medina, *et al.,* 2003).

Although the *in vitro* antimicrobial activity of oils has been moderately effective in meat models, for their potential use in food preservation technologies, oils must be at optimal concentrations to ensure food safety, adequate organoleptic characteristics and consumer acceptance (Barbosa *et al*., 2009).

In the case of fish, the effectiveness of coating fish meats with films enriched with essential oils has been studied, demonstrating a decrease in lipid peroxidation and antimicrobial activity on some bacterial strains, so they could be used as a method of fish muscle preservation (Tongnuanchan and Benjakul, 2014). According to Erkan and Bilen (2010) analysis of sensory properties revealed that the shelf life of frozen tonino treated with laurel, grape seed and flaxseed essential oil extended to 7 months, while the remaining samples treated with thyme, rosemary, black seed, sage and lemon essential oil and untreated had a shelf life of 6 months (Olatunde and Benjakul, 2018). Essential oils have also demonstrated antioxidant properties in vacuum-stored smoked rainbow trout, particularly those treated with clove oil can have their shelf life extended by 6 to 7 weeks (Coban *et al.,* 2014).

On the other hand, the interaction between essential oils and dairy products has been studied, as in the case of cheese. According to Smith-Palmer *et al.* (2001), when evaluating the efficiency of four essential oils; laurel, clove, cinnamon and thyme as natural food preservatives, the composition of the cheese proved to be an important factor in determining the effectiveness of the oils. In the low-fat cheese (16%), the four 1% oils reduced the *L. monocytogenes* population. In contrast, in the full-fat cheese (30%), clove oil was the only oil that achieved this reduction. Thyme oil was ineffective against *S. enteritidis* in the full-fat cheese, but was equally as effective as the other three oils in the low-fat cheese, reducing the *S. enteritidis* count in the product.

Various essential oils can be applied as natural antimicrobial agents in order to inhibit microbial spoilage of cheeses and extend shelf life. Compounds including thymol, carvacrol, eugenol, carvone and cinnamaldehyde are mainly responsible for exerting antimicrobial activity, however, the concentration of these substances applied in cheeses should be carefully considered due to their potential negative impact on organoleptic properties (Khorshidian *et al*., 2018).

Another example is in ice cream where a significant antioxidant capacity of thyme, basil and marjoram essential oils was demonstrated, which in turn had good sensory acceptability (Ramadan *et al*., 2013).

## FUNCTIONAL PACKAGING AND EDIBLE COATINGS

Active packaging are systems in which the packaging, the product and the environment interact to destroy or inhibit the development of pathogenic microorganisms that can contaminate packaged food products such as *Listeria monocytogenes, Escherichia coli O157, Salmonella, Staphylococcus aureus, Bacillus cereus, Campylobacter, Clostridium perfringens, Aspergillus Niger and Saccharomyces cerevisia*, among others (Dini, 2016).

Active packaging systems are produced by direct physical mixing of active agents into the matrix of packaging films during manufacturing or as covalently bound antimicrobial agents in the main chain of a macromolecule as side chains coating the packaging films. The food packaging materials used are either synthetic or edible films. Thus, various packaging materials have been evaluated as synthetic polymeric materials by several researchers such as: polyethylene, polypropylene, polyvinyl chloride, polyester and polyamide. Among these, polyethylene and polypropylene are excellent moisture barriers, but must be coated or laminated with synthetic polymers, including ethylene vinyl alcohol (EVOH) and polyvinyl chloride copolymers to provide an oxygen barrier. Biopolymers have also been developed from film-forming materials such as: hydrocolloids (proteins, polysaccharides and alginate), lipids (fatty acids, acylglycerol, waxes), among others (Dini, 2016).

Monolayer and multilayer active packages with embedded antimicrobial agents have been developed. Typical multilayer films consist of four layers: outer layer, barrier layer, matrix layer (in which the antimicrobial is embedded) and control layer (controls the release of the antimicrobial). In turn, organic and inorganic compounds have been used as antimicrobials; the most commonly used are silver zeolites, organic acids and their derivatives, peptides, enzymes, essential oils, parabens, bacterocins, volatile compounds, among others. For these active packaging systems to be effective, the minimum release of antimicrobials must be maintained. The release follows Fick's Law where there is a diffusion process that depends on several factors, including the diffusion of water in the matrix layer, the relaxation of the matrix due to hydration of this layer and the diffusion of the antimicrobial into the food (Ayala-Zavala *et al*., 2008).

