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RESPONSE OF FRESH-CUT ICEBERG LETTUCE TO FUMIGATION WITH BOTANICAL ESSENTIAL OILS

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ABSTRACT

The study was conducted on iceberg lettuce 'Ice Wave F_1'. The effect of prestorage treatment with seven essential oils (EOs) of rosemary, peppermint, basil, thyme, marjoram, lemon, and oregano on the quality of cut lettuce was evaluated. The lettuce was fumigated with EOs for two hours in airtight containers. Two concentrations of EOs were used: 16.7 $\mu L \cdot L^{-1}$ and 33.3 $\mu L \cdot L^{-1}$. Fumigation with rosemary and thyme EOs lowered the browning of fresh-cut iceberg lettuce and thus the deterioration of its appearance during six days of storage. Lettuce fumigated with thyme EO scored relatively high in sensory quality and consumer acceptability. Lettuce fumigated with rosemary EO was characterized by high intensity of aroma and herbal flavor, significantly lowering its sensory rating. Marjoram EO at a dose of 16.7 $\mu L \cdot L^{-1}$ resulted in the fastest browning of lettuce cut surface and relatively reduced the market value during storage. Other EOs had no significant effect on the quality of cut lettuce during shelf life. It was also found that fumigation did not change bacteria, fungi, and mold populations on fresh-cut iceberg lettuce during short-term storage. The results obtained in the study showed that fumigation with thyme oil at a concentration of 33.3 $\mu L \cdot L^{-1}$ is most recommended for use in the storage of fresh-cut iceberg lettuce, but implementing these results into practice requires further research.

Key words: post-cutting fumigation, short-term storage, sensory quality, microbiological contamination

INTRODUCTION

Demand for fresh-cut vegetables continues to grow, especially in developed countries. Minimally processed vegetables and fruits are perishable due to physiological changes and microbial growth. Consequently, the need to optimize conditions to prevent rapid deterioration and contamination of produce has become a global problem (Antunes & Cavaco 2010; Castro-Ibáñez et al. 2017; Balali et al. 2020). Currently, in the minimum processing of horticultural products, chlorine is the most commonly used disinfectant (Rico et al. 2007; Castro-Ibáñez et al. 2017; Xylia et al. 2017, 2019). The use of synthetic agents raises legitimate concerns among consumers due to chemical residues in food and their impact on human health. In contrast, adding natural substances to reduce losses and improve sanitary safety is widely accepted.

Among natural additives, essential oils (EOs) of plant origin are regarded as nonphytotoxic compounds, that are potentially effective as organic pesticides for crop protection (Lanciotti et al. 2004; Antunes & Cavaco 2010; Calo et al. 2015). EOs and their components are believed to be absorbed and metabolized in the liver of humans and other mammals and urinated by the kidneys (Antunes & Cavaco 2010). They are naturally occurring compounds with a strong odor, synthesized by plants as secondary metabolites (Yousuf et al. 2021). There is evidence that EOs can increase the storage ability and strengthen the microbiological safety of food products (Tripathi et al. 2008; Antunes et al. 2012; Farzaneh et al. 2015; Patrignani et al. 2015). On the other hand, they can profoundly affect the sensory value of the treated product (Yousuf et al. 2021).

