Innovative Food Science and Emerging Technologies 36 (2016) 336–342

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Protective role of vacuum vs. atmospheric frying on PUFA balance and lipid oxidation

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ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form 27 June 2016
Accepted 2 July 2016
Available online 4 July 2016

Keywords:
Vacuum
Frying
Mackerel
Oxidation
Fish patties

ABSTRACT

The effect of vacuum frying processing on proximate composition, fatty acid profile, oxidative status and sensorial properties of fish patties, was evaluated as compared with conventional (atmospheric) frying.

Vacuum frying procedure was carried out at 80 mmHg (water boiling point: 42 °C) and oil temperature (107 °C) determined to obtain an equivalent thermal driving force (Δ65 °C) of that of the atmospheric frying conditions used (165 °C). Frying times of 2, 4, 6, 8 and 10 min were investigated.

Vacuum frying significantly prevented degradation of EPA (Eicosapentaenoic acid) and DHA (Docosahexaenoic acid), reducing the polyene index and maintaining a lower ω6/ω3 fatty acid ratio in samples, while no significant differences with conventional frying in total oil content were observed. The use of vacuum also reduced formation of peroxides and carbonyl derivatives. Tocopherol levels decreased in all samples regardless of the frying conditions used, although vacuum-fried samples maintained higher tocopherol levels after processing. These samples also showed higher lightness and lower a* and b* values, which can be associated to lower non-enzymatic browning levels.

These results support the applicability of vacuum frying technology for fish patties, since it prevents colour changes, improves juiciness and reduces oxidation when compared to conventionally (atmospheric) fried counterparts.

Industrial relevance: Consumers are increasingly aware of the link between food and health, maintaining a high demand for healthy products. In this regard, consumption of fatty fish, with healthy properties widely known, is lower than recommended by health authorities, especially in children. Novel processing technologies focused on increasing the appealing of products based on fatty fish can help in ameliorating this deficient consumption. Vacuum frying is a promising way of obtaining attractive products, due to some product modification after the deep-fat frying process, and yet retaining natural colour, juiciness and healthy properties to a high extent. Vacuum frying allows reducing ω3 fatty acids and tocopherol degradation, differentiating fish products so obtained, which can be launched into the market and benefit from this technology. Compared to conventional frying, the results are better nutritional and sensory properties in a final product.

1. Introduction

Conventional frying is commonly used for fish cooking owing to the unique sensory properties that are produced, highly appreciated by consumers (Dobarganes, Márquez-Ruiz, & Velasco, 2000). Nevertheless, this culinary technique has some disadvantages, such as increased fat content of fish fillet (García-Arias, Álvarez Pontes, García-Linares, García-Fernández, & Sánchez-Muñiz, 2003), changes in its fatty acid profile (Sánchez-Muñiz, Viejo, & Medina, 1992; Sebedio, Ratnayake, Ackman, & Prevost, 1993; Moradi, Bakar, Motalebi, Syed Muhamad, & Che Man, 2011) and production of oxidised and polymerised lipid products as a result of frying oil degradation (Moreira, Castell-Perez, & Barrufet, 1999). Vacuum frying is an alternative to conventional frying, carried out at pressures below atmospheric level, which allows the use of lower temperatures. This leads to several advantages in the final product, such as preservation of thermolabile nutrients, more natural colour and flavour and limited oil degradation. However, it is unclear whether the reason for the observed reduction in oil content is due solely to vacuum frying or to the combined effect of pretreatment and vacuum frying (Tarmizi & Niranjan, 2010).

The main applications found for vacuum frying are those related to the development of fruit and vegetable snacks (Moreira, 2014), but very little research has been carried out on fish (Andrés-Bello, García-Segovia, & Martínez-Monzó, 2010; Chen, Zhang, & Fang, 2014; Pan, Ji, Liu, & He, 2015). A few studies have focused on the effect of

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http://dx.doi.org/10.1016/j.ifset.2016.07.006
1466-8564/

vacuum frying on proximate composition, colour, texture and/or sensory properties of fish (Andrés-Bello et al., 2010; Pan et al., 2015).

The health benefits of long-chain omega-3 polyunsaturated fatty acids (ω3 PUFAs), highly present in fatty fish species, are widely accepted nowadays because of the structural role that these fatty acids play as main components of cell membranes and their contribution to various membrane functions (Lee & Lip, 2003; EFSA, 2012a). In general, dietary recommendations to consumers advise weekly consumption of one or two portions of fatty fish (ISSFAL, 2004). On the basis of the cardiovascular risk considerations for European adults, the European Food Safety Authority (EFSA) recommends consumption of between 250 and 500 mg/day of ω3 PUFA (EFSA, 2012a), and the American Heart Association (AHA) recommends a daily intake of 400–500 mg of EPA (Eicosapentaenoic acid) and DHA (Docosahexaenoic acid) (Kris-Etherton, Harris, & Appel, 2002).

At present, fatty fish consumption is lower than the intake recommended by health authorities, especially in child populations. One strategy to increase consumption among child consumers is the development of new, more attractive products, which can be obtained by frying, among other methodologies. Moreover, the frying process produces significant changes in the fat content, lipid fraction and fatty acid profile of fish, with special emphasis on DHA and EPA, which are easily oxidised, and in this regard vacuum frying may offer many advantages. However, to the best of our knowledge, no research has yet been reported on the effect of using this frying technology (under vacuum conditions) on fatty acid composition and lipid oxidation (Zuta, Simpson, Zhao, & Leclerc, 2007).

