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The effect of partial-fat substitutions with encapsulated and unencapsulated fish oils on the technological and eating quality of beef burgers over storage

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ABSTRACT

The effects of fat substitution (≤15%) with commercial encapsulated and unencapsulated fish oils on the technological and eating quality of beef burgers over storage [modified atmosphere packs (80% O_2:20% CO_2); constantly illuminated retail display at 4 °C; for 15 days] were studied using design of experiment (DOE). Burger formulations comprised beef shin (59.5%), salt (0.5%), vitamin E (0.015%) combined with varying levels of beef-fat/fish oils depending on the treatment. Increasing amounts of encapsulated and unencapsulated fish oils in burgers increased polyunsaturated fatty acid content ($P < 0.001$). Storage decreased ($P < 0.001$) a* values, which was in agreement with oxymyoglobin data. Vitamin E inclusion in burgers resulted in higher ($P < 0.01$) oxymyoglobin values. TBARS values increased ($P < 0.001$) over storage as expected. Fat substitution with unencapsulated oils increased cook loss ($P < 0.001$) and decreased hardness ($P < 0.05$) compared to other treatments. Optimisation predicted a burger formulation with 7.8% substitution in beef-fat with encapsulated fish oil. Panellists scored the optimised burger formulation ($P < 0.05$) lower than controls for overall acceptability.

1. Introduction

Comminuted products consist of a homogeneous distribution of lean meat and fat (Ranken, 2000). Initially developed to make palatable products from less desirable cuts of meat, they can be manufactured from meat containing high levels of fat or connective tissue or meat and fat trimmings produced in the preparation of high value and upgrading of medium value cuts. Some low value offerings contain up to 60% added fat (Tobin, O'Sullivan, Hamill, & Kerry, 2012). Diets high in both fat and salt have been linked to earlier onset of chronic diseases e.g. colorectal cancer, coronary heart disease (Ferguson, 2010; Tobin et al., 2012). Reduction or replacement strategies for fat and salt are thus an immediate health issue for comminuted meat products. However, fat substitution presents significant challenges in comminuted products, as it plays an essential role in their texture, lubricity and mouthfeel.

With increasing consumer awareness of such health issues, the meat industry is examining the possibilities of meat-based functional foods as an opportunity to improve its public image and update dietary goals (Jiménez-Colmenero, 2007). One of the most effective health strategies to enhance the nutritional value of muscle foods of recent years is the substitution of some native saturated animal fat with healthier unsaturated fats from other sources. For example the beneficial effect of partial substitution of animal fat with olive oil has been investigated in various meat products, such as burger patties (Rodríguez-Carpena, Morcuende, & Estévez, 2012) frankfurters (Choi et al., 2010; López-López, Cofrades, & Jiménez-Colmenero, 2009), liver pâté (Martín, Ruiz, Kivikari, & Puolanne, 2008) and sausages (Muguerza, Gimeno, Ansorena, Bloukas, & Astiasrán, 2001). The most relevant ω-3 fatty acids are docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) due to their positive role in infant development and mental illness (Balanzá-Martínez et al., 2011; Hadders-Algra, 2011), and their effects against inflammation platelet aggregation and hyperlipidemia (Kris-Etherton, Harris, & Appel, 2002). These are abundantly present in fish (Gallardo et al., 2013). Furthermore, fish oil is currently recognised as having positive effects on human health (EFSA panel on dietetic product, nutrition & allergies, 2010). However, while the degree of unsaturation in fish oils is desirable from a health perspective, it does increase the risk of faster deterioration, in particular the important EPA and DHA compounds (Barrow, Nolan, & Holub, 2009), in shelf life through lipid oxidation. This is also true for the naturally occurring lipids in meat, which can undergo alterations during their storage with consequent losses in nutritional value (Baggio & Bragagnolo, 2006). This can manifest in the formation of off flavour compounds (Kolanowski, Jaworska, & Weißbrodt, 2007) and toxic by-products (Guillén & Ruiz, 2005).