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EOs, depending on the type and concentration, can exhibit cytotoxic effects on living cells but without genotoxic consequences (Bakkali et al. 2008). According to Burt (2004), hydrophobicity is an integral feature of EOs and their components. This feature allows them to build into the lipids of the bacterial cell membrane, disrupting their structure, which leads to the leakage of the cell's contents and, consequently, its death (Liolios et al. 2009). Nazzaro et al. (2013) confirmed that the cell membrane is the main target of bioactive aromatic compounds. Membrane disruption under terpene activity (components of EOs) occurs in bacteria and fungi. However, EOs are slightly more effective against Gram-positive than Gram-negative bacteria (Lambert et al. 2001; Pintore et al. 2002; Holley & Patel 2005; Gutierrez et al. 2008; Soković et al. 2010). Dorman and Deans (2000) argue that the different components of EOs show different activities against bacteria. The presence and concentration of phenolic compounds are attributed to the primary responsibility for the antimicrobial activity of EOs (Tripathi et al. 2008; Bajpai et al. 2012). Carvacrol and thymol have received the most attention from researchers. These substances occur in various herbal plants EOs, mostly in thyme and oregano (Rathod et al. 2021). Their principle of action is similar to other phenols and involves disruption of the cytoplasmic membrane, electron flow, leakage, and coagulation of cell contents (Burt 2004). Their antimicrobial activity (against bacteria, yeast and molds) is well documented (Burt 2004; Lanciotti et al. 2004; Sakkas & Papadopoulou 2017; Walczak et al. 2021).

Lots of vegetables (fresh broccoli, cabbage, carrots, onions, cucumber, and tomatoes) combine very well with herbs (Ayala-Zavala et al. 2009), so EOs can also be considered of added value as culinary seasonings with natural preservative properties. However, the practical implementation of EOs is limited due to their influence on the sensory properties of vegetables and fruits since even the most health-promoting foods are only accepted and regularly purchased if they have good sensory properties (Ayala-Zavala et al. 2009). Burt (2004) stated that undesirable organoleptic effects can be reduced by selecting EOs for a particular food type. In the study by Gutierrez et al. (2009), ready-to-eat carrots washed in a solution of oregano EO were considered acceptable, while lettuce was rejected due to poor overall appearance on day 7 of storage. Scollard et al. (2013) warn against using EOs that are dark in color, as sprayed vegetables quickly darken and become unattractive to consumers.

This study aimed to evaluate the use of EOs as a nonsynthetic solution to delay spoilage and extend the shelf life of fresh-cut vegetables. Developing a proper application procedure that inhibits the biochemical degradation of vegetables, limits microbial growth, and maintains good sensory quality will contribute to a reduction in food losses and an increase in the consumption of fresh vegetables.

MATERIALS AND METHODS

Plant material and EO types

Iceberg lettuce (*Lactuca sativa* L. var. *capitata*) 'Ice Wave F_1' was purchased from a commercial farm near Skierniewice (Poland). After being transported to the laboratory, the lettuce was placed at 0–1 °C for one night. The following EOs were used for the fumigation of fresh-cut iceberg lettuce: rosemary (Avicenna Oil, Wroclaw), peppermint and basil (Pranarom, Ghislenghien), thyme and lemon (Etja, Elblag), oregano (Hepatica, Nasutow), and marjoram (Farmvit, Szczecin). The oils were extracted by steam distillation without the use of chemicals. It involves passing steam through the plant elements (rosemary – flowering tops and leaves; peppermint – shoots and leaves; basil – leaves and flowers; thyme – flowering plants; marjoram – leaves and flowers; lemon – fruits; oregano – shoots and leaves) and then condensing the steam containing volatile fragrance molecules. The water-insoluble fragrance oil is then separated from the condensed water.

Setting up storage experiments

The storage experiments were set up two days after the iceberg lettuce harvest. The outer yellowed and damaged leaves were removed, and the lettuce was cut into strips 0.5–1.0 cm in width. Immediately after cutting, the strips were packed into polypropylene boxes with external dimensions of 355 mm × 175 mm × 105 mm (L × W × H) and a capacity of 6 L (Plast Team Margarit 6L, no 3629). Two portions of sliced lettuce (600 g in one box) were prepared for each experimental object. The selected EO was pipetted on two cotton disks (4 cm diameter)

taped to the bottom of each box lid. Then, the boxes were tightly closed and left at room temperature for two hours. The EO doses were 100 or 200 µL per box (i.e., 16.7 $\mu L \cdot L^{-1}$ or 33.3 $\mu L \cdot L^{-1}$). Fresh-cut lettuce, not treated with EOs but also tightly closed in a box, was used as the control. After fumigation, the boxes were opened, and the plant material was divided into 100 g samples. Transparent polyethylene boxes, recommended for food products, measuring 154 mm × 98 mm × 70 mm (L × W × H) of 1.0 L capacity (GUILLIN W1/059C) were used to pack the samples. After packing, the boxes were covered with lids (GUILLIN W2/001), which had 77 holes for air exchange. The storage experiment was set up as four replicates. Three additional samples were prepared for microbiological, and two for sensory analyses. All samples were stored at 5°C for six days. The experiments were repeated twice.

