

IMPROVING OXIDATIVE STABILITY AND SENSORY ACCEPTANCE OF DHA-RICH TUNA EYE OIL USING CINNAMON AND MASTIC AS NATURAL MASKING AGENTS

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Abstract

Tuna eye oil (TEO) is a rich source of docosahexaenoic acid (DHA), an essential omega-3 fatty acid vital for cardiovascular, neural, and visual health. However, its high polyunsaturated fatty acid (PUFA) content makes TEO highly susceptible to lipid oxidation, leading to undesirable fishy odors and low consumer acceptance. This study aimed to improve the oxidative stability and sensory acceptability of TEO using natural masking agents, namely, cinnamon and mastic gum. TEO was treated with various formulations containing cinnamon powder, mastic gum, or their combination at concentrations of 0, 5, 10, and 15% (w/w). Sensory evaluation, including hedonic testing and the check-all-that-apply (CATA) method, was conducted with 50 untrained panelists. Oxidative stability was assessed using the free fatty acid (FFA) content, peroxide value (PV), p-anisidine value (AnV), and total oxidation (TOTOX) values. The results showed that increasing the masking agent concentration significantly improved aroma preference and overall acceptance, while reducing fishy odor intensity (p>0.05). A 10% masking treatment with each masking agent was identified as the optimal one. CATA analysis revealed that cinnamon contributed to dominant spicy and warm sensory notes while effectively masking the fishy odor. Mastic gum introduced a pleasant herbal pine-like aroma, further reducing odor intensity. The combination of both treatments provided a complementary effect and enhanced the sensory attributes. Furthermore, the masked samples showed reduced oxidation parameters, with the cinnamon-treated oil displaying the lowest values of FFA 0.53%, PV 6.59 meq/kg, AnV 8.97 meq/kg, and totox 22.15 meq/kg. These findings demonstrate that 10% cinnamon and mastic gum are effective natural masking agents for improving the sensory quality and oxidative stability of TEO in food products.

Keywords: CATA, fish oil, fishery by-products, fishy odors, masking agents

Peningkatan Stabilitas dan Penerimaan Sensori Minyak Mata Tuna Kaya DHA Menggunakan Kayu Manis dan *Mastic* sebagai Agen *Masking* Alami

Abstrak

Minyak mata tuna kaya akan asam dokosaheksaenoat (DHA), yaitu asam lemak omega-3 esensial yang berperan penting dalam menjaga kesehatan kardiovaskular, sistem saraf, dan fungsi penglihatan. Kandungan asam lemak tak jenuh ganda yang tinggi membuat minyak mata tuna sangat rentan terhadap oksidasi lipid, yang menyebabkan bau amis yang tidak diinginkan dan rendahnya penerimaan konsumen. Penelitian ini bertujuan meningkatkan stabilitas oksidatif dan penerimaan sensori minyak mata tuna menggunakan agen *masking* alami berupa kayu manis dan *mastic*. *Masking* minyak mata tuna dilakukan menggunakan bubuk kayu manis, *mastic*, dan kombinasi keduanya pada konsentrasi 0, 5, 10, and 15% (b/b). Evaluasi sensori, termasuk uji hedonik dan metode *Check-All-That-Apply* (CATA), dilakukan dengan melibatkan 50 panelis tidak terlatih. Stabilitas oksidatif dianalisis berdasarkan kandungan asam lemak bebas (FFA), nilai peroksida (PV), nilai p-anisidin (AnV), dan nilai oksidasi total (TOTOX). Hasil menunjukkan bahwa peningkatan konsentrasi bahan *masking* secara signifikan meningkatkan preferensi aroma dan penerimaan keseluruhan serta menurunkan intensitas bau amis (p<0,05). Perlakuan *masking* 10% untuk masing-masing bahan *masking* terpilih sebagai perlakuan optimal. Analisis CATA menunjukkan bahwa kayu manis memberikan atribut sensori dominan berupa aroma pedas dan hangat sekaligus efektif menutupi bau amis. *Mastic* menghasilkan aroma herbal yang menyenangkan seperti pinus dan makin mengurangi intensitas bau. Kombinasi keduanya memberikan efek saling melengkapi dan meningkatkan atribut sensori. Sampel yang di-*masking* menunjukkan penurunan parameter oksidasi, minyak mata tuna dengan perlakuan *masking* kayu manis memiliki nilai oksidasi terendah dengan FFA sebesar 0,53%, PV 6,59 meq/kg, AnV 8,97 meq/kg, dan totox 22,15 meq/kg. Temuan ini menunjukkan bahwa kayu manis dan *mastic* dengan konsentrasi 10% adalah agen *masking* alami yang efektif untuk meningkatkan kualitas sensori dan stabilitas oksidatif TEO untuk aplikasi pangan.

