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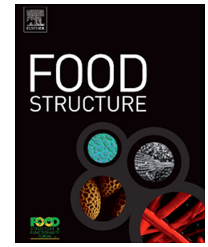

Investigating the influence of inulin as a fat substitute in comminuted products using rheology, calorimetric and microscopy techniques

Derek F. Keenan [a,*], *Mark A.E. Auty* [b,2], *Linda Doran* [b,2], *Joseph P. Kerry* [c,3], *Ruth M. Hamill* [a,1]

[a] *Teagasc, Food Research Centre Ashtown, Dublin 15, Ireland*
[b] *Teagasc, Food Research Centre Moorepark, Fermoy, Co. Cork, Ireland*
[c] *Food Packaging Group, School of Food and Nutritional Sciences, University College Cork, Co. Cork, Ireland*

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ABSTRACT

The present manuscript studied the effects of fat substitution with two commercial inulins on the magnetic resonance, rheological, calorimetric and microscopic properties of breakfast sausages. Sausage formulations were evaluated using mixture design (D-optimal). A total of 17 experimental treatments were employed, with each representing a different substitution level for fat. Sausage batters were formulated to contain lean pork shoulder, pork back fat/inulin, water, rusk and seasoning (44.3, 18.7, 27.5, 7 and 2.5% w/w, respectively). The resultant products' water mobility, deformation and thermal behaviors were analyzed for each treatment group using nuclear magnetic resonance (NMR), rheology, differential scanning calorimetry (DSC), while their ultra-structural properties were analyzed using light, confocal and scanning electron microscopy for selected extremes. Significant models were produced for water mobility with inulin inclusions in sausages increasing the relative proton populations of bound water ($T2_b$) values ($p < 0.0001$) and decreasing free water ($T2_2$) population ($p < 0.0001$). Inulin inclusions significantly altered the rheological characteristics with increases in both the gel strength ($G'_0 - G''_0$) and unit interaction strength (A_n) ($p < 0.0001$, respectively). Complementary temperature-dependent behavior was observed using rheology and DSC which showed increased elastic behavior (G') circa 40 °C that corresponded to the endothermic peaks for the onset of protein denaturation. Cryo-scanning electron and confocal laser microscopy techniques permitted visualization of the aggregation of inulin micro-crystals and distribution of fat within the cooked sausage matrix. Overall, the work presented has improved our understanding of the fundamental properties of sausage products and will enable a more scientific-based approach to future product development.

* *Corresponding author.* Tel.: +353 1 8059500; fax: +353 1 8059550.
E-mail addresses: derek.keenan@teagasc.ie (D.F. Keenan), mark.auty@teagasc.ie (Mark A.E. Auty), joe.kerry@ucc.ie (J.P. Kerry).
[1] Tel.: +353 1 8059500; fax: +353 1 8059550.
[2] Tel.: +353 25 42222; fax: +353 25 42340.
[3] Tel.: +353 21 4903000; fax: +353 21 4903000.
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1. Introduction

Meat gels can be thought of as an ordered three-dimensional network formed by protein–protein interactions in which fat droplets, water, salts and other small components are trapped (Peng & Nielsen, 1986). Sausage batters are structurally complex meat products, comprising of mixtures of lean meat, fat, fillers, seasoning and water with the dispersed phase composed of fat globules and continuous phase made up of protein/water (Morin, Temelli, & McMullen, 2004). This makes them similar to both emulsions and suspensions from a structural perspective (Honikel, 1983; Swasdee, Terrell, Dutson, & Lewis, 1982). Actin and myosin proteins must be properly suspended and solubilized, denatured and heat aggregated to form a gel structure with acceptable water and fat binding and optimum texture properties (Ziegler & Acton, 1984), with salt being commonly applied as a solubilizing agent. Fat is stabilized within the solubilized protein gel network in a sausage and contributes succulence and texture (Feiner, 2006, chap. 12). Therefore, the mechanical dispersal of the fat, which can depend on its hardness and melting point, and the chemical composition of the lipid phase also contribute to the subsequent physical properties of the batters (Lee, Carroll, & Abdollahi, 1981; Lee, Hampson, & Abdollahi, 1981; Whiting, 1987). Fat also helps prevent shrinkage of the protein during cooking by acting as a filler (Feiner, 2006, chap. 12). Overall, it has an important role in this system due to its considerable influence on the binding properties of the proteins (Morin et al., 2004).