Quality assessment

Quality assessment was carried out every two days during storage of fresh-cut plant material. The following quality traits were assessed visually: wilting, browning (darkening) of the cut surface, and rotting. The evaluation was based on a nine-point scale, in which 1 meant no sign of change in a given trait, while 9 meant maximum severity of a given change, i.e., very severe wilting, darkening, and rotting.

The market value was also assessed on a nine-point scale as follows: 1 – no market value, 3 – limited, 5 – fair (market value threshold), 7 – good, 9 – excellent.

Weight loss was calculated as the percentage difference between the initial weight of a plant sample and the weight after a specified storage period.

Sensory analysis

Sensory analyses of sliced lettuce treated with EO were carried out after four days of storage at 5°C. Quantitative descriptive analysis (QDA) following ISO 13299:2016 was used to evaluate the following quality attributes: color, crispness, lettuce flavor, herbal aroma, sweet flavor, overall quality, and consumer acceptance, which were selected based on preliminary tests. The intensity of perception for each attribute was assessed on an unstructured graphical scale marked with the appropriate boundary terms. The scores marked on the scale were converted to numerical values ranging from 0 to 10 contract units, where 0 means no intensity, and 10 means the high intensity of the attribute. Sensory evaluation was performed in the sensory laboratory, meeting all the requirements in PN-EN ISO 8589:2010/A1:2014-07. The profile evaluation was performed by a team of 10 people with verified sensory sensitivity trained in PN-EN ISO 8586:2014-3 sensory evaluation techniques. Each object was assessed in duplicate, in random order. Individual samples of the test product were placed in coded plastic containers (250 mL) covered with lids. Noncarbonated water was used as a flavor neutralizer between the evaluated samples. For initial data processing, ANALSENS data preprocessing software was used. The obtained results were illustrated as a principal component analysis (PCA) graph.

Microbiological analysis

Microbiological analyses were carried out on samples fumigated with EOs at a concentration of 16.7 $\mu L \cdot L^{-1}$ after four days of storage at 5°C. They were performed according to the following standard methodologies: PN-EN ISO 4833-2:2013-12 and PN-ISO 21527-1:2009. A portion of 25 g of cut lettuce was transferred to 225 ml of peptone water in sterile stomacher-type filter bags (400 ml). Samples were homogenized in a stomacher BagMixer® 400 P at a constant speed of 8 strokes per second for 10 minutes. Decimal dilutions were then made using the same diluent and analyzed for microorganisms (aerobic mesophilic bacteria, yeast, and mold). Aerobic mesophilic bacteria were determined on plate agar (PCA, Merck) after incubation at 30°C. Yeast and molds were counted on glucose-chloramphenicol agar with yeast extract (YGC agar, Merck) after incubation at 25°C. Results were expressed as colony-forming units per gram of plant material (CFU per g) and converted to decimal logarithm (log10) for statistical calculations.

Data analysis

Storage experiments were set up in a two-factor design in a completely randomized system. The differentiating factors were the type of EO and EO concentrations used for lettuce fumigation. In this study, seven EOs (rosemary, peppermint, basil, thyme, marjoram, lemon, and oregano) were used, and fumigation was carried out at two concentrations (16.7 $\mu L \cdot L^{-1}$, 33.3 $\mu L \cdot L^{-1}$).

