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Development of consumer accepted low salt and low fat traditional Irish processed meats

Thesis presented by
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To obtain the degree of
Doctor of Philosophy – PhD in Food Science and Technology

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Prof. Yrjo Roos

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Table of Contents

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Declaration

I, Susann Fellendorf, hereby declare that this thesis is my own work and effort, and that it has not been submitted for another degree, neither at the National University Ireland, Cork nor elsewhere. Where other sources of information have been used, they have been acknowledged.

Signature

Abbreviations

a*	Red-green dimension
ANOVA	Analysis of variance
APLSR	ANOVA-Partial Least Squares regression
b*	Yellow-blue dimension
CaMgKCl 1/2	Mixture 1/2 of calcium chloride, magnesium chloride and potassium chloride
CB	Corned beef
CFU/g	Colony Forming Unit per g sample
CMC	Carboxymethylcellulose
FSA	Food Standards Agency
FSAI	Food Safety Authority of Ireland
KCl	Potassium chloride
KClG	Mixture of potassium chloride and glycine
KCPCl	Mixture of potassium citrate, potassium phosphate and potassium chloride
KLCl	Mixture of potassium lactate and potassium chloride
KLG	Mixture of potassium lactate and glycine
L*	Lightness
MAP	Modified atmosphere packaging
MRD	Maximum Recovery Diluents
NaCl	Sodium chloride
OPA/PP	Oriented polyamide and polypropylene
PCA	Plate Count Agar
PuraQ	PuraQ®Arome NA4
RDA	Ranking descriptive analysis
Seaweed	Seaweed wakame

TVC	Total Viable Count
VP	Vacuum packaging
WHO	World Health Organization
WMS	Waxy maize starch

Abstract

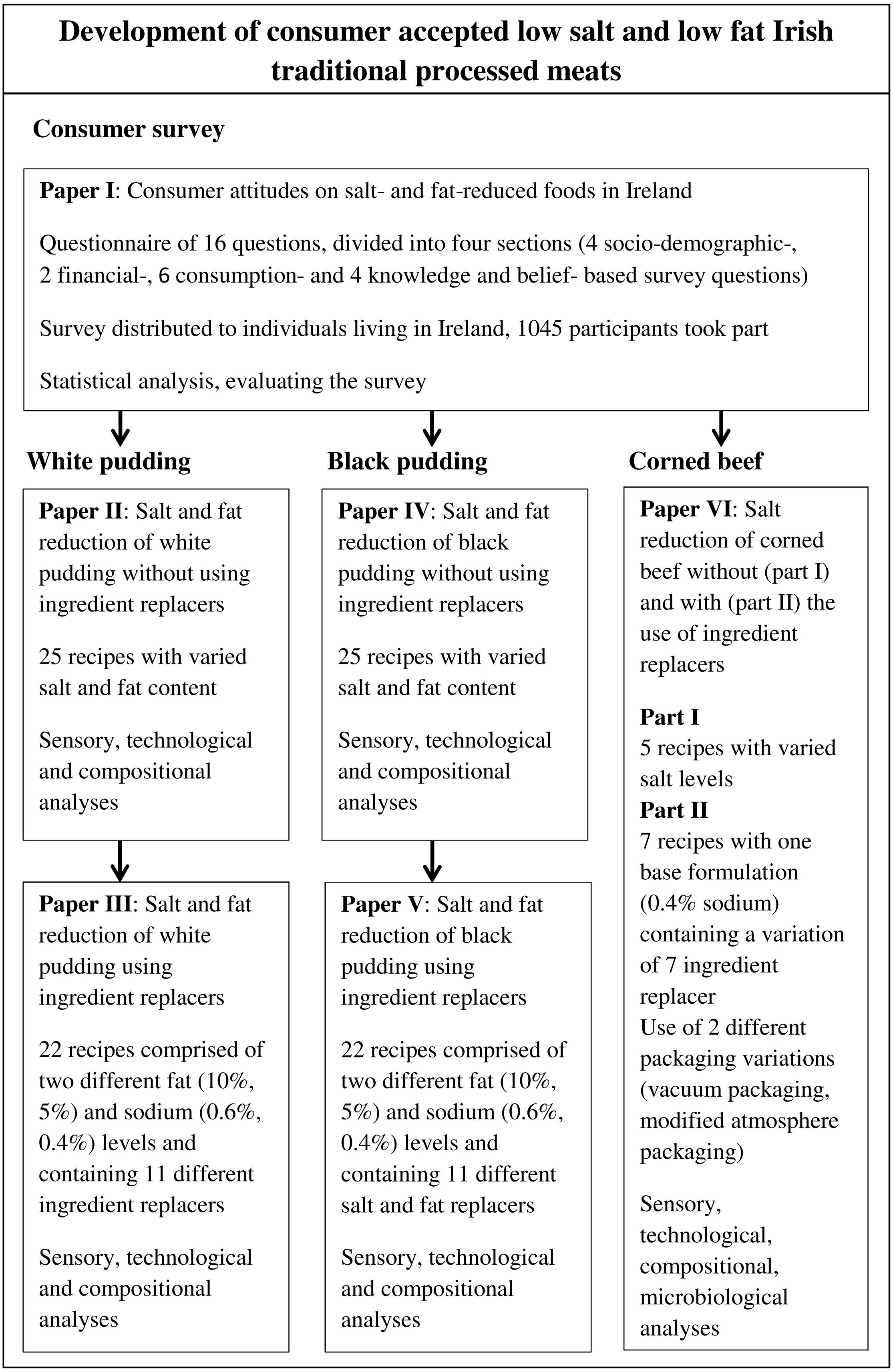
Initially, Irish consumers (n = 1045) were surveyed with respect to their attitudes towards healthier food consumption, particularly in relation to salt and fat reduction. It seems that educational campaigns have generally been adopted by respondents, as only a minority were not concerned about their diet; irrespective of age, gender or educational status. Overall, an increase in purchasing salt-reduced food was observed, although fat-reduced food products were already better adopted.

Following from this positive start, the thesis then focused on development of consumer-accepted low salt and low fat Irish traditional processed meats, in particular, white pudding, black pudding and corned beef, both with and without the use of additives. Initially, salt and fat reductions were carried out by simply reducing salt and fat content without using additives. For that purpose, 25 white and black pudding formulations with varying fat (20%, 15%, 10%, 5%, 2.5% w/w) and sodium (1.0%, 0.8%, 0.6%, 0.4%, 0.2% w/w) contents, and five corned beef samples with varied salt levels (1.0%, 0.8%, 0.6%, 0.4%, 0.2% w/w) were produced in a pilot plant processing facility. White pudding samples containing 15% fat and 0.6% sodium, and black pudding samples containing 0.6% sodium and 10% fat were highly accepted, thereby satisfying the sodium target (0.6%) set by the Food Safety Authority of Ireland (FSAI, 2011). Corned beef samples low in sodium (0.2%, 0.4%) showed reduced saltiness perception and were positively correlated (not significant) to liking of flavour and overall acceptability.

For greater reductions in salt and fat, different ingredient replacer combinations were added to 11 white pudding formulations containing 10% fat and 0.6% sodium, and accordingly 5% fat and 0.4% sodium (both optimum levels from the previous study); 11 black pudding formulations possessing 10% fat and 0.4% sodium, and accordingly 5% fat and 0.6% sodium, and to 7 corned beef formulations containing 0.4% sodium. White pudding formulations containing 10% fat and 0.6% sodium formulated with sodium citrate, as well as the combination of potassium chloride and glycine; black pudding samples with 5% fat and 0.6% sodium containing pectin and a combination of potassium citrate, potassium phosphate and potassium chloride, as well as samples containing 10% fat and 0.4% sodium with waxy maize starch; and accordingly, corned beef containing 0.4% sodium and formulated with potassium lactate and glycine were accepted by assessors. Consequently, ingredient replacers used in white pudding, black pudding and corned beef were shown to be acceptable by assessors when alternative ingredients were used to assist in further replacing fat and salt levels in these products.

Keywords: Health and diet, Consumer survey, Traditional Irish processed meat products, White pudding, Black pudding, Corned beef, Sensory evaluation, Physicochemical analyses, Microbiological analyses, Vacuum packaging, Modified atmosphere packaging

Work flow



Development of consumer accepted low salt and low fat Irish traditional processed meats

Consumer survey

Paper I: Consumer attitudes on salt- and fat-reduced foods in Ireland

Questionnaire of 16 questions, divided into four sections (4 socio-demographic-, 2 financial-, 6 consumption- and 4 knowledge and belief- based survey questions)

Survey distributed to individuals living in Ireland, 1045 participants took part

Statistical analysis, evaluating the survey

White pudding

Paper II: Salt and fat reduction of white pudding without using ingredient replacers

25 recipes with varied salt and fat content

Sensory, technological and compositional analyses

Paper III: Salt and fat reduction of white pudding using ingredient replacers

22 recipes comprised of two different fat (10%, 5%) and sodium (0.6%, 0.4%) levels and containing 11 different ingredient replacers

Sensory, technological and compositional analyses

Black pudding

Paper IV: Salt and fat reduction of black pudding without using ingredient replacers

25 recipes with varied salt and fat content

Sensory, technological and compositional analyses

Paper V: Salt and fat reduction of black pudding using ingredient replacers

22 recipes comprised of two different fat (10%, 5%) and sodium (0.6%, 0.4%) levels and containing 11 different salt and fat replacers

Sensory, technological and compositional analyses

Corned beef

Paper VI: Salt reduction of corned beef without (part I) and with (part II) the use of ingredient replacers

Part I
5 recipes with varied salt levels
Part II
7 recipes with one base formulation (0.4% sodium) containing a variation of 7 ingredient replacer
Use of 2 different packaging variations (vacuum packaging, modified atmosphere packaging)

Sensory, technological, compositional, microbiological analyses

Schematic association of the research articles constituting to the present thesis

Publications and presentations

Publications

(1) Published articles

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding.
Published: Meat Science, 2015, Volume 103, Pages 75-82

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Impact of ingredient replacers on the physicochemical properties and sensory quality of reduced salt and fat black puddings.
Published: Meat Science, 2016, Volume 113, Pages 17-25

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding.
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(2) Submitted articles

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Impact on the sensory properties of salt reduced corned beefs formulated with and without the use of salt replacers.
Revision submitted: Meat Science, October 2015

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Consumer attitudes on salt- and fat-reduced foods in Ireland
Submitted: Appetite, November 2015

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry
Effect of using ingredient replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings.
Revision submitted: European Food Research and Technology, December 2015

Poster presentations

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry (2014).
Sensory optimisation of reduced salt and fat black pudding products.
1st International Pleasure Conference, Salt-Sugar-Lipids reduction, LaRochelle, France.

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry (2014).
Impact of varying salt and fat levels on the sensory quality of white pudding.
1st International Pleasure Conference, Salt-Sugar-Lipids reduction, LaRochelle, France.

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry (2015).
Sensory optimisation methods for reducing salt and fat in processed meat.
The 11th Pangborn Sensory Science Symposium, Gothenburg, Sweden.

Susann Fellendorf, Maurice G. O'Sullivan, Joseph P. Kerry (2015).
Sensory acceptance testing and ranking descriptive analysis (RDA) for optimisation of reduced salt and fat black puddings developed using ingredient replacers.
The 11th Pangborn Sensory Science Symposium, Gothenburg, Sweden.

Chapter 1

Introduction

Humans, being omnivorous, have killed animals as a meat source since prehistoric times. The beginning of civilization allowed the domestication of animals such as chickens, sheep, pigs and cattle, and with modern intensive agricultural practices meat is now used for meat production mainly on an industrial scale (Medeiros & Wildman, 2011). To date, meat is still an integral part of the human diet in most cultures, often seen with a deep symbolic meaning and relative social function (Leroy & Praet, 2015). Despite, many people being vegetarians or even vegans, thus they choose not to eat meat or accordingly any food made from animals, because of ethical objections to killing animals for food, environmental, religious and/or health concerns. Consequently, the meat consumption varies worldwide (Radnitz, Beezhold, & DiMatteo, 2015; Rothgerber, 2015).