Lowering fat levels in comminuted meat products to reduce dietary intake of fat risks altering the structural properties of the meat batter. During heating, the coagulating network of proteins surrounds the melting fat particles, preventing them from coalescing due to the mechanical fixation within the meshes of the coagulated network. The larger these meshes are, the less coalescence of fat that can occur and the better the retention of fluids within the mixture (Hamm, 1975). Structural deterioration occurs if the batter is not adequately prepared leading to an unsightly and unsatisfactory product. In such cases, uncoated fat surfaces, due to excessive comminution, allow fat particles to come together and render from the mixture during heating. This results in fat pockets or 'greasing out' of the emulsion leading to poor structural integrity (Pearson & Gillett, 1996, chap. 9).

Diverse strategies to enhance the structural properties of reduced fat products have been applied with variable results (Choi et al., 2009; Hsu & Sun, 2006; Totosaus & Pérez-Chabela, 2009; Youseff & Barbut, 2009). The long chain oligosaccharide, inulin has been reported to exhibit synergistic effects with most gelling agents, creating stronger gels than the sum of the individual components (Kim, Faqih, & Wang, 2001). The relative solubility of inulin in water allows it to form a three-dimensional gel network of crystalline submicron particles (100 nm diameter). These particles aggregate, trapping water and forming larger crystals (1–5 μm) in aqueous solutions >25% inulin (short chains) or >13% inulin (long chain – with heating or shearing of the solutions). In this regard, examining the potential of inulin to form a sufficiently stable and acceptable gel, while partially compensating for the removal of fat in a sausage matrix is of interest. Furthermore, a more comprehensive understanding of the role of fat substitutes in the structuring of low-fat products in both gel forming and gel stability terms would be desirable.

To date, studies elucidating fundamental physico-chemistry in meat systems have mainly utilized model systems, e.g. combinations of oligosaccharides, purified myofibrils or myofibrillar proteins (Chou & Lin, 2010) and soy fractions (Tseng, Xiong, & Boatright, 2008). While these studies are enlightening, they cannot take full cognizance of the more complex matrix properties of the full-scale product. Studies that do appear (Keenan, Resconi, Kerry, & Hamill, 2014; Mendoza, Garcia, Casas, & Selgas, 2001) concerning full-scale products are largely concerned with technological characteristics of quality and do not consider more fundamental physico-chemistry governing these quality markers. However, more specialized techniques are available for the analyses of the underlying physico-chemistry of meat products. For example, the mobility of water has been studied extensively using nuclear magnetic resonance (NMR) relaxometry in meat (Andersen, Andersen, & Bertram, 2007; Bertram & Andersen, 2004; Bertram et al., 2001; Shaarani, Nott, & Hall, 2006) and could be a useful tool in determining the effects of inulin on water in comminuted meat products, where water plays a key role in the formation of the overall gel. Differential scanning calorimetry can be used to analyze the thermal behavior characteristics of sausages, particularly fat-containing controls and those containing substituted-inulin. This may offer some insight into the similarity of inulin gels which have been reported to exhibit phenomena reminiscent of the melting behavior of fat crystal networks due to the wide molecular weight distribution of the inulin polyfructose (Bot, Flöter, Lammers, & Pelan, 2003; de Bruijne & Bot, 1999). The similarities between the structuring properties of inulin when it crystallizes and how fat structures meat products could be better elucidated by rheological analysis (Bot, Erle, Vreeker, & Agterof, 2004).

Therefore, the principal objective of the present study was to perform a detailed characterization of the impact of substituting inulin for fat in sausages in rheological, calorimetric, NMR spectroscopic and microscopic terms using a mixture design approach.

2. Materials and methods

2.1. *Sausage preparation*

The basic sausage formulation is given in Table 1. Sausage formulations containing the three variable components (X_1 = pork backfat, X_2 = Orafti® GR, and X_3 = Orafti® HP (Orafti products represented two commercial forms of inulin)) were

Table 1 – Sausage formulation.

Ingredient	Composition (%)
Pork shoulder (95% lean)	44.3
Pork back fat	0–18.7
Inulin (Orafti® HP/GR)	0–18.7
Water	27.5
Rusk	7.0
Seasoning	2.5