Two-factor analysis of variance (ANOVA) was used to statistically calculate the results of the visual quality of plant material. Microbial contamination was analyzed only on samples fumigated with one EO concentration (16.7 $\mu L \cdot L^{-1}$), so the results were statistical calculated in a one-factor system. The results of individual experiments did not differ significantly, therefore all means of the two tests (eight for browning and market value and six for microbiological parameters) were analyzed together. The means of storage quality and microbial contamination were compared using the Tukey HSD (Honestly Significant Difference) procedure at $p = 0.05$. Sensory results were described using PCA based on a correlation matrix. Calculations were performed in the STATISTICA 13 statistical package (Dell).

RESULTS

The influence of EO fumigation on the storability of fresh-cut iceberg lettuce

Fresh-cut iceberg lettuce fumigated with EOs and nonfumigated showed no signs of rot or wilting during six days of storage. The natural weight loss was very low and after six days of storage at 5°C was approximately 0.1% for fresh-cut, fumigated and untreated iceberg lettuce. Fumigation with EOs had varying effects on the storage life of the lettuce (Tables 1, 2). After two days of storage, the browning of cut surfaces was the lowest compared with the storage for four and six days. The lowest browning was observed in the samples fumigated with rosemary and thyme, and the highest with marjoram and oregano. After four days of storage, the highest browning notes were obtained in samples fumigated with marjoram, with a higher concentration of oregano, and the lowest with rosemary. After six days of storage, rosemary caused the least intense browning, and marjoram and oregano caused the most intense browning, comparable with the nonfumigated control. Generally, the concentration of EOs did not influence browning. Fumigation with rosemary and thyme EOs was always significantly lower than without fumigation, ensuring better lettuce quality during six-day storage. The market value decreased with storage time (Table 2). After two days, the market value was higher than in the control. After six days of storage, the lowest value was found in lettuce fumigated with basil and marjoram. Lettuce treated with rosemary and a higher thyme concentration received the highest notes. Generally, the concentration of EOs had no effect on market values. Lettuce fumigated with rosemary EO and thyme EO with a higher concentration received the highest notes. Generally, the concentration of EOs did not affect market values. The market value notes mostly agreed with those regarding browning of cut surfaces.

Table 1. The browning of the cut surface of fresh-cut iceberg lettuce fumigated with essential oils (EOs) and stored at 5°C

Source of EO	Concentration of EO ($\mu L \cdot L^{-1}$)	Storage time (d)		
		2	4	6
rosemary	16.7	1.5 ± 0.5 abc	2.8 ± 0.5 ab	3.6 ± 0.2 a
	33.3	1.1 ± 0.2 a	2.4 ± 0.2 a	3.8 ± 0.4 ab
peppermint	16.7	1.6 ± 0.5 abc	3.4 ± 0.4 bcd	4.9 ± 0.8 cde
	33.3	2.0 ± 0.0 cd	3.3 ± 0.4 bc	4.8 ± 0.8 cde
basil	16.7	1.5 ± 0.5 abc	3.6 ± 0.6 cde	5.6 ± 0.6 e
	33.3	2.0 ± 0.4 cd	3.3 ± 0.4 bcd	4.7 ± 0.5 b-e
thyme	16.7	1.5 ± 0.5 abc	3.1 ± 0.5 abc	4.6 ± 0.5 a-d
	33.3	1.2 ± 0.4 ab	2.9 ± 0.4 abc	4.0 ± 0.7 abc
marjoram	16.7	2.5 ± 0.3 d	4.1 ± 0.6 de	5.6 ± 0.7 e
	33.3	2.4 ± 0.2 d	3.4 ± 0.3 bcd	5.1 ± 0.5 de
lemon	16.7	1.6 ± 0.5 abc	3.1 ± 0.4 abc	4.4 ± 0.4 a-d
	33.3	1.8 ± 0.5 bcd	3.4 ± 0.2 bcd	5.1 ± 0.4 de
oregano	16.7	1.6 ± 0.6 abc	3.2 ± 0.4 bc	4.4 ± 0.6 a-d
	33.3	2.4 ± 0.4 d	4.3 ± 0.4 e	4.9 ± 0.6 cde
control	0	2.1 ± 0.7 cd	3.3 ± 0.3 bc	5.1 ± 0. de
means for concentration	16.7	1.7 ± 0.6 A	3.3 ± 0.6 A	4.7 ± 0.9 A
	33.3	1.8 ± 0.6 A	3.3 ± 0.6 A	4.6 ± 0.7 A

