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Improving Fatty Acid Composition and Some Quality Characteristics of Low-Fat Beef Meatballs with Encapsulated Fish Oil and Black Carrot Pomace

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Abstract: The objective of this study was to examine the effects of encapsulated fish oil and black carrot pomace on fatty acid profile as well as on some quality characteristics of low-fat beef meatballs. Four different meatball formulations were improved as; H0: 4% encapsulated fish oil+0% black carrot pomace; H3: 4% encapsulated fish oil+3% black carrot pomace, H6: 4% encapsulated fish oil+6% black carrot pomace, C: control containing no encapsulated fish oil or carrot pomace. Proximate composition (moisture, fat, protein, ash), pH value, color measurement, fatty acid composition and sensory analysis were carried out on samples. Addition of black carrot pomace significantly affected protein, ash, color (*L**, *a**, *b** values) and reduced pH values of the samples *(P<0.05)*. Fatty acid profile of meatballs was significantly improved by using encapsulated fish oil in the formulations *(P<0.05)*. The total amount of saturated fatty acids (SFA) in samples containing encapsulated fish oil decreased by approximately 8-10% and polyunsaturated fatty acids (PUFA) increased 36-47% compared to the controls due to the high supply of n-3 fatty acids from fish oil. Sensory evaluation scores of samples revealed all treatments were comparable to the control sample for attributes in terms of texture, juiciness, flavour and overall acceptance *(P>0.05)*. Results indicate that usage of encapsulated fish oil and black carrot pomace in low fat beef meatball could give an opportunity to obtain a new healthier meat product with improved fatty acid profile and acceptable sensory properties.

Keywords: Black carrot, encapsulated fish oil, fatty acid composition, low fat, meatball.

Enkapsüle Balık Yağı ve Kara Havuç Posası İlavesi ile Az Yağlı Dana Köftelerinin Yağ Asidi Kompozisyonu ve Bazı Kalite Özelliklerinin Geliştirilmesi

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Öz: Bu çalışmanın amacı, enkapsüle balık yağı ve kara havuç posasının az yağlı dana köftelerinin yağ asidi kompozisyonu ve bazı kalite özellikleri üzerine etkilerini incelemektir. Dört farklı köfte örnek grubu formülasyonu geliştirilmiştir; H0: %4 enkapsüle balık yağı + %0 kara havuç posası; H3: %4 enkapsüle balık yağı + %3 kara havuç posası; H6: %4 enkapsüle balık yağı + %6 kara havuç posası, C: enkapsüle balık yağı veya havuç posası içermeyen kontrol örnek grubu. Örneklerde kimyasal kompozisyon (nem, yağ, protein, kül), pH değeri, renk ölçümü, yağ asidi kompozisyonu ve duyusal analiz gerçekleştirilmiştir. Kara havuç posası ilavesi, örneklerin protein, kül miktarını, renk (*L*, a*, b* değerleri*) özelliklerini önemli düzeyde etkilemiştir ve pH değerlerini düşürmüştür *(P<0,05)*. Köfte örneklerinin yağ asidi kompozisyonu, formülasyonlarına enkapsüle balık yağı eklenerek önemli düzeyde geliştirilmiştir *(P<0,05)*. Enkapsüle balık yağı içeren örneklerdeki doymuş yağ asitlerinin (SFA) toplam miktarı, balık yağından gelen yüksek n-3 yağ asitleri sebebiyle kontrol ile karşılaştırıldığında yaklaşık %8-10 oranında azalırken, çoklu doymamış yağ asitleri (PUFA) bakımından %36-47 oranında artmıştır. Duyusal analiz puanları, tüm örnek gruplarının doku, sululuk, lezzet ve genel kabul özellikleri açısından kontrol örneğiyle karşılaştırılabilir olduğunu ortaya koymuştur (*P>0,05).* Sonuçlar, düşük yağlı dana köftede enkapsüle balık yağı ve kara havuç posası kullanımının, geliştirilmiş yağ asidi profili ve kabul edilebilir duyusal özelliklere sahip yeni ve daha sağlıklı bir et ürünü elde etme fırsatı verebileceğini göstermektedir.

Anahtar kelimeler: Düşük yağ, enkapsüle balık yağı, kara havuç, köfte, yağ asidi kompozisyonu.

INTRODUCTION

Meat and meat products have constituted a fundamental element of human diets since ancient times. Meat is a rich source of vitamins and minerals, including all essential amino acids, thus making it an excellent protein source (Geiker et al., 2021). The ingestion of meat has been demonstrated to be a significant source of essential nutrients, including iron, zinc, selenium and vitamin B12 (Libera et al., 2021). Meatball is one of the favourite meat products in Turkiye. The fundamental ingredient constituting meatballs is minced beef, with additional components such as goat and sheep meat, breadcrumbs, parsley, onion, spices and garlic also being utilized (Öğütcü et al., 2018).

Meat and meat products consumption is the association between a high intake of SFA and the incidence of physiological disorders, such as obesity, type 2 diabetes, high blood lipids, high cholesterol level, and cardiovascular diseases. The prevailing perception of meat fat as being high in saturated fatty acids (SFA) has led to the belief that meat, particularly red meat, should be avoided (Badar et al., 2021). These concerns have led the WHO to make future encouragement for replacing SFA in meat products ((López-Pedrouso et al., 2021). Therefore, there has been an increased interest in recent years in ways to manipulate the fatty acid composition of meat and meat products. Fat has respectable importance in meat and meat products, since it affects technological properties. Fat has a significant impact on the quality of meat, with implications for characteristics such as juiciness, tenderness, mouthfeel and flavour release of the product (Wi et al., 2020).