Kata kunci: agen-*masking*, bau amis, CATA, hasil samping perikanan, minyak ikan

INTRODUCTION

Docosahexaenoic acid (DHA), an essential omega-3 fatty acid, plays a crucial role in maintaining cardiovascular health, brain development, and visual function (Rubilar *et al.,* 2012; Trebaticka *et al.,* 2017). Tuna eye oil (*Thunnus* sp.) is a natural source of DHA. Tuna is the second-largest export commodity for Indonesian fisheries, with catches reaching 359.132 tons in 2021 (KKP, 2022). The tuna processing industry primarily utilizes fish flesh, leaving by-products such as the head, bones, skin, fins, spines, and viscera. These by-products account for approximately 30-40% of the total fish weight and consist of the head (12.0%), bones (11.7%), fins (3.4%), skin (4.0%), and spines (2.0%) (KKP, 2020). Tuna eyes, a processing by-product, contain significant amounts of EPA and DHA, ranging from 5-8% and 26-36%, respectively (Trilaksani *et al*., 2021; Ladia *et al*., 2022; Trilaksani *et al.,* 2023; Nurmaida *et al*., 2024).

The high polyunsaturated fatty acid content of tuna eye oil makes it highly susceptible to lipid oxidation, which produces volatile compounds that cause rancidity and degrade oil quality. This unpleasant odor can reduce consumer acceptance; therefore, effective methods are required to improve the sensory quality and oxidative stability of tuna-eye oil. Deodorization has long been recognized as an effective approach for eliminating unpleasant odors from fish oil. Conventionally, fish oil deodorization involves high-temperature steam distillation (230-270°C), inert gas treatment, and solvent extraction (Yang *et al.,* 2021). However, these methods may damage double bonds, induce oxidation, and are often ineffective. An alternative approach involves the use of masking agents containing aromatic compounds. Research on the use of masking agents in tuna eye oil remains limited. A previous study found that the use of vanilla and apple flavors at concentrations of 0.025% and 0.05% could diminish the fishy odor of fish oil, but was not entirely effective (Serfet *et al.,* 2010). Another promising masking agent for fish oil is mastic gum, obtained from the mastic tree (*Pistacia lentiscus*), a traditional flavoring and texturizing agent used in Greek, Turkish, and Arabic cuisines. Yoghurt containing mastic gum has been reported to have a more favorable aroma than yoghurt without mastic gum (Simsek *et al.,* 2019). Mastic gum contains terpenoid compounds, which have potential as natural antioxidants and may enhance the oxidative stability of fish oil (Papada *et al.,* 2019). Cinnamon (*Cinnamomum burmanii*) is a widely available spice in Indonesia, known for its strong cinnamaldehyde aroma and high antioxidant activity (Shan *et al.,* 2020). In a study on goat milk-derived ice cream, cinnamon effectively masked the characteristic goat aroma due to its strong scent (Parera *et al.,* 2018). The use of cinnamon, mastic gum, and their combination is expected to lessen fishy odors while also serving as a flavoring agent for omega-3 fortification in sweet foods.

This study aimed to analyze the effects of cinnamon and mastic as natural masking agents on the oxidative stability and hedonic sensory acceptance of DHA-rich tuna eye oil. The findings of this study are expected to contribute to innovations in enhancing the quality of fish oil, making it more acceptable to consumers while adding functional food value owing to its high DHA content.

MATERIALS AND METHOD

The tuna eyes (*Thunnus albacares*) used in this study were supplied by the tuna loin company Primo Indo Ikan, located in Denpasar, Bali, Indonesia. The materials were transported frozen to the Laboratory of Preservation and Processing, IPB University, in a Styrofoam box lined with plastic and maintained at -18°C for approximately 7 h. Other materials used in this study included cinnamon powder and mastic gum, which were purchased from a commercial supermarket.

Extraction of Tuna Eye Oil

The extraction of tuna eye oil followed the method described by Trilaksani *et al.* (2020). The samples were thawed, and each tuna eye was cut into three parts to remove the sclera and lens. The remaining tissue was homogenized into a paste and centrifuged at 10,000 rpm for 30 min at 4°C to separate tuna eye oil (TEO) from other components, such as muscle tissue, blood, and water. The extracted oil was collected and stored in amber glass bottles wrapped in aluminum foil to prevent oxidation. The purification process was described by Suseno *et al.* (2017), using 5% Magnesol XL with gentle heating at 50°C for 20 min. The purified oil was then analyzed for oxidative stability parameters, including the p-anisidine value (AnV), peroxide value (PV), free fatty acid (FFA) content, total oxidation value (TOTOX), and fatty acid profile.

