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# Flavoured and fortified olive oils - Pros and cons

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ABSTRACT

*Background:* Flavouring and fortifying virgin olive oils is an increasing commercial trend, aiming to meet new consumers' preferences and provide new differentiated products. These practices usually positively impact the oils' sensory profile and chemical composition, increasing their natural richness on bioactive compounds. However, some negative effects have also been reported.

*Scope and approach:* This review provides a summary of common flavouring/fortification techniques as well as of the usual natural agents used. Co-extraction, contact and essential oils incorporation techniques are addressed. Usually, flavouring/fortification enhances desirable sensory sensations, and shelf-life, and promotes the incorporation of bioactive compounds like antioxidants. Also, the excess of flavouring may promote the appearance of unpleasant sensory sensations and, in some cases, results in pro-oxidant activity. Fortification, in turn, involves the incorporation of extracts rich in bioactive compounds, contributing to the nutritional and healthy enrichment of the olive oil. However, fortification may also increase the oil's turbidity and/or promote the appearance of unpleasant sensory sensations, resulting in a less appealing oil, hindering the consumers' purchasing.

*Key findings and conclusions:* Although traditional in the Mediterranean, olive oil flavouring or fortification may have positive/negative effects at chemical and sensory levels. This awareness is of paramount commercial importance and can be used as a decision-maker tool for olive oil producers. Thus, the advantages/disadvantages of the different methodologies are discussed, and some perspectives and possible future directions are proposed and briefly discussed.

## 1. Introduction

Olive (*Olea europaea* L.) growing has a strong implementation in the Mediterranean region, and, nowadays, this is an agronomic activity that has spread in the world, mainly in the geographical regions with a Mediterranean climate. In the regions where olive tree is the main crop, it plays an important role in the economy and landscape preservation, responsible for an outstanding industrial, environmental, gastronomic and cultural heritage (Kandylis et al., 2011). Olive fruits are mainly produced for olive oil extraction; nevertheless, table olives have a lower but relevant expression. Olive oil is a key element of the Mediterranean diet, which popularity has spread worldwide due to the recognized positive effects on consumers' well-being and health (Mariotti & Peri, 2014). Indeed, in recent years, the consumption of olive oil has increased, not only in traditionally consuming countries but also in countries where its consumption was residual.

Virgin olive oil is extracted from freshly harvested healthy fruits, using mechanical processes (milling, malaxation, centrifugation) that allow the preservation of chemical and sensory characteristics (Commission Regulation (EEC) Nº 2568/91). The benefits that come from olive oil consumption are related to its chemical composition. Olive oil comprises a high content of monounsaturated fatty acids, of which oleic acid stands as the most abundant; and a high amount of natural antioxidants, like phenolic compounds, tocopherols and carotenoids, which intake is beneficial to human health (Lolis, Badeka, & Kontominas, 2020). Several studies demonstrate the healthy properties of olive oil, namely anti-cancer and cardiovascular, and the positive effects related to its consumption (Foscolou, Critselis, & Panagiotakos, 2018; Pichierri, Pino, Peluso, & Guido, 2020). However, to ensure an effective and positive health impact, olive oil must contain a minimum amount of some bioactive compounds like phenolics, as stipulated by the polyphenols-related health claim (European Commission Regulation (EU) No 432/2012, 2012). Furthermore, the olive oil must be suitable for human consumption. Only extra virgin and virgin olive oils comply with a set of quality parameters that guarantee the commercial category, which ensures a satisfactory oxidative stability, being delayed and/or

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reduced the natural oxidation that takes place during the shelf-life of the olive oils.

Shelf-life depends on several factors, and its reduction is associated with oxidation reactions that naturally occur during storage, making the olive oil unsuitable for consumption. Thus, all aspects that accelerate oxidation must be carefully considered so that the olive oil retains its exceptional physicochemical and sensory qualities, ensuring a long shelf-life. Olive oil shelf-life is greatly influenced by the oils composition, which is affected by the olive variety, the agro-climatic conditions under which olives grow, the olives harvest time, the oils' extraction conditions and the storage conditions (Lolis, Badeka, & Kontominas, 2020). Thus, to ensure that virgin olive oils preserve their high quality for longer periods of time, it is necessary to control all aspects that can lead to their degradation, such as temperature, contact with oxygen, direct exposition to light, type of packing material, among other.

On the other hand, the novel consumption trends that emerged in the last decades pointed out that consumers seek new sensory sensations and new forms of presentation, with a greater concern regarding health and well-being. That way, there has been a rediscovery of flavoured and fortified olive oils, not only those resulting from the incorporation of traditional aromas and flavours, but also with the inclusion of non-characteristic aromas or by using new flavouring processes. Traditional flavours include those of plants and spices usually used by the Mediterranean cuisine, like garlic, pepper, rosemary and other aromatic plants/herbs. However, in the last years, olive oils flavoured with non-traditional agents, like cinnamon, chocolate, coffee, orange and tomato, have emerged as a novel commercial trend. Flavoured olive oils are oils for which the used flavouring agent promoted a set of differentiated sensory characteristics. In fact, according to Baiano, Gambacorta, and la Notte (2010), a flavoured oil can be defined as an "*olive oil (generally an extra-virgin olive oil) that has been processed with vegetables, herbs, spices or other fruits in order to improve the nutritional value, enrich the sensory characteristics and increase shelf-life*".

Some studies (Baiano et al., 2016; Benmoussa et al., 2016; Sousa et al., 2015) reported that flavoured/fortified olive oils are gaining relevance in the food industry, namely in the section of gourmet products. This fact implies clear innovation strategies, including those associated with the level/type/form of the flavouring agents used, aiming to enhance the value of the olive oil and meet the consumer's sensory requirements. Thus, the incorporation of spices, herbs, fruits, essential oils, or mushrooms is a traditional practice in Mediterranean gastronomy, allowing integrating bioactive compounds with known nutritional or health benefits. Indeed, the incorporation of flavouring agents (e.g., fresh or dried; powders or extracts) enhanced the oils' antimicrobial, anticancer and antioxidant properties, contributing the latter to avoid or delay the undesirable natural oxidation of the olive oils (Caponio et al., 2016).

The flavouring of virgin olive oils affects the physicochemical and sensory characteristics of the oils, and the effects can be either positive or negative (Bittencourt Fagundes et al., 2020; Gambacorta et al., 2007; Sousa et al., 2015). The most striking changes occur at the sensory level. The process may strengthen some typical positive sensations or lead to the appearance of new desirable feelings, related to the used flavouring agent, being sometimes easily perceived. On the other hand, flavouring can mask the presence/intensity of sensory defects, which is a fraudulent practice that can be used to change a low commercial classification of olive oil for a higher-value one (Bobiano et al., 2019). Regarding the oils' chemical characteristics, flavouring can also influence the antioxidant contents and enhance the shelf-life of the oils, since the incorporation of antioxidant compounds from the flavouring agent can promote the oxidative stability and slow down the oxidation, in comparison with non-flavoured olive oils (Baiano, Terracone, Gambacorta, & Notte, 2009; Bittencourt Fagundes et al., 2020; Reboredo-Rodríguez et al., 2017). However, some studies also reported an opposite trend, i.e., a pro-oxidant negative effect due to the incorporation of flavouring agents, which could decrease the oxidative stability of the flavoured oils (Cherif, Rodrigues, Veloso, Zaghdoudi, et al., 2021).

Commonly, three techniques are used for flavouring olive oils, namely the contact method (permanent or temporary), co-extraction, and incorporation of essential oils (Baiano et al., 2016; Benmoussa et al., 2016; Caponio et al., 2016; Caporaso, Paduano, Nicoletti, & Sacchi, 2013; Clodoveo et al., 2016; Romaniello & Baiano, 2018). Among these, the contact method, in which a direct contact is promoted between the olive oil and the flavouring agent, is the most usual and traditional technique. Nowadays, the incorporation of natural extracts, rich in specific bioactive compounds, has gained relevance. For example, the extracts rich in lycopene or lutein from algae, have been incorporated into olive oils, without the objective of enhancing any particular aroma or flavour, but to increase the richness in a certain compound or a family of compounds, with known positive nutritional or healthy properties (Murillo-Cruz, Chova, & Bermejo-Román, 2021, Murillo-Cruz, García-Ruíz, Chova-Martínez, & Bermejo-Román, 2021), being these olive oils classified as fortified oils.

## 2. Flavouring/fortifying olive oils

According to the European Union (EU) regulation (Regulation N° 136/66/EEC), virgin olive oils can be defined, according to the process of extraction, as "*olive oils obtained from the fruit of the olive tree solely by mechanical or other physical processes - under conditions, namely thermal, that do not change the olive oil - and which have not undergone other treatments other than washing, decanting, centrifuging and filtering, with the exclusion of olive oils obtained with solvents or by re-esterification processes and any mixture with oils of another nature*". The legal thresholds regarding the chemical and sensory characteristics established by the EU regulation (Commission Regulation (EEC) N° 2568/91) and its subsequent updates, allow classifying olive oils into the following categories (Commission Implementing Regulation (EU) N° 29/2012):

- Extra virgin olive oil – superior category olive oil obtained directly from olives and solely by mechanical means, whose characteristics are in accordance with those foreseen for this category;
- Virgin olive oil – olive oil obtained directly from olives and solely by mechanical means, whose characteristics are in accordance with those foreseen for this category;
- Lampante olive oil – olive oil obtained directly from olives and solely by mechanical processes, which does not meet the requirements to be classified in previous categories.

On the other hand, taking into account the latest consumers trends, which seek products with unique nutritional, healthy and sensory characteristics, the traditional olive oil sector has been engaged with product innovation in order to deliver novel olive oil-based products like flavoured and fortified olive oils, which research field has become a topic with a growing interest.

Flavoured olive oils are obtained by adding a flavouring agent (e.g., aromatic plants or herbs, spices and fruits) aiming to enhance the chemical, nutritional and sensory characteristics of the oils. Fortified olive oil results from incorporating a fortifying agent aiming to add inexistent compounds or group of compounds or enhance their contents, promoting specific nutritional or healthy characteristics. Thus, extra virgin or virgin olive oils are usually used for flavouring and fortification. However, the flavoured or fortified oils cannot be labelled using the initial commercial category of the olive oil used since these oils were not obtained following the EU regulation guidelines (Regulation N° 136/66/EEC).

## 3. Flavouring techniques

Flavouring olive oils is a very old practice in the Mediterranean region, being nowadays performed by contact, the most common technique, co-extraction or essential oils incorporation (Baiano et al., 2016;

Benmoussa et al., 2016; Caponio et al., 2016; Caporaso et al., 2013; Clodoveo et al., 2016; Romaniello & Baiano, 2018). The flavouring by contact and essential oil incorporation are techniques implemented after the olive oil extraction, while flavouring by co-extraction implies the contact between olive mass and flavouring agent during olive oil extraction. Fig. 1 shows a summarized scheme of the abovementioned forms of flavouring the olive oils.

In the co-extraction technique (Fig. 1A), the flavouring process occurs during the olive oil extraction, being the flavouring agent usually added during the milling step. Thus, a pre-established amount of flavouring agent is added to the olives, which are crushed in its presence, and the remaining extraction steps are not altered. During the malaxation stage, there is a large contact surface between the small olive oil droplets, which aggregate, and the flavouring agent, allowing the easy migration of compounds and aromas, which are then incorporated into the extracted olive oil. Some fruits, such as lemon, orange, and tangerine, have been used as flavouring agents when flavouring by co-extraction is applied (Benkhoud, M'Rabet, Gara ali, Mezni, & Hosni, 2021; Mannina et al., 2012). In these cases, and since the fruit's skin is rich in soluble essential oils, the migration of compounds and aromas to olive oil is promoted. Besides the mentioned fruits, olive leaves have also been used as a form of enrichment/flavouring of olive oils, due to the known functional properties of this by-product (Perito, Coderoni, & Russo, 2020). Furthermore, olive leaves usually increase the oxidative stability of the extracted olive oil (Talhaoui et al., 2014) and improve oils' sensory profiles and olive oil composition (Contreras et al., 2020). This technique allows obtaining a clear flavoured olive oil, ready for consumption, as the flavouring agent is added during the extraction of the olive oil. The olive oils obtained by this technique have different sensory characteristics and can present a high nutritional value as well as an increased shelf-life (Trabelsi et al., 2019).

The flavouring by contact (Fig. 1B) is a technique that consists of flavouring the olive oil after its extraction. The contact between the flavouring agent (entire or milled, fresh or dried) and the previously extracted olive oil is promoted using different methods (ultrasound, microwaves or heating) that facilitate the oil's flavouring. After, the flavouring agent can be, or not, removed from the oils by filtration.

