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The impacts of laurel (*Laurus nobilis*) and basil (*Ocimum basilicum*) essential oils on oxidative stability and freshness of sous-vide sea bass fillets

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Abstract: The purpose of this study was to highlight the effects of natural plant essential oils (EOs) on sous-vide sea bass (*Dicentrarchus labrax*) fillets. Three different treatments were prepared by addition of: 1) no essential oil (C), 2) laurel (*Laurus nobilis*) EO (L), and 3) basil (*Ocimum basilicum*) EO (B). In general, incorporation of the EOs did not cause significant changes in the proximate composition ($P > 0.05$). The addition of L caused a darker and more greenish-yellow colour, while addition of B did not have a considerable alteration in colour parameters. All the evaluated sensory parameters were within the acceptable ranges. No statistical differences ($P > 0.05$) were recorded in sensory parameters among the samples except L samples with the lowest flavour score. Although the initial pH values of the samples were similar to each other, some significant changes were recorded during the storage ($P < 0.05$). B samples had lower thiobarbituric acid reactive substances values in earlier stages of the storage ($P < 0.05$), while L samples barely showed antioxidant effects after 7 days. However, L samples had lower trimethylamine levels for up to 7 days of storage compared to the other samples ($P < 0.05$). Consequently, the findings indicated that the use of natural compounds in sous-vide sea bass fillets was effective to maintain oxidative stability and freshness, particularly in earlier stages of the storage.

Key words: Laurel, basil, essential oils, antioxidants, thiobarbituric acid, trimethylamine, sous-vide cooking, fish

1. Introduction

The beneficial nutritional effects of fish consumption are indisputable since fish is a unique source of high quality protein, essential vitamins, minerals, and polyunsaturated fatty acids of the omega-3 family [1–3]. In the last decades, the global ready to eat (RTE) seafood market sales have dramatically risen due to the changes in consumer demands and lifestyle. The processing factors and ingredients used in the formulation of RTE fish products are two main factors that have a remarkable influence on the overall quality and health profile. Novel technologies that focus on minimal heat treatments have been mentioned to be fundamental for the future development of seafood products [4]. One of these technologies is sous-vide cooking, which is applicable to a wide range of foods including meat and meat products [5]. "Sous-vide" is a phrase of French origin that means "under vacuum" and sous-vide cooking is defined as the process in which raw materials or raw materials with intermediate foods are cooked in heat stable vacuum bags under controlled conditions of temperature and time [1,5]. This technique presents various advantages such as preserving the flavour, texture, and nutritional quality, as well as extending shelf life by preventing oxidative and microbiological changes [4,6,7].

Although sous-vide cooking is said to decrease quality damages, fish muscle is known to be a susceptible material to both chemical and bacterial deteriorations. Fish is regarded as one of the most sensitive muscle foods to oxidative stress due to its high polyunsaturated fatty acid content [8–10]. Another common quality parameter of fish is trimethylamine (TMA), which is the main responsible compound of the"fishy" odour that occurs from the degradation of trimethylamine oxide (TMAO) by the activity of microorganisms [11]. Both of these oxidative reactions and TMA formations are the main indicators of chemical and microbial spoilage during the processing and the storage of fish that result in considerable quality losses in terms of physical, nutritional, and sensory characteristics, as well as food safety [9].

The utilization of antioxidants and antimicrobials in the formulation of muscle foods has long been applied to prevent quality losses and ensure food safety. However, due to the global "clean-label" trends and negative consumer perceptions towards synthetic additives, the application of natural preservatives is an efficient strategy for designing healthier meat products with extended shelf life. The application of plant extracts to RTE meat products is regarded as a potential way to improve shelf life, enhance

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nutritional and organoleptic properties, and manufacture safer products due to the antioxidant, antimicrobial, and health-related properties of these compounds [12]. Laurel (*Laurus nobilis*) and basil (*Ocimum basilicum*) are 2 remarkable aromatic plants that have a high potential to be incorporated as natural preservatives into seafood products due to their unique features. Laurel (or bay) is a common herb native to the southern part of Europe and the Mediterranean region that is used in dishes for its aromatic odour [13,14]. Basil is commonly used in the Mediterranean and Southeast Asian countries, having a clean flavour and sweet herbal smell [15]. The essential oils (EOs) and/or extracts of these plants have good potential as antioxidant and antimicrobial materials since both laurel and basil are functional herbs that were reported to have preservative effects in different meat products [9,13,16]. However, to the best of our knowledge, no study has pointed out the effects of these EOs in sous-vide fish fillets so far. A limited number of recent studies have revealed the promising impacts of the synergic use of antioxidants and sous-vide cooking on the quality of fresh vegetables [17] and fish [3,8]. From this point of view, the present study focuses on the freshness and oxidative quality of sous-vide cooked sea bass fillets marinated with laurel or basil EOs. It was aimed to demonstrate the effects of the combined use of a minimal cooking technique and natural preservatives on overall storage stability and eating quality of RTE fish products.

