

Quality parameters of rainbow trout meatballs incorporated with avocado pulp and peel powder

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Abstract

The integration of dietary fibre into seafood products enhances their technological properties while promoting the development of health-oriented functional foods. The present work investigated the impact of incorporating varying proportions of avocado pulp and peel powders into rainbow trout meatballs on their quality attributes, with the aim of evaluating avocado flour as a functional ingredient in meatball formulation. Physicochemical, microbiological, and sensorial analyses were performed over 18-d refrigerated storage ($4 \pm 1^\circ\text{C}$). The incorporation of avocado powders significantly reduced bacterial counts, total volatile basic nitrogen (TVB-N), and thiobarbituric acid reactive substances (TBARS) compared to the control group. Statistically significant differences ($p < 0.05$) were also observed among the samples in terms of total saturated fatty acids (ΣSFA), monounsaturated fatty acids (ΣMUFA), polyunsaturated fatty acids (ΣPUFA), and omega-3 fatty acids ($\Sigma\text{n-3}$). These findings demonstrated that avocado pulp and peel powders (by-products of avocado processing) can serve as effective functional ingredients in rainbow trout meatball production, enhancing product quality, and contributing to the sustainable utilisation of agricultural waste.

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Introduction

In recent years, a paradigm shift in consumer preferences toward healthier dietary patterns has significantly increased the demand for functional foods-products enriched with bioactive compounds that confer health benefits beyond basic nutrition (Rashidinejad, 2024; Fekete *et al.*, 2025). Among these, dietary fibres are widely recognised as essential functional ingredients in the food industry due to their capacity to enhance both nutritional value and technological performance across a range of food products. Typically derived from cereals, legumes, fruits, vegetables, and their by-products, dietary fibres possess a broad spectrum of nutritional, functional, and health-promoting properties. Their incorporation into fish-based products has been shown to improve physicochemical attributes, chemical composition, textural integrity, and sensorial qualities. Moreover, dietary fibres exhibit biological activities that contribute to the prevention and management of various lifestyle-related disorders, including obesity, certain types of cancer,

type II diabetes, cardiovascular diseases, and gastrointestinal conditions (Mishra *et al.*, 2023).

Nowadays, dietary fibre has attracted considerable interest due to its bioactive constituents and associated health-promoting effects. Among various sources, fibre extracted from the pulp and peel of avocado (*Persea americana* Mill.) has gained popularity for its functional properties and consumer appeal. Native to Mesoamerica, avocado is increasingly recognised for its exceptional nutritional, functional, and technological qualities (Olas, 2024; Nascimento *et al.*, 2025). Classified as a superfood, avocado is rich in phytochemicals such as polyphenols, carotenoids, tocopherols, and sterols (Bhuyan *et al.*, 2019). It contains approximately 10% monounsaturated fatty acids (MUFA) and is also a source of essential vitamins, minerals, dietary fibres, phytosterols, and polyphenols (Wang *et al.*, 2015; Fleming *et al.*, 2025; Mostafazadeh *et al.*, 2025). The pulp is particularly noted for its oil content, which includes carotenoids, hydrocarbons, phytosterols, tocopherols, and aliphatic alcohols (dos Santos *et al.*, 2014). These bioactive compounds contribute to

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protective effects against cardiovascular conditions such as atherosclerosis and thrombosis and may also play a role in cancer prevention (Abaide *et al.*, 2017). Notably, avocado by-products such as seeds and peels once considered waste materials, are now recognised for their high concentrations of phenolic acids (*e.g.*, gallic, chlorogenic, and protocatechuic acids), flavonoids (*e.g.*, catechin and epicatechin), tannins, and starches (Nascimento *et al.*, 2025). Despite their potential, components like leaves, peels, and seeds have historically lacked targeted applications even though they possess significant antioxidant capacity (Rojas-García *et al.*, 2022; Pyrka *et al.*, 2025). In response to growing consumer demand for natural and health-enhancing food products, the food industry is increasingly exploring the use of bioactive compounds derived from such by-products as functional additives, with promising applications in food preservation and product innovation (Pattnaik *et al.*, 2021; Mozafari *et al.*, 2025).

Seafood represents a vital component of a balanced diet and serves as an affordable source of high-quality animal protein. The growing consumer demand for seafood-based products, particularly value-added and ready-to-eat options, has led to a notable expansion in their production and consumption (Shalders *et al.*, 2022; Jawale, 2025). Items such as fish burgers, fish meatballs, and croquettes have become increasingly popular within the convenience food sector, with fish meatballs emerging as one of the most favoured choices among consumers (Rodríguez-Turiénzo *et al.*, 2011; Uçak and Afreen, 2022). The nutritional and functional attributes of fish meat make it a valuable contributor to human health (Ali *et al.*, 2022). To enhance the physicochemical and sensorial properties of fish-based products, various plant-derived flours are frequently incorporated. These flours are known for their water-binding capacity and their ability to reduce fat absorption, thereby improving product texture and stability. In recent years, interest in such flours has intensified due to their bioactive compounds and associated health benefits. Among them, avocado flour, a naturally gluten-free alternative has gained particular attention for its functional potential. Rich in protein, starch, and dietary fibre, plant-based flours can help extend the shelf life of fish products, and when used at optimal levels, may enhance the freeze-thaw stability of fish meatballs (Touhid *et al.*, 2022).

The present work demonstrated a novel approach by utilising dietary fibre extracted from avocado pulp and peel in the formulation of fish meatballs as a topic that has not yet been explored in the existing literature. Key innovation lies in the incorporation of avocado peel, a by-product of fruit processing, thereby contributing to the valorisation of agro-industrial waste through its transformation into a functional ingredient. This ingredient not only enhances the nutritional profile of the product but also improves its technological attributes. The primary objective of the present work was to improve the nutritional and functional qualities of rainbow trout meatballs by incorporating avocado-derived fibre from pulp and peel. To achieve this, the present work evaluated the physicochemical, microbiological, and sensorial properties of rainbow trout meatballs incorporated with two different concentrations (1 and 3%) of avocado fibre, aiming to identify the optimal level for the development of a functional food product.