Masking Tuna Eye Oil

Purified tuna eye oil (TEO) was subjected to a masking process, as described by Song *et al.* (2018). This process involved the addition of cinnamon powder, mastic gum, and a 50:50 combination of cinnamon and mastic at 0, 5, 10, and 15 % (w/w). After the addition of the masking agents at the specified concentrations, tuna eye oil was stirred using a magnetic stirrer at 750 rpm for 15 min at 50°C. The masked oil was centrifuged at 10,000 rpm for 15 min at 4 °C. The resulting oil was subjected to sensory evaluation using the check-all-that-apply (CATA) method and hedonic tests. The oil samples selected based on sensory evaluation were further analyzed for free fatty acid (FFA) content, peroxide value (PV), p-anisidine value (AnV), total oxidation (TOTOX), and fatty acid profile.

Sensory Analysis

This study involved 50 untrained Indonesian participants aged 20–40 years, who were recruited to evaluate the sensory attributes of the samples. All participants provided verbal informed consent before undergoing the sensory tests. They were informed about the purpose of the study and the procedures involved, including smelling the aroma and observing the appearance of samples. As the study involved minimal risk and did not include any invasive procedures or sample consumption, ethical approval was not required.

Two sensory tests were conducted in this study: the first test used a 9-point hedonic scale (1 = extremely dislike, 9 = extremely liked) to assess the overall acceptance of the samples (Wichchukit and O'Mahony, 2014). The second sensory analysis used the check-all-that-apply (CATA) method. In this method, panelists are presented with a list of sensory attributes in the form of terms or phrases related to the characteristics of the food product being evaluated. The panelists were then asked to select the sensory attributes they deemed appropriate and relevant to characterize the aromas of the masked tuna eye oil samples (Delarue *et al.*, 2014).

Tuna Eye Oil Quality Analysis

The quality of tuna eye oil was determined following the standard methods of the Association of Official Analytical Chemists (AOAC) and the American Oil Chemists' Society (AOCS). The free fatty acid (FFA) content was estimated by titration with potassium hydroxide (KOH) in an alcohol solution using phenolphthalein as an indicator (AOCS, 1998). The peroxide value (PV) was determined by titration with sodium thiosulfate ($Na_2S_2O_3$) in the presence of potassium iodide and starch solution (AOAC, 2000). The anisidine value (AV) was measured spectrophotometrically at 350 nm (BMG Labtech, Ortenberg, Germany) (AOCS, 1998). The Totox value was calculated as the sum of the peroxide value and twice the anisidine value (AOCS, 1997). The fatty acid profile was analyzed using gas chromatography–mass spectrometry (GC-MS) (YL Instruments, Anyang, South Korea), according to the method described by AOAC (2005). The analysis was conducted in triplicate (n = 3), using 0.1 g of tuna eye oil sample per replicate, which was methylated into fatty acid methyl esters (FAMEs) before injection into the GC-MS system.

Data Analysis

The experimental design used in this study was a completely randomized design (CRD), with treatments consisting of different concentrations of cinnamon (CN), mastic gum (M), and their combination (CM) at 0%, 5%, 10%, and 15% (w/w), applied to tuna eye oil samples. Each treatment was conducted in triplicate. Data analysis was performed using Microsoft Excel 2013 and SPSS version 22.0. Prior to selecting the appropriate statistical tests, the data were assessed for normality and homogeneity of variance. For hedonic sensory data that did not meet the assumptions of normality, the Kruskal–Wallis test was employed at a 95% confidence interval ($\alpha = 0.05$). When significant differences were found, Dunn's post-hoc test was used to identify specific pairwise differences among treatments. In contrast, oxidative parameters (PV, AnV, and TOTOX) and fatty acid profile data, which met the assumptions of normality and homogeneity, were analyzed using one-way ANOVA, followed by Duncan's Multiple Range Test (DMRT) for post-hoc comparisons. Sensory profiling data collected using the check-all-that-apply (CATA) method were analyzed using Cochran's Q test to determine significant differences in sensory attributes among samples, using a 95% confidence level ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Masking Tuna Eye Oil

Assessing the masking process of tuna eye oil is essential for evaluating its effectiveness in reducing undesirable fishy odors while maintaining the oxidative stability. This process can significantly affect the overall sensory acceptance and quality of the final products. Three different masking treatments were applied to purified tuna eye oil, incorporating cinnamon powder, mastic gum, and a combination of cinnamon and mastic gum at 0, 5, 10, and 15% (w/w). The oil samples were subjected to a standardized mixing and centrifugation process to ensure uniform dispersion and clarity before further analysis. The effectiveness of these masking treatments was evaluated based on sensory attributes (hedonic and CATA analyses), oxidation parameters (FFA, PV, AnV, and TOTOX), and fatty acid profiles.