Values are means of 8 samples ± standard deviation (SD). Means followed by the different letters within columns are significantly different ($p < 0.05$, Tukey's test). Capital letters show means for EOs concentrations. Scoring scales for **cut surface browning** of plant material: 1 – no signs of discoloration, 3 – very beginning of discoloration, 5 – light brown, 7 – medium brown, 9 – brown

Table 2. The market value of fresh-cut iceberg lettuce fumigated with essential oil (EO) and stored at 5°C

Source of EO	Concentration of EO ($\mu L \cdot L^{-1}$)	Storage time (d)		
		2	4	6
rosemary	16.7	8.5 ± 0.5 cd	7.3 ± 0.5 de	6.3 ± 0.3 e
	33.3	8.94 ± 0.2 d	7.6 ± 0.2 e	6.3 ± 0.4 de
peppermint	16.7	8.3 ± 0.7 bcd	6.6 ± 0.4 bcd	5.1 ± 0.8 abc
	33.3	8.0 ± 0.0 abc	6.7 ± 0.4 cd	5.2 ± 0.8 abc
basil	16.7	8.5 ± 0.5 cd	6.4 ± 0.6 abc	4.5 ± 0.6 a
	33.3	8.0 ± 0.4 abc	6.7 ± 0.4 bcd	5.3 ± 0.5 a-d
thyme	16.7	8.5 ± 0.5 cd	6.9 ± 0.5 cde	5.4 ± 0.5 b-e
	33.3	8.8 ± 0.4 d	7.1 ± 0.4 cde	6.0 ± 0.7 cde
marjoram	16.7	7.5 ± 0.3 a	5.9 ± 0.6 ab	4.4 ± 0.7 a
	33.3	7.6 ± 0.2 ab	6.6 ± 0.3 bcd	4.9 ± 0.5 ab
lemon	16.7	8.3 ± 0.7 cde	6.9 ± 0.4 cde	5.6 ± 0.4 b-e
	33.3	8.2 ± 0.5 a-d	6.6 ± 0.3 bcd	4.9 ± 0.4 ab
oregano	16.7	8.4 ± 0.6 cd	6.8 ± 0.4 cd	5.6 ± 0.6 b-e
	33.3	7.6 ± 0.4 ab	5.8 ± 0.4 a	5.1 ± 0.6 abc
control	0	7.9 ± 0.2 abc	6.7 ± 0.3 cd	4.9 ± 0.4 ab
means for EO	16.7	8.3 ± 0.6 A	6.7 ± 0.6 A	5.3 ± 0.9 A
	33.3	8.2 ± 0.6 A	6.7 ± 0.6 A	5.4 ± 0.7 A

Values are means of 8 samples ± standard deviation (SD). Means followed by the different letters within columns are significantly different ($p < 0.05$, Tukey test). Capital letters were used to compare means for EOs concentrations. Scoring scales for the **market value** of plant material: 1 – no market value, 3 – limited, 5 – fairy (marketability threshold), 7 – good, 9 – excellent