Materials and methods

Materials

Rainbow trout (*Oncorhynchus mykiss*) fillets were purchased from the Faculty of Fisheries, Atatürk University. A total of 15 kg of trout fillets, with an average weight 250 ± 25 g and a length of 28 ± 0.8 cm were brought to our faculty's processing laboratory under cold chain conditions. Avocados and other meatball ingredients were purchased from markets in Erzurum, Turkey.

Methods

Preparation of avocado pulp and peel powders

Approximately, 5 kg of fresh avocado fruits were thoroughly washed under running tap water, and the peels were manually separated from the pulp. Both components were dried in a laboratory oven (Memmert, UN 55, Germany) at 70°C for 48 h, or until a constant weight was achieved. The dried pulp and peel were then ground using a laboratory-scale mill and sieved to obtain a uniform powder. The resulting avocado pulp and peel powder were stored in hermetically sealed containers at -18°C until further use in meatball formulation. According to Jimenez *et al.* (2021), the edible portion of the avocado accounts for approximately 52.9 - 81.3% of the total fruit mass, with a nutritional composition

comprising 1.0 - 3.0% protein, 67 - 78% moisture, 0.8 - 4.8% carbohydrates, 0.8 - 1.5% ash, 13.5 - 24% fat, and 1.4 - 3.0% dietary fibre.

Production of trout meatballs and experimental design

The rainbow trout fillets were minced twice using a meat grinder (Empero, EM.08, Turkey) equipped with a 3-mm perforated plate. The resulting minced fish was divided into five separate batches for the preparation of experimental groups. The base formulation, adapted from Can and Çoban (2012), consisted of 2% salt, 5% onion, 3% garlic, 0.5% red pepper, 0.5% black pepper, and 0.5% cumin, which

were uniformly mixed into each batch. The five experimental groups were formulated as follows (Figure 1): Control (A): no avocado powder added; Group B: 1% avocado pulp powder; Group C: 1% avocado peel powder; Group D: 3% avocado pulp powder; and Group E: 3% avocado peel powder.

For quality assessment, raw meatballs from each group were placed on sterile polystyrene trays, sealed in polyethylene zip-lock bags, and stored under refrigerated conditions at $4 \pm 1^\circ\text{C}$ for 18 d. Physicochemical, sensorial, and microbiological evaluations were conducted at regular intervals on days 0, 3, 6, 9, 12, 15, and 18 of storage.



Figure 1. Fish ball production flow chart.

Physico-chemical analysis

The proximate composition of the samples including crude protein, lipid, ash, and dry matter was determined in accordance with the protocols outlined by AOAC (2000). Crude protein content was measured using a protein analyser (Inkjel, Behr Labor Technik, Düsseldorf, Germany). Lipid extraction was carried out *via* the Soxhlet method (Büchi E816 SOX, Flawil, Switzerland), following the procedure established by Folch *et al.* (1957). Fatty acid methyl esters (FAMES) were prepared according to Metcalfe and Schmitz (1961) and analysed using a gas chromatograph (Agilent 6890 N, Santa Clara, USA) equipped with a flame ionisation detector and a 100-m capillary column (CP-Sil 88, Agilent, Santa Clara, USA). Identification of fatty acids was performed by comparing chromatographic profiles with a standard FAME mixture.

The total volatile basic nitrogen (TVB-N) levels were quantified following the method proposed

by Malle and Tao (1987), with results expressed in mg per 100 g of sample. The lipid oxidation was assessed through thiobarbituric acid reactive substances (TBARS) analysis, following the protocol of Lemon (1975), and results were reported as micromoles of malondialdehyde.

The pH of the samples was determined using a SevenMulti pH meter (Mettler Toledo, Greifensee, Switzerland). For each measurement, 10 g of the sample was mixed with 100 mL of distilled water, and homogenised using an Ultra-Turrax homogeniser (IKA Ultra-Turrax T 25 digital, IKA-Werke GmbH & Co. KG, Staufen, Germany), following the method described by Gokalp *et al.* (2001).

Microbiological analysis

Plate count agar was used to determine the count of psychrophilic and total aerobic mesophilic bacteria. Incubation was carried out at 30°C for 48 h for mesophilic bacteria, and at 10°C for 7 d for

psychrophilic bacteria (Baumgart *et al.*, 1993). Potato dextrose agar was used for yeast and mould count with plates were incubated aerobically at 25°C for 5 d (Halkman, 2005).

Sensorial analysis

Sensorial attributes of the meatball samples, cooked at 175°C for 4 min, were evaluated by a panel of eight trained assessors. The panellists rated the samples based on colour, texture, flavour, appearance, odour, and overall acceptability using a nine-point hedonic scale (1 = dislike extremely, 9 = like extremely), according to Choi *et al.* (2014).

Statistical analysis

The experiment was carried out in two replications, with five different treatments (A, B, C, D, and E) and eight different storage times (0, 3, 6, 9, 12, 15, and 18 days). The results were analysed using the SPSS 26.0 program for Windows. Data were subjected to One-way analysis of variance (ANOVA) and Duncan's multiple comparison test to determine significant differences between groups.

Results and discussion

Physico-chemical properties of fish meatball samples *Nutritional composition*

The nutritional composition results of samples are presented in Table 1. Diet, species, size, habitat, and seasons all affect the ratios of chemical components in fish. In addition, some changes occurred in nutritional components as a result of processing techniques (Duzarduc, 2021). The incorporation of avocado pulp and peel powder into trout meatballs resulted in increased protein, lipid, and crude ash contents, accompanied by a decrease in moisture content relative to fresh fish. Overall, no significant differences ($p > 0.05$) were found in proximate composition among the groups. Similarly, Bacaksız and Çakır (2025) found statistically significant differences ($p < 0.05$) in the moisture, protein, and fat contents between the meatball groups prepared with parsley seed, black cumin oil, and fresh mackerel fish. Moisture contents decreased, while protein, fat, and ash contents increased.