Hedonic Sensory Evaluation

The results of the hedonic sensory analysis of TEO with each masking agent and their respective concentrations are listed in Table 1. The masking treatment using cinnamon resulted in significant differences in all sensory parameters, including appearance, aroma, and overall acceptability ($p<0.05$). The highest appearance score was observed in the treatment without cinnamon (CN1), which was categorized as slightly liked. In contrast, the lowest appearance score was recorded for the 15% cinnamon addition treatment (CN4), which was categorized as slightly disliked. This indicates that increasing the cinnamon concentration negatively affected the appearance liking score of fish oil. The highest scores for aroma and overall acceptance were obtained for CN4 (15% cinnamon), both of which were categorized as slightly liked. Conversely, the lowest scores for aroma and overall acceptance were found for CN1 (0% cinnamon), which was categorized as slightly disliked. For the mastic masking treatment, significant differences were observed in the aroma and overall acceptance parameters based on statistical analysis ($p<0.05$), whereas the appearance parameters showed no significant differences across the concentrations. The highest hedonic scores for aroma and overall acceptance of the mastic treatment were recorded for M4 (15%). The combination of cinnamon and mastic resulted in significant

Tabel 1 Hedonic sensory analysis of masked tuna eye oil

Samples	Parameters		
	Appearance	Aroma	Overall Acceptance
Control	6.84±0.95[c]	4.51±1.03[a]	4.68±0.91[a]
Cinnamon 5%	5.94±0.86[b]	5.72±1.12[b]	5.56±0.95[b]
Cinnamon 10%	5.16±1.16[a]	6.26±0.89[bc]	6.04±0.92[bc]
Cinnamon 15%	4.58±1.23[a]	6.44±0.95[c]	6.22±0.84[c]
Control	6.62±0.94[a]	4.28±0.83[a]	4.64±0.87[a]
Mastic 5%	6.36±0.94[a]	5.20±0.94[b]	5.24±0.89[b]
Mastic 10%	6.34±0.93[a]	5.46±0.90[bc]	5.96±0.95[c]
Mastic 15%	6.22±0.86[a]	5.88±0.96[c]	6.28±0.94[c]
Control	6.88±0.87[cb]	4.44±0.74[a]	4.66±0.82[a]
Combination 5%	6.30±0.95[ba]	5.22±0.86[b]	5.68±0.76[b]
Combination 10%	5.76±0.91[a]	6.02±0.93[bc]	6.22±0.93[bc]
Combination 15%	5.34±0.91[a]	6.48±0.97[c]	6.48±0.95[c]

*Different superscript letters (a, b, c) in the same column indicate significant differences among the treatment groups.

differences in all sensory parameters between the treatments ($p<0.05$). The highest appearance score was recorded for CM1 (0%), whereas the lowest was observed for CM4 (15%), which was categorized as neutral. The highest aroma and overall acceptance scores were obtained for CM4 (15%), with values of 6.48 and 6.48, respectively, both categorized as slightly liked. Conversely, the lowest aroma and overall acceptance scores were found for CM1 (0%), which was categorized as slightly disliked by the panelists.

The masking effect of tuna eye oil effectively reduced the fishy aroma. Hedonic sensory analysis results showed that increasing the concentration of masking agents significantly improved the panelists' preference for aroma and overall acceptance. However, higher concentrations, particularly of cinnamon, negatively affected the appearance of the oil, making it noticeably darker. This observation is consistent with the findings of Redondo *et al.* (2022), who reported that higher cinnamon concentrations tended to reduce the lightness (L) of a product, making it appear darker.

In the case of mastic, increasing its concentration also improved aroma and overall acceptance scores but did not significantly affect the appearance. This is likely because mastic is a white powder; therefore, its addition did not alter the visual appearance of the oil. The increasing addition of cinnamon, mastic, and their combination showed a positive correlation with aroma preference and overall acceptance, as both agents were effective in masking the undesirable fishy odor of the oil.