Fish oils are known as a rich source of the long-chain polyunsaturated omega-3 (n-3) fatty acids, containing docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). The high content of n-3 fatty acids in fish oil, along with its beneficial effects on human health, particularly on heart, brain, and nervous system function, has led to its consideration as a functional component (Jamshidi et al., 2020). Fish oil is mainly used in industrial contexts as a raw material for the production of pharmaceuticals and food supplements, owing to its protective and healing properties. Additionally, it is employed as an additive in the animal feed industry (Bayraklı & Duyar, 2019). Fish oil, rich in fatty acids, shows potential as a therapeutic tool for various diseases, including cardiovascular diseases, cancer, obesity, type 2 diabetes, depression, non-alcoholic fatty liver disease, Alzheimer and inflammatory conditions (Ellulu et al., 2015; Jamshidi et al., 2020). Different health organizations have established dietary recommendations for EPA and DHA (Solomando et al., 2021). Meat products has a low content of ω-3 LCPUFA. Enriching meat products with fish oil could be a highly effective strategy for increasing dietary intake of these fatty acids (Raeisi et al., 2021). However, DHA and EPA in fish oil are beneficial for health, the addition of these components to meat products can have a detrimental influence on certain sensory attributes and lipid oxidation stability. This is primarily due to the undesirable off-flavours and off-odours associated with fish oils, as well as the high susceptibility of EPA and DHA to oxidation (Solomando et al., 2020). Encapsulation is an effective method of stabilising highly unsaturated fatty acids, masking the odour of fish oil and preserving the biological activity of nutrients (Pourashouri et al., 2021; Raeisi et al., 2021; Solomando et al., 2021).

The transformation of meat products into more "healthier" forms can be achieved through the incorporation of ingredients that are considered beneficial for health, or by the elimination or reduction of components that are harmful. Fiber is one of the valuable components that can be used in meat products from a health point of view. Dietary fiber is recognized as a crucial component of a healthy human diet. Most meat-based foods are rich in protein and fat but typically deficient in dietary fiber, such as complex carbohydrates. Additionally, fiber is utilized not only as a beneficial additive but also as an extender, binder, and fat replacer in the manufacturing of various meat products (Mehta et al., 2015).The incorporation of different types of dietary fibers in meat products has been researched (Santhi et al., 2020; Younis et al., 2021; Younis & Ahmad, 2017; Bouaziz et al., 2020; Illippangama et al., 2022).

Black carrots (*Daucus carota* L.) are a good source of fibres, sugars, vitamins and minerals, and they have a characteristic bluish-purple colour due to anthocyanins (water soluble). They are an excellent source of phytochemicals, including ascorbic acid, carotenoids, polyacetylenes and phenolic compounds. Black carrots are grown and drained in Turkiye, Afghanistan, Egypt and the Far East conventionally. Turkiye is one of the few countries with extremely favourable conditions for growing carrots (Chhetri et al., 2022; Thakur et al., 2024). Black carrot is a natural food colouring, a natural antioxidant, and a vegetable with a high mineral content. Peel and pomace of black carrot are rich in polyphenols, which possess anti-inflammatory properties (Stoica et al., 2024; Thakur et al., 2024). Carrot pomace is the residual material that is left over after the processing of carrots, typically following the extraction of carrot juice or other processing methodologies. It is constituted of diverse elements, including carrot pulp, skins, seeds, and other remnants (Ikram et al., 2024; Liu et al., 2023). Carrot pomace is a nutritionally rich by-product. Its insoluble fraction is rich in fiber, consisting mainly of pectic polysaccharides, hemicellulose, and cellulose (Granucci et al., 2023).

The objective of this study was to assess the potential of encapsulated fish oil and black carrot pomace in the production of low-fat meatballs, with a focus on their impact on fatty acid composition and selected quality parameters. This research will propose a method for producing low-fat meatballs and investigate the potential for enriching low-fat meatballs with n-3 polyunsaturated fatty acids through encapsulated fish oil and black carrot pomace.

MATERIAL AND METHOD

Lean beef as boneless rounds and fat were obtained from a local processor (Burdur Gucbirligi Meat Facility A.S). Carrot pomace was a by-product from black carrot juice processing and supplied from Erkon Konsantre A.Ş., Konya, Turkey and stored at -18ºC until used. Commercial encapsulated fish oil -Pure Arctic Premium Powder (43% fat; 1.5% moisture) supplied by Orkla Health AS, Division Denomega, Norway. Rusk, onion powder, salt and black pepper were purchased from a local market in Izmir, Turkiye.

Formulation of Meatballs: Lean and fat were ground through a 3 mm plate grinder. Four different low-fat beef meatballs were formulated as: 0% black carrot pomace and 4% encapsulated fish oil (H0); 3% black carrot pomace and 4% encapsulated fish oil (H3) and 6% black carrot pomace and 4% encapsulated fish oil (H6) and 0% black carrot pomace and 0% encapsulated fish oil (C) (Table 1). All meatball mixtures were prepared with equal amounts of fat (8%) and additives (bread crumbs, onion powder, salt, black pepper, cumin). Black carrot pomace (BCP) and encapsulated fish oil (EFO) ratios were replaced by meat ratio in the formulation of the meatballs. All of the additives were added to meatball mixture and kneaded until a homogeneous distribution was obtained. Then each meatball was formed using a metal shaper (1 cm thick and 80 mm diameter). The entire trial was replicated twice at separate times. Proximate composition analysis, pH determination, color measurement, fatty acid composition analysis and sensory evaluation were carried out on samples for each replicate.

Proximate Analysis: Moisture and ash content of the uncooked samples were measured based on AOAC (2000) procedures. Protein content was determined according to Anonymous (1979). The conversion factor was 6.25 for protein analysis. Lipid content was determined using the Soxhlet extraction method according to AOAC (2006).

pH Determination: pH analysis was conducted by directly inserting the pH electrode (Thermo Scientific Orion 3-Star, Singapore) into the uncooked samples for each treatment.