Nevertheless, the world's livestock sector is growing at an unprecedented rate because of population growth, rising urbanization and incomes. It was projected that annual meat production will increase from 218 million tonnes in 1997-1999 to 376 million tonnes by 2030. Urbanization is influencing global demand for livestock products. It stimulates improvements in infrastructure, including cold chains, and thus permitting trade in perishable goods. In comparison to the less diversified diets of rural people, city inhabitants show a more varied diet rich in animal proteins and fats (OECD/FAO, 2014; WHO, 2003).

Substantial structural changes and the shift in diet away from staples (such as roots and tubers) towards more livestock products and vegetable oils resulted in a gradual growth of food consumption on a worldwide basis (FAO, 2002). Following on from this, dietary patterns have shifted to an increased consumption of energy-dense diets high in saturated fat, sugar and salt. The dietary energy intake has increased since the mid-1960s globally by approximately 600 kcal, in developing countries by over 800 kcal and in industrialized countries by over 500 kcal per capita per day. Although, this change has not taken place equally across regions. For example, the per capita supply of calories has been almost stagnant in sub-Saharan Africa, and in contrast, it has risen extremely in East Asia (by almost 1000 kcal per capita per day, mainly in China) and in the Near East/North Africa region (by over 700 kcal per capita per day). In Countries experiencing economic transition, usually countries belonging to Central and Eastern Europe and the former Soviet Union, the per capita supply of calories has even recently fallen. The current energy intakes range from 2850 kcal per capita per day in developing countries, to 3060 kcal per capita per day in transition countries and 3440 kcal per capita per day in industrialized countries (FAO, 2012) .

Due to the recent steep drop in prices, developing countries have experienced higher meat consumption at much lower levels of gross domestic product in comparison to the industrialized countries of 20-30 years ago. A remarkable rise in the consumption of animal products has thus taken place in Brazil and China (WHO, 2003). Prognosticated by OECD/FAO, the global meat consumption per capita is projected to reach 36.3 kg in retail weight by 2023, which means an increase by 1.6% through the next decade. However, meat trade will grow slower than in the past decade and just over 10.6% of meat output will be traded. The most significant import demand growth originates from Asia (OECD/FAO, 2014)

Due to richer and more diverse diets, the high-value protein that meat offers improves nutrition for the majority worldwide. Meat is also an important source of a wide range of essential micronutrients, in particular, minerals such as zinc and iron, and vitamins such as vitamin B-complex (thiamine, riboflavin, vitamin B_{12}, B_6, niacin, folic acid, biotin), α-tocopherol, retinol and vitamin K (Belitz, Grosch, & Schieberle, 2009). Especially for the people in developing countries, meat and processed meat products contribute to a diet high in nutritional value and taste. However, excessive consumption of these products can lead to high intakes of saturated fat and salt (WHO, 2003).

The growing consumption of energy-dense diets high in saturated fat, sugar and salt, combined with a reduction in energy expenditure, related to a sedentary lifestyle (e.g. motorized transport, labour-saving devices at home, less physically demanding manual tasks at work and leisure time with reduced physically activities), is leading to an increase of chronic noncommunicable diseases (NCDs). NCDs, including obesity, diabetes mellitus, hypertension, stroke, cardiovascular disease, and some types of cancer, cause an increasing rate of disability and premature death worldwide. This worrying trend not only shows that already a large proportion of the population is affected, but that they have also started to appear earlier in age. As a consequence of this, the prevention of NCDs are highly discussed (WHO, 1990, 2003).

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) update governments, international agencies and concerned partners in the public and private sectors with recommendations related to diet and health, based on the latest scientific evidence. As nutrition is defined as the major modifiable determinant of NCDs, the focus is directed on altering populations' diet. In consequence, the WHO are currently driving measures to reduce salt and saturated fat content in foods by raising consumers' awareness and setting guidelines for the food processing industry. The WHO have recommended, in an urgent call, to reduce total fat intake by the population as a whole and advised to have a daily intake of polyunsaturated fatty acids between 6% and 11% (WHO, 2003). Furthermore, a sodium intake of less than 5 grams per day is recommended (WHO, 2012).

Cured and other processed meat products are the main contributors to salt intakes in the Irish population, followed by bread. A national guideline for the Irish meat (and bread) industry was agreed by the Food Safety Authority of Ireland (FSAI) in 2011, with the target to decrease sodium content. The following sodium levels for processed meat were set: 600mg Na per/100g for uncured cooked meat products, 1300mg Na per/100g for cured uncooked meat products, 600mg Na per/100g for black & white puddings, 550mg Na per/100g for sausages and 400mg Na per/100g for burgers (FSAI, 2011). However, up to date no guideline is agreed for cured cooked meat products, such as cooked ham and corned beef.

Due to the key role of salt and fat in processed meat products, a reduction of sodium and saturated fat content is challenging. For instance, fat reduction in emulsion-type products affected a variety of quality attributes, including texture, sensory and cook yield (Rogers, 2001). Also technological problems, including reduction in particle binding, rubbery skin formation, production of a soft mushy interior and excessive purge, are experienced (Mallika, Prabhakar, & Reddy, 2009). Developing meat products low in sodium is also not straightforward. Sodium chloride solubilises myofibrillar proteins during manufacturing (Hamm, 1972), which are responsible for activation of the proteins to increase hydration and water-binding capacity, increased binding properties of protein and improved texture (Offer & Knight, 1988). As a consequence, a reduction of salt impacts all these processes with several researchers reported detrimental effects on water binding capacity, texture and flavour (Desmond, 2006; Totosaus & Pérez-Chabela, 2009).

Meat product manufacturers have already and successfully commenced reformulating their recipes, and now are offering lower levels of salt and fat, or even higher levels of polyunsaturated fatty acids in processed meat products on the market (Verbeke, Pérez-Cueto, De Barcellos, Krystallis, & Grunert, 2010). Additionally, several researchers demonstrated that salt and fat reduction (with and without the use of replacers) in processed meat is possible, in particular, in breakfast sausages (Tobin, O'Sullivan, Hamill, & Kerry, 2013), frankfurters (Hughes, Cofrades, & Troy, 1997; Tobin, O'Sullivan, Hamill, & Kerry, 2012a), restructured poultry (Cofrades, López-López, Ruiz-Capillas, Triki, & Jiménez-Colmenero, 2011), beef patties (López-López, Cofrades, Yakan, Sola, & Jiménez-Colmenero, 2010; Tobin, O'Sullivan, Hamill, & Kerry, 2012b), and dry-cured loins (Armenteros, Aristoy, Barat, & Toldrá, 2009), to mention just a few.

Nevertheless, the traditional food sector faces additional challenges of a potential discrepancy between the concept of traditional food and innovation (Guerrero et al., 2012; Stolzenbach, Bredie, & Byrne, 2013), which makes it especially difficult to introduce acceptable novelties. It was even suggested that traditional foods in the future may suffer from a less favourable attitude regarding health and nutritional aspects. The greatest threat for the future is seen in an insufficient adaptation to new requirements demanded by consumers (Jordana, 2000). Stolzenbach et al. (2013) indicated that alterations in traditional foods without a clear understanding of the impact on consumers' perception and acceptance can potentially be more harmful than beneficial. Therefore, insights in consumer requirements and expectations are imperative for a successful market launching of product innovations (Grunert, Verbeke, Kügler, Saeed, & Scholderer, 2011).

The present thesis will investigate how well the Irish consumer has adopted and implemented the message of consuming healthier foods, including reduced salt and fat levels from their diets. It will also clarify if a conflict exists between innovation and traditional food manufacture, especially with respect to processed meat manufacture. Furthermore, the thesis will examine the impact on sensory quality of salt- and fat reduced traditional meat products, in particular, white pudding, black pudding and corned beef with and without the use of additives.

References

Armenteros, M., Aristoy, M.-C., Barat, J. M., & Toldrá, F. (2009). Biochemical and sensory properties of dry-cured loins as affected by partial replacement of sodium by potassium, calcium, and magnesium. *Journal of Agricultural and Food Chemistry*, *57*(20), 9699–705.

Belitz, H. D., Grosch, W., & Schieberle, P. (2009). Food Chemistry (4th ed., p. 563). Springer-Verlag Berlin Heidelberg.

Cofrades, S., López-López, I., Ruiz-Capillas, C., Triki, M., & Jiménez-Colmenero, F. (2011). Quality characteristics of low-salt restructured poultry with microbial transglutaminase and seaweed. *Meat Science*, *87*(4), 373–80.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

FAO. (2002). *World agriculture: towards 2015/2030*. Food and Agriculture Organization of the United Nations, *Rome*. Food and Agriculture Organization of the United Nations.

FAO. (2012). World agriculture towards 2030/2050, (12), 146. Food and Agriculture Organization of the United Nations.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

Grunert, K. G., Verbeke, W., Kügler, J. O., Saeed, F., & Scholderer, J. (2011). Use of consumer insight in the new product development process in the meat sector. *Meat Science*, *89*(3), 251–258.

Guerrero, L., Claret, A., Verbeke, W., Vanhonacker, F., Enderli, G., Sulmont-Rossé, C., Guàrdia, M. D. (2012). Cross-cultural conceptualization of the words Traditional and Innovation in a food context by means of sorting task and hedonic evaluation. *Food Quality and Preference*, *25*(1), 69–78.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

Hughes, E., Cofrades, S., & Troy, D. J. (1997). Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 and 30% fat. *Meat Science*, *45*(3), 273–281.

Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, *33*(3-4), 147–152.

Leroy, F., & Praet, I. (2015). Meat traditions: the co-evolution of humans and meat. *Appetite*, *90*, 200–211.

López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International.*, *43*(5), 1244 – 1254.

Mallika, E. N., Prabhakar, K., & Reddy, P. M. (2009). Low Fat Meat Products - An Overview. *Veterinary World*, *2*(9), 364–366.

Medeiros, D. M., & Wildman, R. E. C. (2011). *Advanced Human Nutrition* (2nd ed.). Jones & Bartlett Publ.

OECD/FAO. (2014). *OECD-FAO Agricultural Outlook 2014. OECD Publishing*. The Organisation for Economic Co-operation and Development / Food and Agriculture Organization of the United Nations.

Offer, G., & Knight, P. (1988). The structural basis of water-holding capacity in meat. In R. Lawrie (Ed.), *Developments in meat science* (Vol. 4, pp. 173–243). London: Elsevier Science Publications.

Radnitz, C., Beezhold, B., & DiMatteo, J. (2015). Investigation of lifestyle choices of individuals following a vegan diet for health and ethical reasons. *Appetite*, *90*, 31–36.

Rogers, P. J. (2001). Manufacturing of reduced-fat, low fat and fat free emulsion sausages. In Y. H. Hui, W.-K. Nip, R. W. Rogers, & O. A. Young (Eds.), *Meat Science and Applications* (pp. 443–458). New York, Marcel Dekker.

Rothgerber, H. (2015). Can you have your meat and eat it too? Conscientious omnivores, vegetarians, and adherence to diet. *Appetite*, *84*, 196–203.

Stolzenbach, S., Bredie, W. L. P., & Byrne, D. V. (2013). Consumer concepts in new product development of local foods: Traditional versus novel honeys. *Food Research International*, *52*(1), 144–152.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Totosaus, A., & Pérez-Chabela, M. L. (2009). Textural properties and microstructure of low-fat and sodium-reduced meat batters formulated with gellan gum and dicationic salts. *LWT - Food Science and Technology*, *42*(2), 563–569.

Verbeke, W., Pérez-Cueto, F. J. A., De Barcellos, M. D., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, *84*, 284–292.

WHO. (1990). *Diet, nutrition, and the prevention of chronic diseases.* World Health Organization.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

Chapter 2

Literature review

2.1 Constitution of meat

2.1.1 Morphology and chemical composition

The unit of muscular tissue is a fibre consisting of myofibrils between which is a solution, the sarcoplasm, and a fine network of tubules (sarcoplasmic reticulum). The fibre is bound by a very thin membrane (the sarcolemma) attached by connective tissue on the outside (Lawrie & Ledward, 2006).

Muscle tissues freed from adhering fat contain on average 75% water, 19% proteins, 2.5% intramuscular fat, 1.2% carbohydrates and 2.3% other soluble non-protein substances (e.g. amino acids, minerals, vitamins) (Greaser, Wang, & Lemanski, 1981; Lawrie, 1975). Composition depends on the species, breed, age, feed, sex, anatomical location of the musculature, and as well as on the condition of the animal (Lawrie & Ledward, 2006).