In the last decades, the flavouring using essential oils has gained relevance (Fig. 1C). In this technique a small amount of essential oil is usually required. Essential oils are concentrated matrices that can be obtained using several techniques like distillation, organic solvent extraction and cold pressing (Dima & Dima, 2015; Pateiro et al., 2021). Usually, a known amount of the essential oil is added to the olive oil and the flavouring process is achieved by mixing and natural diffusion.

## 4. Fortifying techniques

Fortification with a specific compound or with extracts rich in bioactive compounds is a more recent practice, although fortified olive oils are already commercially available. This technique is implemented after the olive oil extraction by adding a fortified rich extract. Fig. 1C shows the flowchart of the olive oil fortification method, for which natural extracts, rich in a specific bioactive compound or a family of compounds, are added to olive oils allowing to obtain fortified oils with enhanced nutritional and/or healthy properties, as well as with a higher shelf-life (Limón et al., 2015). Also, some recent works used olive oil as an extraction agent since some fortifying agents are highly soluble in lipid matrices. Nevertheless, these practices are scarcely used, and due to its drasticity can have a negative impact on olive oil quality.

## 5. Flavouring and fortification agents

Tables from 1 to 4 summarize the different olive oil flavouring strategies described in the literature, respectively, flavouring by contact, co-extraction, incorporation of essential oils or fortification. Details are included regarding the flavouring/fortification agent used, the

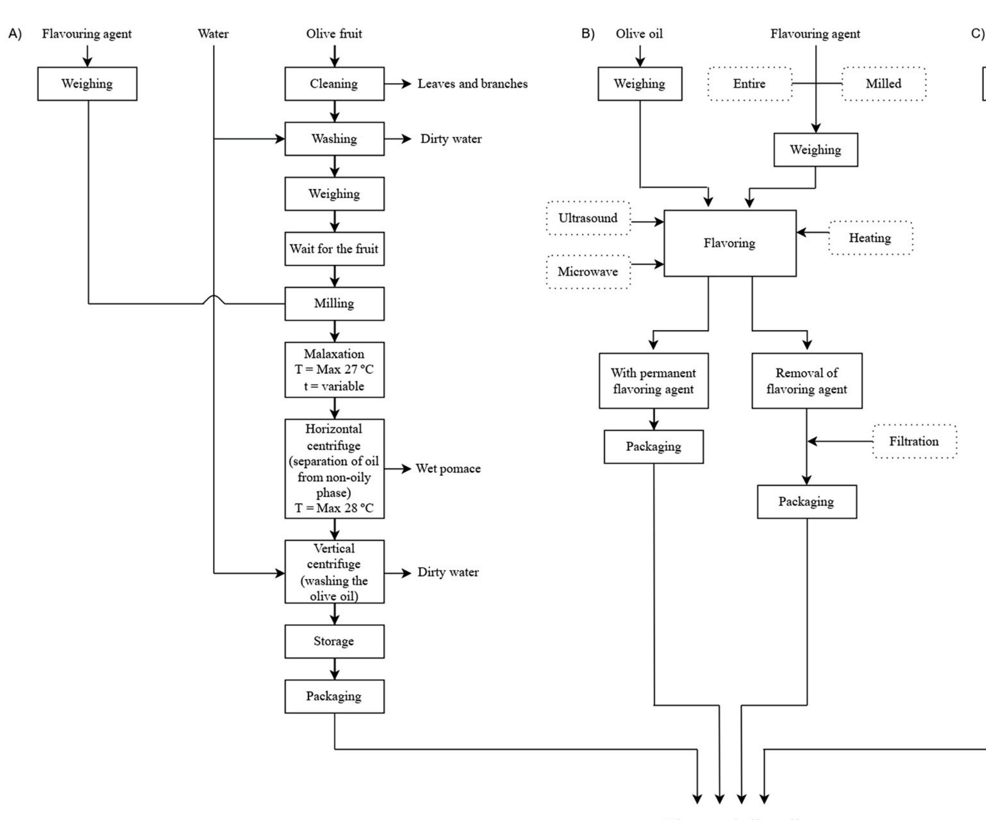


**Fig. 1.** Schematic representation of different techniques of flavouring olive oils: A) Co-extraction; B) Contact; C) Incorporation of essential oil/Fortification.

experimental conditions (e.g., time, temperature, agitation, and amount of agent used) and the main effects observed.

As can be inferred from the information gathered in Tables 1–4, a vast number of studies have been devoted to the flavouring of olive oils, pointing out the interest of this ancient Mediterranean practice as well as the diversity of techniques, agents and effects of the flavouring process. Based on the available data, it can be stated that the use of flavouring by direct contact is the most studied technique, which could be attributed to the easy implementation of this technique, not requiring any change in the usual oil extraction process (Benmoussa et al., 2016; Clodoveo et al., 2016). Furthermore, considering that the flavouring is performed directly on the extracted oils, the desirable sensory properties of the flavouring agent can be delivered/migrated to the oil (Benmoussa et al., 2016). Even so, there is still a considerable number of studies reporting the production of flavoured olive oils by co-extraction or by the addition of essential oils. Finally, a lower number of studies, yet significant, focused on the olive oil enrichment with specific bioactive compounds, mainly antioxidants, to enhance the oils' nutritional and healthy properties.

Regarding the used flavouring agents, and based on the compiled literature (Fig. 2), different classes can be grouped, namely aromatic plants, that represents more than 42% of the references compiled in this work, followed by spices, with around 24% of the references, fruits, with 14%, and the other agents representing about 19%. Within the aromatic plants (Fig. 2), oregano and rosemary were the most common agents (14 references), followed by thyme (12 references), and basil (9 references). The lemon dominates with eight references on fruits, followed by tomatoes (with 7) and orange (3 references). Regarding spices, three flavouring agents should be highlighted, namely garlic (11 references), pepper (7 references) and chilli pepper (4 references). In other flavouring agents, the olive leaves had been frequently used (11 references), which is justified for being a by-product of the olive oil extraction. The huge use of aromatic plants could be related to different factors, such as the wide range of flavours and aromas, the great availability, low price and easiness of use. In fact, choosing agents whose flavours are well-known and appreciated by consumers turn their acceptance easier, overcoming a possible initial resistance to new and, in some cases, exotic sensory sensations (Caporaso et al., 2013). On the other hand, flavouring agents could introduce or facilitate the introduction of olive oil in non-traditional olive oil consumer countries. In fact, the use of agents known or used by consumers on a daily basis together with the emerging consumption trend of olive oil due to the recognized health benefits, may increase the acceptance and respective consumption of olive oil by consumers from non-traditional consuming countries. Also, flavoured olive oils can be more prone to fulfil new consumers' expectations in countries where the olive oil consumption is not comprised in the traditional gastronomy (Baiano et al., 2016).

From the studies mentioned (Tables from 1 to 4), it is also possible to infer that different effects, sometimes contradictory, have been drawn by different studies when using the same flavouring agent or the same flavouring technique. These differences may be due or tentatively attributed to different factors, which must be taken into account when comparing similar studies, such as:

- the conditions under which the flavouring is carried out (e.g., time and temperature);
- the amount of flavouring agent used;
- the state of the flavouring agent used (e.g., fresh or dry, powder or not);
- the chemical composition of the flavouring agent (although the same agent is used, it does not imply the same composition, which would depend on the geographical origin, the production/extraction conditions, etc.); and,
- the storage conditions of the flavouring agent before use.

Indeed, for example, when rosemary is used as a flavouring agent, some studies claim a positive effect regarding the peroxide value, which decreased (Ayadi, Grati-Kamoun, & Attia, 2009; Kasimoglu, Tontul, Soylu, Gulen, & Topuz, 2018; Rodrigues, Silva, Veloso, Pereira, & Peres, 2021; Taleb, Boutoial, Kzaiber, & Oussama, 2016) however, other studies revealed an opposite trend for this same quality parameter (Gambacorta et al., 2007). Similar contradictory trends have also been reported for the flavouring effect on the composition of the phenolics. Another example is oregano, in which the free acidity, the peroxide value and the content of phenolic compounds increase, and in other studies, the values of these parameters decrease (Clodoveo et al., 2016; Sousa et al., 2015).

On the other hand, the quality of the olive oil (i.e., the raw matrix) to be flavoured must also be considered. Different quality grades are available (e.g., extra virgin, virgin or olive oil), some of which are monovarietal and other blended oils. The chemical-sensory profiles of the olive oil chosen to be flavoured would have, for sure, a deep impact on the final attributes of the flavoured olive oil, and thus, the flavouring procedure, even using the same technique and agent, could have both positive or negative effects, either enhancing or hindering the final quality of the flavoured olive oil.

### 5.1. Advantages and disadvantages of flavouring/fortification techniques

#### 5.1.1. Advantages

The incorporation of flavouring/fortifying agents into olive oil can be an advantageous procedure from different points of view. The most usual and accepted is the increase of the sensory acceptation of the olive oil, by enhancing the known and desirable aromas and flavours, thus fulfilling consumers' search for novel sensory sensations. Also, once the used agents are usually rich in antioxidant compounds, such as phenolic compounds, the process may increase the flavoured oil's shelf-life, being assumed that part of the antioxidants migrates from the agent used to the oils, increasing their oxidative stability when compared to unflavoured olive oils (Baiano et al., 2009; Bittencourt Fagundes et al., 2020; Reboredo-Rodríguez et al., 2017). In this way, flavouring agents act as food additives and preservatives promoting the hopeful incorporation of bioactive compounds due to migration, enriching the olive oil's natural nutritional and healthy composition, enhancing the flavour, and improving the sensory properties of the raw olive oil (Sena-Moreno et al., 2018). According to the compiled literature (Fig. 3), the most referred positive effect attributed to the flavouring/fortification of olive oils is the increase of the oxidative stability (46 references) and the increase of the amounts of phenolic compounds (36 references). Nevertheless, a high number of positive effects is highlighted by the literature (Fig. 3), which mainly depend on the flavouring/fortification agent used and the applied methods.

Studies using various flavouring agents (e.g., oregano, pepper, lemon, rosemary and garlic) show that the antioxidant content is higher in flavoured olive oils than in non-flavoured olive oils, which is more noticeable after olive oil storage (Baiano et al., 2009). Flavouring originates changes in quality, composition, bioactive properties and stability on the flavoured olive oils; however, the specific changes and their extents greatly depend on the type of flavouring agent used (Sousa et al., 2015).

Regarding the impact on the fatty acid profile, olive oils flavoured with some herbs or spices, specially laurel and oregano, show a slight higher oleic acid content and a minor reduction of the concentration of saturated fatty acids, which trends although statistically significant, do not reveal a practical impact of the flavouring process (Sousa et al., 2015).