Color Measurements: Color measurements of the uncooked meatballs were carried out using a Color Flex A60-1010-615 Manual Version 23 Hunter Lab spectrocolorimeter. The device was standardized with white tile after black glass before each analysis. Eight measurements were taken for each sample. Color coordinates *L** (lightness), *a** (redness), *b** (yellowness) were recorded for the outside surfaces of the samples.

Table 1. Formulation of Meatballs.

Ingredients (%)	Samples			
	C	H0	H3	H6
Meat	79.9	75.9	72.9	69.9
Encapsulated Fish Oil	0	4	4	4
Black Carrot Pomace	0	0	3	6
Fat	8	8	8	8
Bread crumbs	7	7	7	7
Onion Powder	3	3	3	3
Salt	1.5	1.5	1.5	1.5
Black Pepper	0.3	0.3	0.3	0.3
Cumin	0.3	0.3	0.3	0.3

Fatty Acid Composition Analysis: The extraction of lipids from 10 g samples was performed by using chloroform: methanol (2:1 v/v) (Flynn & Bramblett, 1975) and then methylated (Anon, 1987). A gas chromatograph (HP 5890) fitted with a fused silica capillary column (CP-Sil-88; 50m× 0.25mmi.d., 0.20 µm film thickness of polyethylene glycol) (Chrompack Ltd., London UK) was used for the analyzing of fatty acid methyl esters (FAME). The column temperature was programmed as 100°C to 220°C at 4°C/min and 15 min at 220°C. The injector and the detector (FID) temperatures were 220°C. The carrier gas was hydrogen at a flow rate of 1ml/min. The fatty acids were identified by comparing retention times of the samples with those of the standards and expressed as g/100 g fatty acids.

Sensory Evaluation: Sensory evaluations of the meatball samples were performed at the sensory evaluation laboratory in individualized booths by 10 panelists consisting of graduate students from the Ege University Food Engineering Department. Meatball samples were served to panelists with water and bread after being cooked in the oven for 16 minutes (8 minutes for each surface) until the internal temperature reached at least 75°C. The samples were coded with 3 digit randomized numbers and placed in a random order. Samples were presented right after the cooking process and evaluated in terms of appearance, color, texture, juiciness, flavor, oxidized flavor and overall acceptability using a 9-point hedonic scala (9=like extremely 1=dislike extremely) (Altug & Elmaci, 2005).

Statistical Analysis: The effects of different ratios of black carrot pomace and encapsulated fish oil on proximate composition, pH, color, fatty acid composition and sensory analyses were examined using a one-way ANOVA. Differences among the means were compared by using Duncan's Multiple Range test. A significance level of P $P \leq 0.05$ was used for all evaluations. The data was analyzed using SPSS software version 20 (SPSS, 2011).

RESULTS AND DISCUSSION

pH and Proximate Composition of Meatballs: Moisture, fat, protein, ash and pH values of uncooked meatballs can be seen in Table 2. Moisture content of the control sample was detected to be significantly higher (P<0.05) than those of the H0 sample containing encapsulated fish oil due to the increase in dry matter. There was no significant difference between sample groups containing black carrot pomace in terms of moisture content. Fat content of the samples were not significantly affected (P>0.05) by the addition of encapsulated fish oil and black carrot pomace. Protein content of control sample was significantly higher (P<0.05) than those of the other samples. No significant differences were found between the sample groups containing carrot pomace (P>0.05) in terms of protein content. The ash content of H6 sample including highest amount of black carrot pomace was detected as significantly higher than those of the C sample. Similar findings were reported by Mendiratta et al. (2013) regarding mutton nuggets with carrot paste group showed no significant difference in the moisture. Another study revealed that moisture content in beef patties decreased as the percentage of pomace increased. This decrease was attributed to the replacement of meat with dried carrot pomace, which possesses a considerably lower moisture content than meat.

Table 2. Proximate composition and pH of meatballs (mean ± standard error)

Sample	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	pH
C	66.29^{b} ± 1.01	8.68^{a} ± 2.38	20.34^{b} ± 0.25	2.56^{a} ± 0.04	5.68^{c} ± 0.02
H0	62.92^{a} ± 2.98	9.27^{a} ± 0.65	18.59^{a} ± 1.10	2.61^{ab} ± 0.09	5.62^{b} ± 0.02
H3	63.93^{ab} ± 1.47	9.53^{a} ± 1.07	18.48^{a} ± 0.42	2.60^{ab} ± 0.08	5.48^{a} ± 0.02
H6	63.53^{ab} ± 1.39	9.87 ± 1.14	18.37^{a} ± 0.80	2.72^{b} ± 0.11	5.53^{a} ± 0.03

C: Control; H0: 4% EFO; H3: 4%EFO + 3% BCP; H6: 4%EFO + 6% BCP

$^{a-b:}$ Means in the same column with different superscripts are significantly different (P<0.05)

The use of different amounts of black carrot pomace and encapsulated fish oil in the formulations of the samples caused significant differences in the pH values of the samples (P < 0.05). It was determined that the pH values of the H3 and H6 samples with added black carrot pomace were significantly lower than those of the other samples without black carrot pomace (P < 0.05). The use of fish oil in the sample formulation also caused a decrease in pH value. The pH value of sample H0 was found to be significantly lower than sample C (P < 0.05). However, in a study it was determined that adding carrot pomace into beef patties showed no significant differences in terms of pH values (Richards, 2023). Similarly, in another study the addition of carrot pomace powder at levels of 1%, 2%, and 3%, to chicken meatballs did not affect the pH of product (Santhi et al., 2022a). But nevertheless Santhi et al. (2022b) reported that pH of chicken meatballs significantly (P≤0.01) decreased with the increase in the level of grape pomace powder. They mentioned that the drop in pH by the addition of grape pomace powder was due to the fact that it is rich in phenolic acids and tartaric acid. When the results of the studies were evaluated, it was observed that the addition of microencapsulated fish oil to meat products caused different effects on the pH values of the samples. Domínguez et al. (2017) showed the frankfurter sausages manufactured with microencapsulated fish oil presented the lowest pH values. This fact could be related with the low pH value (4.98) that presented the microencapsulated.