Cinnamon is widely used to enhance flavor intensity and mask off-odors in meat products (Li *et al.,* 2020). For instance, Alosily *et al.* (2022) reported that the addition of cinnamon oil to goat milk ice cream significantly improved aroma preference. Mastic is a natural ingredient commonly used in cooking, baked goods, and ice cream to enhance aroma (Pachi *et al.,* 2020).

For the combination treatment using both cinnamon and mastic, the hedonic results were consistent with the cinnamon-only treatment. Higher concentrations increased the panelists' preference for aroma and overall acceptance but again led to a decline in appearance scores.

CATA And PcoA Analysis

The results of the Correspondence Analysis (CATA) for the masked tuna eye oil are presented in Figure 1, which illustrates the sensory attributes associated with each sample. The findings indicate that TEO samples treated with cinnamon, mastic, or their combination were positioned in a quadrant opposite to that of the control, signifying a distinctly different sensory profile. The principal coordinate analysis (PCoA) plot for the cinnamon-masking treatment (Fig 1b) showed that the panelists' overall liking was highest for the treatment with 10% cinnamon addition (CN3). In the mastic masking treatment (Fig 1d), the highest preference was observed at 10% (M3) and 15% (M4) concentrations of mastic. Similarly, for the combination of cinnamon and mastic (Fig 1e), the panelists' overall liking was recorded at 10% (CM3) and 15% (CM4) concentrations.

The CATA analysis results showed that at a 15% cinnamon concentration, the dominant appearance attributes were brownish and dark, whereas at 5%, the oil was mostly described as yellow. This finding supports the hedonic analysis, which revealed that increasing the concentration of masking agents led to a decline in appearance preference owing to the progressively darker color of the oil.

CATA also demonstrated that cinnamon-treated samples differed significantly from the untreated (control) sample, suggesting that the addition of cinnamon altered the sensory profile of the oil. Higher cinnamon concentrations were associated with aroma descriptors such as weak cinnamon, cinnamon, spice notes, strong cinnamon, and weak fish odor. In contrast, the control sample was characterized mainly by a strong fish odor and distinct fishy aroma. These results are consistent with those of Elmaghriba *et al.* (2023), who reported that cinnamon contains cinnamaldehyde and eugenol, two key compounds responsible for its characteristic aroma and ability to mask unpleasant odors.

PCoA further reinforced these observations, showing that the panelists' overall liking was closely related to sensory attributes, such as spice notes, cinnamon, yellowish appearance, and weak fish odor. This suggests that samples with a balanced profile of cinnamon aroma, light fish odor, and bright color were preferred.

For the mastic treatment, CATA results showed that samples containing mastic were dominated by sensory attributes such as sourish, pine, herbal notes, and weak fish odor. Meanwhile, samples without mastic retained strong fishy odor and aroma. Mastic contains terpenoid compounds, such as α-pinene and β-myrcene, which contribute to a fresh, sourish, green, and pine-like aroma (Rigling *et al.,* 2019). Similar to cinnamon, mastic-treated samples appeared in a separate quadrant from the control in the sensory plots, indicating their effectiveness in masking off-flavors. PCoA analysis supported this finding, showing that overall liking was associated with descriptors such as pine, sourish, herbal notes, and yellowish appearance.

In the combination treatment (cinnamon + mastic), the symmetric plot showed that the samples exhibited a blend of sensory attributes from both individual treatments, including weak fish odor, brownish, yellowish, sourish, and herbal notes, as well as strong cinnamon, pine, and spice notes, and weak cinnamon. These samples were also separated from the control group, which was strongly characterized by fishy attributes. The PCoA results aligned with this, showing that overall preference was associated with sensory characteristics such as spice notes, cinnamon, brownish and yellowish appearance, herbal notes, pine, and weak fish odor.

Based on the overall sensory evaluation, a 10% concentration was identified as the optimal masking level. Although the hedonic scores were significantly better than those of the lower concentrations, they were not statistically different from those of the 15% formulation, making the 10% formulation more efficient in terms of material use. The selected samples were used for further quality analysis.

