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Novel Antioxidant Active Packaging Approach: Combination of Aquafaba and Essential Oil to Prevent Lipid Oxidation in Fish †

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Abstract: Active packaging has commonly consisted of several bioactive compounds that improve sensory characteristics, protect quality, and expand the shelf life of food items. With a better understanding of the importance of plant-based protein sources, the utilization of by-products of any food item has taken interest in both academia and industry. Aquafaba, as an accepted legume by-product, offers several benefits in the food industry owing to its gelling property and high emulsifier and stabilizer capacity. Over the years, essential oils have been used as an antioxidant agent in the active packaging approach to prevent lipid oxidation, especially in highly perishable foods.

Keywords: Aquafaba; seafood; essential oil

1. Introduction

With the increasing world population, and limitations on agricultural production, and climate change, the value of any kind of nutrient source has gained importance over the last decade [1]. In addition to animal-based sources, the usage of plant-based sources is also vital in the valorization process of by-products and wastes originated from food item production and cooking lines [2]. Due to its high protein content and other nutritional elements, cooking water for different food items has also been used in different forms, both commercially and domestically. Aquafaba has emerged as a plant-based vegan emulsifier additive as an alternative to the egg white commonly utilized in the bakery industry [3]. Aquafaba is basically cooking juice from different legumes, and the functional and nutritional characteristics of this material differ depending on the cooking methods and the type of legume [4]. To better understand the advanced properties of aquafaba, it has been used in different applications in the food industry [5].

Edible films, known as active packaging, can contain different types of bioactive compounds to improve the quality of food products and extend their shelf life. The combination of several types of polymers and bioactive compounds such as antioxidants and antimicrobial agents offers a wide range of benefits in the food industry [6]. Essential oils are accepted as excellent antioxidant and antimicrobial ingredients that inhibit microbial and physicochemical deterioration [7]. Especially as an antioxidant, essential oils commonly used in highly perishable foods such as fish and seafood [8]. Due to the impact of lipid oxidation on fish quality and the limited shelf life, essential oils have been used in different ways, such as edible film, edible coating, spray drying, or direct usage.

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In this research, as an active packaging material, edible films are produced with lyophilized aquafaba from boiling chickpeas and lemon essential oil at different levels. The antioxidant capacity of edible films and the lipid oxidation of fish were determined during refrigerated storage.

2. Materials and Methods

Aquafaba, in the form of cooking juice from chickpeas, was kindly donated by commercial producers (Döhler Inc., Turkey). Fresh sea bream (*Sparus aurata*) was purchased from a local fishery market in the Mula province of the Aegean region of Turkey. Lemon essential oil was purchased from commercial markets (Arifoğlu Spice and Food Ind. Trade. Ltd. Co., Turkey). Seabream was transferred to the laboratory at the cold chain on the caching day. Sea bream was then washed and eviscerated prior to the filleting process. Then fresh fish were filleted with a sharp filleting blade. The total amount was divided into five groups for further application.

Edible film solutions were prepared with slight modifications to Hopkins' methodology [9]. Aquafaba in its dried form was mixed with deionized water (10.0% wt/v), glycerol was added as a plasticizer (50% wt/wt), and the mixture was constantly stirred by a magnetic stirrer at 500 rpm (IKA, C-MAG HS 7 (Staufen, Germany)) for 2 hours. The pH of the solutions was adjusted to 9.0 by 0.5 M NaOH. The mixtures were degassed for 20 minutes by an ultrasonic bath (Thermo Fisher, FS140H) at room temperature. Lemon essential oil was added at three different levels (1.0, 1.5, and 2.0% rate (v/v)). Then the solutions were heated secondarily up to 90°C while stirring at the same speed. Finally, edible film solutions were poured into the sterile petri dishes and left to air dry at ambient temperature during the night. Then, the fillets of fresh sea bream were coated with edible films that contained aquafaba and lemon essential oil. A non-coated sample and only aquafaba containing edible film were considered negative and positive controls, respectively. The coated and non-coated fish fillets were placed into sterile refrigerator boxes and sealed, then stored in the refrigerator. All the processing method experiments were conducted at least in triplicate.