Proteins in muscles can be divided into those which are either soluble in water or diluted salt solutions (sarcoplasmic proteins (11.5%): myoglobin and enzymes), those which are soluble in concentrated salt solutions (myofibrillar proteins (5.5%): actin and myosin) and those which are insoluble (connective tissues (collagen and elastin) and membrane proteins (2%)). Most of the sarcoplasmic proteins are enzymes involved in the glycolytic pathway and the myofibrillar proteins, myosin and actin, are responsible for the overall structure of the muscle (Greaser et al., 1981; Lawrie, 1975; Lawrie & Ledward, 2006). Fat in meat can be either adipose tissue (triglyceride) or intramuscular fat (phospholipids and unsaponifiable constituents, e.g. cholesterol) (Lea, 1962). The ratio of unsaturated to saturated fat constitutes 0.11 for beef, 0.15 for lamb and 0.58 for pork (Enser, Hallett, Hewitt, Fursey, & Wood, 1996). Despite meat containing only a small amount of carbohydrates, they are important in developing flavour during cooking through caramelization and Maillard-type reactions between reducing sugars and amino groups. Furthermore, carbohydrates are responsible for the brown colour (Belitz, Grosch, & Schieberle, 2009). Besides the excellent source of protein, meat also contains all of the nine essential amino acids. Furthermore, meat is a good source of minerals (zinc, iron) and possesses relatively high amounts of the vitamin B-complex (thiamine, riboflavin, vitamin B_{12}, B_6, niacin, folic acid, biotin) and vitamin A, E and K (Belitz et al., 2009).

2.1.2 Changes of pH

Irreversible anaerobic glycolysis occurs when oxygen is permanently removed from the muscle at death. Immediately after slaughtering, glycogen, the main energy supplier to the muscle (pH = 7.0), breaks down to lactic acid which establishes the acidity in meat. The final pH achieved, is determined by inactivation of glycolytic enzymes or lack or inaccessibility of glycogen (Callow, 1937). The pH of typical mammalian muscles is about 5.4-5.5 (Ramsbottom & Strandine, 1948), except when exercise or fatigue occur immediately before slaughtering.

Because the iso-electric point of many muscle proteins, including those of myofibrils, is at pH 5.5, the water-holding capacity is lower than *in vivo* (Lawrie & Ledward, 2006). From the processing point of view, meat with pH of 5.6-6.0 show higher water binding capacities and are more suitable for products where higher water binding is required like frankfurters, cooked ham, etc.. In contrast, meat products which lose water during manufacturing and ripening, such as raw ham and dry fermented sausages, meat with a lower pH (5.5–5.2) is preferred (Heinz & Hautzinger, 2007).

2.2 Processed meat

Meat processing involves a wide range of physical and chemical treatment methods. In general, muscle meat and fat are the main ingredients, besides occasionally used internal organs, skins and blood, and certain non-meat additives. Meat processing technologies, normally combining a variety of methods such as cutting, mincing, chopping, salting, tumbling, stuffing/filling into casings/moulds, heat treatment, ripening/drying and/or smoking.

2.2.1 Emulsified sausages

2.2.1.1 Meat emulsion

Emulsified sausages have a continuous hydrophilic salt/protein/water matrix which stabilizes the disperse phase consisting of coarse meat/fat particles, fat globules, connective tissues, insoluble proteins, and seasoning particles. A monomolecular protein film is formed around the fat globules (Fig. 1) (Morrissey, Mulvihill, & O'Neill, 1987).

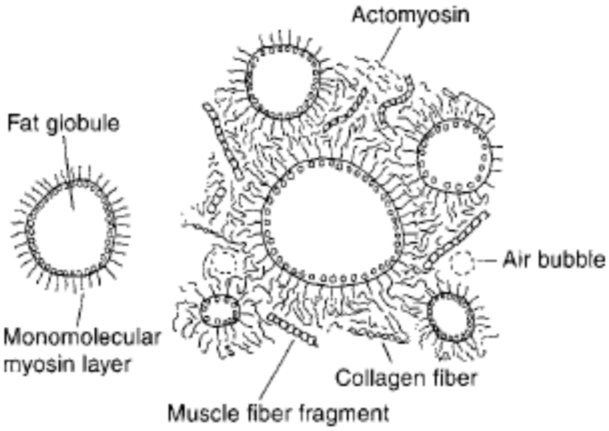

Figure 1 : Schematic representation of a meat-fat emulsion, according to Morrissey et al. (1987)

Emulsification ensures the physicochemical stability of the product and therefore, determining the characteristic structure of the batter. Furthermore, it creates the typical sensory properties (appearance, texture, flavour, cracking noise). Finely produced products are defined by their smooth texture (Allais, 2010). In addition, low-value meat offcuts such as trimmings, parts with higher content of connective tissues or fat can be used (J.G. Sebranek, 2003; Wilson, 1981). Through the addition of salt and other preservatives during the emulsification process and the following thermal treatment the shelf-life of the final product is increased (Allais, 2010).

2.2.1.2 Manufacturing of emulsified sausages

In general, manufacturing of emulsified sausages consists of mincing the muscle meat and fat, followed by mixing and chopping the muscle tissue and other organs, fat, salts, seasonings (herbs and spices). The batter is then stuffed into casings and heat treated if necessary. Sausages are sold as raw, cooked and/or smoked.

Muscles are structured media which have to be disorganized for manufacturing of emulsified sausages. In the course of fragmentation, fiber bundles and their membranes become separated and accordingly broken (Schut, 1976). The collapse of the myofibrillar structure is achieved by mechanical action such as mincing, mixing and chopping (Fernández-Martín, Cofrades, Carballo, & Jiménez-Colmenero, 2002).

Adding of salt and water, in general during chopping, are technological necessary for swelling and dissolving of myofibrillar proteins (Hamm, 1972). The swollen myofibrillar structure becomes wider and the hydrophobic side chains turn at the surface. The hydrophobic parts of proteins interact with each other or with fat particles, and therefore preventing their cohesion to larger fat droplets and following the cookout of fat in the batter (Barbut, 1998). The ability of the different protein components to act as film formers decreases as followed: myosin > actomyosin > sarcoplasma proteins > actin. The hydrophobic molecule heads of myosin dip into the fat globules, thus forming a monomolecular myosin layer, while the tails interact with actomyosin in the continuous phase (Jones, 1984). The multi-molecular actomyosin layer on the outside binds water and contributes to the stabilization of the emulsion, because of its elastic, viscous and cohesive properties (Barbut, 1998). Additionally, when fat particles size decreases during chopping, emulsion stability increases if there is sufficient protein to envelope all of the fat particles. Conversely, a lack of emulsifier results in insufficient binding, leading to a soft texture. In contrast, use of excessive amounts of emulsifier produces a tough and rubbery meat texture (Mandigo & Esquivel, 2004). Additionally, insufficient chopping leads to high interfacial surfaces caused by the presence of thick layers of myofibrillar segments around the fat globules and inefficient distribution of proteins and/or fat throughout the interface (Mandigo & Esquivel, 2004). In contrast, excessive chopping results in a thin protein film which is low in mechanical strength, and consequently, is unable to prevent fat droplets' migration to the product surface. Additionally, temperature rises during chopping causes partial melting of the fat and a decrease in the surface tension of the fat particles. Chopping knives can reach local peak temperatures of up to 75 °C in conventional cutters. This leads to protein denaturation, consequently, forming unwanted small lumps in the sausage and reducing their water-holding capacity (Allais, 2010).

Cooking causes unfolding of proteins and the formation of an ordered three-dimensional network, stabilized by hydrophobic interactions and hydrogen bonding (Whiting, 1988). This results in immobilizations of fat, water, and other constituents (Mandigo & Esquivel, 2004). Therefore, failure to form an adequate gel can lead to excessive losses in water and fat, consequently, producing a final processed meat product with a mushy and mealy texture (Whiting, 1987).

2.2.2 Cured meat products

2.2.2.1 Process of curing

Curing is the addition of salt with or without nitrite and/or nitrate during the manufacturing of meat products (Honikel, 2010). Originally the addition of salt was performed in order to lower the water activity of the product, and therefore to prevent microbial growth, to add flavour and tenderize the meat. In the 19th century it was recognized that other salts such as salpeter (KNO_3) were better at preserving the product, as well as enhancing and stabilizing the red colour (Honikel, 2010).

During curing (dry/dry-wet) Na^+ and Cl^- ions diffuse from the salt source into the muscle, while water and soluble proteins flow outward from the muscle to the brine, via osmotic pressure. The slower the diffusion inwards (lower salt concentrations), the longer the outflow of water from the muscle (Callow, 1931). A rapid method is the injection of brine into the muscle by mechanical means (single or multi-needle device or automatic multi-needle brine injectors).

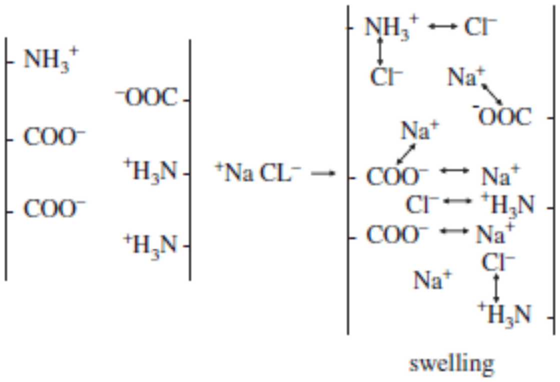

Figure 2: Swelling of myofibers through diffusion of water surrounded Na^+ and Cl^- ions (Hamm, 1972)

Chloride ions are more strongly bound to proteins than sodium ions, as the protein charge is raised. According to Hamm (1972), this induces repulsion between the myofibrillar proteins, resulting in a swelling or even a partial solubilisation (Fig. 2). The actomyosin cross-bridges between the filaments and Z–lines inhibits this unlimited swelling (Offer & Knight, 1988).

In the past, meat curing originally was employed from the use of salt formulated with salpeter ($NaNO_3$ or KNO_3) (Polenske, 1891). In the late 1800s, researchers revealed that nitrate was reduced to nitrite by bacteria. This finding resulted in a shift of using nitrite instead of nitrate as primary curing agent. The utilization of nitrite hastens the curing process which in turn, resulted in higher production capacity (Binkerd & Kolari, 1975; Sebranek & Bacus, 2007). Furthermore, to assure rapid nitrite disappearance cure accelerators, such as sodium ascorbate and erythorbate as reducing agent, can be added to the curing solution just prior to pumping meat pieces. This is a critical control point during manufacturing of cured meat products using cure accelerators in order to avoid premature breakdown of nitrite within the curing solution (Belitz et al., 2009; Heinz & Hautzinger, 2007; Toldrá, Mora, & Flores, 2010).

Nitrite, or nitrous acid (HNO_2) formed in an acidic environment, is able to sequester oxygen in a meat batter, thus preventing oxidative (rancidity) processes (Honikel, 2008), (Fig. 3). Commonly, this change in flavour is called curing flavour.

$$\begin{array}{l} 2HNO_2 \rightleftarrows N_2O_3 + H_2O \\ N_2O_3 \rightleftarrows NO + NO_2 \\ NO + 0.5O_2 \rightarrow NO_2 \\ 2NO_2 + H_2O \rightarrow HNO_2 + HNO_3 \\ \hline 2HNO_2 + 0.5O_2 \rightarrow HNO_2 + HNO_3 \end{array}$$

Figure 3: Oxidation of nitrous acid (HNO_2).

Furthermore, nitrite oxide (NO), the derivate of nitrite, binds to myoglobin and forms nitrosomyoglobin (NO-myoglobin), responsible for the heat-stable pink colour of cured meat products (Haldane, 1901) (Fig. 4).

$$\begin{array}{l} KNO_3 \xrightarrow{Mycroorganisms} KNO_2 \\ KNO_2 + H^+ \rightleftarrows HNO_2 + K^+ \\ 2HNO_2 \rightleftarrows N_2O_3 + H_2O \\ N_2O_3 \rightleftarrows NO + NO_2 \\ NO + myoglobin \rightleftarrows NO - myoglobin \end{array}$$

Figure 4: NO-myoglobin, the pink colour of cured meat products.