Color of Meatballs: Color is an important quality parameter that is effective in consumer acceptance in meat and meat products. The addition of black carrot pomace and encapsulated fish oil into meatballs significantly affected the color of meatball samples (*p<0.05*). The highest $L*$ and $b*$ values determined in the H0 (%4 EFO) sample group. It can be explained as the lighter color of the encapsulated fish oil according to the color of the beef meat resulted that higher $L*$ and $b*$ values in samples.

The lowest $L*$, $a*$ and $b*$ values were determined in the H6 (6% BCF) sample group. The higher a* values were observed in C and H0 samples than H3 and H6 samples. Similarly, Ekici et al. (2015) reported that $a*$ values decreased due to the increase in black carrot concentration in sucuk formulations containing nitrite (p<0.05). Also Richards (2023) was reported that the addition of carrot pomace significantly reduced the redness ($a*$) of beef patties, with a 40% decrease observed in patties containing 4.2% carrot pomace compared to the control patties. Younis & Ahmad (2017) obtained similar results showing that the addition pineapple pomace powder in sausages and patties decreased significantly $L*$ values. The $L*$ results between C and H0 agreed with those observed by Domínguez et al. (2017) who found that $L*$ values significantly increased by the replacement of pork fat with microencapsulated fish oil.

Table 3. $L*$, $a*$ and $b*$ values of meatballs (mean ± standard error)

Sample groups	$L*$	$a*$	$b*$
C	39.44^{c} ±0.46	15.95^{c} ±0.44	20.71^{c} ±0.40
H0	42.95^{d} ±0.40	15.36^{c} ±0.55	21.64^{d} ±0.350
H3	34.60^{b} ±1.13	9.75^{b} ±0.59	12.73^{b} ±0.66
H6	32.49^{a} ±0.53	8.59^{a} ±0.74	9.91^{c} ±0.46

C: Control sample; H0: 4% EFO; H3: 4%EFO + 3% BCP; H6: 4%EFO + 6% BCP

$^{a-d:}$ Means in the same column with different superscripts are significantly different (P<0.05)

Fatty Acid Composition of Meatballs: The influence of using encapsulated fish oil on fatty acid profile of samples can be seen in Table 4. As expected, fatty acid profile of meatballs elaborated with encapsulated fish oil were significantly affected (P < 0.05). The C12:0; C14:0, C16:1, C18:3n-3, C20:1n-9, C20:2, C20:4, C20:3n-3, C22:0, C20:5, C22:1, C22:2, C23:0, C24:0, C22:6, ΣMUFA and ΣPUFA contents of control samples were found to be significantly lower than those of samples containing encapsulated fish oil (P<0.05). While the SFA content of the control samples was the highest compared to the other samples, the MUFA and PUFA contents were determined to be the lowest (*P*<0.05). The total amount of saturated fatty acids (SFA) in the meatballs containing encapsulated fish oil decreased by approximately 8-10% compared to the controls. Polyunsaturated fatty acids (PUFA) increased in samples with encapsulated fish oil 36-47% due to the higher long chain n-3 fatty acids from fish oil. Similarly, monounsaturated fatty acids (MUFA) increased % 6-8 in these samples compared to those of the control samples. These effects are caused by fish oil containing a low amount of SFA (22.5%) and a high amount of PUFA (35.7%) (Ospina-E et al., 2010).

Domínguez et al. (2017) found that the substitution of pork backfat with microencapsulated fish oil in modified sausages reduced the SFA content from 33.14 g/100 g to 31.65 g/100g, the total amount of SFA in the samples decreased by 4.5- 11.8% compared to the control sample. Another study by Keenan et al. (2015), the fatty acid profile of the beef burger was dominated by saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs). Similar to our study, palmitic (hexadecanoic, C16:0), stearic (octadecanoic, C18:0) and myristic (tetradecanoic, C14:0) acids were the most abundant SFA respectively. Similar trends were observed in other studies when pork backfat were substituted by fish oil in sausages formulation (Josquin et al., 2012; Berasategi et al., 2014).