The antioxidant capacity of edible films was determined by the DPPH method following to Varga's method [10]. Approximately 1 cm^2 of each film group and 3.9 mL of a methanolic DPPH solution mixed in a sterilized glass tube. The solution (film and methanolic DPPH solution) was kept in the lightless space for 150 minutes. Following to reaction, the differences in the absorbance of the solutions were measured at a wavelength of 517 nm using a microplate reader (Thermo Scientific Varioskan Flash Vario Scan, USA). A methanolic DPPH solution without any film was measured as a blank. The percentages of the level of inhibition of the DPPH radical, blank sample, and edible film groups were used for the calculation of the DPPH radical scavenging capacity. TBA analyzes representative analyses of lipid oxidation in the fish sample during storage performed according to the Tarladgis method [11]. As the method suggested, following to distillation of fish samples, mixed with TBA reagent and boiled. The absorbance at 538 nm was measured by the above-mentioned microplate reader. The data was analyzed using SPSS 22.0 software (Chicago, IL, USA) by Tukey post-hoc and ANOVA tests at a p value of 0.05 and to determine significant differences among the negative control and edible coating groups. All analyses were performed in triplicate.

3. Results and Discussion

The results of the DPPH analyses of edible films are given in Figure 1. The highest antioxidant capacity was found in the edible film containing lemon essential oil at a 1.5% ratio. As expected, aquafaba-based edible films without any essential oil enrichment had the lowest antioxidant level. The level of essential oil caused a variation in the antioxidant capacity of edible films, which is in line with several studies [12, 13] that reported that the clove, oregano, rosemary, and sage essential oils had an impact on the antioxidant

capacity of edible films. Differences in the antioxidant capacity of edible films undoubtedly caused the variation of these films lipid oxidation protective role on the fish.

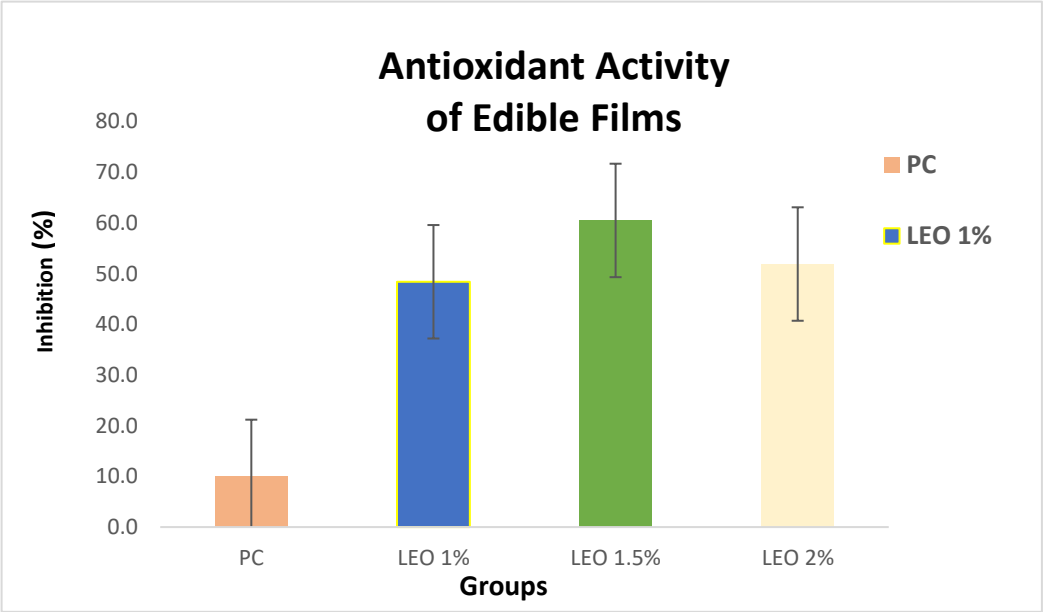

Figure 1. DPPH radical scavenging activity of edible films at different blend ratios.