Additionally, NO_2^- and NO_3^- anions bind cations, like Fe^{2+}/Fe^{3+} existing in cells. Consequently, there are microorganisms such as *Clostridium botulinum* and *Listeria monocytogenes* in which the binding to Fe-ions inhibits their growth (Grever &

Ruiter, 2001; Lücke, 2008). Thus curing of meat is principally undertaken for the prevention of growth of pathogenic bacteria. The use of nitrite as a preservative is increasingly important because of the trends in lowering salt content, the use of vacuum packaging (anaerobic), improved hygiene (less competing flora), and in-package pasteurization (hardly any vegetative flora). Under these conditions the anaerobic spore-forming *Clostridium botulinum* might start to grow and generate the toxic protein-based botulinum. Nevertheless, the addition of nitrite is not a guarantee for full safety (Puolanne, 2010). In the 1970s in the USA a discussion about nitrosamines in cured meat arose. Nitrosamines are well known as potential carcinogens (Belitz et al., 2009). Fiddler et al. (1978) showed that fried bacon produces considerable amounts of nitrosopyrrolidine. Nitrosamines are formed by amines with derivates of nitrite at higher temperature (>130 °C). Hence, grilled cured sausage, fried bacon and fried cured meat products such as pizza topping may experience conditions that form nitrosamine. For that reason, the use of nitrite and nitrate is limited (2006/52/EC, Annex III). In general, 150 mg nitrite/kg is allowed to be added, plus 150mg nitrate/kg for unheated meat products.

2.2.2.2 Curing techniques

The utilized curing technique depends on the nature of the final product (uncooked or cooked). Cured-raw meats are usually dry-cured or dry-wet cured. Cured-raw meats never undergo a heat treatment during the manufacturing process. Hence, controlled climatised conditions are necessary during the processing period, including curing, fermentation/ripening and smoking. A decrease of the moisture level is achieved, resulting in a moderate drying effect of the meat. In contrast, wet curing by brine injection is exclusively used for cured-cooked meat products. After the curing process, a heating step is followed to achieve the desired palatability (Heinz & Hautzinger, 2007).

Dry-salting is a traditional method for raw-cured meat. Meat cuts are rubbed with curing salt and afterwards packed in curing tanks, piled on top of each other with layers of curing salt between them and stored refrigerated (0 to 4°C). The curing salt infiltrates into the meat and liquid from the meat tissue get extracted. The liquid then accumulates at the bottom of the curing container and covers the lower layer of meat cuts which contributes to an additional curing and flavouring effect. Depending on the process, the liquid can also be drained off. Due to the weight of the rubbed meat cuts the pressure within the pile is higher at the bottom of the container, resulting in faster liquid loss and salt infiltration. For that reason re-piling (the lower piles up and the upper ones down) and adding of dry-curing salt should be carried out every seven days to achieve an equal distribution. Depending on the size of the meat cuts, the curing process can last up to several weeks (usually 2 to 4 weeks) for equal salt penetration. After curing, processes of fermentation, drying and ripening take place (Heinz & Hautzinger, 2007).

Dry-Wet curing is used especially for bigger meat cuts of different sizes in one curing container in order to facilitate a standardized curing process. Therefore, meat cuts are dry-salted and piled up layer-by-layer in the curing containers. The extracted liquid at the bottom of the curing container is topped up by separately prepared brine (15-20% curing salt) to reach to upper piles. The brine can also contain spices for enhancing the flavour and sodium ascorbate for stabilizing the curing colour. After 5 - 7 days the meat cuts are re-piled and covered again by the brine. After curing (last about 2 to 4 weeks) a drying/ripening phase is then followed (Heinz & Hautzinger, 2007).

For a fast curing process of large meat cuts the injection of brine is the method of choice. In addition to nitrite curing salt, commonly sodium ascorbate (0.1-0.2%) as cure accelerant can be added to brine for producing cured-cooked meat products (Heinz & Hautzinger, 2007; Toldrá et al., 2010). Brine solutions are injected into the muscle tissue by using either manually operated brine pumps with a single or multi-needle device or automatic multi-needle brine injectors. The curing brine injection should take place in small quantities and repeatedly in various different parts of the muscle tissue. The curing substances migrate from the central to the outer parts. Usually 15-20% of the brine solution (injection rate) with a salt content of 10% to 14% is injected into the meat cuts to achieve usually a salt concentration of between 1.8% and 2.4% in the final product, depending on the product type. For enhancing a uniform distribution of salt and curing agents and for ensuring the development of red curing colour throughout the meat cuts a resting time (24 – 48 hr) under refrigeration is used for products, which are not tumbled. In the case of tumbling, the drip-loss of brine during injection is added to the tumbler and will be reabsorbed by the muscle tissue. Heat treatment is always followed after the curing process (Heinz & Hautzinger, 2007; Pegg, Shahidi, & Samaranayaka, 2004).

2.3 Traditional Irish meat products

2.3.1 Black and white pudding

Black and white puddings are very traditional meat products for the populations of Ireland and England. In 800 BC black pudding appeared in literature for the first time since black pudding was mentioned in Homer's classic saga 'The Odyssey': “As when a man besides a great fire has filled a sausage with fat and blood and turns it this way and that and is very eager to get it quickly roasted”. In the past black pudding was not just food for the poor, it was also included in a nobility breakfast for example held by King Henry VIII (King of England from 1509 - 1547). In the 17th century, the consumption of black pudding was a theological debate. Many Christian scholars believed that nobody should eat it at all. Nowadays black puddings, but also white puddings, are particularly a special feature of the traditional Irish and English breakfast. It is a substantial meal consisting of bacon, a slice black and white pudding, pork breakfast sausages, beans, tomatoes, eggs and toast (The English Breakfast Society, 2014a). Black pudding, typical of those consumed in Ireland and the United Kingdom, contains lean pork meat, pork fat, pork blood powder, grains, onions, salt and seasonings. In contrast, white pudding is manufactured without blood and contains generally a higher amount of cereal grains and spices. All ingredients are chopped and cooked in casings. Consumers usually fry the pudding slices in a pan and served as part of the Irish breakfast or just with bread.

2.3.2 Bacon

Many nations throughout history have cooked slices of salted/cured pork and called it bacon, but only a few countries, like the UK and Ireland, have elevated bacon to a delicacy. Before the industrial revolution (1760 - 1840), bacon was traditionally produced on local farms. It was common to produce it at home as a large percentage of the population kept pigs. Therefore, each family had their own secret recipe. Up until the 19th century, almost all bacon was dry-cured. Today it is less common and more expensive than commercially produced bacon.

Traditionally Irish bacon, also called rashers, is made from the loin in the middle of the back of the pig and belongs to the traditional Irish and English breakfast. The Irish bacon tends to have a layer of fat (pork belly) around the meat cut, unlike Canadian bacon, and is either; wet- or dry-cured and unsmoked. In comparison, traditional Irish bacon is much leaner and cooked until it is done, but not crisped like American style smoked side bacon made only from the pork belly (The English Breakfast Society, 2014b).

2.3.3 Corned beef

Corned beef is a traditional cured meat product popular in Ireland and the United Kingdom. The term “corned” comes from the usage of large grained rock salt, as it looks like a wheat kernel known as a corn of salt (Oxford English Dictionary, 2010).

In the 12th century, corned beef was a delicacy given to the Irish king. Later on, in the 19th century, corned beef was a festive dish for everyone in Ireland. It was served traditionally with cabbage and potatoes on special occasions, like; Christmas, Halloween, weddings, wakes and on St. Patrick’s Day. In the 18th /19th centuries, Irish emigrants carried the tradition of corned beef manufacture all over the world, especially to North America, (Mahon, 1998). Nowadays, corned beef is widely available either as full piece of beef or canned, though the recipes, and consequently the flavour differs extremely (Mac Con Iomaire & Óg Gallagher, 2011).

Besides a beef content of 50% to 95%, corned beef further contains sodium chloride and nitrite. Depending on the type of corned beef being produced, it can also contain additional ingredients, such as; starches, flours (thickeners); phosphate derivate (stabilisers), ascorbate derivate (antioxidants), glutamate derivate (flavour enhancers), dextrose and spices (unpublished data, 2014).

2.4 Reducing salt content in processed meat products

2.4.1 The role of salt in processed meat products

Salt (NaCl) is one of the most commonly used ingredients in processed meat products because of its multi-functional properties. Initially, salt was added mainly to preserve meat from microbial growth (Hutton, 2002), providing preservation (Durack, Alonso-Gomez, & Wilkinson, 2008), and therefore increasing products shelf-life. Salt reduces the water activity of foods in general so that it is unavailable for microorganisms to use. Reduced water activity of the environment can inhibit microbial growth and can slow down the growth rate once it starts. Each type of microorganism has a minimum water activity level. Below this level, the water from the inside of the cells moves outside where there is a higher concentration of salt.

This loss of water results in plasmolysis and in the loss of the rigid cell structure. Plasmolysed cells are unable to grow as long as the water activity is kept below the minimum level. Reducing the concentration of salt in food results in an increase of water activity, and thus, more microorganisms are able to grow (Betts, Everis, & Betts, 2007). In consequence, strategies have to be developed to compensate for the loss of preservation in salt-reduced foods.

Salt added to meat products impacts upon flavour significantly. Perceived saltiness is mainly due to the unique sodium-related transduction mechanism. In general, the chemical identity of sodium converts into an electrical signal, which propagates through the nervous system. However, this mechanism has not yet been determined for humans in detail. In rats the gustatory transduction of NaCl takes place in taste papillae found on the tongue. Sodium flows passively down a concentration gradient, through epithelial sodium channels into taste receptor cells (Heck, Mierson, & Desimone, 1984). The sodium entry increases the membrane potential of cells interior, which might lead to the release of neurotransmitter onto a peripheral nerve, resulting in transmitting a signal to the brain (McCaughey, 2007). NaCl presents the saltiest taste among sodium-containing compounds. As the associated anion becomes larger, the perceived saltiness decreases (Schiffman, Mcelroy, & Erickson, 1980). Furthermore, sodium chloride enhances the overall flavour in meat products (Ruusunen, Simolin, & Puolanne, 2001) and reduces the sensation of bitterness (Hutton, 2002).

Salt plays a major role in developing the texture of meat because if its function in solubilisation of myofibrillar proteins and the impact on water-holding capacity of proteins (Hamm, 1972; Offer & Knight, 1988). Consequently, it increases the viscosity of meat batters (Desmond, 2006), alteration of sensory properties (e.g. tenderness) and processing yields (Barat & Toldrá, 2011).

2.4.2 Health concerns lead from a diet rich in salt

Over 90% of sodium in humans' diet is provided by salt (sodium chloride) (He, Campbell, & MacGregor, 2012). Sodium affects the volume of extracellular fluid, consequently, maintaining blood volume and blood pressure in the human body. Sodium is also essential for sustaining the cellular membrane potential and absorbing nutrients in the small intestine (Brandsma, 2006; He & MacGregor, 2010; Strazzullo, D’Elia, Kandala, & Cappuccio, 2009). With the increased consumption of processed foods, salt intake increased to a level of 9 to 12 g salt per day in nearly all countries worldwide (Henderson et al., 2003) which is 40 to 50 times higher than the evolutionary intake (0.25g salt per day) (Eaton & Konner, 1985). Meat and fish (30%), of which 18% comes from cured/processed meats, are the main contributors to salt intakes in the Irish population, followed by bread (22%) (FSAI, 2013).

The excessive consumption of sodium is associated with negative effects on human health. It is associated with elevated blood pressure (≥ 140/90 mm Hg), where the prevalence exceeds 40% in most European countries (Kearney, Whelton, Reynolds, Whelton, & He, 2004; Strazzullo et al., 2009). The mechanisms whereby salt increases blood pressure are not fully understood. Nevertheless, evidence exists that individuals who develop high blood pressure show a defect in the kidneys' ability to excrete sodium (Dahl, Heine, & Thompson, 1974; Dahl, Heine, & Thompson, 1972).