Table 1. Proximate compositions of rainbow trout meatballs prepared using avocado fruit pulp and peel powders at different ratios (1% and 3%).

	Treatment				
	A	B	C	D	E
Protein	19.50 ± 1.95	18.58 ± 2.00	21.58 ± 2.06	20.54 ± 0.76	20.44 ± 0.48
Lipid	4.90 ± 0.14	6.70 ± 0.70	5.50 ± 1.41	6.50 ± 0.28	6.50 ± 0.70
Moisture	70.00 ± 2.82	69.01 ± 1.42	67.31 ± 0.15	67.79 ± 0.43	67.22 ± 0.49
Ash	3.90 ± 0.42	3.95 ± 0.07	3.92 ± 0.11	4.02 ± 0.08	4.08 ± 0.05

Values are mean ± standard deviation. A: control; B: 1% avocado fruit pulp powder; C: 1% avocado peel powder; D: 3% avocado fruit pulp powder; and E: 3% avocado peel powder.

The highest moisture content was found in the control group, whereas the E group showed the lowest moisture content. It was determined that the added additives reduced the product's moisture. The reduction in moisture content could be attributed to the absorption properties of the added powders. Avocado powders may bind water, leading to a decrease in free moisture in the meatball matrix. This effect could also enhance the shelf life and texture stability of the product, as lower moisture reduces microbial growth and oxidative spoilage. However, the results were in contrast with the report by Kurniasari *et al.* (2019), who found that as the amount of arrowroot flour used in fish meatballs increased, the moisture content also increased. This discrepancy

may be attributed to the differences in the properties of the additives used.

The highest crude protein content was measured in the C group. Avocado peel may contain protein-rich components that contribute to the observed increase. In contrast, Çoban (2021) found that the protein content of burgers containing aloe vera powder decreased compared to control group samples.

The ash content of avocado-enriched meatballs was higher than that of the control group, indicating an increased presence of minerals and salts. Similarly, Altan *et al.* (2023) reported that the ash content in Atlantic salmon meatballs was higher in the MTGase-added group than in the control group.

The crude fat analysis indicated no statistically significant differences among the treatment groups ($p > 0.05$). Nonetheless, samples containing avocado powder exhibited higher fat content compared to the control group. This observation is likely attributed to the natural fat composition of avocado pulp and peel powders, which are rich in monounsaturated and polyunsaturated fatty acids. The incorporation of these powders in the formulation increased the overall fat content. Supporting this, Zaini *et al.* (2019) reported that adding banana peel powder also increased the fat content in fish meatballs.

TVB-N

On day 0 of storage, the TVB-N value of the control group was measured at 8.19 mg/100 g, increasing to 28.15 mg/100 g by day 18 (Table 2). Among all samples, the control group exhibited the highest final TVB-N values, while the lowest levels were observed in group containing 3% avocado pulp powder. It is suggested that certain components in the pulp and peel of avocado may slow the increase of TVB-N in samples containing avocado pulp and peel powder over 18 days. The TVB-N values of all groups increased significantly ($p < 0.05$) as the storage time progressed. TVB-N refers to nitrogenous compounds released during protein degradation. Avocado flour is thought to contribute to lower TVB-N values compared to the control, possibly by stabilising protein structures and hindering the microbial decomposition of amino acids. Similarly, Balikci *et al.* (2022) found that TVB-N values were lower in mackerel meatballs prepared with the addition of rosemary, thyme, and basil herbal extracts compared to the control group. Nguyen *et al.* (2023) also observed an increase in TVB-N values in fish meatballs prepared from knifefish and striped catfish as the storage time progressed. Kızıloğlu and Yıldız (2024) reported that the increase in TVB-N values in fish fingers containing Jerusalem artichoke fibre was significantly slower than in the control group ($p < 0.01$).

TBARS

The TBARS values of all fish meatballs increased as the storage time progressed (Table 2). The TBARS values were lower in fish meatballs containing avocado pulp and peel compared to the control group. Avocado is rich in vitamins, minerals, unsaturated fatty acids, and antioxidants (Dreher and Davenport, 2013). The use of avocado likely affected

the TBARS values due to its antioxidant properties. Phenolic compounds, carotenoids, vitamins E and C, and phytosterols are primarily responsible for the antioxidant capacity of avocado (Bhuyan *et al.*, 2019). These antioxidants delay the oxidation of oils in fish meatballs, thus reducing the TBARS values. The strong antioxidant activity of phenolic compounds likely plays a major role in minimising oxidative damage, while vitamins E and C and carotenoids further slow lipid oxidation. The lowest TBARS value (1.35 $\mu\text{mol MA/kg}$) was observed in the B group. In aquatic products, a TBA value of 3 - 5 mg malonaldehyde/kg indicates good quality, while the consumability limit value is set at 7 - 8 mg malonaldehyde/kg. In the present work, the TBARS values increased significantly following 18-d storage, reaching 10.34 mg malonaldehyde/kg in the control group which exceeded the consumable limit ($p < 0.05$). Similarly, Çorapçı (2018) found that the TBARS value reached approximately three times the consumable limit by the end of storage in anchovies ($p < 0.05$). Trujillo-Mayol *et al.* (2022) also reported lower TBARS values in samples using avocado peel extract in beef and soy-based burgers compared to the control, consistent with the results observed in the present work. TBARS is one of the most important methods for determining lipid oxidation in fish and meat products (Abdel-Wahab *et al.*, 2020; Abeyrathne *et al.*, 2021). Fish meatballs are particularly perishable due to high levels of long-chain PUFAs, especially DHA and EPA, making them more susceptible to oxidative degradation than other meat products. Lipid oxidation can cause deterioration in odour, taste, texture, and colour, as well as the formation of toxic compounds. Chemical changes such as protein denaturation and lipid oxidation in seafood may lead to the loss of functional properties of the product and negatively affect consumer acceptability (Balikci *et al.*, 2022; Çorapçı *et al.*, 2023).

pH

The pH of avocado fruit averages around 6.4 (Rozan *et al.*, 2021). In the present work, the pH of fish meatballs ranged from 6.17 to 6.64 (Table 2), with the lowest initial value observed in the D group. The inclusion of plant-derived additives, such as avocado, generally decreases pH due to the presence of organic acids. Numerous studies have shown that adding plant and fruit-derived ingredients to meat products tends to reduce the pH values. For example,

Table 2. Chemical analysis of rainbow trout meatballs prepared using avocado fruit pulp and peel powders at different ratios (1% and 3%).