2. Materials and methods

2.1. Materials

Aquacultured fresh sea bass fillets (*Dicentrarchus labrax*) were purchased from Tesco Kipa Co. (İzmir, Turkey) 1 day after they were harvested, beheaded, eviscerated, and filleted. Totally 60 individual fillets were sampled from the same batch. The mean length and weight of the samples were 21.25 ± 3.45 cm and 188.36 ± 7.84 g, respectively. The fillets were transported to the Department of Food Engineering, Meat Pilot Plant of Ege University in İzmir, Turkey, on flaked ice inside polystyrene boxes within 1 h after purchase. The fillets were immediately analysed for proximate composition and recorded as having 63.56% moisture, 23.12% protein, 11.80% fat, and 1.42% ash, and the rest were kept at 2 ± 2 °C until their usage. Laurel (*Laurus nobilis*) and basil (*Ocimum basilicum*) EOs having a purity of >99.5% were supplied from Kimbiotek Chemical Substances Co. in İstanbul, Turkey. Other marination ingredients (apple vinegar, extra virgin olive oil, sodium chloride, sodium citrate, and black peppercorn) were purchased from local markets. Sous-vide bags (Polinas Polibarr Y10C1B, thickness of 90 µm, 16 cm^3/m^2/day oxygen permeability) were kindly donated by Polinas Plastics Co. in Manisa, Turkey. All the chemicals used in the analysis were of analytical grade.

2.2. Production of sous-vide sea bass fillets

Figure 1 summarizes the production procedure of sous-vide sea bass fillets including the experimental design. Fresh and clean fillets were weighed and placed into the sous-vide bags, and a marination solution consisting of 15% olive oil, 5% vinegar, 1% sodium citrate, 1% sodium chloride, and 0.2% black peppercorn based on the weight of the fillet (C group) was added. For the preparation of the treatments with EOs, 1.5% laurel EO (L group) or 1.5% basil EO (B group) was incorporated into the marination mixture. The bags were sealed under vacuum (Propack, Çorlu, Tekirdağ, Turkey) and the samples were allowed to stay in the marinade solution for 1 h at 4 °C to let the ingredients penetrate into meat matrix. After that, samples

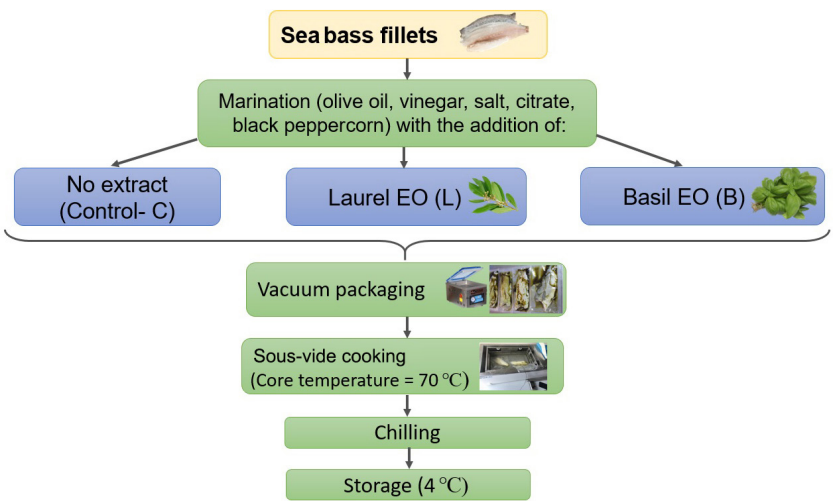

Figure 1. The production flow chart of sous-vide sea bass fillets.

were placed into a water-bath (WiseBath, Germany) heated to 80 °C and were cooked until the core temperature reached 70 °C. The samples were immediately chilled to room temperature after heat treatment. The analysis of the final products was performed as soon as the production was completed and the rest of the samples were stored at 4 °C for 15 days for the mentioned analysis.