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Microencapsulation has emerged as a potential technology to offset the ingress of oxygen that could promote lipid oxidation (Kolanowski, Ziolkowski, Weißbrodt, Kunz, & Laufenberg, 2006). This is a process in which tiny droplets of 'core material' are coated by a microencapsulating agent i.e. food grade materials, such as alginate or a whey protein. Spray drying has been shown to be an effective technique for the protection of vitamins, minerals, flavours, preservatives and leavening agents (Arshady, 1993). One of the challenges facing the incorporation of fish oils into non-fish containing meat products is the undesirable presence of residual fishy odours and taste. This may be offset by the encapsulate material which creates a physical barrier between the fish oil and the inside of the mouth. Some concerns have been raised that the encapsulation process may inhibit the bioavailability of material inside the microcapsule, however, these concerns were not borne out in a recent study (Augustin et al., 2011). Overall, the process converts the oil into a free flowing powder which is more easily handled for food fortification (Gallardo et al., 2013).

While the incorporation of encapsulated oils has been used to fortify some frequently consumed foods e.g. soups and bread, with reasonable consumer acceptability (Garg, Wood, Singh, & Moughan, 2006), their use in meat products has been very limited. For example, Pelser, Linssen, Legger, and Houben (2007) and Josquin, Linssen, and Houben (2012) investigated their use in Dutch-style fermented sausages. Therefore, the aim of this study was to investigate the partial substitution of encapsulated and unencapsulated (positive control) fish oils for native fat in beef patties and assessing the potential of meat products as vehicles for bioactive ingredients.

2. Material and methods

2.1. Burger formulation

All burger batches (0.7 kg) were manufactured to contain 59% shin beef, 40% fat and 1% salt (w/w) according to a previously reported consumer optimised formulation (Tobin et al., 2012). Partial substitution (up to 15% w/w) of the fat component (or 6% of total burger weight) was carried out using two commercial fish oil products, Omega-360™ Pure 22 (unencapsulated), and Meg-3® (encapsulated), obtained from Denomega (Norway), and Ocean Nutrition (Canada) respectively. These fish oils were selected on the basis that they were representative of the commercial products available to the meat industry. The purpose of the unencapsulated fish oil was to act as a positive control to better assess the potential benefits of encapsulation. Meg-3® oil was prepared from a mix of fish species i.e. anchovies (*Engraulis ringens*) and sardines (*Sardinops sagax sagax*) and subsequently encapsulated, while Omega-360™ Pure 22 was a combination of cod (*Gadus morhua*) liver and salmon (*Salmo salar*). A small quantity (up to 0.015% w/w) of food grade vitamin E [Tocopherols (W530066), Sigma-Aldrich, Dublin Ireland] was added as an antioxidant. Burger treatments were monitored throughout their storage over a typical retail storage range of 15 days. A total of 40 formulations were prepared using a D-optimal design (Design Expert v. 7.6.1, Stat-Ease Inc., Minneapolis, MN, USA) to efficiently represent the design space for the multitude of possible combinations of ingredients/storage (Table 1). Formulations were produced in random order over a period of 4 weeks.

Table 1
Experimental design of four varying components in the burger formulations over storage (15 days).