	Storage time (day)	Treatment				
		A	B	C	D	E
TVB-N (mg/100 g)	0	8.19 ± 0.14 ^{aG}	7.34 ± 0.09 ^{cdG}	7.66 ± 0.11 ^{bG}	7.11 ± 0.10 ^{dG}	7.47 ± 0.16 ^{bcG}
	3	13.24 ± 0.00 ^{aF}	11.01 ± 0.28 ^{cf}	11.22 ± 0.11 ^{bF}	10.48 ± 0.06 ^{eF}	10.80 ± 0.03 ^{dF}
	6	16.62 ± 0.19 ^{aE}	14.23 ± 0.09 ^{ce}	14.87 ± 0.10 ^{bE}	13.69 ± 0.16 ^{dE}	14.03 ± 0.01 ^{cE}
	9	19.93 ± 0.12 ^{aD}	17.28 ± 0.13 ^{cd}	18.31 ± 0.21 ^{bD}	16.98 ± 0.07 ^{dD}	17.15 ± 0.14 ^{cdD}
	12	23.43 ± 0.08 ^{aC}	20.18 ± 0.12 ^{cC}	20.98 ± 0.03 ^{bC}	18.04 ± 0.06 ^{eC}	19.48 ± 0.39 ^{dC}
	15	25.04 ± 0.07 ^{aB}	22.25 ± 0.21 ^{cB}	23.11 ± 0.10 ^{bB}	20.37 ± 0.34 ^{eB}	21.05 ± 0.10 ^{dB}
	18	28.15 ± 0.12 ^{aA}	25.32 ± 0.11 ^{cA}	26.16 ± 0.09 ^{bA}	23.54 ± 0.09 ^{eA}	24.40 ± 0.15 ^{dA}
TBARS (µmol MA/kg)	0	1.43 ± 0.04 ^{aG}	1.12 ± 0.10 ^{bG}	1.37 ± 0.07 ^{bF}	1.18 ± 0.18 ^{abG}	1.35 ± 0.25 ^{bG}
	3	3.10 ± 0.15 ^{aF}	2.92 ± 0.04 ^{abF}	2.92 ± 0.08 ^{abE}	2.34 ± 0.16 ^{bF}	2.47 ± 0.18 ^{bF}
	6	4.97 ± 0.02 ^{aE}	4.61 ± 0.16 ^{bE}	4.95 ± 0.08 ^{aD}	4.12 ± 0.15 ^{cE}	4.02 ± 1.00 ^{cE}
	9	6.03 ± 0.06 ^{aD}	5.99 ± 0.01 ^{abD}	5.99 ± 0.01 ^{abC}	5.56 ± 0.44 ^{bD}	5.70 ± 0.73 ^{bD}
	12	8.06 ± 0.06 ^{aC}	7.62 ± 0.13 ^{abC}	7.91 ± 0.09 ^{abB}	7.44 ± 0.06 ^{bC}	7.53 ± 0.91 ^{bC}
	15	9.15 ± 0.14 ^{aB}	8.77 ± 0.20 ^{bb}	8.29 ± 0.57 ^{cB}	8.57 ± 0.03 ^{bb}	8.84 ± 0.27 ^{bb}
	18	10.34 ± 0.12 ^{aA}	10.25 ± 0.22 ^{aA}	10.13 ± 0.13 ^{abA}	9.77 ± 0.22 ^{bA}	9.76 ± 0.22 ^{bA}
pH	0	6.42 ± 0.02 ^{aC}	6.35 ± 0.09 ^{aCD}	6.43 ± 0.02 ^{aBC}	6.17 ± 0.01 ^{bC}	6.28 ± 0.00 ^{bb}
	3	6.53 ± 0.01 ^{abAB}	6.45 ± 0.09 ^{bBC}	6.52 ± 0.02 ^{abAB}	6.44 ± 0.00 ^{aA}	6.52 ± 0.01 ^{abA}
	6	6.52 ± 0.01 ^{aB}	6.52 ± 0.02 ^{aAB}	6.53 ± 0.00 ^{aA}	6.46 ± 0.02 ^{aAB}	6.44 ± 0.00 ^{aAB}
	9	6.60 ± 0.01 ^{aA}	6.64 ± 0.02 ^{aA}	6.51 ± 0.01 ^{aAB}	6.46 ± 0.02 ^{aAB}	6.45 ± 0.00 ^{aAB}
	12	6.39 ± 0.03 ^{aC}	6.42 ± 0.07 ^{aBCD}	6.39 ± 0.05 ^{aC}	6.34 ± 0.08 ^{aABC}	6.36 ± 0.07 ^{aAB}
	15	6.53 ± 0.09 ^{aAB}	6.34 ± 0.05 ^{bCD}	6.43 ± 0.10 ^{abBC}	6.32 ± 0.04 ^{bBC}	6.29 ± 0.00 ^{bb}
	18	6.30 ± 0.06 ^{bD}	6.21 ± 0.13 ^{bE}	6.30 ± 0.03 ^{bD}	6.46 ± 0.05 ^{bAB}	6.48 ± 0.03 ^{bAB}

Values are mean ± standard deviation. Means followed by different uppercase superscripts in similar column are significantly different between storages ($p < 0.05$). Means followed by different lowercase superscripts in similar row are significantly different between treatments ($p < 0.05$); A: control; B: 1% avocado fruit pulp powder; C: 1% avocado peel powder; D: 3% avocado fruit pulp powder; and E: 3% avocado peel powder.