The n-6/n-3 fatty acid ratio is widely regarded as a significant health parameter. The lower this ratio, the better the product is in terms of health. The ratio of n-6 to n-3 acids in tissues has been related to chronic diseases, including cancer, cardiovascular diseases and inflammatory diseases, as well as to the microbiome. The optimal n-6/n-3 fatty acid ratio to achieve beneficial health effects is a matter of variation among institutions and countries. The values proposed by Canada, the Food and Agriculture Organization of the United Nations, and the Chinese Nutrition Society (2000) were 4–10, 5–10, and 4–6, respectively. In general, the n-6/n-3 ratio should not exceed 5 (Cao et al., 2024). On the other side, increased consumption of products with n−3 PUFA and reduced n−6/n−3 PUFA ratio are associated with health benefits (Liput et al. 2021; Mariamenatu & Abdu, 2021). In the current study, the n-6/n-3 ratio in samples using fish oil decreased significantly compared to the control sample. The decrease in n-6/n-3 ratio was determined as 74.45%, 75.05% and 77.66% in H0, H3 and H6 samples, respectively, compared to the control sample. Similar results were reported by Domínguez et al. (2017) who studied Frankfurter sausages reformulated by replacing 50% of the pork backfat with microencapsulated fish oil. The n-6/n-3 ratios of the reformulated Frankfurter sausages decreased from 14.52 for the control batch to 5.70 with the addition of microencapsulated fish oil. In a study by Domínguez et al. (2017) two sausages samples were manufactured: control (CO) with 100% of pork backfat, and modified sausages where the pork backfat was replaced with 50% by microencapsulated fish oil (ME). DHA increased 1.17 g/100g from 0.05 g/100g and EPA increased 0.35 g/100g from 0.02 g/100g. They mentioned that the higher PUFA content in modified frankfurter sausages than in the CO batches were caused by the high long-chain n-3 PUFA content in fish oil (4.78% of EPA and 20.55% of DHA). In agreement investigation by Aquilani et al. (2018) was conducted into the presence of EPA and DHA in fresh and cooked Cinta Senese burgers. The investigation revealed the absence of EPA and DHA in burgers that had not undergone enrichment. In contrast, burgers that had been enriched with microencapsulated fish oil (M) exhibited concentrations of 0.07% EPA and 0.09% DHA in raw samples and 0.07% EPA and 0.10% DHA in cooked samples. Also, in M samples, cooking did not significantly influence EPA and DHA percentages. However, in other samples where fish oil was added directly to meat, there was a decreasing in the EPA and DHA percentages from fresh to cooked samples, which was not observed in M burgers. This finding indicate that microcapsules offer a protective effect on these omega-3 fatty acids during heating or cooking. In agreement with these results, in our study four n−3 fatty acids were identified, amongst which DHA and EPA are important. The addition of encapsulated fish oil to meatballs increased the long chain n-3 PUFA's EPA and DHA, characteristic of this oil type. Levels of EPA significantly increased (*P*<0.05) from 0.03% in control meatballs to 0.05%, 0.05% and 0.06% in H0, H3 and H6 samples respectively. Also, DHA levels increased from 0.04% to 0.1%, 0.11% and 0.1% in H0, H3 and H6 samples respectively.

It was determined that as the ratio of black carrot pomace used in the sample formulations increased, the amounts of C14:1, C16:0, C20:4 and C24:1 fatty acids decreased, while the amounts of C18:3n-3, C20:1n-9, C20:3n-3, C22:0, C22:1, C23:0, C24:0 increased *(P<0.05).* The use of black carrot pomace in higher amounts in sample formulations, such as encapsulated fish oil, by replacing the amount of meat and adding it to the samples, resulted in the use of less meat, which in turn caused changes in the fatty acid composition of the samples depending on the ratio.

Sensory Evaluation of Meatballs: Sensory evaluation is an important test technique for the acceptance of the product. Sensory analysis scores for meatballs were given in Table 5. Sensory evaluation scores of all samples except H6, which were evaluated with a scale where the highest score was 9, were determined to be above 6.85.

There were no significant differences between C and H0 samples containing encapsulated fish oil in terms of appearance, color, texture, juiciness, flavor, oxidized flavor and overall acceptance (P<0.05). The use of fish oil in encapsulated form instead of direct use prevented negative changes in the sensory properties of the samples. Similarly, Keenan et al. (2015) reported that there was no significant difference in the appearance, chewiness, tenderness, juiciness and overall acceptability scores between burger meatballs containing 3% encapsulated fish oil and burger meatballs not containing fish oil (*P<0.05).* In current study the use of high amounts of carrot pulp in the samples caused a significant decrease in the appearance and color scores of the samples. The appearance and color scores of sample H6 were found to be significantly lower compared to samples C and H0. Besides this H3 and H6 samples showed no significant difference in terms of appearance, color, texture, juiciness, flavor, oxidized flavor and overall acceptance *(P>0.05)*. Richards (2023) revealed that no significant differences were observed between patties made with 1% or 3% carrot pomace in terms of appearance, aroma, taste, chewiness, beef flavor, sweetness, texture, and overall acceptance.

Table 4. Fatty acid profiles of meatballs (g/100 g fatty acids) (mean ± standard error)