2.3. Methods

2.3.1. Chemical composition

Total moisture [18], protein (LECO nitrogen analyser, St. Joseph, MI, USA), fat [19], and ash [18] contents were determined in triplicate to express the proximate composition of sea bass fillets.

2.3.2. Colour

The surface colour parameters of the samples were measured in triplicate using a portable colorimeter (CR-200, Konica Minolta, Japan) with D65 illuminant setting and 10° standard observer and expressed as CIE L* (lightness), a* (redness), and b* (yellowness).

2.3.3. Sensory assessment

The sensory panel was performed in one session by an untrained volunteer group selected from the students and the staff of the Food Engineering Department of Ege University. The participants consisted of 20 (11 women and 9 men) regular fish consumers aged on average 29 ± 7.7 years (range: 22-52 years). A 9-point hedonic scale (9- like extremely to 1- dislike extremely) was utilized to score the appearance, colour, texture, flavour, and overall acceptability of different treatments. Representative portions of the fillets (approximately 100 g) were served warm to the panellists with randomly coded numbers.

2.3.4. pH value

The pH value was measured during the storage of the samples from 3 different points by using a pH meter (330i/SET, WTW, Weilheim, Germany) equipped with a penetration probe.

2.3.5. 2-Thiobarbituric acid reactive substances (TBARS)

Analysis of TBARS was performed according to Witte et al. [20]. First, 20 g of sample was homogenized with 50 mL of cold solution containing 20% trichloroacetic acid (TCA) in 2 M phosphoric acid for 2 min. Distilled water (50 mL) was then added and the sample was homogenized again for 1 min. After that, the slurry was filtered through Whatman No. 1 filter paper into a 100 mL flask. The volume was completed to 100 mL by a solution of TCA : distilled water at a ratio of 1:1 and 5 mL of the filtrate was then pipetted into a test tube while another 5 mL of fresh chilled TBA (0.02 M in distilled water) was added. The tubes were incubated at 80 °C for 35 min and then cooled to room temperature. The absorbance of the solution was measured with a spectrophotometer (T-60, PG Instruments, UK) at 532 nm against a blind solution of TCA : distilled water at a ratio of 1:1. The results were expressed as TBARS values (mg of malondialdehyde/kg sample), which was calculated by multiplying the absorbance by 5.2. Each sample was analysed in triplicate at each storage time.

2.3.6. TMA

The levels of TMA in fish fillets during storage were determined 3 times at each storage time point using the standard method of the Food and Agriculture Organization of the United Nations [21]. Fillet samples (100 g) were minced and mixed with 200 mL of 7.5% TCA in a blender. The homogeneous solution was centrifuged at 2000 × *g*. After centrifugation, 4 mL of supernatant was pipetted into a test tube. A blank and the standards were prepared. For the blank, 4 mL of distilled water was used, and for the standards, 1.0, 2.0, and 3.0 mL of TMA working standard solutions (0.01 M/mL) were diluted to 4 mL with distilled water. Then 1 mL of formaldehyde (20%), 10 mL of anhydrous toluene, and 3 mL of saturated potassium carbonate (K_2CO_3) solutions were added to each tube. After that, 8 mL of the toluene phase was added to tubes containing 0.2 g of anhydrous sodium sulphate (Na_2SO_4) to dry the toluene. The sample (5 mL) was taken from the tube and 5 mL of picric acid working solution (0.02%) was added. The content was properly mixed and transferred to a spectrophotometer cell and the absorbance was measured at 410 nm against the blank. The TMA concentration (mg of N/100 g sample) was calculated according to the equation below:

$$TMA = \frac{A/A_1 \times V_x \times V_t \, x \, 300}{V_s}$$

where A = the absorbance of the sample, A_1 = the absorbance of the standard nearest to the absorbance of the sample, V_x = mg of TMA standard solution, V_t = mL of solution used, and V_s = mL of an aliquot of the sample used.

2.3.7. Statistical assessment

The statistical analyses were performed with SPSS for Windows version 22.0 (IBM Corp., Armonk, NY, USA). Homogeneity of the variance was assessed by Levene's F test prior to one-way analysis of variance (ANOVA). The intergroup comparison of the means was achieved with ANOVA and Duncan's multiple range test was used for post hoc comparisons to identify significant differences between the formulations and the storage times. Probability values were considered statistically significant at $\alpha = 0.05$ level.