Ajik-Cerbas *et al.* (2022) found that the pH of crab balls decreased as storage progressed, consistent with our findings. Similarly, Kuzgun (2024) reported regular decreases in the pH of fish meatballs supplemented with bay and lemon essential oils during storage. Çoban (2024) reported that the differences in pH between fish cakes containing goji berry extract and the control group were statistically significant ($p < 0.05$). Additionally, it is thought that fluctuations in pH values during storage are related to the use of different chemical and microbiological activities.

Fatty acid composition

The fatty acid composition of rainbow trout meatballs is detailed in Table 3. The contents of palmitic acid (C16:0) and palmitoleic acid (C16:1)

increased in meatballs enriched with avocado pulp and peel increased compared to the control group, while stearic acid (C18:0) content decreased. The highest level of 22:6n-3 (DHA) was observed in the C group, and the lowest in the E group. Additionally, the highest 18:2n-6 (linoleic) content was found in groups enriched with avocado pulp and peel powder. Total n-3 and n-6 levels were significantly affected by experimental treatments ($p < 0.05$). The total n-3 levels decreased in the D and E groups as the incorporation rates of pulps and peels increased, while the highest n-6 level, predominant in vegetable oils, was found in 3% avocado peel powder group. There were also statistically significant differences between groups in oleic acid (OA; 18:1n-9) content ($p < 0.05$). Oleic acid increased in meatball groups incorporated with avocado pulp and peel compared to

Table 3. Fatty acid composition of rainbow trout meatballs prepared using avocado fruit pulp and peel powders at different ratios (1% and 3%).

	Treatment				
	A	B	C	D	E
14:0	13.00 ± 0.20 ^a	11.50 ± 1.50 ^a	13.50 ± 0.20 ^a	10.30 ± 0.42 ^a	10.40 ± 0.56 ^a
16:0	15.35 ± 0.21 ^a	15.95 ± 0.35 ^a	15.85 ± 1.62 ^a	16.50 ± 1.41 ^a	16.10 ± 0.14 ^a
16:1	3.50 ± 0.28 ^a	4.60 ± 0.56 ^{bc}	3.80 ± 0.28 ^{ab}	5.30 ± 0.28 ^c	4.40 ± 0.28 ^{abc}
17	0.00 ± 0.00	0.40 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
18:0	3.90 ± 0.14 ^a	3.15 ± 0.49 ^a	3.50 ± 0.70 ^a	2.60 ± 0.56 ^a	2.70 ± 0.42 ^a
18:1 n-9	22.35 ± 0.21 ^a	26.40 ± 0.84 ^b	23.75 ± 0.35 ^a	32.75 ± 0.35 ^c	32.50 ± 0.70 ^c
18:1 n-7	2.25 ± 0.21 ^a	2.90 ± 0.14 ^{ab}	2.40 ± 0.56 ^{abc}	4.00 ± 0.70 ^c	3.65 ± 0.49 ^{bc}
18:2 n-6	10.55 ± 0.63 ^a	10.40 ± 0.56 ^a	10.75 ± 0.35 ^a	10.50 ± 0.70 ^a	11.80 ± 0.28 ^a
20	0.10 ± 0.14 ^a	0.20 ± 0.14 ^a	0.20 ± 0.14 ^a	0.10 ± 0.00 ^a	0.30 ± 0.14 ^a
18:3 n-3	2.90 ± 0.14 ^a	2.70 ± 0.42 ^a	2.80 ± 0.28 ^a	2.10 ± 0.14 ^a	2.50 ± 0.42 ^a
21:1 n9	4.25 ± 0.21 ^b	0.00 ± 0.00 ^a	0.10 ± 0.00 ^a	0.00 ± 0.00 ^a	0.10 ± 0.14 ^a
18:4 n-3	0.70 ± 0.28 ^a	0.80 ± 0.14 ^a	0.80 ± 0.00 ^a	0.50 ± 0.42 ^a	0.50 ± 0.14 ^a
21:0	0.50 ± 0.14 ^a	0.40 ± 0.28 ^a	0.40 ± 0.00 ^a	0.30 ± 0.00 ^a	0.30 ± 0.28 ^a
22:0	0.10 ± 0.00 ^{ab}	0.00 ± 0.00 ^a	0.20 ± 0.00 ^b	0.00 ± 0.00 ^a	0.10 ± 0.14 ^{ab}
20:2 n-6	0.30 ± 0.28 ^a	0.30 ± 0.14 ^a	0.10 ± 0.00 ^a	0.10 ± 0.00 ^a	0.10 ± 0.14 ^a
20:3 n-6	0.30 ± 0.28 ^a	0.60 ± 0.28 ^a	0.60 ± 0.14 ^a	0.45 ± 0.21 ^a	0.40 ± 0.28 ^a
20:4 n6	0.50 ± 0.28 ^a	0.40 ± 0.42 ^a	0.35 ± 0.35 ^a	0.30 ± 0.00 ^a	0.25 ± 0.35 ^a
20:5 n-3	3.30 ± 0.14 ^b	3.40 ± 0.28 ^b	3.50 ± 0.42 ^b	2.30 ± 0.28 ^a	2.30 ± 0.14 ^a
24:1 n-9	0.20 ± 0.14 ^a	0.30 ± 0.00 ^a	0.30 ± 0.00 ^a	0.20 ± 0.14 ^a	0.30 ± 0.28 ^a
22:6 n-3	15.95 ± 0.2 ^b	15.60 ± 0.56 ^b	17.10 ± 0.14 ^c	11.70 ± 0.42 ^a	11.30 ± 0.42 ^a
∑SFA	32.90 ± 0.28 ^c	31.60 ± 0.56 ^b	33.70 ± 0.42 ^c	30.10 ± 0.14 ^a	29.70 ± 0.28 ^a
∑MUFA	32.40 ± 0.56 ^b	34.30 ± 0.28 ^c	30.40 ± 0.28 ^a	42.10 ± 0.56 ^d	40.95 ± 0.63 ^d
∑PUFA	34.70 ± 0.28 ^c	34.10 ± 0.28 ^c	35.90 ± 0.28 ^d	27.80 ± 0.28 ^b	29.60 ± 0.28 ^a
∑n3	22.60 ± 0.56 ^b	22.50 ± 0.42 ^b	24.25 ± 1.34 ^b	16.60 ± 0.84 ^a	16.70 ± 1.13 ^a
∑n6	11.90 ± 0.56 ^{ab}	11.60 ± 0.28 ^{ab}	11.90 ± 0.42 ^{ab}	11.10 ± 0.84 ^a	12.70 ± 0.42 ^b
n3/n6	1.90 ± 0.00 ^c	1.90 ± 0.00 ^c	2.05 ± 0.07 ^d	1.50 ± 0.00 ^b	1.30 ± 0.00 ^a