Fatty acids (g/100g)	C	H0	H3	H6
C8:0	0.01±0.00	0.01±0.00	0.02±0.00	0.02±0.00
C10:0	0.04±0.00	0.04±0.01	0.04±0.00	0.05±0.00
C12:0	0.31±0.03^{a}	0.35±0.01^{b}	0.36±0.03^{b}	0.38±0.01^{b}
C13:0	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00
C14:0	2.96±0.16^{a}	3.29±0.13^{b}	3.18±0.07^{b}	3.14±0.02^{b}
C14:1	0.31±0.04^{b}	0.26±0.01^{b}	0.27±0.03^{b}	0.23±0.02^{a}
C15:0	0.63±0.02^{c}	0.58±0.02^{b}	0.55±0.01^{a}	0.55±0.02^{ab}
C15:1	0.43±0.02^{b}	0.37±0.04^{a}	0.35±0.01^{a}	0.35±0.01^{a}
C16:0	27.91±0.27^{c}	24.89±0.42^{b}	24.83±0.12^{b}	23.93±0.19^{a}
C16:1	2.09±0.02^{a}	3.33±0.07^{b}	3.52±0.07^{c}	3.49±0.13^{c}
C17:0	1.07±0.02^{c}	0.88±0.05^{b}	0.84±0.02^{ab}	0.82±0.04^{a}
C17:1	0.39±0.01^{b}	0.34±0.01^{a}	0.32±0.02^{a}	0.32±0.02^{a}
C18:0	23.69±0.36^{b}	19.60±0.54^{a}	19.30±0.28^{a}	19.22±0.40^{a}
C18:1n-9c	33.20±0.29^{b}	31.89±0.18^{a}	31.64±0.17^{a}	31.62±0.32^{a}
C18:2n-6t	0.49±0.08^{b}	0.15±0.01^{a}	0.16±0.02^{a}	0.16±0.02^{a}
C18:2n-6c	4.11±0.13^{a}	4.31±0.21^{ab}	4.53±0.08^{bc}	4.65±0.15^{c}
C18:3n-6	0.16±0.02	0.16±0.01	0.16±0.01	0.15±0.01
C18:3n-3	0.29±0.01^{a}	0.46±0.03^{b}	0.48±0.02^{b}	0.53±0.03^{c}
C20:0	0.24±0.03	0.21±0.01	0.21±0.02	0.20±0.01
C20:1n-9	0.20±0.01^{a}	2.90±0.15^{b}	3.08±0.07^{c}	3.55±0.10^{d}
C20:2	0.08±0.01^{a}	0.13±0.01^{b}	0.14±0.01^{b}	0.14±0.01^{b}
C20:3n-6	0.15±0.01^{a}	0.22±0.04^{c}	0.21±0.02^{bc}	0.17±0.02^{ab}
C20:4	0.42±0.02^{a}	0.60±0.07^{c}	0.60±0.03^{c}	0.50±0.02^{b}
C20:3n-3	0.14±0.18^{a}	1.65±0.10^{b}	1.77±0.05^{b}	2.00±0.03^{c}
C21:0	0.03±0.00	0.04±0.00	0.03±0.00	0.03±0.01
C22:0	0.02±0.00^{a}	0.14±0.01^{b}	0.16±0.01^{b}	0.22±0.02^{c}
C20:5	0.03± 0.00^{a}	0.05± 0.01^{b}	0.05± 0.01^{b}	0.06± 0.00^{b}
C22:1	0.01±0.00^{a}	0.09±0.00^{b}	0.09±0.01^{b}	0.10±0.01^{c}
C22:2	0.07±0.01^{a}	0.34±0.02^{b}	0.35±0.00^{bc}	0.38±0.02^{c}
C23:0	0.13±0.18^{a}	2.29±0.14^{b}	2.38±0.18^{b}	2.67±0.14^{c}
C24:0	0.01±0.00^{a}	0.08±0.00^{b}	0.08±0.01^{b}	0.10±0.01^{c}
C22:6	0.04± 0.01^{a}	0.10± 0.01^{b}	0.11± 0.01^{b}	0.10± 0.00^{b}
C24:1	0.17±0.01^{c}	0.05±0.01^{b}	0.04±0.01^{b}	0.02±0.02^{a}
ΣSFA	57.06±0.30^{b}	52.41±0.42^{a}	51.99±0.24^{a}	51.34±0.37^{a}
ΣMUFA	36.80±0.25^{a}	39.23±0.12^{b}	39.31±0.25^{b}	39.68±0.55^{b}
ΣPUFA	5.98±0.53^{a}	8.17±0.36^{b}	8.56±0.13^{b}	8.84±0.22^{b}
ΣMUFA+ ΣPUFA/ SFA	0.75	0.9	0.92	0.95
PUFA/SFA	0.10	0.16	0.16	0.17
n3	0.50	2.26	2.41	2.69
n6	4.99	5.76	5.99	5.99
n6/n3	9.98	2.55	2.49	2.23

$^{a-d}$ Means in the same row with different superscripts are significantly different (P<0.05)
C: Control sample; H0: 4% EFO; H3: 4%EFO + 3% BCP; H6: 4%EFO + 6% BCP

Table 5. Appearance, color, texture, juiciness, flavor, oxidized flavor and overall acceptance of meatballs (mean ± standard error)

Samples	Appearance	Color	Texture	Juiciness	Flavor	Oxidized Flavor	Overall Acceptance
C	7.45±0.66^{b}	7.35±0.66^{b}	7.55±0.47	7.50±0.26	7.35±0.55	7.50±0.62	7.60±0.49
H0	7.20±0.33^{b}	7.20±0.49^{b}	7.25±0.19	7.10±0.26	7.00±0.43	7.50±0.26	7.35±0.53
H3	6.85±0.44^{ab}	6.75±0.70^{ab}	7.40±0.28	7.70±0.20	7.75±0.30	7.90±0.26	7.55±0.50
H6	**6.20±0.37^{a}**	**5.90±0.26^{a}**	**7.40±0.23**	**7.50±0.60**	**7.20±0.71**	**7.45±0.93**	**7.05±0.62**

$^{a-b}$ Means in the same row with different superscripts are significantly different (P<0.05)
C: Control sample; H0: 4% EFO; H3: 4%EFO + 3% BCP; H6: 4%EFO + 6% BCP

CONCLUSION

In this study the potential use of encapsulated fish oil and black carrot as fat substitute and enrichment material to create an alternative product that addresses global health problems attributed to increased SFA consumption. Results showed that encapsulated fish oil and black carrot pomace addition had a significant effect on the color properties and the sensory scores. Addition of black carrot pomace caused darker color so appearance and color scores of H6 samples were determined lower than C, H0 and H3 samples. Consequently, it can be recommended that addition of 3% black carrot pomace with 4% encapsulated fish oil to the low-fat meatball for acceptable sensory properties.

PUFA/SFA ratio increased due to usage of encapsulated fish oil and n-6/n-3 ratio decreased. Long chain n-3 PUFA's EPA and DHA were observed higher in the sample groups containing encapsulated fish oil than those of the control sample. The findings of the study suggest that the incorporation of encapsulated fish oil and black carrot pomace in low-fat meatballs has the potential to obtain a novel meat product that is both healthier and more nutritious.