Elevated blood pressure is estimated to induce 7.5 million deaths annually, equivalent to ~12.8% of all deaths worldwide as it is the major risk factor for cardiovascular disease (strokes, heart attacks, heart failure), the leading cause of deaths globally (WHO, 2010).

There is increasing evidence that a high salt intake causes further harmful effects on health, independent or in additive to the impact of salt on blood pressure. Furthermore, a diet rich in salt is linked to left ventricular hypertrophy (Kupari, Koskinen, & Virolainen, 1994; Schmieder & Messerli, 2000) progression of renal disease and albuminuria (Cianciaruso et al., 1998; Heeg, De Jong, Van Der Hem, & De Zeeuw, 1989; Swift, Markandu, Sagnella, He, F., & Macgregor, 2005), stomach cancer (Joossens et al., 1996; Tsugane, Sasazuki, Kobayashi, & Sasaki, 2004) and bone demineralization (Devine, Cridle, Dick, Kerr, & Prince, 1995).

A diet low in salt decreases the occurrence of high blood pressure. It is estimated that a salt intake of less than 5 g per day reduces the risk of stroke by 23% and thus, the general rates of cardiovascular disease by 17% (WHO, 2013). The WHO called on all countries to decrease the average population salt intake to 5 g/day with the aim of reducing salt intake by 30% by 2025 (WHO, 2012). The daily salt intake of most Europeans is about 8–11 g, which far exceeds the recommended level of 5 g per day (WHO, 2013). The Food Safety Authority of Ireland (FSAI) recommends a salt intake for the Irish population of 6g salt per/day (2.4g sodium). The FSAI considers this as an achievable target level for the Irish population and not as an ideal level (FSAI, 2014).

2.4.3 Strategies to reduce the salt content in processed meat products

It is assumed that a high salt intake is a consequence of habits (Beauchamp & Engelman, 1991; Bourne et al., 1993). Consequently, individuals which habitually follow a diet rich in salt presumably require a higher sodium concentration for a product to be palatable. In contrast, following a low-sodium diet, higher concentrations of salt in foods will become more intense and less pleasant (Beauchamp, Bertino, & Moran, 1982; Bertino, Beauchamp, & Engleman, 1982). This hypothesis is corroborated by the study of Beauchamp et al. (1982), individuals placed on very low-sodium diets were able to detect lower salt levels in water than individuals following higher-sodium diets. In summary, the salt taste is not innate and adaption to lower salt levels is possible. Furthermore, human flavour recognition and tolerance for salt is relatively small, for example, in frankfurters, 2.4% salt is assessed as very salty while 1.6% salt is considered mildly salty (Wirth, 1991). However, a small gradual reduction of salt from the recipe might be unnoticed by assessors (Bertino, Beauchamp & Engleman, 1982; Puolanne, 2010). Larger reductions might be achieved with a gradual salt reduction over a period of years and consequently, allowing consumers to get used to lower salt levels in food. For instance, in Finland it took 20 years to reduce the sodium chloride content in cooked sausages from (2.3 - 2.4%) to (1.5 - 1.7%). Previous studies revealed that an even larger reduction of salt in meat products is possible straightaway. For instance, 50% decrease of salt content in beef patties (Tobin, O'Sullivan, Hamill, & Kerry, 2012), 60% in pork breakfast sausages (Tobin, O'Sullivan, Hamill, & Kerry, 2013) and 44% in ham (Aaslyng, Vestergaard, & Koch, 2014) were achieved. Nevertheless, a significant salt reduction by stealth cannot be applied in general to processed meat products. A threshold will be reached by reducing salt levels by stealth as consumers will notice a flavour gap. Additionally, international governments might look for a significant salt reduction in the short term. Consequently, the use of salt replacers and enhancers are then essential. The basis of using salt replacers is to reduce sodium cations with, for instance; potassium, magnesium, calcium or to reduce the chloride anions with ingredients such as glutamates, phosphates, etc. as a means of providing salty tastes or flavours (Wheelock & Hobbiss, 1999). The most common choice of salt replacer is potassium chloride, although it is limited in usefulness due to its bitterness perception (Dzendolet & Meiselman, 1967). The bitterness perception of potassium chloride can be suppressed by using it in combination with further salt replacers. Zanardi, Ghidini, Conter, & Ianieri (2010) reduced successfully the sodium content in Cacciatore salami, a typical Italian dry fermented sausage, by using a mixture of KCl, $CaCl_2$, and $MgCl_2$.

A second approach is the use of salt enhancers. These are substances which possess no salty taste themselves, but with the correct combination of sodium chloride, they enhance the salty flavour (Desmond, 2006). Known salt enhancers include amino acids, lactates, yeast extracts and monosodium glutamate. Researchers have already published successful treatments for salt-reduced processed meat products with added salt enhancers, but also in combination with salt replacers. For example, in bologna-type sausages, salt reductions of 20% - 25% were achieved by adding sodium citrate, carrageenan or carboxlmethylcellulose (Ruusunen et al., 2003a). The authors Guàrdia, Guerrero, Gelabert, Gou, & Arnau (2008) substituted successfully 50% of NaCl by a mixture of KCl and potassium lactate in small fermented sausages. Recently, the authors dos Santos, Campagnol, Morgano, & Pollonio (2014) reported that fermented cooked sausages containing monosodium glutamate combined with lysine, taurine, disodium inosinate and disodium guanylate masked the unpalatable sensory attributes linked with the replacement of 50% and 75% NaCl with KCl. Recently, published studies have also presented the use of different types of edible seaweed (Sea Spaghetti, Wakame and Nori) in meat products (Cofrades, López-López, Solas, Bravo & Jiménez-Colmenero, 2008; Jiménez-Colmenero et al., 2010; López-López, Cofrades, Yakan, Sola & Jiménez-Colmenero, 2010). Seaweeds are a rich source of minerals, trace elements, proteinaceous compounds and flavour precursors (reducing sugars) which can simple act as flavour enhancers, or even as reactants in the flavour developing process (Maillard reaction, caramelisation). Additionally, seaweeds comprise a unique taste profile, which might replenish lost flavour in reduced salt and fat processed meat products (Hotchkiss, 2012). For instance, Lopez-Lopez, Cofrades & Jimenez-Colmenero (2009) obtained 50% to 75% salt reduction in frankfurters using KCl, seaweed and olive oil.

2.5 Reducing saturated fat content in processed meat products

2.5.1 The role of animal fat in processed meat products

Animal fats, part of the meat cuts added during the manufacturing process, play important nutritional, sensory and functional roles in processed meat products. It is relevant in developing taste, texture, inducing mouth-feel and lubrication (Dransfield, 2008; Giese, 1996; Hughes, Mullen, & Troy, 1998; Francisco Jiménez-Colmenero, 2007; Malone, Appelqvist, & Norton, 2003; Youssef & Barbut, 2009).

Fat taste is still not accepted as a basic taste, although evidence for the role of fat in gustation has been found in the last decade (Mattes, 2005). Specific receptors (e.g. CD36) have been located in the lingual gustatory papillae of rats, which are involved in the detection of long-chain fatty acids in the oral cavity (Fukuwatari et al., 1997; Laugerette, Gaillard, Passilly-Degrace, Niot, & Besnard, 2007). Nevertheless, the mechanism responsible for fat perception in human taste cells is not fully understood. So far, free fatty acids (and not triglycerides) have been shown to stimulate taste receptor cells (Kawai & Fushiki, 2003). Therefore, the presence of lingual lipase which cleaves triglycerides into glycerol, mono- and diglycerides and free fatty acids, may play an important role in the gustatory detection of fat (Kawai & Fushiki, 2003; Schiffman, Graham, Sattely-Miller, & Warwick, 1998).

A very well emulsified fat droplet can behave as an inert colloid with surface properties of the surfactant. The stability of the surface coating and its interaction with the food matrix determine the contribution of the fat to the food texture (McClements, 2004). In particular, emulsified sausages are formed by a monomolecular protein film around the fat globules. Heating then forms a three-dimensional network.

In general, fats from animal sources can be ranked regarding their degree of saturation as follows: beef > pork > chicken. The degree of saturation affects the melting point, plasticity at a certain temperature and behaviour in the meat product. Furthermore, animal fat plays an important role in providing a unique taste profile. In fresh and processed meat products the typical meat flavour is developed during heating by a complex series of reactions occurring between non-volatile components of lean and fatty tissues. Over 1000 volatile compounds have been identified, including aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters (Dransfield, 2008; Mottram, 1998).

2.5.2 Health concerns lead from a diet rich in saturated fat

Animal fat of adipose tissue consists mainly of triglyceride (> 99%). Fat from muscles has a considerable content of phospholipids and unsaponifiable contents, such as cholesterol (Lea, 1962). Fatty acid composition varies (Wood et al., 2008) though compared to vegetable oils (olive oil and rapeseed oil), animal fats are relatively high in saturated fatty acids. The fat content of processed meat products differ extremely, for example, frankfurters contain 20-30% fat, fresh pork sausages 30-50% fat, liver sausages 30-45% fat, salami 30-50%, beef patties 20-30% and ham < 10% fat (Jiménez-Colmenero, 2000).

Saturated fatty acids and cholesterol are linked in increasing the plasma low-density lipoprotein (LDL) level. High LDL levels can lead to plaque build up in arteries and result in cardiovascular diseases (strokes, heart attacks, heart failure) (Grundy & Denke, 1990). Furthermore, fat has one of the highest energy densities (9kcal/g) of all macronutrients. A diet rich in fat can easily lead to issues such as excessive weight gain and obesity. Although obesity should be considered as a disease in its own right, it is also linked to further diseases. The non-fatal but restricting health problems related with obesity include respiratory difficulties, chronic musculoskeletal problems, infertility and skin problems. The chronic health problems associated with obesity are cardiovascular problems (including hypertension, stroke and coronary heart disease), conditions associated with insulin resistance (e.g. non-insulin-dependent diabetes mellitus), certain types of cancers (especially the hormonally related and large-bowel cancers) and gallbladder disease (WHO, 2000).

This has resulted in the concerted reduction of the saturated fatty acid content of high fat food products, including numerous meat products (Dransfield, 2008; Giese, 1992). Furthermore, the WHO recommends a daily intake of polyunsaturated fatty acids (PUFAs) between 6% and 11% based on daily energy intake (WHO, 2003)

2.5.3 Strategies to reduce the saturated fat content in processed meat products

Research on fat reduction in processed meat products started to appear in the scientific literature in the 1970s, intensified in the early 1990s and has been a hot topic for the last decade. Strategies to reduce animal fat in meat products, include;

formulating with leaner meats (partially defatted), substituting some of the fat with water, changing the fat profile with plant, fish and/or algal oils or utilizing fat replacers (categorized in fat substitutes and fat mimetics) (Weiss, Gibis, Schuh & Salminen, 2010). The most common approach today is to employ a combination of these strategies.

Reitmeier and Prusa (1987) reported that fat-reduced beef patties (without adding any additives) were less tender and juicy and had a lower oily mouth coating. Additionally, flavour was less pronounced in beef patties containing 4% fat. To enhance eating quality, the authors suggested using additional ingredients. In a comminuted-type sausage, Bishop, Olson & Knipe (1993) partially replaced fat with water which prevented the increase in firmness normally associated with low fat bologna sausages. However, water derived from the products accumulated as purge in vacuum packages during storage. Furthermore, Claus, Hunt, & Kastner (1989) also observed that low-fat and high-added water bologna sausages became generally more cohesive, softer, juicier, and darker in colour, with greater cooking and vacuum package purge loss. than the control. Results indicated that low-fat emulsion formulations substituted only with water causes major problems.

The use of different vegetable oils in processed meat products as animal fat substitute has also been investigated by various researchers (Bloukas, Paneras, & Fournitzis, 1997; Pappa, Bloukas, & Arvanitoyannis, 2000; Severini, De Pilli, & Baiano, 2003; Tan, Aminah, Affandi, Atil, & Babji, 2001). Vegetable oils with a high amount of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) are able to decrease LDL levels in plasma. In addition, higher levels of PUFA can raise plasma high density lipoprotein (HDL) and therefore, decrease incidences of coronary heart disease (Mozaffarian, 2005). For example, Hammer (1992) investigated frankfurter-type sausages using olive oil and sunflower oil. No processing problems occurred and the only differences observed with products were that they appeared lighter in colour. Youssef & Barbut (2009) recorded higher cook-loss of emulsified beef frankfurter-type products formulated with canola oil (25%) when protein level was raised above a certain level. Bloukas and Paneras (1993) recorded lower processing yield and overall palatability for low-fat frankfurters formulated with olive oil.