Values are mean ± standard error. Means followed by different lowercase superscripts in similar row are significantly different between treatments ($p < 0.05$). A: control; B: 1% avocado fruit pulp powder; C: 1% avocado peel powder; D: 3% avocado fruit pulp powder; and E: 3% avocado peel powder.

the control group due to its vegetable origin. Valenzuela-Melendres *et al.* (2014) reported that adding avocado pulp and using avocado and tomato paste in formulations increased the lipid content of the final product, improving meat quality due to the high proportion of monounsaturated fatty acids in avocado. Rozan *et al.* (2021) noted that avocado oil primarily consists of oleic acid (50 - 60% of fatty acid content), palmitic acid (15 - 20%), linoleic acid (11 - 15%), palmitoleic acid (6 - 10%), and linolenic acid (about 1%). Izci *et al.* (2011a) found that C18:1 n-9 and C18:2 n-6 contents increased with pre-frying in fish fingers, while another study showed that pre-frying fish chips decreased all fatty acid compositions

except for C18:1 n-9 and C18:2 n-6 (Izci *et al.*, 2011b). Significant differences ($p < 0.05$) were found among meatball groups in terms of saturated fatty acids (∑SFA), monounsaturated fatty acids (∑MUFA), polyunsaturated fatty acids (∑PUFA), and omega-3 (∑n3). Due to the high oleic acid content in avocado, higher rates of MUFA were detected in samples with avocado incorporation. Tarhan (2019) found that avocados contain approximately 15 - 20% SFA, 60 - 80% MUFA, and 5 - 10% PUFA. When 20% avocado was incorporated into the product formulation, the proportion of SFA decreased by 8%, while the MUFA content increased by the same amount. Izci (2010) determined that the fatty acid

contents of C16:0, C16:1, C18:1 n-7, and C18:3 n-6 in fish croquettes decreased significantly ($p < 0.05$).

Microbiological analysis

Total aerobic mesophilic bacterial count

The total aerobic mesophilic bacterial counts (log CFU/g) were measured in rainbow trout meatballs produced with the incorporation of avocado pulp and peel powders. Both treatment condition and storage duration, as well as their interaction, significantly affected ($p < 0.05$) the bacterial counts. During storage, total aerobic mesophilic bacterial levels ranged from 3.04 to 9.92 log CFU/g (Table 4). In the control samples, the initial bacterial count of 3.40 log CFU/g steadily increased, reaching 9.92 log CFU/g by the end of the storage period. While the control samples surpassed this limit by the 12th day, the experimental groups containing avocado

components reached it on the 15th day, indicating a delay in bacterial growth. The slower bacterial growth observed in meatballs enriched with avocado pulp and peel powders can likely be attributable to the antibacterial effects of phenolic compounds present in avocado peel. These compounds are known to disrupt bacterial cell walls, interfere with intracellular processes, and inhibit microbial enzyme activity, thereby reducing microbial proliferation compared to the control group. Furthermore, possible synergistic effects of other bioactive constituents in avocado peel may also have contributed to this outcome. Similar findings were reported by Da Silva *et al.* (2021), who demonstrated that coconut flour coatings effectively maintained bacterial counts within acceptable limits in fish nuggets during storage. Total viable counts (TVC) are widely regarded as key indicators of microbial spoilage in processed seafood products.

Table 4. Microbiological analysis of rainbow trout meatballs prepared using avocado fruit pulp and peel powders at different ratios (1% and 3%) (log CFU/g).