Oxidation Parameters TEO

The quality of fish oil is a crucial aspect that must be analyzed. Table 2 presents the

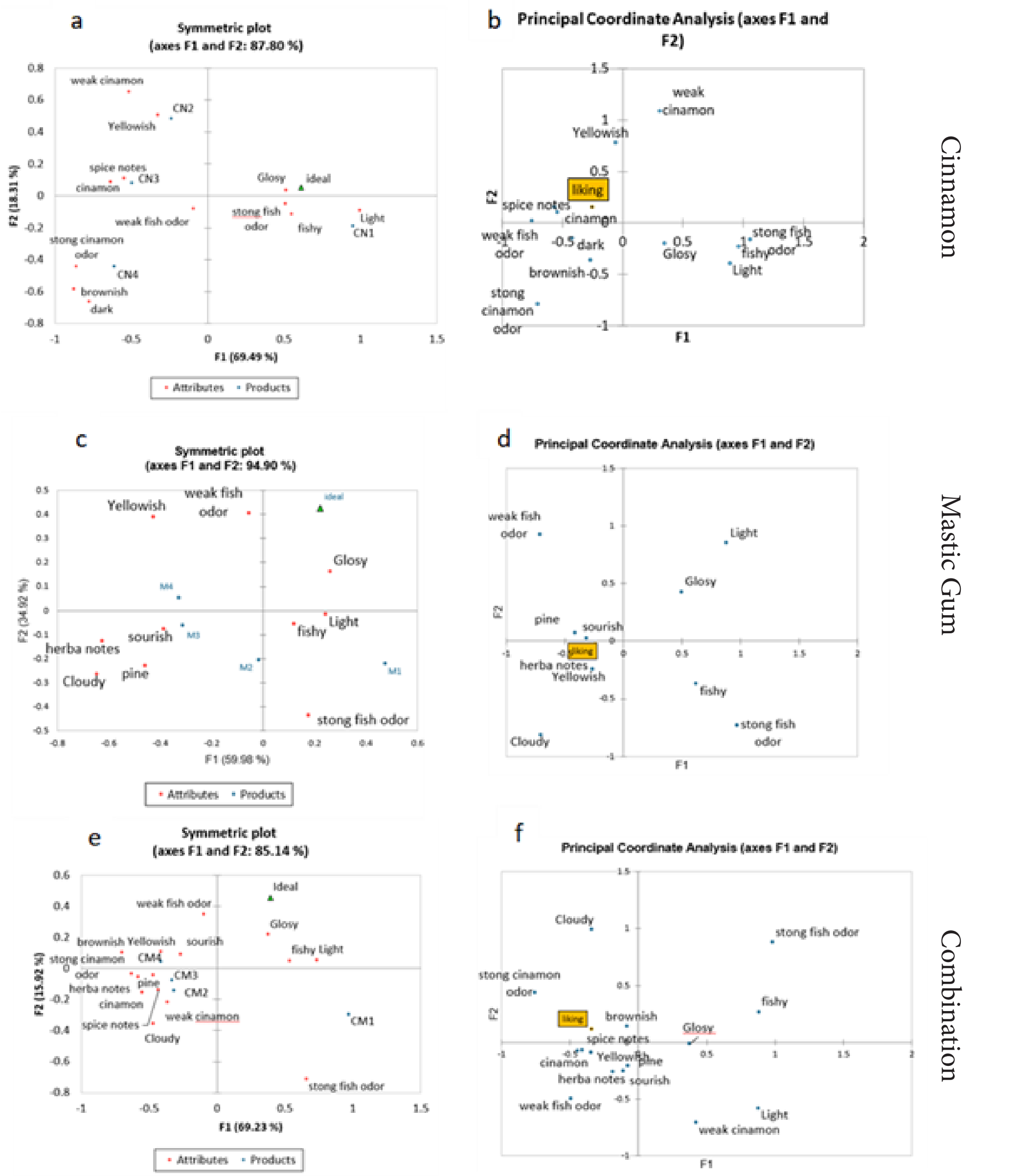

Figure 1 Symmetric plot tuna eye oil masking with cinnamon (a), principal coordinate analysis (PCoA) of tuna eye oil masking with cinnamon (b), symmetric plot for tuna eye oil masking mastic (c), principal coordinate analysis (PCoA) of tuna eye oil masking mastic (d), symmetric plot for tuna eye oil masking with a combination of cinnamon and mastic (e), principal coordinate analysis (PCoA) of tuna eye oil masking with a combination of cinnamon and mastic (f).

oxidative parameters of each fish oil sample. The oxidation parameters, including the peroxide value (PV), anisidine value (AnV), and total oxidation (TOTOX), showed significant differences among the treatments. The highest oxidation values were observed in the control treatment (TEO), whereas the lowest values were recorded in the masking treatment using cinnamon oil.

