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Modelling the influence of inulin as a fat substitute in comminuted meat products on their physico-chemical characteristics and eating quality using a mixture design approach

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ABSTRACT

The effects of fat substitution using two commercial inulin products on the physico-chemical properties and eating quality of a comminuted meat product (breakfast sausage) were modelled using a specialised response surface experiment specially developed for mixtures. 17 treatments were assigned representing a different substitution level for fat with inulin. Sausages were formulated to contain pork shoulder, back fat/inulin, water, rusk and seasoning (44.3, 18.7, 27.5, 7 and 2.5% w/w). Composition, sensory, instrumental texture and colour characteristics were assessed. Fructan analysis showed that inulin was unaffected by heat or processing treatments. Models showed increasing inulin inclusions decreased cook loss ($p < 0.0017$) and improved emulsion stability ($p < 0.0001$) but also resulted in greater textural and eating quality modification of sausages. Hardness values increased ($p < 0.0001$) with increasing inulin concentration, with panellists also scoring products containing inulin as less tender ($p < 0.0112$). Optimisation predicted two acceptable sausage formulations with significantly lower fat levels than the control, which would contain sufficient inulin to deliver a prebiotic health effect.

1. Introduction

While lean meat is an important component of a healthy diet as it contributes protein and essential fat-soluble vitamins and minerals (McAfee et al., 2010), the reduction or removal of fat and salt from meat products is desirable from a health perspective as high consumption is linked with many chronic health conditions e.g. cardiovascular disease (Kaliora & Dedoussi, 2007). A sausage batter is an emulsion-like system made up of a suspension of fat globules (dispersed phase) in a protein–water solution (continuous phase) (Morin, Temelli, & McMullen, 2004). Fat contributes to essential quality attributes in sausages (e.g. texture, flavour, appearance) and also plays an important role in governing the binding properties of protein molecules. The structural integrity of sausage batters is governed by the strength of the interacting forces within the protein network and the binding of free water within this network on mixing and subsequent heating (Morin et al., 2004). Therefore, fat removal or substitution represents a significant technical challenge.

Many fat reducing strategies have been investigated in meat products involving a number of different substitutes e.g. gels (Jiménez-Colmenero et al., 2012) and gums (Lin & Huang, 2003), whey protein (Sampaio, Castellucci, Pinto e Silva, & Torres, 2004), and hydrocolloids, such as carrageenan and starches (Candogan & Kolsarici, 2003). Inulin is a natural storage oligosaccharide of various plants, typically part of the *Compositae* family, including chicory, dahlia and Jerusalem artichoke (Barclay, Ginic-Markovic, Cooper, & Petrovsky, 2010). It consists of linear polyfructose chains joined together by β (2-1) linkages, with almost every molecule terminating with a glucose unit (Tárrega, Torres, & Costell, 2011). Inulin forms opaque gels at high concentrations when mixed with water. The manner in which it traps water results in lubricant and flow properties that are similar to those of fats (Yackel & Cox, 1992). These unique properties are the reason inulin has been identified as a promising ingredient for structuring in reduced or fat-free foods (Teeuwen, Thoné, & Vandorpe, 1992) and it has been shown to be a successful fat mimetic in a variety of food products e.g. cheese (Hennelly, Dunne, O'Sullivan, & O'Riordan, 2006), quick breads (Röβle, Ktendioudaki, & Gallagher, 2011) and fermented sausages (Mendoza, Garcia, Casas, & Selgas, 2001). Inulin is not absorbed by the small intestine, but is extensively fermented by colon bacteria. As inulin possesses a high dietary fibre content and prebiotic properties, it is considered to be a functional food ingredient (Arihara, 2006).

The general approach of the previous studies that have examined the addition of inulin or fructo-oligosaccharide (FOS) to meat products has been to examine the technological and quality parameters of low fat products (fat replaced by extra lean meat), with inulin added in place of rusk (Hayes, Auty, & Allen, 2011; Selgas, Cáceres, & García, 2005). In the present study, an alternative strategy to directly substitute

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fat with inulin was investigated using mixture design to optimise product formulations. Mixture design is a specialised form of response surface methodology (RSM) in which the factors are ingredients/components of a mixture and the response is a function of each ingredient. The factors are proportional and must add up to 100% (dependent) unlike traditional RSM were the factors are perceived as independent of each other (e.g. time, temperature). Design of experiment (DOE) strategies, such as mixture design, are efficient approaches to reducing experimental workload in an efficient and cost-effective manner, while at the same time allowing for the successful assessment of experimental factors using an approach which ensures that the most important factors are identified and assessed (Leardi, 2009). Therefore, the principal objective of the present study was to perform a detailed characterisation and optimisation of the effects of inulin as a healthier alternative to fat in sausages using a mixture design approach.