3. Results and discussion

3.1. Chemical composition

The proximate composition of sous-vide sea bass fillets is presented in Figure 2. In general, addition of the EOs did not seem to have considerable impacts on the chemical composition of the fillets. The moisture contents of all

the cooked fillets were very close to the moisture content of the raw form of the material, indicating that the sous-vide technique allowed water to be held in the meat matrix and prevented liquid release and drying of meat upon cooking. This result is thought to be a promising impact affecting the eating quality because of the desired water holding capacity of the final product. Similarly, Çetinkaya et al. [8] stated that the moisture contents of vacuum packed or sous-vide cooked rainbow trout fillets did not differ from each other. The lowest protein content belonged to L samples ($P < 0.05$), while protein contents of C and B samples were not significantly different. The changes in the protein content of L samples could probably be due to the slight numerical differences of the components like water and lipids. Though L samples had similar lipid contents to C group ($P > 0.05$), Cropotova et al. [3] recorded no significant variations in total lipid contents of sous-vide Atlantic mackerel samples treated with different antioxidants. In general, fish is classified as fatty (>8 g/100 g fat), moderately fatty (3–8 g/100 g), or lean (<3 g/100 g) [22]. According to this classification, the samples in the present study could be referred to as fatty since they contain more than 12% total fat. Here it is a notable point that high lipid content with unsaturated fatty acids is a major factor affecting the oxidative changes. Overall, as seen, some slight differences were obtained in compositional parameters of the fillets, most probably due to the negligible variances between raw muscles.

3.2. Colour

Figure 3 depicts colour parameters of sous-vide fillets. L*, a*, and b* values were recorded between 75.82 and 79.92, –2.92 and 0.06, and 11.30 and 20.06, respectively. The results showed that incorporation of laurel and basil EOs led to significant changes in instrumental colours of the samples ($P < 0.05$). Among treatments, L samples had the lowest L* and a* values, while they had the highest b* values ($P < 0.05$), which indicated that the addition of laurel EO led to a darker and more greenish-yellow appearance. However, samples C and B had similar lightness and yellowness, meaning that incorporation of basil EO did not have a remarkable alteration in colour. Nevertheless, it was effective to increase the redness of the samples ($P < 0.05$). Apparently, especially laurel EO had a more distinguishable effect on colour variation of the fillets compared to the basil EO. Since both EO concentrations were equal in the marinade solutions, this result might arise from the natural pigments of laurel that were intensely distributed on the surface of the fillets. Conversely, Erkan et al. [23] reported that no significant changes were observed in the colour of bluefish samples treated with thyme and laurel EOs. Compared to the present results, these differences may be attributed to the differences in the raw material, processes, and addition level of the antioxidants. Although the instrumental colour results are different, it is also important to evaluate the scores of the sensory analysis of the colour to better understand the degree of acceptance.

3.3. Sensory assessment

Although utilization of natural preservatives is needed to maintain the quality, their concentrations are limited due to the sensorial changes they cause in final products. For this reason, their impacts on sensory attributes are another point to be highlighted. The sensory scores of sous-vide fillets are presented in Figure 4. The appearance, colour, texture, flavour, and general acceptability of the samples were 6.92–7.33, 6.75–7.33, 6.92–7.17, 6.17–7.58, and 6.58–7.25, respectively. The scores indicated that all the evaluated sensory parameters were within the acceptable ranges, which could be attributed to the protective impacts of sous-vide cooking on taste and texture. Accordingly, Çetinkaya et al. [8] stated that sous-vide cooked rainbow trout fillets had desired texture scores compared to vacuumed fresh samples throughout storage. In addition, Iborra-Bernad