Masking treatments using cinnamon, mastic, or their combination significantly mitigated the oxidation values of TEO (Table 2). Masking treatment with cinnamon resulted in the lowest oxidation values for FFA, PV, AnV, and TOTOX. Free fatty acids (FFA) reflect the hydrolysis of triacylglycerol and serve as indicators of potential rancidity in oils. FFA levels are influenced by various

Tabel 2 Oxidation parameters of tuna eye oil

Sample	FFA (%)	PV (meq/kg)	AnV (meq/kg)	TOTOX (meq/kg)
Tuna eye oil	0.53±0.03[a]	12.57±0.41[d]	11.84±0.38[b]	36.98±0.12[d]
Cinnamon FO	0.52±0.07[a]	6.59±0.30[a]	8.97±0.40[a]	22.15±0.34[a]
Mastic FO	0.58±0.01[a]	9.37±0.16[c]	11.67±0.46[b]	30.41±0.30[c]
Cinnamon mastic FO	0.56±0.05[a]	8.41±0.34[b]	11.99±0.49[b]	28.81±0.35[b]
Codex 329-2017	<3.5	<5	<20	<26

*Different superscript letters in the row indicate significant differences

factors, including lipid composition, lipase activity, extraction method, moisture content, temperature, and storage conditions of the sample. The decrease in FFA levels in fish oil is consistent with that reported by Rizwan *et al.* (2025), who demonstrated that FFA levels in flaxseed oil decreased with the addition of cinnamon oil. This reduction was attributed to the presence of bioactive compounds in cinnamon, which act as antioxidants. Natural antioxidants can prevent triglyceride breakdown, thereby extending the shelf life of oils (Rangani & Ranewara, 2023). Furthermore, masking with cinnamon also resulted in a reduction in (Peroxide Value) of tuna eye oil. This finding is consistent with the results of Shahid *et al.* (2018), who reported that cinnamon extract reduced the peroxide values in palm oil. The peroxide value is a key indicator for measuring primary oxidation products, such as peroxides and hydroperoxides, which are formed in the early stages of lipid oxidation. The observed decrease in peroxide value is likely due to the presence of phenolic and flavonoid compounds in cinnamon, which exhibit strong antioxidant activity. Cinnamon extract is effective in scavenging free radicals and chelating superoxide, hydroxyl, and DPPH cation radicals (Khan *et al.,* 2023). Cinnamon extract possesses high antioxidant activity, with an antioxidant value of 84.58% (Rizwan *et al.,* 2025). In addition to FFA and PV, AnV and TOTOX values showed significant reductions. The p-anisidine value (AnV) test is commonly used to detect secondary oxidation products, providing insight into non-volatile carbonyl compounds generated during oil oxidation. During lipid oxidation, free radicals are formed owing to the loss of hydrogen atoms from unsaturated fatty acid double bonds (Khan *et al.,* 2024). Antioxidants in cinnamon can scavenge free radicals, thereby preventing lipid oxidation and inhibiting chain reactions through the activity of phenolic compounds (Ericson *et al.,* 2023).

Fatty Acid Profile

Table 3 presents the fatty acid profiles of TEO for each masking treatment. Fatty acid composition analysis of tuna eye oil revealed that it contains 43% PUFA, including 7% EPA and 30% DHA. Tuna eye oil contains 31% SFA and 24–25% MUFA.

The fatty acid profile of tuna eye oil is dominated by PUFA, particularly DHA (Table 3). The high DHA levels in TEO can be attributed to the fact that DHA reaches its highest concentration in the photoreceptor membranes (in the orbital eye region), where it functions as a neuroprotective agent against oxidative stress and plays a crucial role in the development of the retina (Van Leeuwen *et al.,* 2018). Trilaksani *et al.* (2020) also confirmed that DHA is the predominant fatty acid in tuna eye oil. In addition to DHA, palmitic acid is the second most abundant fatty acid in tuna eye oils. Ozogul *et al.* (2008) reported that various marine fish species have high palmitic acid content, reaching up to 70% of total SFA. Compared to previous studies, the SFA and MUFA contents in this study were lower than those reported by Djamaludin *et al.* (2023) for tuna viscera oil (36.18% SFA and 35.19% MUFA). However, the SFA content was slightly higher than the 31.06% reported by Ladia *et al.* (2022) for *Thunnus sp*. The PUFA, EPA, and DHA contents in this study were also higher