The incorporation of essential oils usually is a beneficial procedure in terms of the oils' quality parameters, limiting the oxidation of the lipid fraction, thus enhancing the shelf-life, which can be related to the expected natural antioxidant potential of the essential oils (Asensio, Nepote, & Grosso, 2013). However, there are differences according to the methods of obtaining flavoured olive oils. Co-extraction allows

**Table 1**
Olive oil flavouring by contact: type of flavouring agent, flavouring conditions and main effects observed.

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| Basil (*Ocimum basilicum*) | Dry basil<br>5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Ayadi et al. (2009) |
| | Dry basil<br>15% | Ultrasound<br>466 W for 10 min | (−) Decrease of the content of the terpenes, esters and volatile compounds<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents | Soares et al. (2020) |
| | Dry basil<br>15% (w/w) | 7 and 15 days at room temperature | (+) Increase of the content of the terpenes, esters and ketones volatile compounds<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents<br>(−) Decrease ofthe oxidative stability | |
| | Dry basil<br>5% (w/w) | 15 days at 15–18 °C | (+) Increase of the oxidative stability<br>(+) Increase of the sensory attributes<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents | Baiano et al. (2016); Caponio et al. (2016); Romaniello and Baiano (2018) |
| | Dry basil<br>0.011, 0.055 and 0.110 g/kg | 15 days at room temperature | (+) Increase of the sensory attributes<br>(−) Increase of the peroxide value only by 0.110 g/kg<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the oxidative stability | Bobiano et al. (2019) |
| | Fresh basil leaves<br>50 and 150 g/L | Ultrasound<br>25 kHz | (+) Use of ultrasound accelerated the aromatization process | Veillet, Tomao, and Chemat (2010) |
| Black pepper (*Piper nigrum*) | Dry black pepper<br>10 g/L | 90 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Sousa et al. (2015) |
| Caraway (*Carum carvi*) | Crushed caraway seeds<br>150 g/L | 6 h at 25 °C | (+) Increase of the antioxidant activity<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Assami, Chemat, Meklati, and Chemat (2016) |
| | Crushed caraway seeds<br>150 g/L | Ultrasound<br>25 kHz | (+) Increase of the antioxidant activity<br>(+) Decrease of the time of flavouring due to the use of ultrasounds<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | |
| Chili pepper (*Capsicum frutescens*) | Dry chili pepper<br>10 g/L | 90 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Sousa et al. (2015) |
| | Dry chili pepper<br>20% (w/w) | 7 days at 15–18 °C | (+) Increase of the phenolic compounds content<br>(+) Increase of the oxidative stability | Baiano et al. (2016); Romaniello and Baiano (2018) |
| Cinnamon (*Cinnamomum verum*) | Dry cinnamon<br>1.5% (w/v) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds | Rodrigues et al. (2021) |

(*continued on next page*)

**Table 1** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| | | | content<br>(+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the oxidative stability | |
| Garlic (*Allium sativum*) | Fresh garlic<br>10 g/L | 90 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Sousa et al. (2015) |
| | Dry garlic<br>10% (w/w) | 7 days at 15–18 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Baiano et al. (2016); Romaniello and Baiano (2018) |
| | Fresh garlic<br>40 g/200 g | 5 min at 100 °C | (+) Increase of the antioxidant activity<br>(+) Decrease of the peroxide value<br>(−) Decrease of the phenolic compounds contents | Kishimoto and Kashiwagi (2020) |
| | Fresh garlic<br>10% (w/w) | 7 days at 15–18 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the sensory attributes | Caponio et al. (2016) |
| | Dry garlic<br>50 g/L | 15 days at room temperature | (+) Increase of the content of the terpenes volatile compounds | Perestrelo, Silva, Silva, and Câmara (2017) |
| | Dry garlic<br>20, 30 and 40 g/L | 210 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the fruitiness intensity<br>(−) Increase of the peroxide value | Gambacorta et al. (2007) |
| | Dry garlic<br>1.5% (w/v) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the oxidative stability | Rodrigues et al. (2021) |
| Ginger (*Zingiber officinale*) | Dry ginger<br>1% | 60 days at 4 ± 2 °C or 20 ± 2 °C | (−) Increase of the free acidity<br>(−) Decrease of the contents of oleic acid | Ambrosewicz-Walacik and Tanska (2015) |
| Laurel leaves (*Laurus nobilis*) | Dry laurel leaves<br>10 g/L | 90 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Sousa et al. (2015) |
| | Fresh laurel leaves<br>5% | 12 h at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity | Taleb et al. (2016) |
| Lavender (*Lavandula*) | Dry lavender<br>5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Ayadi et al. (2009) |
| Lemon (*Citrus limonum*) | Lemon zest dried<br>5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Ayadi et al. (2009) |
| | Dry lemon<br>20, 40, 60 and 80 g/L | 2 months at room temperature | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value | Issaoui, Flamini, Hajaij, Cioni, and Hammami (2011) |
| Mint (*Mentha* spp.) | Dry mint<br>5% (w/w) | 15 days at room temperature | (+) Increase of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated | Ayadi et al. (2009) |

(*continued on next page*)

**Table 1** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| | | | fatty acids<br>(+) Increase of the oxidative stability<br>(−) Decrease of the phenolic compounds contents | |
| Oleaster (*Olea europaea* var. *sylvestris*) | Dry olive leaves powder<br>10 g/100 mL | 1 day at 25 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the antioxidant activity<br>(+) Increase of the oxidative stability | Ayadi, Yahia, Othman, and Hannachi (2020) |
| | Dry olive leaves powder<br>4 g/20 mL, 7 g/110 mL and 10 g/200 mL | 12, 30 and 48 h at room temperature | (+) Increase of the phenolic compounds content<br>(+) Increase of the organoleptic quality<br>(+) Increase of the oxidative stability | Hannachi and Elfalleh (2020) |
| Olive tree leaves (*Olea europaea*) | Ground dry olive leaves<br>1 g/10 mL | Ultrasound<br>225 W for 20 min at 25 °C | (+) Increase of the phenolic compounds contents | Japón-Luján et al. (2008) |
| | Dry olive leaves<br>5, 10 and 15% (w/w) | 3000 rpm for 30–40 s | (+) Increase of the phenolic compounds contents<br>(+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the content of total chlorophylls | Nenadis, Moutafidou, Gerasopoulos, and Tsimidou (2010) |
| | Dry olive leaves<br>150 g/L<br>Ground dry olive leaves<br>150 g/L | Ultrasound<br>60 W for 45 min at 16 °C<br>45 min at 16 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Achat et al. (2012) |
| Orange (*Citrus sinensis*) | Fresh orange peel<br>1, 3 and 5% (w/w) | 10 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the carotenoid content<br>(−) Increase of the free acidity<br>(−) Decrease of the oxidative stability | Khemakhem, Yaiche, Ayadi, and Bouaziz (2015) |
| Oregano (*Origanum vulgare*) | Dry oregano<br>10 g/L | 90 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Sousa et al. (2015) |
| | Dry oregano<br>5 g/100 mL | 11 days at room temperature | (+) Increase of the antioxidant activity | Nevado, Robledo, and Callado (2012) |
| | Dry oregano<br>50 g/L | 15 days at room temperature | (+) Increase of the content of the terpenes volatile compounds | Perestrelo et al. (2017) |
| | Dry oregano<br>0.011, 0.055 and 0.110 g/kg | 14 days at room temperature | (+) Decrease of the free acidity<br>(−) Increase of the peroxide value only for 0.110 g/kg<br>(−) Increase of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(−) Decrease of the oxidative stability | Bobiano et al. (2019) |
| | Dry oregano<br>5% (w/w) | 1, 2 or 3 days at 40 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the content of total chlorophylls<br>(+) Increase of the oxidative stability | Damechki, Sotiropoulou, and Tsimidou (2001) |
| | Dry oregano<br>10 g/kg | 15 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Clodoveo et al. (2016) |
| | Dry oregano<br>10, 20 and 40 g/L | 210 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the fruitiness and bitterness intensity<br>(−) Increase of the peroxide value | Gambacorta et al. (2007) |
| | Dry oregano<br>1, 2, 3.5, 5 and 7 g/mL | 400 and 700 rpm at 37 ± 3 °C for 30 h | (−) Decrease of the oxidative stability | Peñalvo et al. (2016) |
| Paprika (*Capsicum annuum*) | Dry paprika<br>10 and 20% (w/w) | 30 days at room temperature | (+) Increase of the content of the terpenes volatile compounds<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Caporaso et al. (2013) |
| Pepper (*Capsicum* spp.) | Dry pepper<br>20% (w/w) | 7 days at 15–18 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(+) Increase of the sensory attributes | Caponio et al. (2016) |

(*continued on next page*)

**Table 1** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| | | | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | |
| | Fresh pepper<br>10, 20 and 40 g/L | 210 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the fruitiness intensity<br>(−) Increase of the peroxide value | Gambacorta et al. (2007) |
| | Dry pepper<br>1% | 60 days at 4 ± 2 °C and 20 ± 2 °C | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Decrease of the contents of oleic acid | Ambrosewicz-Walacik and Tanska (2015) |
| | Dry pepper<br>50 mg/5 g | 30 days at 20 °C | (+) Increase of the oxidative stability | Plastina et al. (2021) |
| | Dry pepper<br>10% | 14 days at room temperature | (+) Decrease of the free acidity<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the antioxidant activity<br>(+) Increase of the carotenoid content<br>(+) Increase of the content of the terpenes volatile compounds<br>(−) Increase of the peroxide value | Zellama et al. (2022) |
| Pink pepper (*Schinus terebinthifolius*) | Dry pink pepper<br>10% (w/w) | Ultrasound<br>37 min at 35 °C and 25 kHz | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid<br>(+) Increase of the content of the terpenes volatile compounds<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the extinction coefficients | Bittencourt Fagundes et al. (2020) |
| | Dry pink pepper<br>10% (w/w) | 7 and 15 days at room temperature | | |
| Rosemary (*Salvia rosmarinus*) | Dry rosemary<br>5 g/100 mL | 11 days at room temperature | (+) Increase of the antioxidant activity | Nevado et al. (2012) |
| | Dry rosemary<br>5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid and all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Ayadi et al. (2009); Kasimoglu et al. (2018) |
| | Dry rosemary<br>10% (w/w) | Ultrasound<br>798 W during 10 min | (+) Increase of the content of terpenes, esters and ketones volatile compounds<br>(+) Increase of the phenolic compounds contents<br>(−) Decrease of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Soares et al. (2020) |
| | Dry rosemary<br>10% (w/w) | 7 and 15 days at room temperature | | |
| | Dry rosemary<br>5% (w/w) | 1, 2 and 3 days at 40 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of in total chlorophyll content<br>(+) Increase of the oxidative stability | Damechki et al. (2001) |
| | Dry rosemary<br>5 g/50 mL | Microwave at 400 W during 10 min | (+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the content of the terpenes volatile compounds<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Benmoussa et al. (2016) |
| | Dry rosemary<br>5 g/50 mL | 12 h at room temperature | | |
| | Dry rosemary<br>10, 20 and 40 g/L | 210 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the fruitiness intensity<br>(−) Increase of the peroxide value | Gambacorta et al. (2007) |
| | Fresh rosemary<br>5% | 12 h at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity | Taleb et al. (2016) |
| | Dry rosemary<br>1.5% (w/v) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the oxidative stability | Rodrigues et al. (2021) |
| | Dry rosemary<br>5% (w/w) | 15 days at room temperature | (+) Increase of the content of the terpenes volatile compounds | Perestrelo et al. (2017) |
| Sage (*Salvia officinalis*) | Dry sage<br>5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents all vitamin E | Ayadi et al. (2009) |

(*continued on next page*)

**Table 1** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| | | | isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Decrease of the phenolic compounds contents<br>(−) Increase of the free acidity | |
| Sweet lemon (*Citrus limetta*) | Fresh sweet lemon peel 1, 3 and 5% (w/w) | 10 days at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the carotenoid content<br>(−) Increase of the free acidity<br>(−) Decrease of the oxidative stability | Khemakhem et al. (2015) |
| Thyme (*Thymus vulgaris*) | Dry thyme 5 g/100 mL | 11 days at room temperature | (+) Increase of the antioxidant activity | Nevado et al. (2012) |
| | Dry thyme 5% (w/w) | 15 days at room temperature | (+) Decrease of the peroxide value<br>(+) Increase of the contents all vitamin E isoforms<br>(+) Decrease of the contents of saturated fatty acids<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Decrease of the phenolic compounds contents | Ayadi et al. (2009) |
| | Dry thyme 50 g/L | 15 days at room temperature | (+) Increase of the content of the terpenes volatile compounds | Perestrelo et al. (2017) |
| | Dry thyme 10 g/kg | 15 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Clodoveo et al. (2016) |
| | Dry thyme 20, 40, 60 and 50 g/L | 60 days at room temperature | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value | Issaoui et al. (2011) |
| | Dry thyme 1% | 60 days at 4 ± 2 °C and 20 ± 2 °C | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Decrease of the contents of oleic acid | Ambrosewicz-Walacik and Tanska (2015) |

(−) negative effect; (+) positive effect; n.a.: information not available (i.e., not provided by the author(s)).

obtaining cleaner flavoured olive oils and enables reaching a faster sensory stability than the contact method, which requires greater contact periods, depending on the flavouring agent under evaluation (Caponio et al., 2016). In addition, the co-extraction method is usually more efficient regarding the extraction of phenolic compounds, thus leading to a flavoured olive oil richer in bioactive antioxidant compounds, as well as in flavour-related compounds (Dalgic, Ozkan, & Karacabey, 2018).

As for the use of essential oils, these can be obtained from different parts of the plants such as bark, flowers, fruits, leaves, roots and stems (Pateiro et al., 2021), with the advantage of being directly added to the oils and thus avoiding the degradation of their constituents, since they are not subjected to the usual oil extraction conditions (Marić et al., 2020). In fact, essential oils are known as natural preservatives due to their antioxidant and antimicrobial activities, allowing the aroma to last longer, being in general used in very small amounts for flavouring the olive oils (Torres-Alvarez et al., 2020).