Sensory evaluation of fresh-cut iceberg lettuce fumigated with herbal EOs

The PCA graphic projection (Fig. 1) shows the sensory quality of fresh-cut EO-treated iceberg lettuce in the two principal components system (as coordinates). The evaluated lettuce treatments are scattered on the surface of Figure 1, indicating substantial differences in their sensory scoring. The overall quality was closely related to product acceptance and sweet flavor (vectors have the same direction). High notes of sensory quality were obtained by the lettuce fumigated with marjoram (33.3 $\mu L \cdot L^{-1}$) and thyme (16.7 $\mu L \cdot L^{-1}$). These objects are located in places closest to the features that distinguish overall quality and consumer acceptability. Thyme oil-fumigated lettuce (33.3 $\mu L \cdot L^{-1}$), oregano (33.3 $\mu L \cdot L^{-1}$), and lemon (33.3 $\mu L \cdot L^{-1}$) were highly scored due to their high intensity of sweet flavor. High intensity of aroma and herbal flavor characterized the objects of lettuce fumigated with basil, rosemary, and peppermint EOs. These objects are located in the closest places to these distinguishing features, adversely affecting the lowest overall quality and product acceptance (on the opposite side of the evaluation vectors of overall quality and consumer acceptance). The results indicate that the type of EO used to fumigate fresh-cut iceberg lettuce significantly affects the sensory quality. On average, there were no statistical differences in the quality of lettuce treated with different concentrations of EO (16.7 and 33.3 $\mu L \cdot L^{-1}$). However, in the case of marjoram EO, better acceptance was obtained for lettuce treated with the higher concentration (33.3 $\mu L \cdot L^{-1}$). In contrast, in the case of peppermint EO, a higher score was obtained for lettuce fumigated with a lower concentration (17.7 $\mu L \cdot L^{-1}$).

Microbiological assessment of fresh-cut iceberg lettuce fumigated with herbal EOs

Fumigation of fresh-cut lettuce with EOs did not significantly change the number of microorganisms in stored plant material. After four days of incubation at 5°C, the number of bacteria reached an average of 7.4 log10 cfu$\cdot g^{-1}$ (from 7.3 to 7.6). Mean number of yeasts was 6.7 log10 cfu$\cdot g^{-1}$ (from 6.4 to 7.1). The density of molds in plant material was generally low and ranged from 0 to 1.25 log10 cfu$\cdot g^{-1}$. The relatively high standard deviations (0.4 to 0.7) indicate significant differences between samples from the same object.