Tabel 3 fatty acid profile of tuna eye oil

Fatty Acids	Fatty Acids Profile			
	TEO	Cinnamon TEO	Mastic TEO	Combination TEO
Lauric Acid, C12:0	0.03±0.00	0.15±.17	0.03±0.00	0.03±0.00
Tridecanoic Acid, C13:0	0.03±0.00	0.03±0.00	0.03±0.00	0.03±0.00
Myristic Acid, C14:0	3.10±0.01	3.05±0.00	3.06±0.01	3.12±0.03
Pentadecanoic Acid, C15:0	0.96±0.04	0.94±0.03	0.92±0.00	0.95±0.01
Palmitic Acid, C16:0	18.59±0.02	18.60±0.01	18.57±0.04	18.60±0.07
Heptadecanoic Acid, C17:0	0.98±0.00	0.99±0.01	0.99±0.00	0.98±0.00
Stearic Acid, C18:0	4.80±0.00	4.74±0.01	4.74±0.00	4.78±0.00
Arachidic Acid, C20:0	0.32±0.00	0.35±0.01	0.35±0.00	0.34±0.01
SFA (Saturated Fatty Acid)	31.08±0.01[a]	31.60±0.00[d]	31.44±0.06[c]	31.25±0.13[b]
Myristoleic Acid, C14:1	0.09±0.00	0.08±0.00	0.09±0.00	0.48±0.56
Palmitoleic Acid, C16:1	5.75±0.00	5.67±0.00	5.66±0.01	5.73±0.01
Cis-10-Heptadecenoic Acid, C17:1	1.11±0.00	1.08±0.01	1.08±0.01	1.10±0.01
Oleic Acid, C18:1n-9c	16.94±0.00	16.55±0.04	16.55±0.01	16.87±0.03
Cis-11-Eicosenoic Acid, C20:1	1.36±0.00	1.35±0.01	1.35±0.00	1.36±0.00
MUFA (Monounsaturated Fatty Acid)	25.35±0.01[c]	24.88±0.04[a]	24.87±0.02[a]	25.24±0.01[b]
Linoleic Acid, C18:2n-6c	1.19±0.00	1.21±0.00	1.24±0.02	1.20±0.00
Linolenic Acid, C18:3n-3	0.39±0.00	0.39±0.00	0.39±0.00	0.39±0.00
γ-Linolenic Acid, C18:3n-6	0.08±0.00	0.44±0.51	0.09±0.00	0.08±0.00
Cis-11,14-Eicosadienoic Acid, C20:2	0.41±0.00	0.36±0.02	0.38±0.00	0.40±0.00
Cis-8,11,14-Eicosatrienoic Acid, C20:3n-6	0.14±0.00	0.14±0.00	0.15±0.00	0.14±0.00
Arachidonic Acid, C20:4n-6	3.09±0.00	3.05±0.00	3.04±0.00	3.07±0.01
EPA (Eicosapentaenoic Acid), C20:5n-3	7.45±0.00[d]	7.31±0.01[a]	7.34±0.01[b]	7.42±0.02[c]
DHA (Docosahexaenoic Acid), C22:6n-3	30.41±0.00[b]	30.42±0.02[b]	30.45±0.04[b]	30.33±0.09[a]
PUFA (Polyunsaturated Fatty Acid)	43.54±0.01[ab]	43.46±0.05[a]	43.60±0.08[b]	43.44±0.13[a]

*Superscript with different letters in the same row indicates significant difference

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than those in tuna viscera oil (19.94%, 7.70%, and 5.88%, respectively (Djamaludin *et al.,* 2023). In contrast, *Thunnus* sp. eye oil showed higher PUFA and DHA levels, reaching 44.66% and 33.44%, respectively (Ladia *et al.,* 2023). The fatty acid composition of fish oil varies depending on the species, habitat, and extraction methods (Souza *et al.,* 2020; Rahman *et al.,* 2023). Additionally, the size of the tuna eye may influence the DHA content of the extracted oil (Trilaksani *et al.,* 2023). Additionally, the results showed an increase in SFA and PUFA levels and a decrease in MUFA levels. This decline in MUFA is likely due to heat exposure during the masking process, as unsaturated fatty acids tend to have unstable double bonds that are highly susceptible to oxidation when exposed to heat (Isamu *et al.*, 2017).

CONCLUSION

This study demonstrated that cinnamon and mastic gum effectively improved the oxidative stability and sensory acceptance of DHA-rich tuna eye oil. The 10% masking treatment was identified as optimal, as it reduced fishy odor, enhanced aroma, and maintained oil quality. Cinnamon showed the greatest effect in lowering oxidation parameters. This suggests its potential for developing stable and consumer-acceptable omega-3 sources. Future research should optimize the concentration levels, explore alternative masking agents, and assess market acceptance for product development.

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