### 5.1.2. Disadvantages

Olive oils flavouring is a traditional and ancient practice, namely in the Mediterranean region, allowing the valorisation of several by-products, which would be considered and treated as waste. However, this procedure can also intentionally mask the presence of some sensory defects or their intensities. For example, an olive oil can be classified as lampante only due to the sensory evaluation, showing a chemical quality similar to that of extra virgin or virgin olive oils. Thus, masking the intensity of the sensory defects through the incorporation of flavouring agents may allow its fraudulent commercialization as flavoured olive oils or, depending on the intensity perception of the flavouring agent as virgin olive oil (Bobiano et al., 2019).

Besides flavouring can also result in poorer oil from a chemical point of view. For example, attention should be paid to the amount of flavouring agent that is added to the olive oil. The use of high levels of these agents may promote an excess of flavouring, completely masking the usual and appreciated olive oil flavour and making it unpleasant for consumers. However, the amount used depends on each flavouring agent, as the properties vary according to each one (Sousa et al., 2015).

The most negative effects reported in the literature due to the use of flavouring/fortification agents are linked with the impact on the quality parameters of olive oils (Fig. 3). Furthermore, it should be remarked that, according to the findings of some studies, some flavouring agents promote a pro-oxidant effect, for example, when pepper is used in high concentrations (Baiano et al., 2009) or when lemon verbena essential oil was used (Cherif, Rodrigues, Veloso, Zaghdoudi, et al., 2021). This behaviour could be attributed to the intrinsic and specific composition of the flavouring agent (e.g., presence of ascorbic acid, reducing sugars or other reducing compounds). Another issue to consider is the water activity of the flavouring agent since water can act as a catalyst for the oxidation reaction, thus affecting the oxidative stability of the flavoured olive oils (Kasimoglu et al., 2018). The high water content of fresh versus dehydrated garlic was suggested as a possible explanation for the lower antioxidant activity found in olive oils flavoured with the former, which may have promoted unwanted oxidation reactions leading to a decrease of the antioxidant activity (Sousa et al., 2015). The flavour agents' incorporation can also introduce microorganisms, like moulds, yeasts and bacteria (Ciafardini, Zullo, & Peca, 2004), as well as heavy metals (Ziarati, Makki, Vambol, & Vambol, 2019), but further studies are needed to fully understand the real impact on the flavoured oils.

**Table 2**
Olive oil flavouring by co-extraction: type of flavouring agent, flavouring conditions and main effects observed.

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| Basil (*Ocimum basilicum*) | Dry basil 5% (w/w) | 30 min of malaxation at 26 °C | (+) Increase of the oxidative stability<br>(+) Increase of the sensory attributes<br>(−) Decrease of the phenolic compounds contents<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Caponio et al. (2016) |
| Cape gooseberry (*Physalis peruviana*) | Fresh cape gooseberry 0.40, 0.99, 1.58 and 1.98% (w/w) | 20, 30, 45, 60 and 70 min of malaxation at 18, 25, 35, 45 and 52 °C | (+) Increase of the content of total chlorophylls<br>(+) Increase of the carotenoid content<br>(+) Increase of the oxidative stability<br>(−) Increase of the content of the undesired volatile compounds (i.e. 2-furaldehyde and 1,2-xylene) | Dalgic et al. (2018) |
| Cumin (*Cuminum cyminum*) | Seeds cumin 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2018) |
| Cardamom (*Elettaria cardamomum*) | Seed cardamom 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2019) |
| Cinnamon (*Cinnamomum verum*) | Bark of cinnamon 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the cinnamaldehyde volatile compounds | Trabelsi et al. (2019) |
| Clove (*Syzygium aromaticum*) | Dry clove 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2018) |
| Garlic (*Allium sativum*) | Dehydrated garlic 10 kg/300 kg | malaxation at 30–35 °C | (+) Increase of the sensory attributes<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents | Baiano et al. (2009) |
| | Fresh garlic 10% (w/w) | 30 min of malaxation at 26 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(+) Increase of the sensory attributes<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Caponio et al. (2016) |
| Ginger (*Zingiber officinale*) | Dry ginger 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2019) |
| Leaves laurel (*Laurus nobilis)* | Dry leaves laurel 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2019) |
| Lemon (*Citrus limon*) | Fresh lemon 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2018) |
| | Fresh whole lemon 60 kg/300 kg | Malaxation at 30–35 °C | (+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents | Baiano et al. (2009) |
| | Fresh lemon 0.35 kg/kg | 30–40 min of malaxation at 32–34 °C | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the contents of oleic acid<br>(+) Increase of the content of the terpenes volatile compounds<br>(+) Increase of the oxidative stability<br>(−) Decrease of the phenolic compounds contents | Sacchi, della Medaglia, Paduano, Caporaso, and Genovese (2017) |
| Olive tree leaves (*Olea europaea*) | Fresh olive leaves 5 and 10% (w/w) | 30 and 40 min of malaxation at 25 °C | (+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the content of the esters and aldehyde volatile compounds | Malheiro et al. (2017) |
| | Fresh olive leaves 1% (w/w) | 45 min of malaxation at 22 °C | (+) Increase of the sensory attributes<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Marx et al. (2022) |

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**Table 2** (*continued*)

| Agent | Conditions: Type and amount | Conditions: Time and temperature | Effect | References |
|---|---|---|---|---|
| | | | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Increase of the contents of saturated fatty acids | |
| | Fresh olive leaves 1, 2, 3 and 5% (w/w) | 60 min of malaxation at 24 °C | (+) Increase of the fruitiness and bitterness intensity<br>(+) Iincrease of the content of the aldehyde volatile compounds | Di Giovacchino, Angerosa, and di Giacinto (1996) |
| | Fresh olive leaves 1, 2.5, 5 and 10% (w/w) | 30 min of malaxation at 27 °C | (+) Increase of the intensity of the positive sensory attributes<br>(+) Increase of the contents all vitamin E isoforms<br>(+) Increase of the oxidative stability | Malheiro, Casal, Teixeira, Bento, and Pereira (2013) |
| | Fresh olive leaves 2 and 5%/ 3500 g | 40 min of malaxation with ultrasound 200 W and 26 kHz during 5, 10, 15, 20, 25, 30, 35 and 40 min | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Sari and Ekinci (2017) |
| | Olive leaves water extract 500 g/5 L/ 20 kg | 60 min of malaxation | (+) Increase of the fruitiness and bitterness intensities<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the antioxidant activity | Kiritsakis, Rodríguez-Pérez, Gerasopoulos, and Segura-Carretero (2017) |
| | Fresh olive leaves 1.5–2 kg | 30 min of malaxation at 27 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Ammar et al. (2017); Sonda, Akram, Boutheina, Flamini, and Mohamed (2014) |
| | Fresh olive leaves 1 and 3% (w/w) | 30 min of malaxation at 30 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the antioxidant activity | Sevim, Tuncay, and Koseoglu (2013) |
| Olive mill wastewater | Olive mill wastewater extracts 5 L/20 kg | 60 min of malaxation | (+) Decrease of the peroxide value<br>(+) Increase of the antioxidant activity<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Suárez et al. (2011) |
| Orange (*Citrus sinensis*) | Fresh orange peel | 30 min of malaxation at 25 °C | n.a. | Mannina et al. (2012) |
| Oregano (*Origanum vulgare*) | Powder oregano 30 kg/300 Kg | Malaxation at 30–35 °C | (+) Decrease of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Baiano et al. (2009) |
| | Dry oregano 0.4 and 4.6% (w/w) | 30 min of malaxation at 28–30 °C | (+) Increase of the phenolic compounds contents<br>(+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(+) Increase of the oxidative stability | Peres, Roldão, Mourato, Martins, and Ferreira-Dias (2021) |
| | Dry oreganoat 10 g/kg | Olive past sonication with ultrasound 2, 4, 6 and 8 min, after malaxation | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Clodoveo et al. (2016) |
| Pepper (*Capsicum* spp) | Dry pepper 10 kg/300 kg | Malaxation at 30–35 °C | (+) Decrease of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Baiano et al. (2009) |
| | Dry pepper 20% (w/w) | 30 min of malaxation at 26 °C | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(+) Increase of the sensory attributes<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Caponio et al. (2016) |
| | | | | Baiano et al. (2009) |

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**Table 2** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| Rosemary (*Salvia rosmarinus*) | Fresh rosemary 5.5 kg/300 kg | Malaxation at 30–35 °C | (+) Decrease of the phenolic compounds contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | |
| | Dry rosemary 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2019) |
| Thyme (*Thymus vulgaris*) | Dry thyme 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2018) |
| | Dry thyme at 10 g/kg | Olive past sonication with ultrasound 2, 4, 6 or 8 min, after malaxation | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Clodoveo et al. (2016) |
| Tomato (*Solanum lycopersicum*) | Lyophilized skin and seeds 0.240 kg/40 kg, 1 kg/40 kg, 0.270 kg/60 kg and 1.125 kg/60 kg | 35 min of malaxation at 27 °C | (+) Enrichment in the carotenoids<br>(+) Enrichment in the lycopene<br>(+) Increase of the antioxidant activity | Bendini et al. (2015) |
| Turmeric (*Curcuma longa*) | Dry thyme 50 g/kg | 30 min of malaxation at room temperature | (+) Increase of the content of the terpenes volatile compounds | Trabelsi et al. (2018) |

(−) negative effect; (+) positive effect; n.a.: information not available (i.e., not provided by the author(s)).

The flavouring technique applied may also be responsible for some disadvantages. For instance, in the case of the contact method, turbidity may occur as well as the extraction of undesirable compounds, such as waxes and bitter compounds, being possible the incorporation of some not native microorganisms. Also, the contact method can promote an excess of olive oil flavouring since it usually takes several weeks or months (Mannina et al., 2012; Yilmazer, Göksu Karagöz, Ozkan, & Karacabey, 2016). Once again, the possible negative effects may arise on the shelf-life of the flavoured oil, on its sensory characteristics and stability. Therefore, optimising the amount of flavouring agent used and the flavouring conditions would be of paramount importance as well as the standardization of the flavouring procedures. The co-extraction method also possesses several drawbacks regarding the non-homogeneous distribution of the flavouring agent during the oil extraction and its consequences in the extracted flavoured olive oil. Indeed, during the olives milling process, it is not ensured that the addition of the flavouring agent would allow obtaining, in each extraction batch, olive oils with similar characteristics. For example, when leaves and woody olive tree parts are used, the migration of compounds from the flavouring agent to the olive paste is affected as well as from this latter to the olive oil, influencing the quality and composition of the extracted oil (Bittencourt Fagundes et al., 2020).

Regarding the essential oil incorporation, the main disadvantages are related to the usual low yields and high costs involved in obtaining it. In fact, its attainment usually requires high consumption of energy, long periods of extraction at high temperatures, involving successive re-distillations of the extracts, which promotes the extraction and concentration of different polar compounds, some of them undesirable and that may cause the degradation of temperature-sensitive bioactive compounds (Dima & Dima, 2015; Pateiro et al., 2018). New extraction technologies are being developed to overcome these drawbacks, such as ultrasound-assisted extraction or microwave-assisted extraction, allowing the preservation of the bioactive compounds due to the use of low temperatures and avoiding/reducing the use of organic solvents. The use of essential oils presents other challenges due to their high volatility and low water solubility (Torres-Alvarez et al., 2020).

Concerning the usual quality parameters assessed during the olive oil analysis, it should be highlighted that the free acidity may not be an adequate parameter for the quality control of flavoured olive oils. This is because free acidity can be affected by several acids (e.g., citric acid) that may be present in plants or aromas arising during the preparation of the flavoured olive oil (Mannina et al., 2012).

Nevertheless, it should be strengthened that the research carried out on flavoured olive oils evidenced the difficulty to perform a fair comparison regarding the overall effects of the different flavouring strategies reported in the literature on the chemical-sensory quality of the flavoured olive oils. Namely, in the impact on the phenolic profiles since different olive cultivars were used to extract the oils evaluated, the olive trees were grown in different geographical locations under different agro-climatic conditions. The extraction scale and conditions are not usually comparable (Baiano et al., 2016).

## 6. Concluding remarks

The flavouring of olive oils is a traditional activity in Mediterranean countries that, in recent years, has emerged as an impactful commercial trend in the oil market. This trend appears as a response from the olive oil sector to innovate and provide novel and differentiated products, aiming to increase the olive oil consumption as well as to conquer new consumers. One way to achieve this is to modify olive oil's typical and

**Table 3**
Olive oil flavouring using essential oils: type of flavouring agent, flavouring conditions and main effects observed.