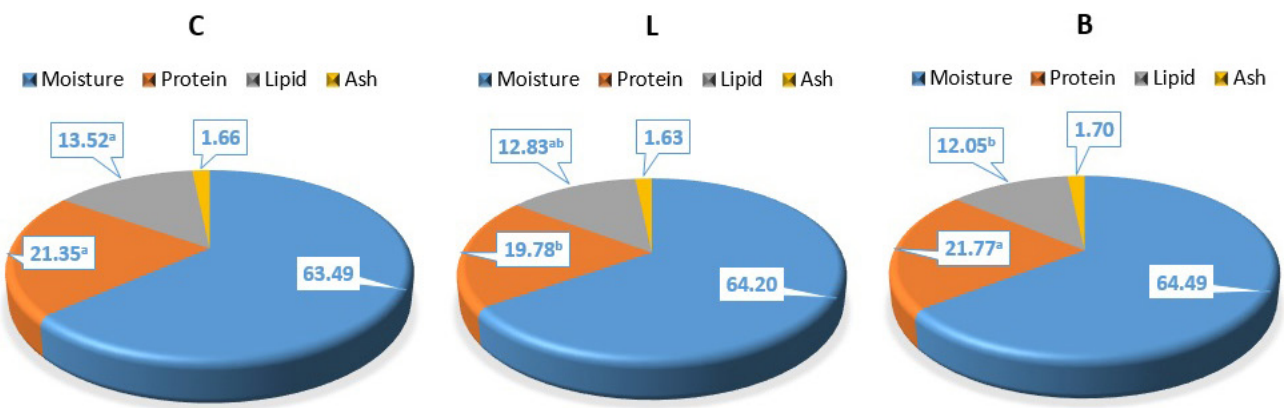

Figure 2. The chemical composition of sous-vide sea bass fillets. Treatments were formulated with C (control): no essential oil (EO), L: 1.5% laurel EO, B: 1.5% basil EO. The data are presented as the mean values of replications. a, b, c, …: Means with different letters for the same parameter are significantly different ($P < 0.05$).

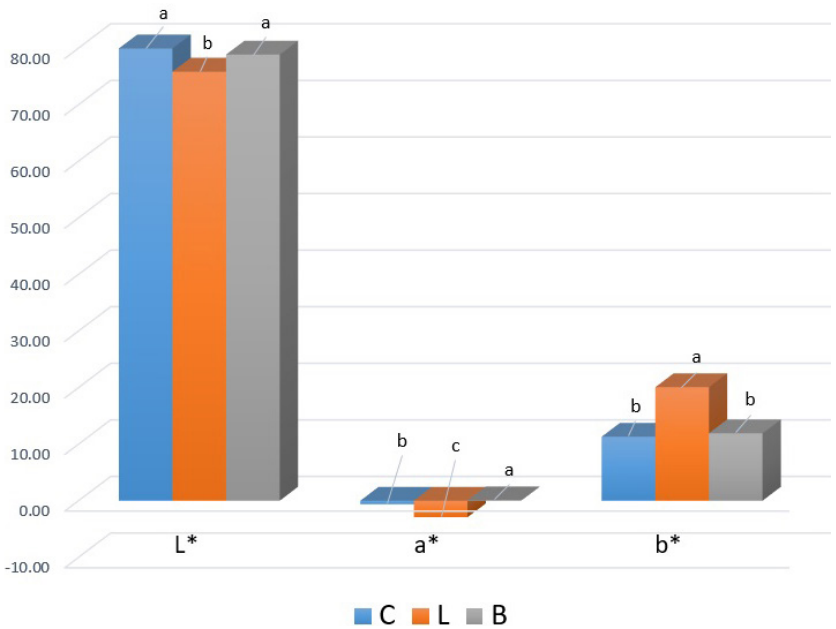

Figure 3. The colour parameters (L*, a*, b*) of sous-vide sea bass fillets. Treatments were formulated with C (control): no essential oil (EO), L: 1.5% laurel EO, B: 1.5% basil EO. The data are presented as the mean values of replications. a, b, c, …: Means with different letters for the same parameter are significantly different (P < 0.05).

et al. [24] indicated that sous-vide treatment in vegetables presented advantages over cook-vide (vacuum boiling) treated products in terms of flavour.

No statistical differences (P > 0.05) were recorded in sensory parameters of the sea bass fillets except flavour. Among the treatments, the lowest flavour score belonged to L samples (P < 0.05). These results indicated that laurel EO resulted in an intense aroma that did not appeal to the taste buds, while samples with basil EO provided a desired flavour. Nevertheless, all the samples had similar general acceptability in terms of sensory features. Although some natural extracts were mentioned to improve sensory properties of different seafood products [8,23,25–27], in general it is a challenge to maintain sensory quality by the incorporation of high concentrations of extracts. Recently, some solutions have been proposed to compensate for the potential negative sensory effects of natural extracts, such as encapsulation of the compounds or using them in active food packaging [9]. These strategies would assist to add natural compounds to the products without diminishing the sensory quality.