2. Material and methods

2.1. Sausage preparation

Full fresh pork shoulder (95% visual lean) and pork back fat were purchased from a local meat supplier (Granby Meats, Dublin, Ireland). The raw material was sourced from 6 month old female pigs purchased at commercial weight. Excess fat and connective tissue was removed manually. Two commercial inulin products, Orafti® GR and Orafti® HP (Beneo-Orafti, Tienen, Belgium) were supplied by O'Brien ingredients (Dublin, Ireland). Type of inulin was selected on the basis of Orafti application notes that described their use for similar comminuted/sausage products. Both inulin preparations were compositionally similar but did differ in some key respects. Orafti® HP contained *circa*. 100% inulin; solubility <5 g L^{-1} and degree of polymerisation (DP) >23, while Orafti® GR contained <92% inulin glucose and >8% glucose, fructose and sucrose; <120 g L^{-1} and DP >10. Both meat and fat were sliced and minced (model PT-82/22 Mainca Barcelona, Spain) twice through a 5 mm steel plate. All breakfast sausage formulations (1 kg) were manufactured containing pork shoulder (44.3%), pork fat/inulin (18.7%), water (27.5%), rusk (a filler material primarily used to aid water absorption made from wheat flour, chemically raised, baked and ground into specified particle sizes) (7%) and seasoning (2.5% — containing breadcrumbs, spices, pea protein, starch, phosphate, sodium metabisulphite and ascorbic acid). Table 1 represents the experimental design (Design Expert v. 7.6.1, Stat-Ease Inc., Minneapolis, MN, USA) for the three variable ingredient components (X_1 = pork back fat, X_2 = Orafti® GR, and X_3 = Orafti® HP) used in sausage formulations. Pork was placed in a bowl chopper and chopped for 30 s to ensure a smooth mixture. Fat and/or powdered inulin were placed in a bowl chopper with half the ice water (to minimise temperature increases in product during manufacture) and further mixed for 30 s. Seasoning, rusk and the remaining water were added and mixed for 1 min. Sausage batter was piped into a cellulose casing (23 mm diameter) (Viscofon, Food Process Technology) using an F-Dick 6 l hand-linked sausage stuffer (McDonnells, Dublin, Ireland). Samples were blast frozen (air speed 3.75 m/s) and stored (−20 °C) for all subsequent analyses.

Table 1
Experimental design of three components in sausage formulation.

Treatment	Pork back fat (X_1)	Orafti® GR (X_2)	Orafti® HP (X_3)
1	0	0	18.70
2	0	9.35	9.35
3	9.35	0	9.35
4	7.79	3.12	7.79
5	12.47	3.12	3.12
6	18.70	0	0
7	0	18.70	0
8	3.12	12.47	3.12
9	7.79	7.79	3.12
10	0	0	18.70
11	0	18.70	0
12	3.12	3.12	12.47
13	0	9.35	9.35
14	18.70	0	0
15	6.23	6.23	6.23
16	9.35	9.35	0
17	9.35	0	9.35

Where $X_1 + X_2 + X_3 = 18.7\%$.

2.2. pH measurement, thermal treatment and weight loss

Prior to thermal treatment, pH measurement was carried out on all samples with an Orion pH meter (Model 420A; Orion Research Inc., Boston, MA) and calibrated with phosphate buffers of pH 4 and 7 until a slope value between 90 and 105 was obtained. Five vacuum packed sausages were thermally treated by water bath immersion (85 °C) until they had achieved a core temperature of 73 °C. Sample core temperature profile was recorded during the process, using an Ellab E-Val TM TM9608 data module (Ellab [UK] Ltd., Norfolk, England) connected to a laptop. A standard Ellab SSA-12080-G700-TS temperature probe was inserted through an Ellab GKM-13009-C020 packing gland (20 mm) into the largest sample in the vacuum bag. Cook loss of sausages was calculated from the differential in weights before and after thermal treatment. An empirical measurement of emulsion stability (ES) was assessed as described by Seri Chempaka and Babji (1996) with slight modifications.10 g of raw sausage was placed in a centrifuge tube and centrifuged for 5 min at 2000 *g*. Samples were transferred to a water bath and heated to 70 °C for 30 min. Samples were centrifuged for a second time at 2000 *g* for 5 min. Sample pellets were removed and re-weighed, while supernatants were transferred into pre-weighed crucibles and dried overnight at 100 °C.

2.3. Compositional analyses

Five cooked and uncooked sausages were blended in a Robot Coupe Blender and triplicate sub-samples were analysed. Moisture and fat content were determined by Smart Trac5 rapid moisture/fat analyser (Smart Trac 5 Model 907875, CEM Corporation, NC, USA) as described by Hayes, Stepanyan, Allen, O'Grady, and Kerry (2011). Protein (LECO Nitrogen Determinator) and salt (NaCl by the Mohr titration method) were determined as described by Keenan, Desmond, Hayes, Kenny, and Kerry (2010). Total fructan content was determined using modifications of the AOAC (999.03) and AACC (32.32) methods by Megazyme Fructan HK assay kit (Megazyme International Ireland, Wicklow, Ireland). Samples for fructan analysis were freeze dried prior to testing for ≥5 days in an A6/14 freeze dryer (Frozen in Time Ltd., York, UK) and expressed on a gram per 100 g dry weight (DW) basis.

2.4. Measurement of texture

Texture profile analysis (TPA) was carried out according to the method described by Bourne (1978). Five sausages per treatment were cored (diam. 25 × ht. 20 mm) and axially compressed to 50% of their original height in a two-cycle compression test using an Instron Universal Testing Machine Model 4464 (Instron (UK) Ltd., High Wycombe, UK). Force time deformation curves were obtained using a 500 N load cell applied at a cross speed of 50 mm min^{-1}. TPA recorded the following attributes: hardness (N), peak force required for first õcompression; springiness (mm), distance sample recovers after first compression; cohesiveness (dimensionless), ratio of positive force area during the second compression; gumminess (N), the product of hardness and cohesiveness; chewiness (J), the product of gumminess and springiness.