Run	A: Fat %	B: MEG-3 %	C: OIL %	D: Vitamin E %	E: Storage (days)
1	34.74	1.13	4.13	0.003	3
2	37.75	1.13	1.13	0.003	3
3	33.99	6.00	0.02	0.000	0
4	33.99	0.00	6.00	0.015	7
5	33.99	3.00	3.00	0.015	0
6	40.00	0.00	0.00	0.000	7
7	34.74	4.13	1.13	0.003	3
8	33.99	6.00	0.00	0.015	7
9	39.99	0.00	0.00	0.015	0
10	39.99	0.00	0.00	0.015	7
11	40.00	0.00	0.00	0.000	0
12	34.00	6.00	0.00	0.000	15
13	36.99	3.00	0.00	0.008	7
14	33.99	0.00	6.00	0.015	15
15	34.74	4.13	1.13	0.010	10
16	33.99	0.02	6.00	0.000	0
17	40.00	0.00	0.00	0.000	7
18	40.00	0.00	0.00	0.000	15
19	33.99	6.00	0.00	0.015	0
20	37.00	3.00	0.00	0.000	0
21	36.99	3.00	0.00	0.008	15
22	33.99	6.00	0.00	0.015	15
23	33.99	3.00	3.00	0.008	7
24	39.99	0.00	0.00	0.015	7
25	35.99	2.00	2.00	0.015	7
26	33.99	3.00	3.00	0.015	0
27	33.99	3.00	3.00	0.008	7
28	34.00	0.00	6.00	0.000	7
29	39.99	0.00	0.00	0.015	15
30	35.19	2.40	2.40	0.000	15
31	37.00	0.00	3.00	0.000	0
32	34.00	6.00	0.00	0.000	7
33	33.99	0.00	6.00	0.015	0
34	33.99	3.00	3.00	0.008	0
35	35.19	2.40	2.40	0.000	15
36	36.99	0.00	3.00	0.008	7
37	33.99	3.00	3.00	0.008	15
38	34.74	1.13	4.13	0.010	10
39	36.99	0.00	3.00	0.008	15
40	33.99	0.02	6.00	0.000	15

Where: MEG-3: encapsulated oil; OIL: unencapsulated oil; (low) 33.99 < A: Fat < 40.00 (high); (low) 0.00 < B: MEG-3 < 6.00 (high); (low) 0.00 < C: OIL < 6.00 (high); (low) 0.00 < D: vitamin E < 0.015 (high); and A + B + C + D = 40% of total burger content.

2.2. Burger manufacture

Fresh beef shin (95% lean) and beef fat were purchased from a local meat supplier (Kepak, Dublin, Ireland). All 40 treatments were mixed on an individual basis due to their varying compositions. Typically, eight to ten beef shins (≈0.8 kg/shin) were sliced and minced (PT-82/22 Mainca Barcelona, Spain) through a 5 mm steel plate. Salt was mixed with the lean meat to promote the formation of exudate on the surface fragments in order to promote binding. The mincing procedure was repeated for the added-fat. Fish oil (encapsulated and unencapsulated) and vitamin E were mixed with the minced fat. Vitamin E was taken from an inverted vial by syringe (SGE, Supelco, Bellefonte, PA, USA) of varying volumes (depending on the treatment) and distributed drop-wise onto the fat/oil mixture before mixing. Finally, the salted lean meat and fat mixture were combined, mixed by hand and pressed into a standard burger mould (0.07 kg burger patties). Burgers were packed in black PET trays (containing an absorbent strip) heat sealed (low oxygen permeable film <2 mL/24 h/38 °C) and gas flushed using a modified atmosphere of 80% O_2:20% CO_2 (BOC Ltd., Ireland) using an Ilpra Foodpack Basic V/G (Ilpra, Italy). All treatments were placed in a random order in an open-front retail display cabinet (Cronos fan-assisted cabinet, Criosbanc, Italy; lighting: lux ≈ 600, 58 W deluxe cool white bulbs) and constantly illuminated for up to 15 days at 4 °C. After the storage period had elapsed, samples were blast frozen (air speed 3.75 ms^{-1}) and stored (−20 °C) for subsequent analyses.

2.3. Analyses of raw samples

2.3.1. Fatty acid analysis

Total lipids of muscle tissue were extracted and hydrolysed as outlined by McArdle, Marcos, Kerry, and Mullen (2010) with slight modifications. Duplicate samples (100 mg) were saponified in 6 ml of 5 M KOH in methanol/water (50:50) at 60 °C for 1 h, and the