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and temperature | | |
| Black pepper (*Piper nigrum*) | 500 ppm | 365 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(+) Increase of the content of the terpenes volatile compounds | Benkhoud et al. (2021) |
| Chili pepper (*Capsicum frutescens*) | 0.5% (w/w) | 15–23 MPa for 10 min at 40 °C | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Gouveia, Duarte, Beirão Da Costa, Bernardo-Gil, and Moldão-Martins (2006) |
| | 0.05% (v/w) | n.a. | (+) Increase of the content of the terpenes volatile compounds | Kiralan, Goksu Karagoz, Ozkan, Kiralan, and Ketenoglu (2021) |
| Garlic (*Allium sativum*) | Crushed fresh garlic 2.5 g/10 mL | 9 days at room temperature | (−) Increase of the free acidity | González et al. (2017) |
| Laurel leaves (*Laurus nobilis*) | 0.05% (v/w) | n.a. | (+) Increase of the content of the terpenes volatile compounds | Kiralan et al. (2021) |
| Lemon verbena (*Aloysia citrodora*) | 0.1, 0.2, 0.3 and 0.4% (w/w) | 15 days at 18–25 °C | (+) Promote of the antioxidant and total reducing capacities (i.e., higher phenolic content)<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the oxidative stability | Cherif, Rodrigues, Veloso, Zaghdoudi, et al. (2021) |
| | 0.2–0.4% (w/w) | 15 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the carotenoid content<br>(+) Increase of the oxidative stability<br>(−) Increase of the extinction coefficients | Cherif, Rodrigues, Veloso, Pereira, and Peres (2021) |
| Orange (*Citrus sinensis*) | 500 ppm | 365 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(+) Increase of the content of the terpenes volatile compounds | Benkhoud et al. (2021) |
| Oregano (*Origanum vulgare*) | 0.05% (w/w) | 126 days at room temperature (23 °C) | (+) Increase of the phenolics contents<br>(+) Increase of the oxidative stability<br>(−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Asensio et al. (2013) |
| | 0.05% (v/w) | n.a. | (+) Increase of the content of the terpenes volatile compounds | Kiralan et al. (2021) |
| | 0.05% (w/w) | 28 days at room temperature; 28 days at 60 °C | (+) Decrease of the peroxide value<br>(+) Increase of the contents of oleic acid<br>(+) Increase of the oxidative stability | Asensio, Nepote, and Grosso (2011) |
| Rosemary (*Salvia rosmarinus*) | 500 ppm | 365 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(+) Increase of the content of the terpenes volatile compounds | Benkhoud et al. (2021) |
| Thyme (*Thymus vulgaris*) | 0.05% (v/w) | n.a. | (+) Increase of the content of the terpenes volatile compounds | Kiralan et al. (2021) |
| | 500 ppm | 365 days at room temperature | (+) Decrease of the free acidity<br>(+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the sensory attributes<br>(+) Increase of the content of the terpenes volatile compounds | Benkhoud et al. (2021) |
| Zataria multiflora (*Shirazi thyme*) | 1000 ppm | n.a. | (+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Increase of the antioxidant activity<br>(+) Avoided the degradation of chlorophyll and carotenoids | Keramat, Aminlari, and Shekarforoush (2018) |

(−) negative effect; (+) positive effect; n.a.: information not available (i.e., not provided by the author(s)).

unique aroma by introducing new flavours more attractive to young and/or non-traditional consumers accustomed to spicier and/or aromatic sensations. The bibliographic survey highlighted that the most common flavouring agents studied by the academia are rosemary, oregano, garlic and basil, being flavouring by contact the most common technique, in-line with the commercially available flavoured oils that can be found on the markets. Nevertheless, the use of non-traditional Mediterranean flavour agents like cinnamon, coffee, chocolate, cloves, ginger, mint, cardamom, aniseed, mustard, poppy, and cannabis, can open new uses for this key ingredient, attracting new clients that are prone to novel sensations and gastronomic experiences. In this sense, flavoured olive oils can also increase the sales as well as the price of this food in traditional and not traditionally consuming countries. In this latter, the use of aromas and flavours typical of those cultures can

**Table 4**
Olive oil fortification: type of fortification, conditions and main effects observed.

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and Temperature | | |
| *Blakeslea trispora* | Direct contact with β-carotene 0.082 mg/mL | Direct addition | (+) Enrichment in the carotenoids<br>(+) Increase of the oxidative stability<br>(+) Increase of the shelf-life<br>(+) Enhance of the nutritional value<br>(−) Increase of the peroxide value<br>(−) Changed colour to yellow-orange | Murillo-Cruz et al. (2021a) |
| | Direct contact with β-carotene 0.041 and 0.082 mg/mL | Direct addition | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Changed colour to yellow-orange | Murillo-Cruz et al. (2021b) |
| | Direct contact with β-carotene 0.05, 0.1 and 0.15 mg/mL | Ultrasound 30 min | (−) Increase of the free acidity<br>(−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents<br>(−) Changed colour to orange | Murillo-Cruz et al. (2022) |
| Carrot (*Daucus carota*) | Carotenoid extract 200 and 400 ppm | Mixed by stirring for 30 min | (+) Increase of the oxidative stability | Yamani, Sakar, Boussakouran, and Rharrabti (2020) |
| Goji berries (*Lycium barbarum*) | Extraction of carotenoids 1.5 mg/100 g | Ultrasound 2 min | (+) Enrichment in the carotenoids<br>(+) Increase of the oxidative stability<br>(−) Decrease of the phenolic compounds content and α-tocopherol | Blasi et al. (2018); Montesano et al. (2019) |
| Marigold flowers (*Tagetes erecta*) | Direct contact with lutein 0.05, 0.1 and 0.15 mg/mL | Ultrasound 30 min | (−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients<br>(−) Decrease of the phenolic compounds contents<br>(−) Decrease of the oxidative stability<br>(−) Changed colour to orange | Murillo-Cruz et al. (2022) |
| Microalgae (*Chlorella vulgaris*) | Microalgae extract 0.5, 1 and 1.5% (w/w) | Ultrasound 50 W for 20 s at 25 °C | (+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Enrichment in the carotenoids<br>(+) Increase of the oxidative stability | Alavi and Golmakani (2017b) |
| Microalgae (*Scenedesmus almeriensis*) | Microalgae extract 0.1 and 0.21 mg/mL | Direct addition | (+) Decrease of the peroxide value<br>(+) Increase of the concentration of lutein, β-carotene<br>(+) Increase of the oxidative stability<br>(−) Increase of the extinction coefficients<br>(−) Changed colour to yellow-orange | Limón et al. (2015) |
| Myrtle (*Myrtus communis*) | Leaves extract 500 μL/500 g<br>Leaves extract 500 μL/500 g | Ultrasound 700 W for 1 min<br>60 min at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the phenolic compounds contents | Dairi et al. (2017) |
| Olive oil refining water | Dry extract 25 mL/25 mL | Mixed by stirring for 2 h at room temperature | (+) Increase of the antioxidant activity<br>(+) Increase of the phenolic compounds contents | Venturi et al. (2017) |
| Sage (*Salvia officinalis*) and Rosemary (*Rosmarinus officinalis*) | Extraction of carnosic acid 0.01 and 0.1% (w/w) | Direct addition | (−) Increase of the peroxide value<br>(−) Increase of the extinction coefficients | Zunin, Leardi, Bisio, Boggia, and Romussi (2010) |
| Spinach (*Spinacia oleracea*) | Lutein-zeaxanthin enrichment 75:25, 50:50, 25:75 (w/w) | 12, 24, 36, 48 and 60 h at 30 °C | (+) Enrichment in the lutein-zeaxanthin<br>(+) Enrichment in the carotenoids | Valle-Prieto et al. (2017) |
| Spirulina (*Arthrospira platensis*) | Spirulina powder 0.5, 1 and 1.5% (w/w) | Ultrasound 50 W for 42 days at 70 °C | (+) Decrease of the peroxide value<br>(+) Decrease of the extinction coefficients<br>(+) Enrichment in the carotenoids<br>(+) Increase of the oxidative stability | Alavi and Golmakani (2017a) |

(*continued on next page*)

**Table 4** (*continued*)

| Agent | Conditions | | Effect | References |
|---|---|---|---|---|
| | Type and amount | Time and Temperature | | |
| Thyme (*Thymus zygis*) and Wet bagasse | Thyme extract and olive pomace<br>2.5 g/100 g | Ultrasound and centrifugation for 10 min at 3500 rpm | (−) Decrease of the phenolic compounds contents<br>(+) Increase of the fruitiness and bitterness intensity<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Rubió et al. (2012) |
| Tomato (*Solanum lycopersicum*) | Pure lycopene<br>0.5 and 1 mg/100 mL | Room temperature | (+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Montesano, Cossignani, D'Arco, Simonetti, and Damiani (2006) |
| | Lycopene extraction<br>300 ppm | Commercial samples (n.a.) | (+) Enrichment in the lycopene<br>(+) Increase of the phenolic compounds contents<br>(+) Increase of the oxidative stability | Nieva-Echevarría et al. (2020) |
| | Lycopene extraction<br>350 mg/L | Commercial samples (n.a.) | (+) Increase of the antioxidant activity<br>(+) Increase of the oxidative stability | Garrido et al. (2013) |
| | Addition of oleoresin<br>250, 500, 1000 and 2000 μg/g | 200 rpm at 25 °C | (+) Increase of the antioxidant activity<br>(+) Increase of the oxidative stability | Kehili, Choura, Zammel, Allouche, and Sayadi (2018) |
| | Lycopene obtained from dried and ground skin and seeds<br>200, 500 and 1000 ppm | Stirring for 30 min | (+) Enrichment in the lycopene<br>(+) Increase of the antioxidant activity<br>(+) Increase of the phenolic compounds contents<br>(−) Decrease of content of unsaturated fatty acids | Azabou et al. (2020) |
| White tea and green tea | Lyophilized aqueous extract<br>1 mg/mL | Microwave<br>1000 W for 1, 3, 5 and 10 min | (−) Increase of the extinction coefficients<br>(−) Decrease of the α-tocopherol<br>(−) Decrease of the antioxidant activity<br>(−) Decrease of the oxidative stability | Malheiro, Casal, Lamas, Bento, and Pereira (2012) |

(−) negative effect; (+) positive effect; n.a.: information not available (i.e., not provided by the author(s)).

facilitate the inclusion of olive oil into their food style and normal diets.

Additionally, the fortification of olive oils with specific bioactive compounds, can be another strategy to enhance the already recognized nutritional/healthy characteristics of olive oils, allowing to enlarge the target consumers, namely by contributing to the recommended daily intake of some bioactive compounds (ex: carotenoids) through the usual oils consumption. Fortified oils can even be a vehicle for promoting the intake of several other compounds with beneficial effects, such as lycopene or fat-soluble vitamins (A, D, E and K). On the other hand, the fortification of olive oils by incorporating olive tree by-products (e.g., olive leaves or olive pomace), matrices rich in bioactive compounds such as phenolics, has gained relevance, namely from an academic point of view. This strategy is in-line with the basis of a circular economy aiming at the by-products valorisation, contributing to their incorporation into the production chain and reducing waste generation. Extracts prepared from other agro-industrial by-products have also been used for fortification. For example, tomato skins and seeds or their extracts, as lycopene sources, are well established. In addition, other plant-based by-products have also been applied, namely, leftovers from carrots, lettuce, spinach, orange, among others, allowing their reuse and consequently the valorisation of endogenous resources.

This integrated flavouring/fortification approaches clearly enhance the sustainability of the olive/olive oil sector, generating alternative high-value chains and promoting a positive impact at the environmental and social sustainability levels. This is of utmost relevance for small producers from low-density territories from inland areas of the Mediterranean basin, where olive growing is one of the few wealth-generating activities, favouring short-chain commercial circuits and encouraging the fair trade of these products.

It should be noticed that based on the compiled studies, there is no consensus regarding the benefits and/or disadvantages related with the flavouring/fortification processes, which greatly depend on several factors, such as the amount of flavouring/fortifying agent used, the contact time and temperature, as well as the quality of the raw olive oil chosen to be flavoured/fortified. Among all these, the flavouring/fortifying agent used plays a crucial role. Its choice is critical since it influences the oils' chemical characteristics, especially the peroxide value, acidity, oxidative stability, phenolic and other bioactive compounds contents, which can act as antioxidants or pro-oxidants.