Fat substitutes display a chemical structure close to fats, have similar physicochemical properties, and are either low in calories or indigestible, such as; Olestra, Caprenin and Salatrim (Kosmark, 1996; Peters, Lawson, Middleton & Triebwasser, 1997). By contrast, fat mimetics show distinctly different chemical structures from fat, though the physicochemical attributes and eating qualities of fat can be simulated, such as mouth feel, appearance and viscosity (Duflot, 1996; Harrigan & Breene, 1989). The use of fat mimetics in foods is generally more common. For this purpose, hydrocolloids, usually protein and/or carbohydrate-based ingredients, are used. The term hydrocolloids are defined as high molecular weight hydrophilic polymers, containing polar or charged functional groups, which enable them to be soluble in water. The hydrocolloids applied within the food industry are derived from many different sources, such as animal (casein, whey gelatine blood protein), plants (soy, starches, cellulose, gums, fibre) and microorganisms (xanthan, curdlan, gellan, yeast extract) (Cutter, 2006). The decision on which kind of hydrocolloid within the meat formulation to use can be complex as each hydrocolloid impacts on product yield, texture and mouthfeel in a slightly different way (Shand, Sofos, & Schmidt, 1993). For example, Chevance et al. (2000) achieved a fat reduction of 46% in salami, 60% – 83% in frankfurters and 55% in beef patties with tapioca starch and oat fibre or maltodextrin or milk protein ingredients. Desmond, Troy, & Buckley (1998) concluded that beef burgers containing pectin, micro-crystalline cellulose, oat fiber and carrageenan were scored high in flavour and overall quality. Burgers formulated with blood protein showed poor overall quality and flavour attributes. Sampaio, Castellucci, Pinto e Silva, & Torres (2004) determined the effect of the fat replacers carrageen gum, modified cassava starch, microparticulated whey protein, and oat bran in beef frankfurters. Use of whey protein resulted in a 72% decrease in total lipids, followed by oat bran, carrageen, and cassava starch. In terms of acceptability, the panellists rated the formulation with cassava starch similar to the control. Hughes, Cofrades & Troy (1997) stated that carrageenan or oat fibre reduced cook-loss, increased water-holding capacity and emulsion stability in fat-reduced frankfurters. Carrageenan and oat fibre did not alter colour and neither ingredient had a significant effect on the flavour characteristics assessed. Crehan, Hughes, Troy & Buckley (2000) suggested that maltodextrin can be used in frankfurters as a suitable fat replacer since it off-sets some of the changes brought by fat reduction.

However, the concept of healthier food products also includes functional foods. This is an emerging field regarding health-promoting or disease-preventing properties, additional to basic nutritional value (Jiménez-Colmenero, Carballo, & Cofrades, 2001). Many hydrocolloids (e.g. locust bean gum, guar gum, konjac mannan, xanthan) were determined to reduce blood cholesterol levels and others (e.g. inulin) have shown prebiotic effects (Hecker, Meier, Newman, & Newman, 1998). Consequently, hydrocolloids are additives that have grown in importance in recent years with a view to meeting fat (and salt) targets and assessing the relevance of novel processed meat products as a delivery mechanism for bioactive compounds (Tobin, O'Sullivan, Hamill, & Kerry, 2014).

2.6 Consumer trends within the food sector

Convenience and wellness are the two global ongoing consumer trends. The modern time-pressured consumer is more aware of diet-related lifestyle diseases, looking for healthy and natural foods. Convenience foods are also a solution for consumers with lacking time and culinary skills (Barcellos, Grunert, & Scholderer, 2011).

Relationships between food/health and food/disease have been widely reported. Meat, in particular, is nutritionally dense, thus an important source of proteins, minerals, vitamins but also fat (Verbeke, Pérez-Cueto, De Barcellos, Krystallis, & Grunert, 2010). Despite this, the consumption of meat and processed meat products has been associated with a number of unfavourable health conditions (section 2.4.2 and 2.5.2). Just recently, the International Agency for Research on Cancer (IARC), part of the World Health Organization, classified red meat and processed meat as carcinogenic to humans. Each 50 gram portion of processed meat eaten daily is seen to increase the risk of colorectal cancer by 18% (WHO, 2015).

The meat sector still faces an additional challenge as vegetarianism rises worldwide. Vegetarians and vegans are motivated by a number of different concerns, but in general, animal welfare is the major motivator in choosing a vegetarian diet. In contrast, the motivation of non-vegetarians to reduce meat consumption is clearly indicated by health concerns. However, meat consumption and consumer attitudes towards meat production are also affected by the fact that livestock is responsible for nearly one-fifth of global greenhouse gas emissions (Verbeke et al., 2010).

The raising concerns over health and wellbeing are shifting consumer trends towards ‘going natural’ worldwide. Consumers show a considerable preference for natural over processed or artificial food products (Rozin et al., 2004; Verbeke et al., 2010). One way or another, especially the meat industry is noticing the massive impact of global societal changes.

2.7 Outlook of the global meat market situation for 2014 -2023

Despite all of the negativity surrounding the production and consumption of fresh and processed meat products, the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization (FAO) of the United Nations recently published the Agricultural Outlook for the ten-year period 2014-2023 (OECD/FAO, 2014) has projected positively for the national and international meat markets. The demand for meat is prognosticated to increase extensively through the next decade spurred by higher income levels and increasing urbanisation in developing regions. Thus, consumers’ level of protein intake relative to starches will raise. Furthermore, global meat consumption per capita is projected to reach 36.3 kg in retail weight by 2023, which means an increase of 2.4 kg and more than 58 million tonnes of additional meat consumed by 2023. Developing countries will consume more than 80% of the additional meat, because of the markedly higher population and income growth relative to developed countries, but also due to the already high meat consumption per capita in developed regions.

Currently, pork accounts for the greatest share in world total meat production. A comparatively slower growth rate of pork production is expected which will result in it being beaten by poultry by 2020. Consequently, this additional meat consumption will mostly (72%) comprise poultry, followed by pig, sheep and bovine meat. The cheapest and most accessible source of meat for lower income consumers remains poultry. And due to the low amount of saturated fats it is being seen as the healthiest meat choice. Additionally, poultry faces few cultural barriers that affect pig meat.

It is projected that the global meat trade patterns will stay stable. Poultry will account for 42% of total meat trade, followed by beef with 31% and pork with 22%. The poultry exports will dominate North and South America, while the greatest importers are expected to be Asia, Africa and the Middle East. By far the greatest share of beef will be imported by Asia, most of that supplied by South America. Furthermore, India continues exporting beef to developing regions. It is also projected that India will become the largest beef exporter by 2023. The greatest export rates for pork will come from North America and Europe, while the greatest share of pork imports will be demanded by Asia and Sub-Saharan Africa. Countries in Asia will, on one hand, be the largest producers of pig meat, while on the other the largest importers.

References

Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, *96*(1), 47–55.

Allais, I. (2010). Emulsification. In F. Toldrá (Ed.), *Handbook of meat processing* (pp. 143–168). WILEY-Blackwell, A John Wiley & Sons, Inc., Publication, USA.

Barat, J., & Toldrá, F. (2011). Reducing salt in processed meat products. In J. Kerry & J. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (First, pp. 331 – 345). Woodhead Publishing Limited, Oxford, Cambridge, Philadelphia, New Delhi.

Barbut, S. (1998). Use of a fi ber optic probe to predict meat emulsion breakdown. *Italian Journal of Food Science*, *3*(10), 253–259.

Barcellos, de M. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: consumer trends and emerging markets. In J. P. Kerry & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Oxford, Cambridge, Philadelphia, New Dehli: Woodhead Publishing Ltd.

Beauchamp, G. K., Bertino, M., & Moran, M. . (1982). Sodium regulation: sensory aspects. *Journal of The American Dietetic Association*, *80*(1), 40–45.

Beauchamp, G. K., & Engelman, K. (1991). High Salt Intake. Sensory and Behavioral Factors. *Hypertension*, *17*, I176–I181.

Belitz, H. D., Grosch, W., & Schieberle, P. (2009). Food Chemistry (4th ed., p. 563). Springer-Verlag Berlin Heidelberg.

Bertino, M., Beauchamp, G. K., & Engleman, K. (1982). Long term reduction in dietary sodium alter the taste of salt. *The American Journal of Clinical Nutrition*, *36*, 1134–1144.

Betts, G., Everis, L., & Betts, R. (2007). Microbial issues in reducing salt in food products. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 174–200). Woodhead Publishing Limited, Cambridge, England.

Binkerd, E. F., & Kolari, O. E. (1975). The history and use of nitrate and nitrite in the curing of meat. *Food and Cosmetics Toxicology*, *13*, 655–661.

Bishop, D. J., Olson, D. G., & Knipe, C. L. (1993). Pre-emulsified corn oil, pork fat, or added moisture affect quality of reduced fat bologna quality. *Journal of Food Science*, *58*(3), 484–487.

Bloukas, J. G., & Paneras, E. D. (1993). Substituting olive oil for pork for pork backfat affects quality of low-fat frankfurters. *Journal of Food Science*, *58*, 705–709.

Bloukas, J. G., Paneras, E. D., & Fournitzis, G. C. (1997). Effect of replacing pork backfat with olive oil on processing and quality characteristics of fermented sausages. *Meat Science*, *45*(2), 133–144.

Bourne, L. T., Langenhoven, M. L., Steyn, K., Jooste, P. L., Laubscher, J. A., & Van der Vyver, E. (1993). Nutrient intake in the urban African population of the

Cape Peninsula, South Africa. The Brisk study. *Central African Journal of Medicine*, *3*(4), 238–246.

Brandsma, I. (2006). Reducing sodium: A European perspective. *Food Technology*, *60*, 25–29.

Callow, E. H. (1931). The theory of curing. *Food of Investment Report*, 144–147.

Callow, E. H. (1937). Callow, E. H. () Ann. Rept. Fd. Invest. Bd., Lond.,pp. 34, 49. *Annual Report Food Investment London*, 34, 49.

Chevance, F. F., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *Journal of Agricultural and Food Chemistry.*, *48*(8), 3476 – 3484.

Cianciaruso, B., Bellizzi, V., Minutolo, R., Tavera, A., Capuano, A., Conte, G., & De Nicola, L. (1998). Salt intake and renal outcome in patients with progressive renal disease. *Mineral and Electrolyte Metabolism*, *24*(4), 296–301.

Claus, J. R., Hunt, M. C., & Kastner, C. L. (1989). Effects of substituting added water for fat on the textural, sensory and processing characteristics of bologna. *Journal of Muscle Foods*, *1*, 1–21.

Cofrades, S., López-López, I., Solas, M. T., Bravo, L., & Jiménez-Colmenero, F. (2008). Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems. *Meat Science*, *79*(4), 767–76.

Crehan, C., Hughes, E., Troy, D., & Buckley, D. (2000). Effects of fat level and maltodextrin on the functional properties of frankfurters formulated with 5, 12 and 30% fat. *Meat Science*, *55*, 463–469.

Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, *74*(1), 131–142.

Dahl, L. K., Heine, M., & Thompson, K. (1972). Genetic influence of renal homografts on the blood pressure of rats from different strains. *Proceedings of the Society for Experimental Biology and Medicine*, *140*(3), 852–856.

Dahl, L. K., Heine, M., & Thompson, K. (1974). Genetic influence of the kidneys on blood pressure. Evidence from chronic renal homografts in rats with opposite predispositions to hypertension. *Circulation Research*, *40*(4), 94–101.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Desmond, E. M., Troy, D. J., & Buckley, D. J. (1998). Comparative Studies of Nonmeat Adjuncts Used in the Manufacture of Low-Fat Beef Burgers. *Journal of Muscle Foods*, *9*(3), 221–241.

Devine, A., Cridle, A. R., Dick, I. M., Kerr, D. A., & Prince, R. L. (1995). A longitudinal study of the effect of sodium and calcium intakes on regional bone density in postmenopausal women. *The American Journal of Clinical Nutrition*, *62*, 740–745.

dos Santos, B. A., Campagnol, P. C. B., Morgano, M. A., & Pollonio, M. A. R.