	Storage time (day)	Treatment				
		A	B	C	D	E
Total aerobic mesophilic bacterial count	0	3.40 ± 0.19 ^{aG}	3.13 ± 0.08 ^{bG}	3.10 ± 0.14 ^{bF}	3.04 ± 0.07 ^{bG}	3.29 ± 0.16 ^{abF}
	3	4.85 ± 0.10 ^{aF}	4.23 ± 0.10 ^{bF}	4.24 ± 0.20 ^{bE}	3.97 ± 0.03 ^{cF}	4.02 ± 0.05 ^{bcE}
	6	5.72 ± 0.17 ^{aE}	5.07 ± 0.11 ^{bE}	5.76 ± 0.12 ^{aD}	5.54 ± 0.29 ^{aE}	5.53 ± 0.04 ^{aE}
	9	6.77 ± 0.07 ^{cD}	5.62 ± 0.28 ^{bD}	6.16 ± 0.00 ^{bD}	6.12 ± 0.07 ^{bD}	6.42 ± 0.17 ^{aD}
	12	7.75 ± 0.14 ^{aC}	6.42 ± 0.24 ^{cC}	6.99 ± 0.00 ^{bC}	6.81 ± 0.19 ^{bC}	6.90 ± 0.08 ^{bC}
	15	8.97 ± 0.05 ^{aB}	7.59 ± 0.52 ^{bB}	8.40 ± 0.51 ^{aB}	7.79 ± 0.15 ^{bB}	7.63 ± 0.37 ^{bB}
	18	9.92 ± 0.24 ^{aA}	9.07 ± 0.12 ^{bA}	9.20 ± 0.18 ^{bA}	9.00 ± 0.00 ^{bA}	9.37 ± 0.32 ^{bA}
Psychrotrophic Bacterial count	0	3.78 ± 0.22 ^{aG}	3.29 ± 0.27 ^{bF}	3.29 ± 0.22 ^{aG}	3.09 ± 0.16 ^{aG}	3.37 ± 0.24 ^{aE}
	3	5.11 ± 0.10 ^{aF}	4.26 ± 0.15 ^{bcE}	4.36 ± 0.13 ^{bF}	4.05 ± 0.09 ^{cF}	4.19 ± 0.02 ^{bcD}
	6	5.74 ± 0.28 ^{aE}	5.50 ± 0.17 ^{aD}	5.78 ± 0.16 ^{aE}	5.54 ± 0.32 ^{aE}	5.57 ± 0.18 ^{aD}
	9	6.74 ± 0.19 ^{aD}	6.72 ± 0.05 ^{bC}	6.24 ± 0.22 ^{bD}	6.34 ± 0.09 ^{bD}	6.54 ± 0.18 ^{abC}
	12	7.82 ± 0.16 ^{aC}	6.74 ± 0.08 ^{cC}	7.08 ± 0.14 ^{bC}	6.92 ± 0.05 ^{bcC}	6.94 ± 0.05 ^{bcC}
	15	8.96 ± 0.06 ^{aB}	8.73 ± 0.19 ^{abB}	8.18 ± 0.32 ^{bcB}	7.70 ± 0.22 ^{bcB}	8.17 ± 0.50 ^{cB}
	18	10.08 ± 0.13 ^{aA}	9.05 ± 0.06 ^{bA}	9.18 ± 0.22 ^{bA}	9.00 ± 0.00 ^{bA}	9.30 ± 0.33 ^{bA}
Yeast and mould	0	< 2.00 ± 0.00 ^F	< 2.00 ± 0.00 ^F	< 2.00 ± 0.00 ^E	< 2.00 ± 0.00 ^E	< 2.00 ± 0.00 ^E
	3	< 2.00 ± 0.00 ^F	< 2.00 ± 0.00 ^F	< 2.00 ± 0.00 ^E	< 2.00 ± 0.00 ^E	< 2.00 ± 0.00 ^E
	6	2.39 ± 0.20 ^{aE}	2.57 ± 0.13 ^{aE}	2.26 ± 0.18 ^{aE}	2.29 ± 0.21 ^{aE}	2.36 ± 0.14 ^{aE}
	9	3.68 ± 0.21 ^{aD}	3.05 ± 0.08 ^{cD}	3.12 ± 0.12 ^{bcD}	3.47 ± 0.38 ^{abD}	3.17 ± 0.10 ^{bcD}
	12	4.51 ± 0.18 ^{aC}	4.97 ± 0.02 ^{bC}	4.70 ± 0.23 ^{abC}	4.63 ± 0.08 ^{bC}	4.49 ± 0.14 ^{bC}
	15	5.33 ± 0.08 ^{aB}	5.37 ± 0.12 ^{aB}	5.42 ± 0.10 ^{aB}	5.21 ± 0.16 ^{aB}	5.32 ± 0.17 ^{aB}
	18	6.71 ± 0.16 ^{aA}	6.14 ± 0.25 ^{bA}	6.25 ± 0.26 ^{bA}	6.02 ± 0.05 ^{bA}	6.26 ± 0.15 ^{bA}

Values are mean ± standard deviation. Means followed by different uppercase superscripts in similar column are significantly different between storages ($p < 0.05$). Means followed by different lowercase superscripts in similar row are significantly different between treatments ($p < 0.05$); A: control; B: 1% avocado fruit pulp powder; C: 1% avocado peel powder; D: 3% avocado fruit pulp powder; and E: 3% avocado peel powder.

According to the International Commission on Microbiological Specifications for Foods (ICMSF, 1986), 7 log CFU/g is considered the upper acceptable limit for processed fishery products. Consistent with this, İnanlı and Amin (2022) observed that the TVC of fish fingers exceeded 7 log CFU/g on the 12th day in control samples, whereas this threshold was reached on the 18th day in samples containing 1% goji berry extract. Similarly, in the present work, bacterial loads exceeded 6 - 7 log CFU/g after day 12, which coincided with the onset of sensory deterioration.

Psychrotrophic bacterial count

The psychrotrophic bacterial counts for rainbow trout meatballs were significantly influenced by treatment condition, storage duration, and their interaction ($p < 0.05$; Table 4). Psychrotrophic bacterial levels increased progressively throughout the storage period, starting from 3.09 - 3.78 log CFU/g on day 0 and reaching 10.08 log CFU/g in the control group by day 18, while the lowest count at the end of storage (9.00 log CFU/g) was observed in the C group. The increase in bacterial counts over time was statistically significant ($p < 0.05$) for all storage periods. Additionally, meatballs incorporated with avocado powder exhibited slower bacterial compared to the control group. This can be attributed to natural antimicrobial compounds present in avocado peel and fruit, such as phenolic compounds, flavonoids, and tannins, which inhibit microbial proliferation. Similar antimicrobial effects of avocado fruit and peel have been reported by Gumustepe *et al.* (2022). Additionally, Yıldız and Arslan (2022) observed lower psychrotrophic bacterial counts in catfish meatballs enriched with flax and chia seeds compared to the control group. Comparable findings were also reported by Çapkın *et al.* (2020), who reported a continuous increase in psychrotrophic bacterial counts during the storage of Tench fish cakes. Furthermore, Boulares *et al.* (2013) demonstrated that sea bass fillets maintained mesophilic aerobic plate counts and psychrotrophic bacterial counts below 7 and 8 log CFU/g, respectively, until the end of storage, whereas control fillets exceeded these upper acceptability limits. This highlights the potential of natural antimicrobial agents, such as those present in avocado, to extend the shelf life of fish products by inhibiting the growth of spoilage bacteria. Similarly in their study, examining the effect of some essential

oils in meatball production from rainbow trout, Keser and İzci (2020) found that the specified limit value (7 log CFU/g) in meatball samples was exceeded on the 7th day for both TMAB and TPAB.