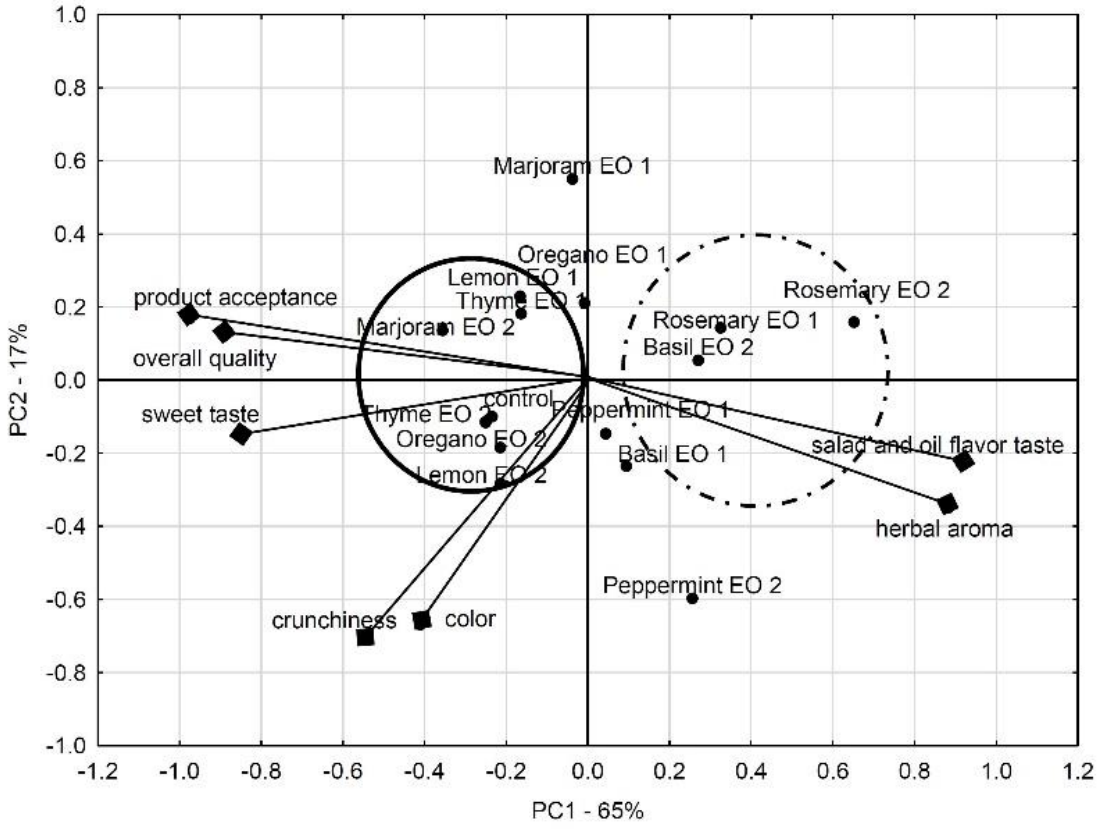


Figure 1. Principal component analysis of sensory profiling results of fresh-cut iceberg lettuce fumigated with the following essential oils: rosemary, peppermint, basil, thyme, marjoram, lemon, and oregano

Tag 1 indicates the concentration of 16.7 $\mu L \cdot L^{-1}$, while tag 2 indicates the 33.3 $\mu L \cdot L^{-1}$. ○ – group with the best sensory properties, ◌ – group with the worst sensory properties

DISCUSSION

Fumigation of fresh-cut vegetables with EOs is a method previously recommended by Laird and Phillips (2011). According to these authors, vapor treatment has an antimicrobial effect and has no or less impact on the sensory properties of foodstuffs compared to dipping treatment. Flavor tests showed that using 100 or 200 µL of EOs per 600 g of lettuce placed in a 6-liter box may be accepted by consumers. Taking sensory considerations into account, Gutierrez et al. (2009) recommended a solution of oregano oil at a concentration below 250 $\mu L \cdot L^{-1}$ and thyme oil below 500 $\mu L \cdot L^{-1}$ for dipping treatment. In the current study, the EO concentrations used as vapors were much lower. The sensory evaluation showed that the flavor and smell of lettuce fumigated with thyme, oregano, lemon, and marjoram EOs were acceptable. Worse flavor and smell were found after treatment with rosemary and basil EOs. In a study by Gutierrez et al. (2008), basil, lemon balm, marjoram, oregano, and thyme EOs used in fresh carrots were organoleptically acceptable. However, for lettuce, only the oregano and marjoram EOs were acceptable. Also, Xylia et al. (2021) recommended the marjoram EO for fresh-cut lettuce. Lettuce leaves are delicate and have a relatively weak flavor and smell, facilitating better absorption of foreign flavors and odors. The fumigation method used in the present study is less aggressive than dipping, which was the reason for retaining better flavor parameters after using a more comprehensive range of oils. Other authors, such as Uyttendaele et al. (2004), de Azeredo et al. (2011), Scollard et al. (2016), and Ding and Lee (2019), reported that vegetables sanitized with herb EOs scored lower in most of the sensory attributes than untreated vegetables.

The best external appearance during six days of storage at 5°C was maintained by lettuce fumigated with rosemary EO at 33.3 and 16.7 $\mu L \cdot L^{-1}$ concentrations and with thyme EO at 33.3 $\mu L \cdot L^{-1}$. In general, there was a lack of uniformity in the available literature regarding the effects of EOs on the physiological alteration of cut vegetables during storage. Mousavizadeh et al. (2011) reported that rosemary, thyme, and coriander EOs exhibited antioxidant properties and can reduce peroxidase activity, thus enzymatic browning in white and red cabbage. In contrast, in a study by de Azeredo et al. (2011), the immersion of leafy vegetables (iceberg lettuce, rocket, and beet) in EOs from rosemary and oregano resulted in more intensive browning of the cut surfaces after two or three days of refrigerated storage. Also, Ponce et al. (2011) claimed that lettuce leaves immersed in EO solution got browned during storage. The above information shows that the effects of EOs vary according to application methods, concentrations, and types of vegetables.