(2014). Monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine improve the sensory quality of fermented cooked sausages with 50% and 75% replacement of NaCl with KCl. *Meat Science*, *96*(1), 509–513.

Dransfield, E. (2008). The taste of fat. *Meat Science*, *80*(1), 37–42.

Duflot, P. (1996). Starches and Sugars Glucose polymers as sugar/fat substitutes. *Trends in Food Science & Technology.*, *7*, 206.

Durack, E., Alonso-Gomez, M., & Wilkinson, M. (2008). Salt: A Review of its Role in Food Science and Public Health. *Current Nutrition & Food Science*, *4*(4), 290–297.

Dzendolet, E., & Meiselman, H. L. (1967). Gustatory quality changes as a function of solution concentration. *Perception & Psychophysics.*, *2*, 29–33.

Eaton, S., & Konner, M. (1985). Paleolithic nutrition. A consideration of its nature and current implications. *The New England Journal of Medicine*, *312*(5), 283–289.

Enser, M., Hallett, K., Hewitt, B., Fursey, G. A. J., & Wood, J. D. (1996). Fatty acid content and composition of english beef, lamb and pork at retail. *Meat Science*, *42*(4), 443–456.

Fernández-Martín, F., Cofrades, S., Carballo, J., & Jiménez-Colmenero, F. (2002). Salt and phosphate effects on the gelling process of pressure/heat treated pork batters. *Meat Science*, *61*(1), 15 – 23.

Fiddler, W., Pensabene, J. W., Piotrowski, E. ., Philips, J. ., Keating, J., Mergens, W. J., & Newmark, H. L. (1978). Inhibition of formation of volatile nitrosamines in fried bacon by the use of cure-solubized α-tocopherole. *Journal of Agricultural Food Chemistry*, *26*(3), 653–656.

FSAI. (2013). *Monitoring of Salt in Processed Foods : September 2003 to December 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period : September 2003 to July 2014*. The Food Safety Authority of Ireland.

Fukuwatari, T., Kawada, T., Tsuruta, M., Hiraoka, T., Iwanaga, T., Sugimoto, E., & Fushiki, T. (1997). Expression of the putative membrane fatty acid transporter (FAT) in taste buds of the circumvallate papillae in rats. *FEBS Letters*, *414*, 461–464.

Giese. J. (1992). Developing low-fat meat products. *Food Technology*, *46*, 100–108.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Greaser, H. L., Wang, S. H., & Lemanski, L. F. (1981). New myofibrillar proteins. In *34th Annual Reciprocal Heat Conference of the American Heat Science Association , National Livestock and Heat Board, Chicago ll.* (Vol. 34, pp. 12–16).

Grever, A. B. G., & Ruiter, A. (2001). Prevention of Clostridium outgrowth in heated and hermetically sealed meat products by nitrite – a review. *European Food Research Technology*, *213*(3), 165–169.

Grundy, S., & Denke, M. (1990). Dietary influences on serum lipids and lipoproteins. *The Journal of Lipid Research*, *31*, 1149–1172.

Guàrdia, M. D., Guerrero, L., Gelabert, J., Gou, P., & Arnau, J. (2008). Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. *Meat Science*, *80*(4), 1225–30.

Haldane, J. (1901). The red color of salted meat. *Journal of Hygiene*, *1*, 115–122.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

Hammer, G. F. (1992). Processing vegetable oils into frankfurter-type sausages. *Fleischwirtschaft*, *72*, 1258–1265.

Harrigan, K. A., & Breene, W. M. (1989). Fat substitutes: Sucrose esters and simplesse. *Cereal Foods World.*, *34*, 261–267.

He, F. J., Campbell, N. R. C., & MacGregor, G. a. (2012). Reducing salt intake to prevent hypertension and cardiovascular disease. *American Journal of Public Health*, *32*(4), 293–300.

He, F. J., & MacGregor, G. A. (2010). Reducing population salt intake worldwide: from evidence to implementation. *Progress in Cardiovascular Diseases*, *52*, 363–382.

Heck, G. I., Mierson, S., & Desimone, J. A. (1984). Salt taste transduction occurs through an amiloride-sensitive sodium transport pathway. *Science*, *223*, 403 – 405.

Hecker, K. D., Meier, M. L., Newman, R. K., & Newman, C. W. (1998). Barley beta-glucan is effective as a hypocholesterolaemic ingredient in foods. *Journal of the Science of Food and Agriculture*, *77*, 179–183.

Heeg, J. E., De Jong, P. E., Van Der Hem, G. K., & De Zeeuw, D. (1989). Efficacy and variability of the antiproteinuric effect of ACE inhibition by lisinopril. *Kidney International*, *36*(2), 272.

Heinz, G., & Hautzinger, P. (2007). *Meat processing technology for small- to medium-scale producers*. *Meat Processing Technology for Small to Medium Scale Producers*. Food and Agriculture Organization of the United Nations, Regional Office forAsia and the Pacific, Rap Publication 2007/20,Bangkok.

Henderson, L., Irving, K., Gregory, J., Bates, C., Prentice, A., Perks, J., Farren, M. (2003). *National Diet & Nutrition Survey: Adults aged 19 to 64. Vitamin and mineral intake and urinary analytes*.

Honikel, K. O. (2010). Curing. In F. Toldrá (Ed.), *Handbook of meat processing* (First, pp. 125 – 141). WILEY-Blackwell, A John Wiley & Sons, Inc., Publication, USA.

Honikel, K.-O. (2008). The use and control of nitrate and nitrite for the processing of meat products. *Meat Science*, *78*(1-2), 68–76.

Hotchkiss, S. (2012). Edible Seaweeds. A rich source of flavor components for sodium replacement. *Agro FOOD Industry Hi Tech*, *23*(6), 30–32.

Hughes, E., Cofrades, S., & Troy, D. J. (1997). Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 and 30% fat. *Meat Science*, *45*(3), 273–281.

Hughes, E., Mullen, a. M., & Troy, D. J. (1998). Effects of fat level, tapioca starch and whey protein on frankfurters formulated with 5% and 12% fat. *Meat Science*, *48*(1-2), 169–180.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

Jiménez-Colmenero, F. (2000). Relevant factors in strategies for fat reduction in meat products. *Trends in Food Science & Technology*, *11*, 56–66.

Jiménez-Colmenero, F. (2007). Healthier lipid formulation approaches in meat-based functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends in Food Science and Technology*, *18*, 567–578.

Jiménez-Colmenero, F., Carballo, J., & Cofrades, S. (2001). Healthier meat and meat products: their role as functional foods. *Meat Science*, *59*(1), 5–13.

Jiménez-Colmenero, F., Cofrades, S., López-López, I., Ruiz-Capillas, C., Pintado, T., & Solas, M. T. (2010). Technological and sensory characteristics of reduced/low-fat, low-salt frankfurters as affected by the addition of konjac and seaweed. *Meat Science*, *84*(3), 356–63.

Jones, K. W. (1984). Protein lipid interactions in processed meats. In *In Proceedings of the 37th annual reciprocal meat conference* (pp. 52–57). Chicago, IL.

Joossens, J. V., Hill, M. J., Elliott, P., Stamler, R., Lesaffre, E., Dyer, A., Kesteloot, H. (1996). Dietary salt, nitrate and stomach cancer mortality in 24 countries. European Cancer Prevention (ECP) and the INTERSALT Cooperative Research Group. *International Journal of Epidemiology*, *25*(3), 494–504.

Kawai, T., & Fushiki, T. (2003). Importance of lipolysis in oral cavity for orosensory detection of fat. *The American Journal of Physiology*, *285*, R447–R454.

Kearney, P. M., Whelton, M., Reynolds, K., Whelton, P. K., & He, J. (2004). Worldwide prevalence of hypertension: a systematic review. *Journal of Hypertension*, *22*(1), 11–19.

Kosmark, R. (1996). Salatrim: Properties and applications. *Food Technology*, *50*, 98–101.

Kupari, M., Koskinen, P., & Virolainen, J. (1994). Correlates of left ventricular mass in a population sample aged 36 to 37 years. Focus on lifestyle and salt intake. *Circulation*, *89*(3), 1041–1050.

Laugerette, F., Gaillard, D., Passilly-Degrace, P., Niot, I., & Besnard, P. (2007). Do we taste fat? *Biochemie*, *89*, 265–269.

Lawrie, R. A. (1975). *Meat*. (J.A. Cole and R.A. Lawrie, Ed.)*Butterworths, London* (1st ed.).

Lawrie, R. A., & Ledward, D. A. (2006). *Lawrie's Meat Science*. *Lawrie's Meat Science*.

Lea, C. H. (1962). *Recent Advances in Food Research*. (J. Hawthorn & J. M. Leitch, Eds.). Butterworths, London.

Lopez-Lopez, I., Cofrades, S., & Jimenez-Colmenero, F. (2009). Low-fat frankfurters enriched with n-3 PUFA and edible seaweed: Effects of olive oil and chilled storage on physicochemical, sensory and microbial characteristics. *Meat Science*, *83*(1), 148−154.

López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International.*, *43*(5), 1244 – 1254.

Lücke, F. K. (2008). Nitrit und die Haltbarkeit und Sicherheit erhitzter Fleischerzeugnisse. *Mitteilungsblatt Der Fleischforschung Kulmbach*, *47*(181), 177–185.

Mac Con Iomaire, M., & Óg Gallagher, P. (2011). Irish Corned Beef: A Culinary History. *Journal of Culinary Science & Technology*, *9*(1), 27–43.

Mahon, B. (1998). *Land of Milk and Honey: The Story of Traditional Irish Food and Drink.* (B. Mahon, Ed.) (Second). Irish Amer Book Co.

Malone, M. E., Appelqvist, I. A. M., & Norton, I. . T. (2003). Oral behaviour of food hydrocolloids and emulsions. Part 1. Lubrication and deposition considerations. *Food Hydrocolloids*, *17*, 763 – 773.

Mandigo, R. W., & Esquivel, O. (2004). Emulsions and batters. In *In Encyclopedia of Meat Sciences* (p. 266). C. Devine and M. Dikeman. Oxford : Elsevier.

Mattes, R. D. (2005). Fat taste and lipid metabolism in humans. *Physiology & Behaviour*, *86*, 691–697.

McCaughey, S. (2007). Dietary salt and flavor: mechanisms of taste perception and physiological controls. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 77–91). Woodhead Publishing Limited, Cambridge, England.

McClements, D. J. (2004). *Food emulsions: Principles, Practice and Techniques.* (2nd ed.). CRC Press, Boca Raton, New York.

Morrissey, P. A., Mulvihill, D. M., & O'Neill, E. (1987). Functional properties of muscle proteins. In *In Developments in Food Proteins* (5.ed ed., pp. 195–257). B.J.F. Hudson. Elsevier Applied Science Publishing, London.

Mottram, D. S. (1998). Flavor formation in meat and meat products: a review. *Food Chemistry*, *62*, 415–424.

Mozaffarian, D. (2005). Interplay Between Different Polyunsaturated Fatty Acids and Risk of Coronary Heart Disease in Men. *Circulation*, *111*(2), 157–164.

OECD/FAO. (2014). *OECD-FAO Agricultural Outlook 2014. OECD Publishing*. The Organisation for Economic Co-operation and Development / Food and Agriculture Organization of the United Nations.

Offer, G., & Knight, P. (1988). The structural basis of water-holding capacity in meat. In R. Lawrie (Ed.), *Developments in meat science* (Vol. 4, pp. 173–243). London: Elsevier Science Publications.

Oxford_English_Dictionary. (2010). “Corn, N.1”. A small hard particle, a grain, as of sand or salt. Oxford University Press.

Pappa, I. C., Bloukas, J. G., & Arvanitoyannis, I. S. (2000). Optimization of salt, olive oil and pectin level for low-fat frankfurters produced by replacing pork backfat with olive oil. *Meat Science*, *56*(1), 81–88.

Pegg, R. B., Shahidi, F., & Samaranayaka, A. G. P. (2004). Curing. In *Encyclopedia of Meat Science* (first, pp. 349–360). Elsevier Ltd.