The mean value and standard deviation of inhibition capacity of different edible film groups. PC (Positive Control: Aquafaba edible film without any essential oil addition; LEO%1: Aquafaba edible film containing 1 % lemon essential oil, LEO%1.5: Aquafaba edible film containing 1.5 % lemon essential oil, LEO % 2: Aquafaba edible film containing 2 % lemon essential oil.

The results of TBA analyses of fish samples during refrigerated storage are shown in Table 1. The higher antioxidant capacity of edible aquafaba film (LEO 1.5%) prevents lipid oxidation in the sea bream within the storage period. Negative control without any edible coating approach for sea bream. Due to the fact that TBA analyses are critical for both consumer acceptance and the shelf-life of products, the lipid oxidation level is vital for assessing the quality of fish samples. Positive control as an aquafaba-based edible film without any essential oil also prevents lipid oxidation that could be acting as a barrier to the surface of the fish fillets. Similar results were also highlighted by different research. Jouki et al. [14] reported that edible films contained oregano or thyme essential oil and had an impact on the refrigerated rainbow trout fillets. Additionally, Ding et al. [15] highlighted that the use of eugenol inhibited the TBA values in fish fillets.

Table 1. Lipid oxidation of sea bream groups during refrigerated storage.

Day	Groups				
	NC	PC	LEO 1%	LEO 1.5%	LEO 2%
0	0.54 ± 0.06^{a1}	0.51 ± 0.03^{a1}	0.55 ± 0.07^{a1}	0.50 ± 0.02^{a1}	0.51 ± 0.03^{a1}
3	1.21 ± 0.07^{c2}	1.18 ± 0.02^{b2}	1.14 ± 0.06^{b2}	0.84 ± 0.04^{a2}	0.96 ± 0.08^{ab2}
6	1.63 ± 0.03^{c3}	1.32 ± 0.04^{bc2}	1.16 ± 0.03^{b2}	0.99 ± 0.07^{a2}	1.09 ± 0.05^{a2}
9	1.88 ± 0.06^{d4}	1.61 ± 0.03^{d}	1.36 ± 0.06^{c23}	1.11 ± 0.03^{a23}	1.24 ± 0.04^{b3}
10	2.99 ± 0.13^{c5}	2.95 ± 0.11^{c3}	2.63 ± 0.09^{b3}	2.37 ± 0.03^{a3}	2.48 ± 0.06^{a4}
11	3.85 ± 0.07^{e6}	3.66 ± 0.07^{d4}	3.50 ± 0.08^{c4}	3.01 ± 0.03^{a4}	3.35 ± 0.09^{b5}
13	5.19 ± 0.03^{e7}	4.99 ± 0.03^{d5}	4.25 ± 0.05^{b5}	4.09 ± 0.03^{a5}	4.49 ± 0.13^{c6}

(NC: Negative Control, without any coatings, PC: Positive Control: Aquafaba edible film without any essential oil addition; LEO%1: Aquafaba edible film containing 1 % lemon essential oil,

LEO%1.5: Aquafaba edible film containing 1.5 % lemon essential oil, LEO % 2: Aquafaba edible film containing 2 % lemon essential oil). Values followed by different letters and numbers indicate significant differences among lipid oxidation values in different groups during storage period**.**

4. Conclusion

The results of this research clearly showed that aquafaba can be used alone or combined with essential oil as a bioactive compound in edible films. The developed aquafaba lemon essential oil edible films have the potential to be used as active antioxidant packaging in the food industry, especially for highly perishable food items.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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