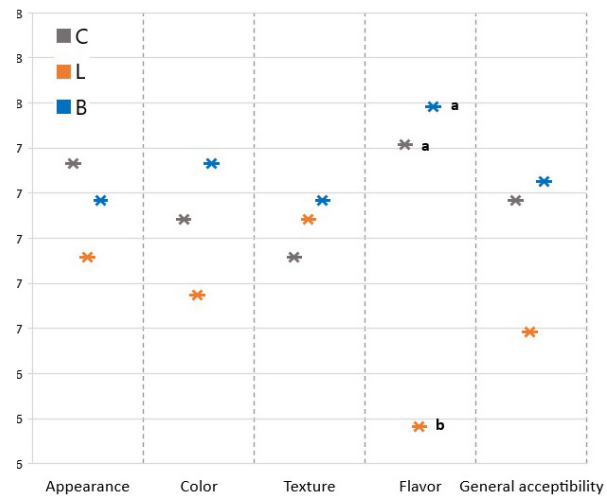

Figure 4. The sensory scores of sous-vide sea bass fillets. Treatments were formulated with C (control): no essential oil (EO), L: 1.5% laurel EO, B: 1.5% basil EO. The data are presented as the mean values of replications. a, b, c, …: Means with different letters for the same parameter are significantly different (P < 0.05).

3.4. pH value

The pH value of meat is a critical quality indicator since most of the physical, chemical, sensory, and microbiological features are affected by the rate of pH drop in muscle and the ultimate pH of the meat/product. A high postmortem pH value of fish muscle is one of the most important characteristics that promote the growth of bacteria [9]. The initial pH values of the sea bass fillets (Figure 5) were between 6.05 and 6.12 with no significant differences (P > 0.05), meaning that incorporation of either EO did not show a remarkable change in the pH value. Similarly, the use of thyme and oregano EOs in

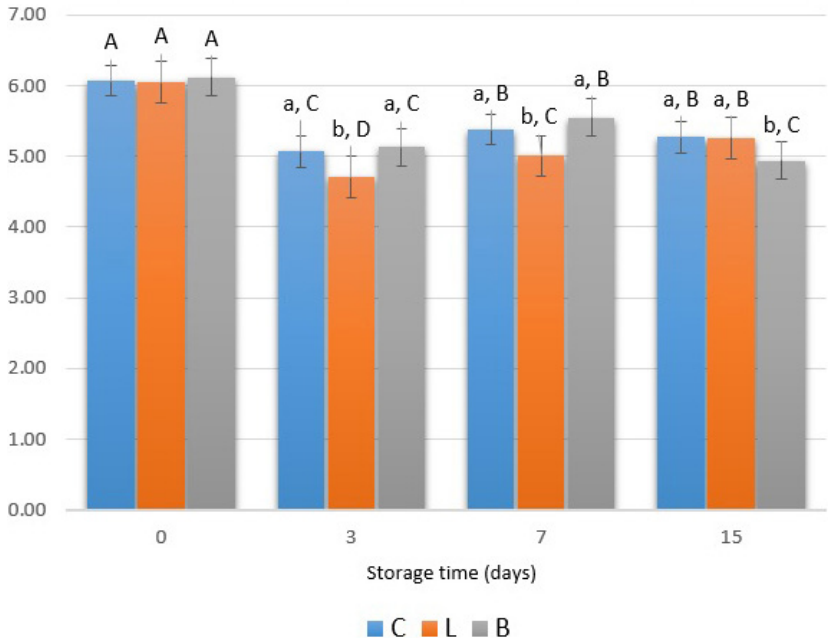

Figure 5. The pH values of sous-vide sea bass fillets during the storage. Treatments were formulated with C (control): no essential oil (EO), L: 1.5% laurel EO, B: 1.5% basil EO. The data are presented as the mean values of replications. a, b, c, …: Means with different small letters for the same storage day are significantly different ($P < 0.05$). A, B, C, …: Means with different capital letters for the same treatment are significantly different ($P < 0.05$).

salmon and seaweed burgers did not affect the pH values [28]. Despite the similar initial values, the pH values of the samples significantly differed from each other on the other days of the storage ($P < 0.05$). On days 3 and 7, the lowest pH values were recorded in L samples. However, on day 15 those samples had higher pH values compared to B samples ($P < 0.05$). Samples with basil EO mostly had pH values similar to those of control samples during storage (except day 15). The decrease in pH value could be associated with the formation of free acids, while thereafter increment might arise from the formation of basic compounds by the degradation of proteins. A similar pattern was also observed by Dolea et al. [28] in salmon and seaweed burgers produced with thyme or oregano EOs. Anyanwu et al. [13] recorded lower pH values in surimi gels that were treated with bay EO compared to untreated samples, reporting that pH increase in control samples could be related to the formation of ammonia by microbial growth. Similar results were obtained by Karoui and Hassoun [29], who reported that Atlantic mackerel fish treated with basil EO had lower pH values compared to samples treated with rosemary or samples that were untreated, suggesting that basil addition may delay pH increases in regard to antimicrobial effects.