Yeast and mould count

The yeast and mould counts for the trout meatballs are presented in Table 4. Treatment had a significant effect ($p < 0.05$) on yeast and mould counts, which increased over the storage period. Initial counts were below 2.00 log CFU/g on days 0 and 3, rising to 6.02 - 6.71 log CFU/g by the final day. The lowest counts were observed in the D group (3% avocado pulp powder), while the control samples exhibited the highest levels. These results agreed with previous studies. For instance, Uçak (2020) reported that at the end of storage (15th day) of burger samples enriched with pomegranate peel extract, yeast and mould counts in the control, 0.5%, and 1% enriched groups were 6.09, 5.99, and 5.61 log CFU/g, respectively, demonstrating the antifungal effect of phenolic compounds in fruit peels. The antifungal properties of phenolic compounds in avocado peel, which can disrupt cell membranes and inhibit enzymatic activity, likely contributed to these findings. Yeasts and moulds are not part of the normal flora of fish but typically originates from soil and can be introduced through water or contaminated tools (Kaba *et al.*, 2013). Consistent with the present work, Patır and Duman (2006) observed increasing yeast and mould levels during storage in shrimp-based croquettes.

Sensorial evaluation

Sensorial assessments of rainbow trout meatballs incorporated with varying levels of avocado pulp and peel powders are summarised in Figure 2. The interaction between treatment and storage time significantly influenced ($p < 0.05$) the appearance and texture of the samples, while odour, colour, taste, and overall acceptability were not significantly affected ($p > 0.05$). Both the type of avocado incorporation and storage time had notable effects on all sensorial attributes ($p < 0.05$). On the first day, the control group received the highest scores for appearance, texture, odour, and colour. However, sensory ratings declined across all groups over time, with the E group (3% avocado peel powder) receiving the lowest scores by the end of storage. Previous research supports these trends. For example, Ali *et al.*

(2019) found that sensorial attributes of fish burgers were unaffected by the inclusion of mashed pumpkin and potato, while Duman (2022) reported high appearance scores for flaxseed-enriched fish burgers. Similarly, Vanitha *et al.* (2015) observed a decrease in texture scores due to storage in Indian carp fish meatballs. Hashim *et al.* (2019) reported that catfish meatballs with different vegetables were well-received in terms of odour. Laso *et al.* (2020) found that fish meatballs enriched with seaweed scored

highest in colour parameters compared to the control group. Alkuraieef *et al.* (2020) indicated that among croquettes and meatballs made from mackerel, fish croquettes received the highest taste scores. In the present work, the control group was most acceptable overall, possibly due to the unusual taste of avocado in the fish meatballs. Nonetheless, studies such as Santillán-Álvarez *et al.* (2017) demonstrated similar sensory acceptability for carp meat restructured with chia flour when compared to control formulations.

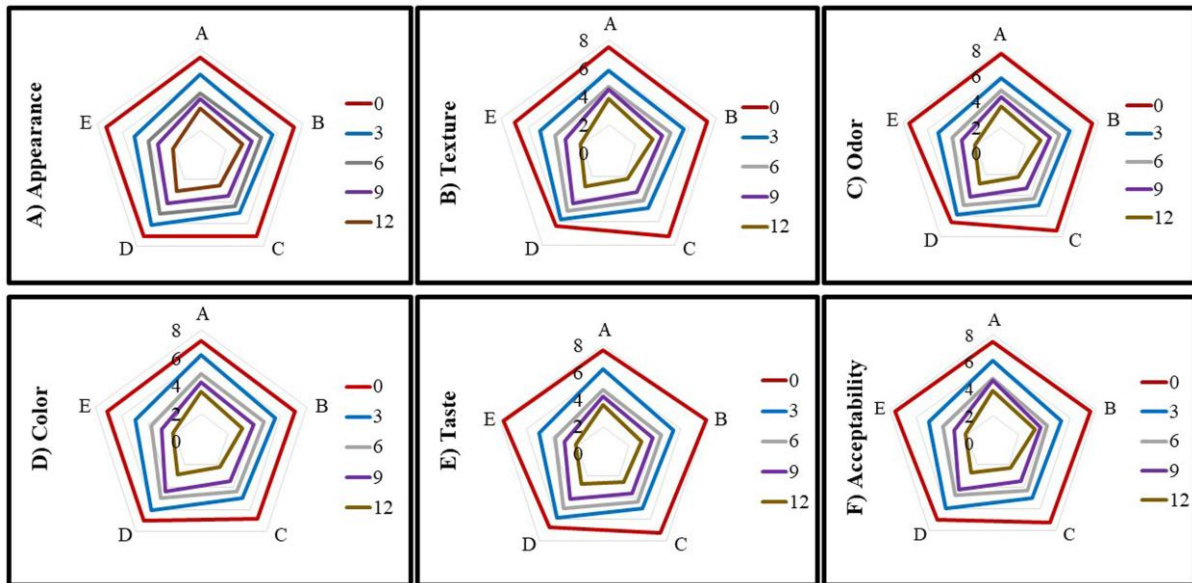


Figure 2. Sensory evaluations of rainbow trout meatballs prepared using avocado fruit pulp and peel powders at different ratios (1% and 3%). A: control; B: 1% avocado fruit pulp powder; C: 1% avocado peel powder; D: 3% avocado fruit pulp powder; and E: 3% avocado peel powder.

Conclusion

The present work evaluated the quality changes in rainbow trout meatballs produced with avocado pulp and peel powders during refrigerated storage ($4 \pm 1^\circ\text{C}$). The incorporation of avocado powder slowed microbial growth and led to reductions in TVB-N and TBARS values. Sensory evaluation indicated that the control group meatballs were more acceptable to panellists. Increasing the proportion of pulp and peel powder was associated with lower total n3 levels and higher n6 levels, with the highest observed in the group containing 3% avocado peel powder. As avocado is a rich source of omega-3 and -6 fatty acids, it can potentially replace wheat flour in meatball formulations. Furthermore, utilising avocado peel waste helps prevent environmental pollution, promotes product diversity, and provides economic benefits.

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