Furthermore, it is clear that the aromatization and fortification of olive oils still present several challenges, namely concerning the technological methods applied and the standardization of the physicochemical-sensory quality of the final flavoured oil. In fact, it is required that the producers can guarantee that the legal limits regarding the quality parameters are not exceeded due to the flavouring process. Regarding the technological process, most of the oils are still flavoured in an artisanal way with very incipient monitoring/controlling tools. It is necessary to optimize the flavouring technologies, especially those by contact or co-extraction, to ensure the consistency of the product characteristics at the production and also the use of greener emerging technologies. Vacuum, microwave and ultrasound technologies should be envisaged and optimized in view of establishing a better aromatization/extraction process. These techniques may promote the incorporation of a greater amount of the flavouring agent and respective bioactive

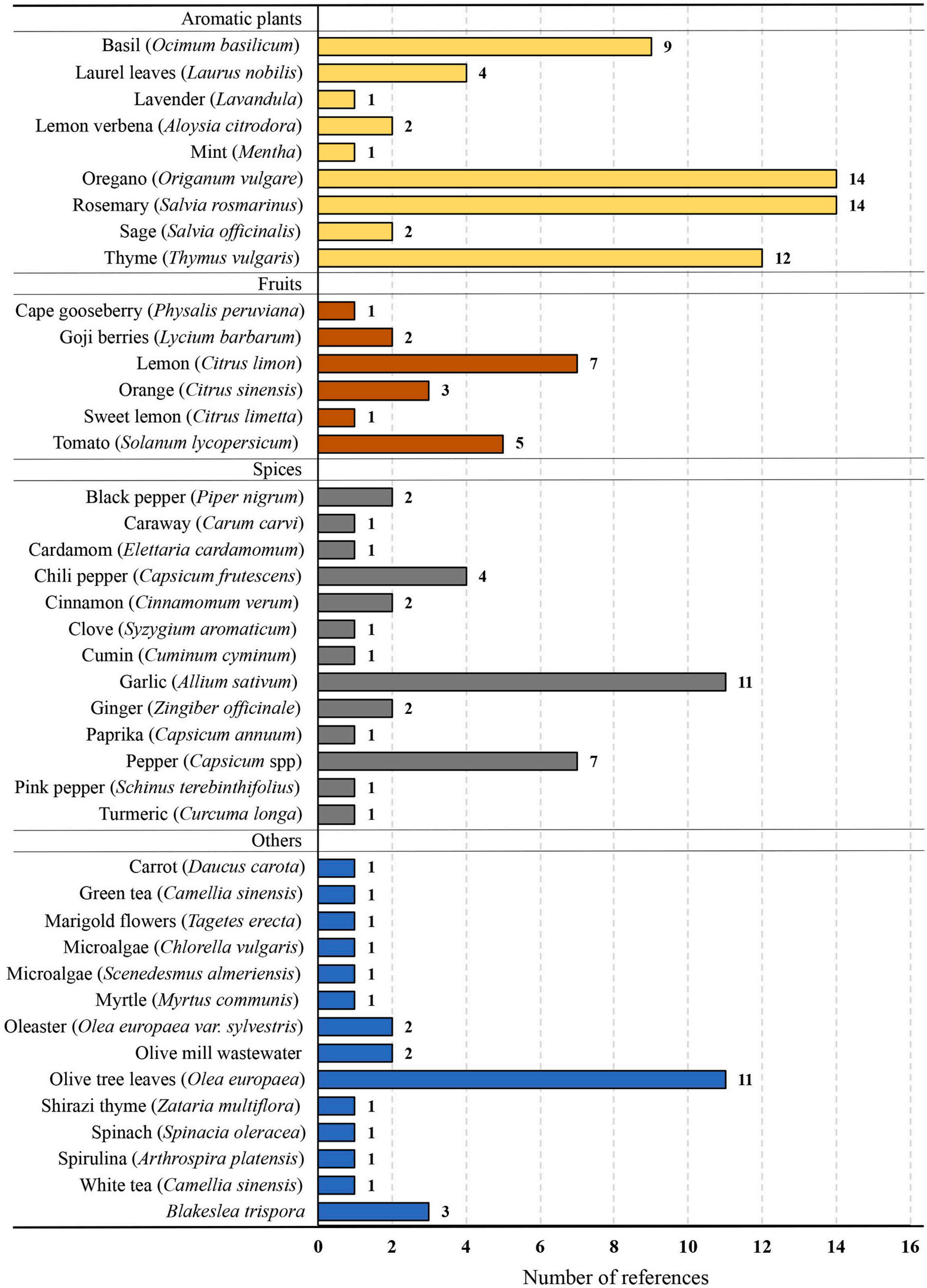


**Fig. 2.** Frequency, in number of references, compiled from the literature (1996–2022), of each flavouring and fortification agent used for obtaining flavoured olive oils.

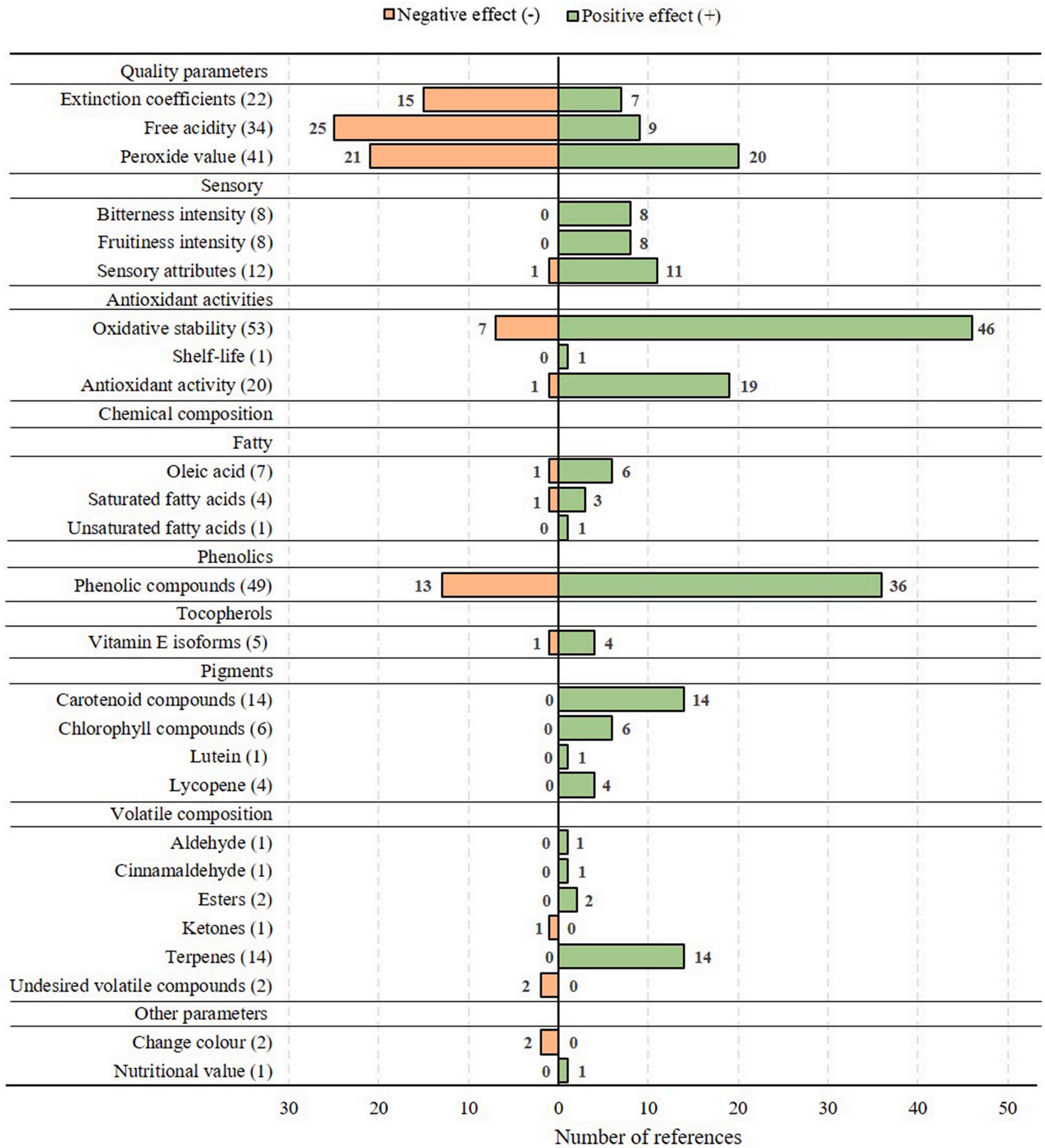


**Fig. 3.** Frequency, in number of references, compiled from the literature (1996–2022), of positive (+) and negative (−) effects attributed to the olive oil flavouring or fortification with different agents.

compounds into the oils, minimizing at the same time possible negative impacts on the known olive oils quality and bioactivity. In this sense, the optimization of the flavouring/fortifying process must be implemented, considering life cycle carbon-energy footprint analysis studies.

Another key aspect to be considered within the quality/safety assurance is the traceability throughout the production chain, including the raw materials (olives/commercial olive oil categories and flavouring/fortifying agents). For flavouring, the commercial categories of "extra virgin olive oil" and "virgin olive oil" should be preferably used. The latter category has been the most used, contributing to the economic sustainability of the olive oil sector since the lower-value oils are being flavoured, allowing increasing their selling price. However, flavouring can also have risks of fraudulent use of "Lampante Olive Oil". According to European legislation, this oil cannot be marketed directly to the consumer without undergoing a refining process. However, these oils could often be classified as virgin olive oils from a physicochemical quality point of view, being only classified as lampante oils due to the perception of intense sensory defects. The use of flavouring agents with a strong aroma can mask the defects, making fraud detection a hard task. On the other hand, flavouring organic and varietal oils and the capacity to guarantee authenticity is a growing analytical challenge. In organic olive oils, to keep the designation of "organic", the flavouring agents must also be produced under organic agronomic guidelines, while in varietal oils, the use of these agents still poses other challenges in terms of traceability throughout the chain. Thus, several concerns have emerged regarding questions of authenticity and product traceability. Also, the use of flavouring agents or flavouring methods poses serious concerns regarding the chemical-microbiological safety of the agents applied. For example, many pesticides and other contaminants have lipophilic properties and can easily migrate into the oil. Thus, good production practices must be guaranteed regarding the olive/olive oil production and the production chain of the flavouring agents.

Last but not least, there is a lack of legislation at the European Union level regarding the production and commercialization of flavoured/fortified olive oils, being not possible until now to market them in any oil commercial category. This aspect is of utmost importance since the lack of clear legislation and regulations leaves the market and the regulatory agents without any official guidelines/tools. This concern is evident in the recommendation of the "French Interprofessional Olive Association" (www.afidol.org). Depending on the flavouring/fortification method applied, this Association recommend the use of a denomination like "*Food preparation based on olive oil extra virgin/virgin olive oil flavoured with* …. " or "*Cooking preparation based on extra virgin olive oil/virgin olive oil flavoured with* …. " among other possible designations. However, the lack of regulations for these products introduces an undesirable entropy in the economic agents and does not favour the market transparency, not safeguarding the consumer's expectations.

Hence, the world of flavoured olive oils still needs to be further studied, being clear the need to go through a path that would allow the standardization of this Mediterranean tradition, aiming to limit and/or overcome the intrinsic variabilities of the flavouring/fortification commercial strategies.

## Declaration of competing interest

None.

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## References

Achat, S., Tomao, V., Madani, K., Chibane, M., Elmaataoui, M., Dangles, O., et al. (2012). Direct enrichment of olive oil in oleuropein by ultrasound-assisted maceration at laboratory and pilot plant scale. *Ultrasonics Sonochemistry, 19*, 777–786.

Alavi, N., & Golmakani, M. T. (2017a). Antioxidant properties of whole-cell Spirulina (*Arthrospira platensis*) powder expressed in olive oil under accelerated storage conditions. *Journal of Applied Phycology, 29*, 2971–2978.

Alavi, N., & Golmakani, M. T. (2017b). Improving oxidative stability of virgin olive oil by addition of microalga *Chlorella vulgaris* biomass. *Journal of Food Science & Technology, 54*, 2464–2473.

Ambrosewicz-Walacik, M., & Tanska, M. (2015). Stability of flavoured olive oils under different storage conditions. *Mitteilungen Klosterneuburg, 65*, 214–226.

Ammar, S., Kelebek, H., Zribi, A., Abichou, M., Selli, S., & Bouaziz, M. (2017). LC-DAD/ESI-MS/MS characterization of phenolic constituents in Tunisian extra-virgin olive oils: Effect of olive leaves addition on chemical composition. *Food Research International, 100*, 477–485.

Asensio, C. M., Nepote, V., & Grosso, N. R. (2011). Chemical stability of extra-virgin olive oil added with oregano essential oil. *Journal of Food Science, 76*, 445–450.