REFERENCES

Aquilani, C., Pérez-Palacios, T., Sirtori, F., Jiménez-Martín, E., Antequera, T., Franci, O., Acciaioli, A., Bozzi, R. & Pugliese, C. (2018). Enrichment of Cinta Senese burgers with omega-3 fatty acids. Effect of type of addition and storage conditions on quality characteristics. *Grasas y Aceites*, ***69***(1). DOI: 10.3989/gya.0671171

Badar, I.H., Liu, H., Chen, Q., Xia, X. & Kong, B. (2021). Future trends of processed meat products concerning perceived healthiness: A review. *Comprehensive Reviews in Food Science and Food Safety*, ***20***(5), 4739-4778. DOI. 10.1111/1541-4337.12813

Bayraklı, B. & Duyar, H.A. (2019). The Effect of Raw Material Freshness on Fish Oil Quality Produced in Fish Meal & Oil Plant. *Journal of Anatolian Environmental and Animal Sciences*, ***4***(3), 473-479. DOI: 10.35229/jaes.636002

Berasategi, I., Navarro-Blasco, Í., Calvo, M.I., Cavero, R.Y., Astiasarán, I. & Ansorena, D. (2014). Healthy reduced-fat Bologna sausages enriched in ALA and DHA and stabilized with Melissa officinalis extract. *Meat Science*, ***96***(3), 1185-1190. DOI: 10.1016/j.meatsci.2013.10.023

Cao, M., Yang, F., McClements, D.J., Guo, Y., Liu, R., Chang, M., Wei, W., Jin, J. & Wang, X. (2024). Impact of dietary n-6/n-3 fatty acid ratio of atherosclerosis risk: A review. *Progress in Lipid Research*, ***95***. 101289. DOI: 10.1016/j.plipres.2024.101289

Chhetri, L., Rizwan, M.D., Munkombwe, S., Dorji, N. &. Mutum, E. (2022). Utilization and characteristics of black carrot (Daucus carrot L.): Potential health benefits and effect of processing. *The Pharma Innovation Journal*, ***11***(6), 30-41.

Domínguez, R., Pateiro, M., Agregán, R., & Lorenzo, J. M. (2017). Effect of the partial replacement of pork backfat by microencapsulated fish oil or mixed fish and olive oil on the quality of frankfurter type sausage. *Journal of Food Science and Technology*, ***54***(1), 26-37. DOI: 10.1007/s13197-016-2405-7

Ekici, L., Ozturk, I., Karaman, S., Caliskan, O., Tornuk, F., Sagdic, O. & Yetim, H. (2015). Effects of black carrot concentrate on some physicochemical, textural, bioactive, aroma and sensory properties of sucuk, a traditional Turkish dry-fermented sausage. *LWT-Food Science and Technology*, ***62***(1), 718-726

Ellulu, M.S., Khaza'ai, H., Abed, Y., Rahmat, A., Ismail, P. & Ranneh, Y. (2015). Role of fish oil in human health and possible mechanism to reduce the inflammation. *Inflammopharmacology*, ***23***(2-3), 79-89). DOI: 10.1007/s10787-015-0228-1

Geiker, N.R.W., Bertram, H.C., Mejborn, H., Dragsted, L. Kristensen, L., Carrascal, J.R., Bügel, S. & Astrup, A. (2021). Meat and human health-current knowledge and research gaps. *Foods* ***10***(7). DOI: 10.3390/foods10071556

Granucci, N., Harris, P.J. & Villas-Boas, S.G. (2023). Chemical compositions of fruit and vegetable pomaces from the beverage industries. *Waste and Biomass Valorization*, ***14***(11), 3841-3856. DOI: 10.1007/s12649-023-02095-7

Ikram, A., Rasheed, A., Ahmad Khan, A., Khan, R., Ahmad, M., Bashir, R. & Hassan Mohamed, M. (2024). Exploring the health benefits and utility of carrots and carrot pomace: a systematic review. *International Journal of Food Properties* ***27***(1), 180-193. DOI: 10.1080/10942912.2023.2301569

Jamshidi, A., Cao, H., Xiao, J. & Simal-Gandara, J. (2020). Advantages of techniques to fortify food products with the benefits of fish oil. *Food Research International*, ***137***, 109353. DOI: 10.1016/j.foodres.2020.109353

Josquin, N.M., Linssen, J.P.H. & Houben, J.H. (2012). Quality characteristics of Dutch-style fermented sausages manufactured with partial replacement of pork back-fat with pure, pre-emulsified or encapsulated fish oil. *Meat Science*, ***90***(1), 81-86. DOI: 10.1016/j.meatsci.2011.06.001

Keenan, D.F., Resconi, V.C., Smyth, T.J., Botinestean, C., Lefranc, C., Kerry, J.P. & Hamill, R.M. (2015). The effect of partial-fat substitutions with encapsulated and unencapsulated fish oils on the technological and eating quality of beef burgers over storage. *Meat Science*, ***107*,** 75-85. DOI: 10.1016/j.meatsci.2015.04.013

Libera, J., Iłowiecka, K. & Stasiak, D. (2021). Consumption of processed red meat and its impact on human health: A review. *International Journal of Food Science and Technology* ***56***(12), 6115-6123. DOI: 10.1111/ijfs.15270

Liput, K.P., Lepczyński, A., Ogłuszka, M., Nawrocka, A., Poławska, E., Grzesiak, A., Ślaska, B., Pareek, C.S., Czarnik, U. & Pierzchała, M. (2021). Effects of dietary n–3 and n–6 polyunsaturated fatty acids in inflammation and cancerogenesis. In *International Journal of Molecular Sciences* ***22***(13). DOI: 10.3390/ijms22136965