At the end of the storage, the pH values of the treatments were between 4.94 and 5.27, indicating that all the samples had lower pH values compared to their initial results ($P < 0.05$). During storage, besides the formation of acidic or basic compounds by chemical reactions, some acidic compounds in the marinades such as vinegar or citric acid may also contribute to the development of the acidity and decrease the pH value at the end of the storage.

3.5. TBARS values

Lipid oxidation is one of the most critical issues that limit the shelf life of seafood products since fish is an easily perishable raw material due to its lipid composition. In addition, heat treatment can trigger lipid oxidation reactions by disrupting cell membranes and thus promotes the "warmed-over flavour" (WOF) that rapidly progresses in cooked meat products during refrigerated storage [15]. Therefore, incorporation of natural compounds might be an effective way to protect sous-vide fish products from oxidation and WOF during cold storage. The analysis of TBARS is the most common technique for the determination of secondary lipid oxidation products (malondialdehydes). The TBARS values of the sea bass fillets are presented in Figure 6a. The initial values were between 0.29 and 0.50 mg malondialdehyde/kg. In final products and on day 3, the lowest TBARS values belonged to sea bass fillets formulated with basil EO ($P < 0.05$). However, B samples showed the highest oxidation level on day 7, whereas this time the lowest oxidation level was

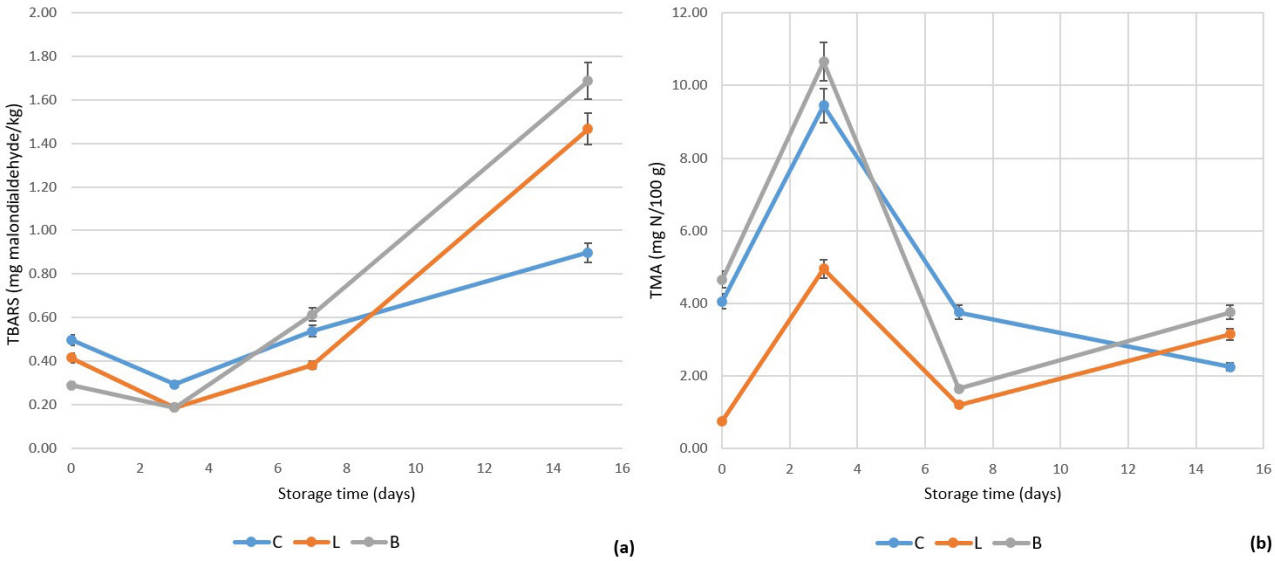

Figure 6. a) The TBARS values (mg malondialdehyde/kg sample). b) The TMA levels (mg N/100 g) of sous-vide sea bass fillets during storage. Treatments were formulated with C (control): no essential oil (EO), L: 1.5% laurel EO, B: 1.5% basil EO. The data are presented as the mean values of replications.

recorded in L samples ($P < 0.05$). These results indicated that addition of basil EO was effective to retard lipid oxidation in earlier stages of the storage, while addition of laurel EO barely showed antioxidant effects after 7 days.