Asensio, C. M., Nepote, V., & Grosso, N. R. (2013). Consumers' acceptance and quality stability of olive oil flavoured with essential oils of different oregano species. *International Journal of Food Science and Technology, 48*, 2417–2428.

Assami, K., Chemat, S., Meklati, B. Y., & Chemat, F. (2016). Ultrasound-assisted aromatisation with condiments as an enabling technique for olive oil flavouring and shelf-life enhancement. *Food Analytical Methods, 9*, 982–990.

Ayadi, M. A., Grati-Kamoun, N., & Attia, H. (2009). Physico-chemical change and heat stability of extra virgin olive oils flavoured by selected Tunisian aromatic plants. *Food and Chemical Toxicology, 47*, 2613–2619.

Ayadi, A., Yahia, Y., Othman, K. ben, & Hannachi, H. (2020). Oxidative stability of olive oil enriched with oleaster leaves under accelerated storage conditions. *Journal of Applied Botany and Food Quality, 93*, 168–176.

Azabou, S., Sebii, H., Taheur, F. ben, Abid, Y., Jridi, M., & Nasri, M. (2020). Phytochemical profile and antioxidant properties of tomato by-products as affected by extraction solvents and potential application in refined olive oils. *Food Bioscience, 36*, 100664.

Baiano, A., Gambacorta, G., & la Notte, E. (2010). Aromatization of olive oil. *Transworld Research Network, 37/661*(2), 1–29.

Baiano, A., Previtali, M. A., Viggiani, I., Varva, G., Squeo, G., Paradiso, V. M., et al. (2016). As oil blending affects physical, chemical, and sensory characteristics of flavoured olive oils. *European Food Research and Technology, 242*, 1693–1708.

Baiano, A., Terracone, C., Gambacorta, G., & Notte, E. la (2009). Changes in quality indices, phenolic content and antioxidant activity of flavoured olive oils during storage. *JAOCS, Journal of the American Oil Chemists' Society, 86*, 1083–1092.

Bendini, A., di Lecce, G., Valli, E., Barbieri, S., Tesini, F., & Gallina Toschi, T. (2015). Olive oil enriched in lycopene from tomato by-product through a co-milling process. *International Journal of Food Sciences & Nutrition, 66*, 371–377.

Benkhoud, H., M'Rabet, Y., Gara ali, M., Mezni, M., & Hosni, K. (2021). Essential oils as flavouring and preservative agents: Impact on volatile profile, sensory attributes, and the oxidative stability of flavoured extra virgin olive oil. *Journal of Food Processing and Preservation*, 1–13, 00:e15379.

Benmoussa, H., Farhat, A., Elfalleh, W., di Maio, I., Servili, M., & Romdhane, M. (2016). A rapid application to flavour the olive oil with dried *rosmarinus officinalis* L. leaves: Microwave-assisted maceration. *Journal of Food Processing and Preservation, 41*, Article e12885.

Bittencourt Fagundes, M., Ballus, C. A., Perceval Soares, V., de Freitas Ferreira, D., Sena Vaz Leães, Y., Sasso Robalo, S., et al. (2020). Characterization of olive oil flavoured with Brazilian pink pepper (*Schinus terebinthifolius* Raddi) in different maceration processes. *Food Research International, 137*, 109593.

Blasi, F., Rocchetti, G., Montesano, D., Lucini, L., Chiodelli, G., Ghisoni, S., et al. (2018). Changes in extra-virgin olive oil added with *Lycium barbarum* L. carotenoids during frying: Chemical analyses and metabolomic approach. *Food Research International, 105*, 507–516.

Bobiano, M., Rodrigues, N., Madureira, M., Dias, L. G., Veloso, A. C. A., Pereira, J. A., et al. (2019). Unmasking sensory defects of olive oils flavoured with basil and oregano using an electronic tongue-chemometric tool. *JAOCS, Journal of the American Oil Chemists' Society, 96*, 751–760.

Caponio, F., Durante, V., Varva, G., Silletti, R., Previtali, M. A., Viggiani, I., et al. (2016). Effect of infusion of spices into the oil vs. combined malaxation of olive paste and spices on quality of naturally flavoured virgin olive oils. *Food Chemistry, 202*, 221–228.

Caporaso, N., Paduano, A., Nicoletti, G., & Sacchi, R. (2013). Capsaicinoids, antioxidant activity, and volatile compounds in olive oil flavoured with dried chili pepper (*Capsicum annuum*). *European Journal of Lipid Science and Technology, 115*, 1434–1442.

Cherif, M., Rodrigues, N., Veloso, A. C. A., Pereira, J. A., & Peres, A. M. (2021). Kinetic study of the microwave-induced thermal degradation of cv. Arbequina olive oils flavoured with lemon verbena essential oil. *JAOCS, Journal of the American Oil Chemists' Society, 98*, 1021–1032.

Cherif, M., Rodrigues, N., Veloso, A. C. A., Zaghdoudi, K., Pereira, J. A., & Peres, A. M. (2021). Kinetic-thermodynamic study of the oxidative stability of Arbequina olive oils flavoured with lemon verbena essential oil. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 140*, 110711.

Ciafardini, G., Zullo, B. A., & Peca, G. (2004). Presence of microorganisms in flavoured extra-virgin olive oil. *Annals of Microbiology, 54*, 161–168.

Clodoveo, M. L., Dipalmo, T., Crupi, P., Durante, V., Pesce, V., Maiellaro, I., et al. (2016). Comparison between different flavoured olive oil production techniques: Healthy value and process efficiency. *Plant Foods for Human Nutrition, 71*, 81–87.

Commission Implementing Regulation (EU) Nº 29/2012 on marketing standards for olive oil. Official Journal of the European Union (L.12, p.14-22).

Commission Regulation (EEC) Nº. 2568/91 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. Official Journal of the European Communities (L.248, p.1-82).

Contreras, M. del M., Lama-Muñoz, A., Espínola, F., Moya, M., Romero, I., & Castro, E. (2020). Valorization of olive mill leaves through ultrasound-assisted extraction. *Food Chemistry, 314*, 126218.

Dairi, S., Carbonneau, M. A., Galeano-Diaz, T., Remini, H., Dahmoune, F., Aoun, O., et al. (2017). Antioxidant effects of extra virgin olive oil enriched by myrtle phenolic extracts on iron-mediated lipid peroxidation under intestinal conditions model. *Food Chemistry, 237*, 297–304.

Dalgic, L., Ozkan, G., & Karacabey, E. (2018). Transition optimization of bioactive and volatile compounds from cape gooseberry to olive oil during malaxation process. *Journal of Food Processing and Preservation, 42*, Article e13470.

Damechki, M., Sotiropoulou, S., & Tsimidou, M. (2001). Antioxidant and pro-oxidant factors in oregano and rosemary gourmet olive oils. *Grasas y Aceites, 52*, 207–213.

Di Giovacchino, L., Angerosa, F., & di Giacinto, L. (1996). Effect of mixing leaves with olives on organoleptic quality of oil obtained by centrifugation. *JAOCS, Journal of the American Oil Chemists' Society, 73*, 371–374.

Dima, C., & Dima, S. (2015). Essential oils in foods: Extraction, stabilization, and toxicity. *Current Opinion in Food Science, 5*, 29–35.

European Commission Regulation (EU) No 432/2012. (2012). Establishing a list of permitted health claims made on foods other than those referring to the reduction of disease risk and to children's development and health. *Official Journal of the European Union, L136*, 1–40.

Foscolou, A., Critselis, E., & Panagiotakos, D. (2018). Olive oil consumption and human health: A narrative review. *Maturitas, 118*, 60–66.

Gambacorta, G., Faccia, M., Pati, S., Lamacchia, C., Baiano, A., & la Notte, E. (2007). Changes in the chemical and sensorial profile of extra virgin olive oils flavoured with herbs and spices during storage. *Journal of Food Lipids, 14*, 202–215.

Garrido, M., González-Flores, D., Marchena, A. M., Prior, E., García-Parra, J., Barriga, C., et al. (2013). A lycopene-enriched virgin olive oil enhances antioxidant status in humans. *Journal of the Science of Food and Agriculture, 93*, 1820–1826.

González, R., Vidoni, M., Locatelli, D., & Camargo, A. (2017). Quality evaluation and discrimination of flavouring process of garlic-flavoured vegetable oils. *International Journal of Food Properties, 20*, 1016–1024.

Gouveia, A. F., Duarte, C., Beirão Da Costa, M. L., Bernardo-Gil, M. G., & Moldão-Martins, M. (2006). Oxidative stability of olive oil flavoured by *Capsicum frutescens* supercritical fluid extracts. *European Journal of Lipid Science and Technology, 108*, 421–428.

Hannachi, H., & Elfalleh, W. (2020). Enrichment of olive oil with polyphenols from oleaster leaves using central composite design for the experimental measurements. *Analytical Letters, 54*, 590–607.

Issaoui, M., Flamini, G., Hajaij, M. E., Cioni, P. L., & Hammami, M. (2011). Oxidative evolution of virgin and flavoured olive oils under thermo-oxidation processes. *JAOCS, Journal of the American Oil Chemists' Society, 88*, 1339–1350.

Japón-Luján, R., Janeiro, P., & de Castro, M. D. L. (2008). Solid-liquid transfer of biophenols from olive leaves for the enrichment of edible oils by a dynamic ultrasound-assisted approach. *Journal of Agricultural and Food Chemistry, 56*, 7231–7235.

Kandylis, P., Vekiari, A. S., Kanellaki, M., Grati Kamoun, N., Msallem, M., & Kourkoutas, Y. (2011). Comparative study of extra virgin olive oil flavour profile of Koroneiki variety (*Olea europaea* var. *Microcarpa alba*) cultivated in Greece and Tunisia during one period of harvesting. *Lebensmittel-Wissenschaft und -Technologie-Food Science and Technology, 44*, 1333–1341.

Kasimoglu, Z., Tontul, I., Soylu, A., Gulen, K., & Topuz, A. (2018). The oxidative stability of flavoured virgin olive oil: The effect of the water activity of rosemary. *Journal of Food Measurement and Characterization, 12*, 2080–2086.

Kehili, M., Choura, S., Zammel, A., Allouche, N., & Sayadi, S. (2018). Oxidative stability of refined olive and sunflower oils supplemented with lycopene-rich oleoresin from tomato peels industrial by-product, during accelerated shelf-life storage. *Food Chemistry, 246*, 295–304.

Keramat, M., Aminlari, M., & Shekarforoush, S. (2018). Improving oxidative stability of virgin olive oil: Comparison of *zataria multiflora* essential oil with α-tocopherol. *Nutrition and Food Sciences Research, 5*, 19–28.

Khemakhem, I., Yaiche, C., Ayadi, M. A., & Bouaziz, M. (2015). Impact of aromatization by *Citrus limetta* and *Citrus sinensis* peels on olive oil quality, chemical composition and heat stability. *JAOCS, Journal of the American Oil Chemists' Society, 92*, 701–708.

Kiralan, S. S., Goksu Karagoz, S., Ozkan, G., Kiralan, M., & Ketenoglu, O. (2021). Changes in volatile compounds of virgin olive oil flavored with essential oils during thermal and photo-oxidation. *Food Analytical Methods, 14*, 883–896.

Kiritsakis, K., Rodríguez-Pérez, C., Gerasopoulos, D., & Segura-Carretero, A. (2017). Olive oil enrichment in phenolic compounds during malaxation in the presence of olive leaves or olive mill wastewater extracts. *European Journal of Lipid Science and Technology, 119*, 1600425.

Kishimoto, N., & Kashiwagi, A. (2020). Evaluation of the process of flavouring olive oil with garlic. *Food Science and Technology Research, 26*, 605–610.

Limón, P., Malheiro, R., Casal, S., Acién-Fernández, F. G., Fernández-Sevilla, J. M., Rodrigues, N., et al. (2015). Improvement of stability and carotenoids fraction of virgin olive oils by addition of microalgae *Scenedesmus almeriensis* extracts. *Food Chemistry, 175*, 203–211.

Lolis, A., Badeka, A. V., & Kontominas, M. G. (2020). Quality retention of extra virgin olive oil, Koroneiki cv. packaged in bag-in-box containers under long term storage: A comparison to packaging in dark glass bottles. *Food Packaging and Shelf Life, 26*, 100549.

Malheiro, R., Casal, S., Lamas, H., Bento, A., & Pereira, J. A. (2012). Can tea extracts protect extra virgin olive oil from oxidation during microwave heating? *Food Research International, 48*, 148–154.