Mackerel (*Scomber scombrus*) is a fish of high nutritional interest, being caught with other fish as bycatch, and in the past the muscle has been mechanically processed (Martelo-Vidal, Mesas, & Vázquez, 2012). However, at the moment there are equipments and processes to recover the fish proteins, increasing its use in commercially more attractive products (García-Sifuentes et al., 2009; Larrazábal, Escriche, & Camacho, 2010; Uresti, Téllez-Luis, Ramírez, & Vázquez, 2004). The use of mackerel for restructured products such as ready-to-cook frozen fillets and/or fish patties is an opportunity provided by the volume produced, although the main drawback would be their susceptibility to oxidation, especially after processing, owing to their fatty acid composition, which is high in PUFAs.

The aim of this paper was to study the effect of vacuum versus conventional frying on fish patties by the analysis of oxidative parameters and their impact on the organoleptic properties.

2. Material and methods

2.1. Materials

2.1.1. Chemicals

All the chemicals were analytical grade obtained from Panreac Química S.A (Barcelona, Spain) and Sigma-Aldrich Co. (Madrid, Spain). All the solvents were HPLC grade (Lab-Scan, Dublin, Ireland).

2.1.2. Fish

Six kilos of Atlantic mackerel (*Scomber scombrus*) caught in early March 2014 was purchased in a local supermarket (Valladolid, Spain). The average weight per mackerel was 200 g.

2.2. Methods

2.2.1. Processing

Fillets were manually skinned and minced using a blender with a 7 mm exit pore (Lacor 69067, Guipúzcoa, Spain). Patties weighing 50 g were prepared manually with a round mould. All samples were processed immediately in order to avoid oxidative processes. The assay was performed twice.

2.2.2. Frying process

Vacuum frying (VF) and Conventional frying (CF) procedures were performed in the same frying equipment, an electrically heated vacuum fryer (GASTROVAC®, International Cooking Concepts, Barcelona, Spain), which was slightly modified by connecting the stainless steel frying vessel to a rotary vacuum pump (Model RA 0025 F, BUSCH Ibérica SA, Granollers, Spain). For CF experiments, the vacuum pump was switched off. In order to compare the effects of VF and CF, the same thermal driving force was used in both experiments. A CF temperature of 165 °C was selected, and the thermal driving force calculated as 65 °C (temperature difference above the water boiling point). Taking into account the pressure and resulting boiling point used for vacuum frying conditions (80 mmHg and 42 °C, respectively), a temperature of 107 °C was set for the experimental VF runs. Frying times of 2, 4, 6, 8 and 10 min were investigated for both types of frying (CF and VF). The frying vessel had a 3-L capacity and was filled with high-oleic sunflower oil (Casado Group, S.L.U, Valladolid, Spain), heated to the corresponding final temperature (107 °C for VF and 165 °C for CF), and maintained for 30 min prior to the frying procedure to ensure that the oil temperature was constant. The first batch of fried patties was discarded. Once the oil had reached the temperature, samples were placed in the frying basket in a ratio of 50 g per litre of oil and immersed in the frying oil. At the end of frying, the basket was raised and the vessel internal pressure was gradually restored in approximately 1 min to atmospheric level using an auxiliary valve. The samples were allowed to cool down and placed on towel paper to eliminate the surface excess oil. Patties were packaged under vacuum in co-extruded polyamide/polyethylene (30/130 μm thickness) flexible bags with oxygen permeability of 30 mL mm^{-2} day^{-1} bar^{-1} and water vapour transmission of 1.4 g m^{-2} day^{-1} (Industrias Pargón, Salamanca, Spain). Three independent experimental procedures were carried out and the frying trials were randomised to avoid the effect of temperature modifications. In total, six patties of each treatment were obtained and pooled together, taking randomly different pieces of several patties for the different analyses to reduce the variability.

Proximate analyses, colour and sensory determinations were carried out on the same day of the frying procedure. Samples were stored at −80 °C until further analysis. All determinations were performed in triplicate with the exception of colour measurements and sensory analysis.

2.2.3. Proximate analyses

Moisture content was determined gravimetrically (AOAC, 1997). Oil content was extracted with petroleum ether (BP 40–60 °C) in a Soxtec System 2055 Tecator extracting unit (FOSS, Hillerød, Denmark) and gravimetrically determined. Nitrogen content was analysed by the Kjeldahl technique (AOAC, 1984) and protein content determined by multiplying nitrogen by the factor 6.25. Ash content was determined by heating in a 550 °C furnace for 24 h (AOAC, 1990). Oil content, protein and ash were expressed as percentage in dry matter (%).

2.2.4. Lipid fatty acid composition and lipid oxidation

2.2.4.1. Lipid extraction. Lipids were extracted according to the method of Bligh and Dyer (1959).

2.2.4.2. Fatty acid composition (FA). Bligh and Dyer extracts were evaporated under nitrogen, the lipid phase dissolved in hexane (1 mL), and methylated with 0.5 M methanolic KOH (100 μL) for 10 min. The upper layer was analysed for fatty acid methyl esters (FAME) in a gas chromatograph (Agilent 7890 A) equipped with a DB-23 column (60 m × 0.32 mm, 0.25 μm film thickness) and a flame ionisation detector. Helium was used as the carrier gas. The oven temperature was programmed at 50 °C for the first 7 min and increased up to 200 °C at a rate of 25 °C/min; the temperature was further increased to 230 °C at a rate of 3 °C/min and held for 26 min. Injection and detector temperatures were 250 °C and 280 °C, respectively. One microlitre of hexane extract