The effectiveness of essential oils of fennel *(Foeniculum vulgare Mill.),* thyme *(Thymus vulgaris L.),* savory *(Satureja hortensis L.) and* basil *(Ocimum basilicum L.)* on table grapes inoculated with Botrytis *cinerea* has been evaluated.*)* in the packaging of table grapes inoculated with *Botrytis cinerea*, where bunch appearance improved when essential oil solutions were applied to the bunches prior to packaging; however, the applications had a sensory impact on the flavor of the fruit (Abdolahi *et al*., 2010)

The effects of a sheet of active paper treated with encapsulated essential oil of oregano and cinnamon on ethylene biosynthesis and quality degrading enzymes of flat peaches (*Prunus persica* var. platycarpa) during postharvest were evaluated; where samples were studied for 5 days (continental land transport) or 26 days (long sea transport) under storage at 2 and 8 °C, both followed by marketing simulations (4 days at 22 °C). Oils released from active containers reduced ethylene production by 40-50% and up to 70% after the marketing periods, helped with the decrease in fruit weight loss and caused noticeable improvements in color and firmness preservation (López-Gómez *et al*., 2020).

Edible coatings can act as barriers against moisture and gases; they can preserve product color, texture and moisture. Edible films have received considerable attention in recent years because they are biodegradable and help reduce environmental pollution. Some coating materials currently in use are polysaccharides (cellulose derivatives, starch, chitin, gums), proteins (soy, milk, gelatin, corn zein, wheat gluten) and lipids (oils, waxes, resins). The use of a minimum amount of plasticizers (sorbitol, glycerol) may be of interest to improve the mechanical properties of the film (Sanchez *et al.*, 2011).

When essential oils are incorporated into edible films, they can either migrate to the food surface or remain retained in the film, both of which determine the antimicrobial efficacy of the edible film. The diffusion of essential oil into edible films is influenced by the polymer, plasticizer, processing, food characteristics such as pH and water activity, hydrophilic properties of the film, storage time and environmental conditions to which the films are exposed (Avila-Sosa *et al.*,2016).

Several researchers have tested the use of essential oils as antimicrobial agents in coatings for various types of foods, including meat and meat products, fish, fruits and vegetables (Sanchez *et al.*, 2011; Tongnuanchan and Benjakul, 2014).

The addition of lemon essential oil to strawberries inoculated with a suspension of *Botrytis cinerea* spores improved the antifungal activity of chitosan coatings, both in *vitro* and during cold storage (Jianglian and Shaoying, 2013). Trejo-Ramirez *et al.* (2015) compared the effectiveness of coatings based on cactus mucilage and carboxymethylcellulose with eucalyptus essential oil on raspberries, showing a clear decrease in the deterioration of fruits treated with coating and a greater effect on those containing essential oil.

## CONCLUSIONS

Essential oils are natural substances, generally recognized as safe, which are applied as food additives, mainly in the agro-industry for flavoring or flavoring food and beverages.

In turn, the components of essential oils play an important role in food preservation, contributing to food safety and extending the shelf life of food products due to their antioxidant and antimicrobial properties.

The extension of the shelf life of food products is due to a reduction in the propagation of oxidation, mainly due to the antioxidant activity of their phenolic compounds. They also have the ability to inhibit the development of pathogenic microorganisms that can be found in food and favor its deterioration, so they can become a healthy and natural alternative to synthetic preservatives and chemical additives. However, their activity is variable, depending on the chemical composition of the essential oil, the type of interaction with the food matrix and the environmental conditions of storage, so that, for their use, a case-by-case study of the preservative effects (in relation to the type of essential oil and the concentration used) for a given food will be necessary.

The main disadvantage of essential oils as food additives is the possibility of affecting organoleptic characteristics, particularly aroma and flavor, limiting consumer acceptability.

Finally, essential oils require study and research to continue developing their interesting and attractive potential for their application in multiple areas of the agroindustry, providing alternatives to the use of synthetic additives in food products or enabling new techniques that allow further progress in the technological development of food preservation with additives of natural origin, which are currently a trend in the world market.

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