In a study regarding the utilization of ground rosemary and the application of sous-vide cooking to rainbow trout fillets, it was found that the initial TBARS values were not different in vacuumed fresh fillets or sous-vide ones with or without rosemary. However, in the storage period, sous-vide samples with rosemary had lower TBARS values compared to the samples without rosemary [8]. In a similar study, it was found that incorporation of rosemary extract, either alone or in combination with α-tocopherol and ascorbyl palmitate, into Atlantic mackerels showed efficient impacts regarding the delay of secondary lipid oxidation, suggesting that natural antioxidants could be successfully applied before sous-vide cooking of fish [3].

Previously, thyme and laurel EOs in bluefish [23], bay EO in surimi gels [13], rosemary extract in sardine [30], and sage, oregano, and grape seed extracts in hairtail fish balls [31] were also reported to provide the desired oxidative stability due to their phenolic compounds acting as free radical scavengers. Apparently, though, the EOs of the herbs used in this study did not show a similar trend in retarding lipid oxidation and showed their impacts in different periods of storage, which were presumably due to the differences in their active substances.

Final TBARS values showed that samples with laurel EO had higher oxidative stability compared to the samples with basil EO ($P < 0.05$). In final products, the data pointed out the increment in TBARS values of all the samples regardless of the use of EOs: in all treatments, final TBARS values were significantly higher compared to the initial ones ($P < 0.05$), due to the propagation of the chain reactions leading to increment in the concentrations of secondary products. Nevertheless, Schormuller [32] stated that the upper limit of TBARS indicating rancidity for fish acceptability was less than 5 mg malondialdehyde/kg. Thus, final TBARS values of all the fillet samples were safely below this limit and within the acceptable ranges. Moreover, Dolea et al. [28] underlined that in addition to the antioxidant effect of extracts, vacuum storage would play a decisive role in slowing the oxidation rate. Therefore, this could also be a reason for the low oxidation rates of the sea bass samples in the present study during the storage.

3.6. TMA level

The presence of TMAO in fish as a part of the nonprotein nitrogen fraction is one of the most important intrinsic factors that greatly affect the microbiological spoilage [33]. A number of well-defined spoilage bacteria are able to decompose TMAO by anaerobic metabolism resulting in off odours and off flavours due to the formation of TMA [11,33]. Thus, TMA level is considered as a valuable tool in the quality evaluation of fish [23]. Since natural preservatives are good sources of antimicrobial compounds, it is important to evaluate TMA level as a freshness indicator in samples formulated with herbal EOs.

TMA levels of sea bass fillets can be seen in Figure 6b. Among the treatments, the lowest initial concentration was recorded in L samples ($P < 0.05$). These samples also had lower TMA levels on day 3 and on day 7 compared to

the other groups ($P < 0.05$). The data were good indicators of the protective effect of laurel EO for up to 7 days of storage. In similar research, it was found that the use of thyme and laurel EOs in bluefish was effective to decrease TMA concentrations during ice storage [23]. Dolea et al. [28] also reported that salmon and seaweed burgers formulated with thyme or oregano extracts showed lower values of TMA than untreated samples.

In all samples, we recorded a sharp increment in TMA concentrations on day 3 ($P < 0.05$). Thereafter, TMA levels dramatically decreased on day 7 ($P < 0.05$), which could be attributed to the decrease in the substrate (TMAO). Despite the fact that laurel EO showed a particularly strong protective effect against microbial deteriorations for up to 7 days, at the end of the storage the lowest TMA level was detected in C samples without antioxidants ($P < 0.05$). This output supports that the EOs may lose their activity after a while by being decomposed or by interacting with other ingredients, or due to environmental conditions. Therefore, some alternative solutions should be sought to maintain their protective effects for longer durations.

Previously, Dalgaard et al. [34] mentioned that the acceptable limit of TMA of fresh fish in terms of sensory quality could typically be 10–15 mg N/100 g. Although significant increments in TMA levels of the sea bass fillets were recorded during the storage period, none of the samples had a TMA content higher than this range and thereby might be considered as acceptable. In this situation, sous-vide cooking treatment and vacuum conditions during the storage could be the key factors in the suppression of spoilage.

3.7. Conclusions

The results of the present study indicate that the utilization of laurel and basil EOs in sous-vide sea bass fillets is effective to maintain oxidative stability and freshness, particularly in earlier stages of storage, without diminishing the sensory characteristics. Although significant impacts of the EOs were obtained, the behaviours were not sustainable enough, indicating that the stability of the herbal extracts used in marination solutions of the fillets could be affected during the storage. Therefore, further research should be performed regarding some alternative solutions to stabilize the impact of natural compounds and assess the synergistic effects of novel cooking techniques and natural ingredients in different kinds of seafood.

Acknowledgement/Disclaimers/Conflict of interest

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