Malheiro, R., Casal, S., Teixeira, H., Bento, A., & Pereira, J. A. (2013). Effect of olive leaves addition during the extraction process of overmature fruits on olive oil quality. *Food and Bioprocess Technology, 6*, 509–521.

Malheiro, R., Rodrigues, N., Bissaro, C., Leimann, F., Casal, S., Ramalhosa, E., et al. (2017). Improvement of sensorial and volatile profiles of olive oil by addition of olive leaves. *European Journal of Lipid Science and Technology, 119*, 1700177.

Mannina, L., D'Imperio, M., Gobbino, M., D'Amico, I., Casini, A., Emanuele, M. C., et al. (2012). Nuclear magnetic resonance study of flavoured olive oils. *Flavour and Fragrance Journal, 27*, 250–259.

Marić, B., Abramović, B., Ilić, N., Krulj, J., Kojić, J., Perović, J., et al. (2020). Valorization of red raspberry (*Rubus idaeus* L.) seeds as a source of health beneficial compounds: Extraction by different methods. *Journal of Food Processing and Preservation, 44*, Article e14744.

Mariotti, M., & Peri, C. (2014). The composition and nutritional properties of extra-virgin olive oil. *The Extra-Virgin Olive Oil Handbook, 1*, 22–33.

Marx, Í. M. G., Casal, S., Rodrigues, N., Cruz, R., Veloso, A. C. A., Pereira, J. A., et al. (2022). Impact of incorporating olive leaves during the industrial extraction of cv. Arbequina oils on the physicochemical–sensory quality and health claim fulfillment. *European Food Research and Technology, 248*, 171–183.

Montesano, D., Cossignani, L., D'Arco, G., Simonetti, M. S., & Damiani, P. (2006). Pure lycopene from tomato preserves extra virgin olive oil from natural oxidative events during storage. *JAOCS, Journal of the American Oil Chemists' Society, 83*, 933–941.

Montesano, D., Rocchetti, G., Cossignani, L., Senizza, B., Pollini, L., Lucini, L., et al. (2019). Untargeted metabolomics to evaluate the stability of extra-virgin olive oil with added *lycium barbarum* carotenoids during storage. *Foods, 8*, 179.

Murillo-Cruz, M. C., Chova, M., & Bermejo-Román, R. (2021a). Effect of adding fungal β-carotene to picual extra virgin olive oils on their physical and chemical properties. *Journal of Food Processing and Preservation, 45*, Article e15186.

Murillo-Cruz, M. C., García-Ruíz, A. B., Chova-Martínez, M., & Bermejo-Román, R. (2021b). Improvement of physico-chemical properties of Arbequina extra virgin olive oil enriched with β-carotene from fungi. *Journal of Oleo Science, 70*, 459–469.

Murillo-Cruz, M. C., Rodrigues, N., Bermejo-Román, R., Veloso, A. C. A., Pereira, J. A., & Peres, A. M. (2022). An electronic tongue as a tool for assessing the impact of carotenoids' fortification on cv. Arbequina olive oils. *European Food Research and Technology, 248*, 1287–1298.

Nenadis, N., Moutafidou, A., Gerasopoulos, D., & Tsimidou, M. Z. (2010). Quality characteristics of olive leaf-olive oil preparations. *European Journal of Lipid Science and Technology, 112*, 1337–1344.

Nevado, J. J. B., Robledo, V. R., & Callado, C. S. C. (2012). Monitoring the enrichment of virgin olive oil with natural antioxidants by using a new capillary electrophoresis method. *Food Chemistry, 133*, 497–504.

Nieva-Echevarría, B., Goicoechea, E., & Guillén, M. D. (2020). Oxidative stability of extra-virgin olive oil enriched or not with lycopene. Importance of the initial quality of the oil for its performance during in vitro gastrointestinal digestion. *Food Research International, 130*, 108987.

Pateiro, M., Barba, F. J., Domínguez, R., Sant'Ana, A. S., Mousavi Khaneghah, A., Gavahian, M., et al. (2018). Essential oils as natural additives to prevent oxidation reactions in meat and meat products: A review. *Food Research International, 113*, 156–166.

Pateiro, M., Munekata, P. E. S., Sant'Ana, A. S., Domínguez, R., Rodríguez-Lázaro, D., & Lorenzo, J. M. (2021). Application of essential oils as antimicrobial agents against spoilage and pathogenic microorganisms in meat products. *International Journal of Food Microbiology, 337*, 108966.

Peñalvo, G. C., Robledo, V. R., Callado, C. S. C., Santander-Ortega, M. J., Castro-Vázquez, L., Victoria Lozano, M., et al. (2016). Improving green enrichment of virgin olive oil by oregano. Effects on antioxidants. *Food Chemistry, 197*, 509–515.

Peres, F., Roldão, M., Mourato, M., Martins, L. L., & Ferreira-Dias, S. (2021). Co-processed olive oils with *thymus mastichina* L. - new product optimization. *Life, 11*, 1048.

Perestrelo, R., Silva, C., Silva, P., & Câmara, J. S. (2017). Global volatile profile of virgin olive oils flavoured by aromatic/medicinal plants. *Food Chemistry, 227*, 111–121.

Perito, M. A., Coderoni, S., & Russo, C. (2020). Consumer attitudes towards local and organic food with upcycled ingredients: An Italian case study for olive leaves. *Foods, 9*, 1325.

Pichierri, M., Pino, G., Peluso, A. M., & Guido, G. (2020). The interplay between health claim type and individual regulatory focus in determining consumers' intentions toward extra-virgin olive oil. *Food Research International, 136*, 109467.

Plastina, P., Tundis, R., Torre, C. la, Sicari, V., Giuffré, A. M., Neri, A., et al. (2021). The addition of *Capsicum baccatum* to Calabrian monovarietal extra virgin olive oils leads to flavoured olive oils with enhanced oxidative stability. *Italian Journal of Food Science, 33*, 61–72.

Reboredo-Rodríguez, P., Figueiredo-González, M., González-Barreiro, C., Simal-Gándara, J., Salvador, M. D., Cancho-Grande, B., et al. (2017). State of the art on functional virgin olive oils enriched with bioactive compounds and their properties. *International Journal of Molecular Sciences, 18*, 668.

Regulation Nº 136/66/EEC establishing a common organization of the market in oils and fats. Official Journal (Nº172, p.3025-3066).

Rodrigues, N., Silva, K., Veloso, A. C. A., Pereira, J. A., & Peres, A. M. (2021). The use of electronic nose as alternative non-destructive technique to discriminate flavoured and unflavored olive oils. *Foods, 10*, 2886.

Romaniello, R., & Baiano, A. (2018). Discrimination of flavoured olive oil based on hyperspectral imaging. *Journal of Food Science & Technology, 55*, 2429–2435.

Rubió, L., Motilva, M. J., Macià, A., Ramo, T., & Romero, M. P. (2012). Development of a phenol-enriched olive oil with both its own phenolic compounds and complementary phenols from thyme. *Journal of Agricultural and Food Chemistry, 60*, 3105–3112.

Sacchi, R., della Medaglia, D., Paduano, A., Caporaso, N., & Genovese, A. (2017). Characterisation of lemon-flavoured olive oils. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 79*, 326–332.

Sari, H. A., & Ekinci, R. (2017). The effect of ultrasound application and addition of leaves in the malaxation of olive oil extraction on the olive oil yield, oxidative stability and organoleptic quality. *Food Science and Technology, 37*, 493–499.

Sena-Moreno, E., Alvarez-Ortí, M., Serrano-Díaz, J., Pardo, J. E., Carmona, M., & Alonso, G. L. (2018). Olive oil aromatization with saffron by liquid–liquid extraction. *Journal of Food Science & Technology, 55*, 1093–1103.

Sevim, D., Tuncay, O., & Koseoglu, O. (2013). The effect of olive leaf addition on antioxidant content and antioxidant activity of "memecik" olive oils at two maturity stages. *JAOCS, Journal of the American Oil Chemists' Society, 90*, 1359–1369.

Soares, V. P., Fagundes, M. B., Guerra, D. R., Leães, Y. S. V., Speroni, C. S., Robalo, S. S., et al. (2020). Ultrasound assisted maceration for improving the aromatization of extra-virgin olive oil with rosemary and basil. *Food Research International, 135*, 109305.

Sonda, A., Akram, Z., Boutheina, G., Flamini, G., & Mohamed, B. (2014). Effect of addition of olive leaves before fruits extraction process to some monovarietal tunisian extra-virgin olive oils using chemometric analysis. *Journal of Agricultural and Food Chemistry, 62*, 251–263.

Sousa, A., Casal, S., Malheiro, R., Lamas, H., Bento, A., & Pereira, J. A. (2015). Aromatized olive oils: Influence of flavouring in quality, composition, stability, antioxidants, and antiradical potential. *Lebensmittel-Wissenschaft und -Technologie-Food Science and Technology, 60*, 22–28.

Suárez, M., Romero, M. P., Ramo, T., & Motilva, M. J. (2011). Stability of a phenol-enriched olive oil during storage. *European Journal of Lipid Science and Technology, 113*, 894–903.

Taleb, S. A., Boutoial, K., Kzaiber, F., & Oussama, A. (2016). Effect of aromatization by aromatic plants on the physicochemical, sensorial and oxidative stability of

Moroccan virgin olive oil. *International Journal of Chemical, Material and Environmental Research, 3*, 73–77.

Talhaoui, N., Gómez-Caravaca, A. M., León, L., de la Rosa, R., Segura-Carretero, A., & Fernández-Gutiérrez, A. (2014). Determination of phenolic compounds of "Sikitita" olive leaves by HPLC-DAD-TOF-MS. Comparison with its parents "Arbequina" and "Picual" olive leaves. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 58*, 28–34.

Torres-Alvarez, C., Castillo, S., Sánchez-García, E., Aguilera González, C., Galindo-Rodríguez, S. A., Gabaldón-Hernández, J. A., et al. (2020). Inclusion complexes of concentrated orange oils and β-cyclodextrin: Physicochemical and biological characterizations. *Molecules, 25*, 5109.

Trabelsi, N., Marotta, S. M., Giarratana, F., Taamali, A., Zarrouk, M., Ziino, G., et al. (2018). Use of Tunisian flavoured olive oil as anisakicidal agent in industrial anchovy marinating process. *Journal of the Science of Food and Agriculture, 98*, 3446–3451.

Trabelsi, N., Nalbone, L., Marotta, S. M., Taamali, A., Abaza, L., & Giarratana, F. (2019). Effectiveness of five flavoured Tunisian olive oils on *Anisakis* larvae type 1: Application of cinnamon and rosemary oil in industrial anchovy marinating process. *Journal of the Science of Food and Agriculture, 99*, 4808–4815.

Valle-Prieto, M. B. de, Delgado-Adámez, J., Gil, M. V., Martillanes, S., Franco, M. N., & Martín-Vertedor, D. (2017). Virgin olive oil enriched with lutein-zeaxanthin from *Spinacia oleracea*. *Journal of Oleo Science, 66*, 463–468.

Veillet, S., Tomao, V., & Chemat, F. (2010). Ultrasound assisted maceration: An original procedure for direct aromatisation of olive oil with basil. *Food Chemistry, 123*, 905–911.

Venturi, F., Sanmartin, C., Taglieri, I., Nari, A., Andrich, G., Terzuoli, E., et al. (2017). Development of phenol-enriched olive oil with phenolic compounds extracted from wastewater produced by physical refining. *Nutrients, 9*, 916.

Yamani, M. el, Sakar, E. H., Boussakouran, A., & Rharrabti, Y. (2020). Activity of two natural additives in improving the stability of virgin olive oil quality during storage. *Oilseeds & Fats Crops and Lipids, 27*, 44.

Yilmazer, M., Göksu Karagöz, S., Ozkan, G., & Karacabey, E. (2016). Aroma transition from rosemary leaves during aromatization of olive oil. *Journal of Food and Drug Analysis, 24*, 299–304.

Zellama, M. S., Chahdoura, H., Zairi, A., Ziani, B. E. C., Boujbiha, M. A., Snoussi, M., et al. (2022). Chemical characterization and nutritional quality investigations of healthy extra virgin olive oil flavoured with chili pepper. *Environmental Science and Pollution Research, 29*, 16392–16403.

Ziarati, P., Makki, F. M., Vambol, S., & Vambol, V. (2019). Determination of toxic metals content in iranian and Italian flavored olive oil. *Acta Technologica Agriculturae, 2*, 64–69.

Zunin, P., Leardi, R., Bisio, A., Boggia, R., & Romussi, G. (2010). Oxidative stability of virgin olive oil enriched with carnosic acid. *Food Research International, 43*, 1511–1516.