Treatment with EOs did not affect lettuce weight losses, which aligns with earlier reports by Viacava et al. (2018). The weight losses were irrelevant, and the lettuce showed no signs of wilting, indicating that the plastic boxes protected the plant material from moisture loss.

The effect of EO lettuce fumigation on antimicrobial resistance was undetectable in the study. The differences between EO-fumigated and nonfumigated fresh-cut lettuce were not significant. Although the inhibitive properties of EOs in vitro were previously reported by Sakkas and Popadopoulou (2017) and Guo et al. (2021), Kraśniewska et al. (2020) suggested that a single treatment can be not sufficient to improve the microbiological safety of fresh products. In the in vitro model of Soković et al. (2010), of the ten EOs tested (orange, lemon, peppermint, lavender, chamomile, basil, curly mint, oregano, thyme, and sage), the highest activity was shown for oregano EO. According to Burt (2004), the EO solution for washing fruits and vegetables should be at a concentration of 0.1–10 $mL \cdot L^{-1}$ to achieve a significant antibacterial effect. Ding and Lee (2019) claimed that the fumigation with thyme EO retarded the growth of microorganisms in plums and apricots but also caused higher surface browning of fresh-cut apricots. It is crucial to balance the sanitary requirements of the treated product, its external quality, and sensory properties. This requires adapting the application method by using the right type and dose of EO.

The effect of thyme oil fumigation on lettuce quality is promising. When used at a higher concentration (33.3 $\mu L \cdot L^{-1}$), it improves shelf life and does not worsen the sensory quality of lettuce. Although the best at reducing browning at the cut surface, rosemary oil causes a noticeable foreign odor and inferior flavor in lettuce. Other authors obtained variable results. According to Scollard et al. (2016), thyme EO applied as a spray showed strong antimicrobial activity against *Listeria*, but had an adverse sensory effect on freshly cut melon and iceberg lettuce. A chopped bell pepper submerged in a 1.0% solution of thyme oil also significantly reduced the indigenous microflora, but according to Uyttendaele et al. (2003), intense chemical smell, softening of the tissue, and some moisture loss limit the practical application of this method. Antunes and Cavaco (2010) and Antunes and Cavaco (2010) admitted that the residual thymol flavor on fumigated cherries made this treatment unsuitable for commercial use. Moreover, de Azeredo et al. (2011) reported that vegetables disinfected with rosemary and oregano EOs reduced most of the sensory attributes compared to untreated samples. However, when tomatoes were treated with EO thymol at the "breaker" or "turning" stage, tests performed ten days after treatment showed no residual flavor on the fruit (Antunes & Cavaco 2010). An important issue related to the activity of EOs may be the high variability in the composition and concentration of active substances due to the geographic origin of the plants, climatic and agronomic factors, age of the donor plants, and time of the harvesting period (Lanciotti et al. 2004; Tripathi et al. 2008; Antunes et al. 2012; Mari et al. 2016).

CONCLUSIONS

During storage, essential oils fumigation did not change the populations of bacteria, yeasts, and molds on fresh-cut iceberg lettuce. Rosemary and thyme EO fumigation lowered the browning on the cut surface of lettuce, influencing its better

appearance during storage; however, rosemary EO worsened the flavor and aroma of the lettuce. After treatment with thyme EO, the sensory quality of lettuce was found to be relatively high. Considering consumers' expectations, for whom appearance, flavor, and smell are the most important, the most recommendable of those tested in the study is thyme EO, used at a dose of 33.3 $\mu L \cdot L^{-1}$. However, fumigation with herbal EOs to preserve fresh-cut iceberg lettuce for practical use cannot be recommended at this stage of research.

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