Liu, Z., de Souza, T.S.P., Holland, B., Dunshea, F., Barrow, C. & Suleria, H.A.R. (2023). Valorization of food waste to produce value-added products based on its bioactive compounds. *Processes*, ***11***(3), 840. DOI: 10.3390/pr11030840

López-Pedrouso, M., Lorenzo, J.M., Gullón, B., Campagnol, P.C.B., & Franco, D. (2021). Novel strategy for developing healthy meat products replacing saturated fat with oleogels. *Current Opinion in Food Science*, ***40***(40-45). DOI: 10.1016/j.cofs.2020.06.003

Mariamenatu, A.H. & Abdu, E.M. (2021). Overconsumption of omega-6 polyunsaturated fatty acids (pufas) versus deficiency of Omega-3 PUFAs in modern-day diets: the disturbing factor for their "Balanced antagonistic metabolic functions" in the human body. *Journal of Lipids*, ***2021***, 1-15. DOI: 10.1155/2021/8848161

Mehta, N., Ahlawat, S.S., Sharma, D.P. & Dabur, R.S. (2015). Novel trends in development of dietary fiber rich meat products-a critical review. *Journal of Food Science and Technology*, ***52***(2), 633-647. DOI: 10.1007/s13197-013-1010-2

Mendiratta, S.K., Shinde, A.T. & Mane, B.G. (2013). Effect of added vegetable (carrot, radish and capsicum) as functional ingredients in mutton nuggets. *Journal of Meat Science and Technology*, ***1***(2), 71-76.

Öğütcü, M., Gevrek, S. & Arifoğlu, N. (2018). Physico-chemical, textural, microbial and sensory properties of Turkish Tire meatball. *Journal of Food Processing and Preservation*, ***42***(10). DOI: 10.1111/jfpp.13768

Ospina-E,J.C., Cruz-S, A., Pérez-Álvarez, J.A. & Fernández-López, J. (2010). Development of combinations of chemically modified vegetable oils as pork backfat substitutes in sausages formulation. *Meat Science*, ***84***(3), 491-497. DOI: 10.1016/j.meatsci.2009.10.003

Pourashouri, P., Shabanpour, B., Heydari, S. & Raeisi, S. (2021). Encapsulation of fish oil by carrageenan and gum tragacanth as wall materials and its application to the enrichment of chicken nuggets. *LWT*, ***137***. DOI: 10.1016/j.lwt.2020.110334

Raeisi, S., Ojagh, S.M., Pourashouri, P., Salaün, F. & Quek, S.Y. (2021). Shelf-life and quality of chicken nuggets fortified with encapsulated fish oil and garlic essential oil during refrigerated storage. *Journal of Food Science and Technology*, ***58***(1), 121128. DOI: 10.1007/s13197-020-04521-3

Richards, J.O.A. (2023). Physical treatments to modify the functionality of carrot pomace and the development of an enhanced beef patty. *ProQuest Dissertations & Theses Global.*

Santhi, D., Kalaikannan, A. & Elango, A. (2022). Functional Low-Fat Chicken Meatballs Enriched with Grape (Vitis Vinifera) Pomace Powder. *Journal of Meat Science*, ***17***(2), 42-50. DOI: 10.48165/jms.2022.170207

Santhi, D., Kalaikannan, A., Elango, A. & Natarajan, A. (2022). Functional Chicken Meatballs with Carrot Pomace Powder. *Journal of Meat Science*, ***17***(1), 31-36. DOI: 10.48165/jms.2022.1705

Santhi, D., Kalaikannan, A. & Natarajan, A. (2020). Characteristics and composition of emulsion-based functional low-fat chicken meat balls fortified with dietary fiber sources. *Journal of Food Process Engineering*, ***43***(3). DOI: 10.1111/jfpe.13333

Solomando, J. C., Antequera, T., & Perez-Palacios, T. (2020). Lipid digestion products in meat derivatives enriched with fish oil microcapsules. *Journal of Functional Foods*, ***68***, 1-12**.** DOI: 10.1016/j.jff.2020.103916

Solomando, J.C., Antequera, T., Ventanas, S. & Perez-Palacios, T. (2021). Sensory profile and consumer perception of meat products enriched with EPA and DHA using fish oil microcapsules. *International Journal of Food Science and Technology*, ***56***(6), 2926-2937. DOI: 10.1111/ijfs.14932

Stoica, F., Rațu, R.N., Motrescu, I., Cara, I.G., Filip, M., Țopa, D. & Jităreanu, G. (2024). Application of Pomace Powder of Black Carrot as a Natural Food Ingredient in Yoghurt. *Foods*, ***13***(7), 1-19. DOI: 10.3390/foods13071130

Thakur, P., Anika, Suhag, R., Dhiman, A. & Kumar, S. (2024). Insights into the current status of bioactive value, postharvest processing opportunities and value addition of black carrot. *Food Science and Biotechnology* ***33***(4), 721-747. DOI: 10.1007/s10068-023-01436-5

Wi, G., Bae, J., Kim, H., Cho, Y. & Choi, M.J. (2020). Evaluation of the physicochemical and structural properties and the sensory characteristics of meat analogues prepared with various non-animal based liquid additives. *Foods*, ***9***(4), 1-19. DOI: 10.3390/foods9040461

Younis, K. & Ahmad, S. (2017). *Investigating the Functional Properties of Pineapple Pomace Powder and Its Incorporation in Buffalo Meat Products*.

Younis, K., Ahmad, S. & Malik, M.A. (2021). Mosambi peel powder incorporation in meat products: Effect on physicochemical properties and shelf life stability. *Applied Food Research*, ***1***(2), 1-10. DOI: 10.1016/j.afres.2021.100015