Peters, J. C., Lawson, K. D., Middleton, S. J., & Triebwasser, K. C. (1997). The Nutritional Effects of Olestra Assessment of the Nutritional Effects of Olestra , a Nonabsorbed Fat Replacement. *American Society for Nutritional Sciences*, 1539–1546.

Polenske, E. (1891). Über den Verlust, welchen Rindfleisch durch das Pökeln erleidet sowie die Veränderungen salpeterhaltiger Pökellaken. *Arbeiten Aus Dem Kaiserlichen Gesundheitsamt*, *7*, 471–474.

Puolanne, E. (2010). Cooked Sausages. In F. Toldrá (Ed.), *Handbook of meat processing* (First, pp. 313–377). WILEY- Blackwell Publishing, John Wiley & Sons Publication.

Ramsbottom, J. M., & Strandine, E. I. (1948). (1948) 13, 315. *Food Res.*, *13*, 315.

Reitmeier, C. A., & Prusa, K. J. (1987). Cholesterol content and sensory analysis of ground pork as influenced by fat level and heating. *Journal of Food Science*, *52*, 916–918.

Rozin, P., Spranca, M., Krieger, Z., Neuhaus, R., Surillo, D., Swerdlin, A., & Wood, K. (2004). Preference for natural: instrumental and ideational/moral motivations, and the contrast between foods and medicines. *Appetite*, *43*(2), 147–154.

Ruusunen, M., Simolin, M., & Puolanne, E. (2001). The effect of fat content and flaour enhancers on the perceived saltiness of cooked bologna-type sausages. *Journal of Muscle Foods*, *12*(2001), 107–120.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003). Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. *Meat Science*, *64*, 371–381.

Sampaio, G. R., Castellucci, C. M. N., Pinto e Silva, M. E. M., & Torres, E. a. F. S. (2004). Effect of fat replacers on the nutritive value and acceptability of beef frankfurters. *Journal of Food Composition and Analysis*, *17*(3-4), 469–474.

Schiffman, S. S., Graham, B. G., Sattely-Miller, E. A., & Warwick, Z. S. (1998). Orosensory perception of dietary fat. *Current Directions in Psychological Science*, *7*, 137–143.

Schiffman, S. S., Mcelroy, A. E., & Erickson, R. P. (1980). The range of taste quality of sodium salts. *Physiology & Behavior*, *24*(2), 217–224.

Schmieder, R. E., & Messerli, F. H. (2000). Hypertension and the heart. *Journal of Human Hypertension*, *14*, 597–604.

Schut, J. (1976). Meat emulsions. In S. Friberg (Ed.), *Food Emulsions*. New York, Marcel Dekker.

Sebranek, J. G. (2003). Sausages and comminuted products. In *Encyclopedia of Food Sciences and Nutrition*. Oxford. Elsevier Academic Press.

Sebranek, J. G., & Bacus, J. N. (2007). Cured meat products without direct addition of nitrate or nitrite: what are the issues? *Meat Science*, *77*(1), 136–147.

Severini, C., De Pilli, T., & Baiano, A. (2003). Partial substitution of pork backfat with extra-virgin olive oil in “salami” products: effects on chemical, physical and sensorial quality. *Meat Science*, *64*(3), 323–31.

Shand, P. J., Sofos, J. N., & Schmidt, G. R. (1993). Properties of algin/calcium and salt/phosphate structured beef rolls with added gums. *Journal of Food Science, 58*, 1224–1230.

Strazzullo, P., D’Elia, L., Kandala, N.-B., & Cappuccio, F. P. (2009). Salt intake, stroke, and cardiovascular disease: meta-analysis of prospective studies. *British Medical Journal*, *339*(nov24 1), b4567–b4567.

Swift, P. A., Markandu, N. D., Sagnella, G. A., He, F., J., & Macgregor, G. A. (2005). Modest salt reduction reduces blood pressure and urine protein excretion in black hyper-tensives. A randomised control trial. *Hypertension*, *46*, 308–312.

Tan, S. S., Aminah, A., Affandi, Y. M. S., Atil, O., & Babji, A. S. (2001). Chemical, physical and sensory properties of chicken frankfurters substituted with palm fats. *International Journal of Food Sciences and Nutrition*, *52*, 91–98.

The English Breakfast Society. (2014a). The Black Pudding.

The English Breakfast Society. (2014b). Traditional British Back Bacon.

Tobin, B. D., O’Sullivan, M. G., Hamill, R., & Kerry, J. P. (2014). European consumer attitudes on the associated health benefits of neutraceutical-containing processed meats using Co-enzyme Q10 as a sample functional ingredient. *Meat Science*, *97*(2), 207–213.

Tobin, B. D., O’Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O’Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Toldrá, F., Mora, L., & Flores, M. (2010). Cooked Ham. In F. Toldrá (Ed.), *Handbook of meat processing* (pp. 301–311). WILEY- Blackwell Publishing, John Wiley & Sons Publication.

Tsugane, S., Sasazuki, S., Kobayashi, M., & Sasaki, S. (2004). Salt and salted food intake and subsequent risk of gastric cancer among middle-aged Japanese men and women. *British Journal of Cancer*, *90*(1), 128–134.

Verbeke, W., Pérez-Cueto, F. J. A., De Barcellos, M. D., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, *84*, 284–292.

Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, *86*(1), 196–213.

Wheelock, V., & Hobbiss, A. (1999). *All you ever wanted to know about salt but were afraid to ask. Skipton, Yorkshire. Verner Wheelock Associates.* Skipton. Yorkshire. Verner Wheelock Associates.

Whiting, R. C. (1987). Influence of various salts and water soluble compounds on the water and fat exudation and gel strength of meat batters. *Journal of Food Science*, *52*(5), 1130 – 1132.

Whiting, R. C. (1988). Ingredients and processing factors that control muscle protein functionality. *Food Technology*, *42*(4), 104–114.

WHO. (2000). Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organization Technical Report Series*, *894*, i–xii, 1–253. World Health Organization.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2010). *Global status report on noncommunicable diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

WHO. (2013). Mapping salt reduction initiatives in the WHO European Region, 1–64. World Health Organization.

WHO. (2015). IARC Monographs evaluate consumption of red meat and processed meat and cancer risk. World Health Organization.

Wilson, N. R. (1981). Sausages and other comminuted meat products. In *Meat and Meat products, Factors Affecting Quality Control*. London. Applied Science Publishers.

Wirth, F. (1991). Reducing the fat and sodium content of meat products: What possibilities are there? *Fleischwirtschaft*, *71*(3), 294–297.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Whittington, F. M. (2008). Fat deposition, fatty acid composition and meat quality: A review. *Meat Science*, *78*(4), 343–358.

Youssef, M. K., & Barbut, S. (2009). Effects of protein level and fat/oil on emulsion stability, texture, microstructure and color of meat batters. *Meat Science*, *82*(2), 228–233.

Zanardi, E., Ghidini, S., Conter, M., & Ianieri, A. (2010). Mineral composition of Italian salami and effect of NaCl partial replacement on compositional, physico-chemical and sensory parameters. *Meat Science*, *86*(3), 742–747.

Chapter 3

Consumer attitudes on salt- and fat-reduced foods in Ireland

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Abstract

The following survey reflects how Irish consumers (302 male, 743 female) have responded to the message of healthier food consumption, particularly salt and fat reduction. It appears that educational campaigns have generally been well adopted by respondents, as only a minority were not concerned about their diet; irrespective of age, gender or educational background. More than half carefully maintained a balanced diet. Furthermore, an increase in purchasing salt-reduced food was observed, although fat-reduced food products were already better accepted. Men, young adults (<30 years) and the less well-educated purchased less of salt- and fat-reduced foods and took less care maintaining a balanced diet. The purchase of traditional food products with reduced salt and fat content were unaffected as long as the intrinsic sensory character was maintained for each product. The majority of the participants were aware of the health risks associated with the consumption of diets rich in salt and fat, although less participants transferred this knowledge into their dietary selection. From respondents, it was clear that there was, and is, a high demand for salt- and fat-reduced products and that they would like to buy more of these kinds of products if available on the market. Younger and lower income respondents pointed to concerns in relation to unit cost prices for such products, but highlighted that if commodity cost prices were reduced, they would purchase more of these reformulated products over conventional equivalents. Clearly, government initiatives around taxation and subsidies might be avenues by which companies and consumers would be encouraged to produce and consume more of these products, respectively.

3.1 Introduction

Background

Changing consumer lifestyle patterns has significantly impacted upon consumer diets in recent years. A greater number of women are at work, people generally work longer and spend more time on leisure activities (Hitchman, Christie, Harrison, & Lang, 2002). Equally, children have an increased number of extra-curricular school activities which leads to irregular, but convenient eating patterns. Fewer families eat together and increases in snacking patterns occur (Bardsley, 2000; Davies, 2001). With less time for food preparation, the primary meal of the day is currently prepared and served in less than 30 minutes in many domestic settings, in contrast to 2.5 hours during the 1930's (Harrison, 2001). These changes ultimately brought about an increased demand for convenience foods, with most being energy-dense and nutritionally poor.

With the increased consumption of processed foods, salt intake increased to a level of 9 to 12 g salt per day in nearly all countries worldwide (Henderson et al., 2003) which is 40 to 50 times higher than the evolutionary intake (0.25g salt per day) (Eaton & Konner, 1985). The high amounts of salt offered through dietary intake presents major physiological challenges to kidneys by way of excreting salt from the body and this in turn can result in hypertension (systolic 140 mmHg and/or diastolic 90 mmHg) (Chobanian et al., 2003). It is estimated to globally account for approximately 7.5 million deaths annually, the equivalent of 12.8% of all deaths (WHO, 2010). A consistent linear relationship between blood pressure levels and risk of coronary heart disease (CVD) and stroke are evident (Lewington, Clarke, Qizilbash, Peto, & Collins, 2002; MacMahon et al., 1990) as the first and third, respectively, leading causes of death globally (Lopez & Murray, 1998). Furthermore, there is increasing evidence that hypertension may also cause heart failure, renal disease (Whelton, Perneger, He, & Klag, 1996) and stomach cancer (Joossens et al., 1996).

Due to the higher consumption of processed foods which are typically higher in saturated fatty acids, the prevalence of obesity has increased severely in most countries (WHO, 2000). Fat has the highest energy densities (9kcal/g) of all macronutrients. In contrast, carbohydrate and protein provide less than half of this energy (4kcal/g) (EU-Regulation 90/496/EEC, article 5). A diet rich in fat can easily lead to issues such as excessive weight gain and obesity which are major risk factors for a number of chronic diseases, including diabetes, cardiovascular diseases and cancer. Ecological studies demonstrated a link between consumption of saturated fats and rates of coronary heart disease (Keys, 1970). Dietary saturated fatty acids raise the level of serum low-density lipoprotein (LDL)-cholesterol, an identified risk factor for cardiovascular disease (Zock, 2006).

From a food consumption perspective, people of a higher socio-economic status consume a greater variety of food products with a higher nutritional value (Mennell, Murcott, & Van Otterloo, 1993). In contrast, the diet of the lower socio-economic group comes from food cheap in energy (James, Nelson, Ralph, & Leather, 1997). Therefore, the occurrence of hypertension, stroke, heart disease and cancer are higher in this latter socio-economic consumer grouping.

Consequently, the World Health Organization (WHO) called on all countries to reduce daily salt consumption to less than 5 g/day with the aim of reducing salt intake by 30% by 2025 (WHO, 2012). This target is founded on strong evidence and cost-effective measures aimed at preventing *inter alia* CVD. Furthermore, the WHO suggest a total fat intake between 15% and 30% of the dietary energy and a daily intake of polyunsaturated fatty acids (PUFAs) between 6% and 11% based on daily energy intake (WHO, 2003).

The WHO are currently driving measures to reduce salt and saturated fat content in foods by raising consumers' awareness and setting guidelines for the food processing industry. Therefore, food reformulation is considered in coordination with food manufacturers, distributors and providers. The challenge, however, is that sensory-based influences have the greatest impact on the individual acceptance of any food or beverage (Booth & Shepherd, 1988) and consequently, product reformulation must be handled with great care. The consumer will ultimately decide if the product will accepted or rejected based on its appearance, texture, aroma and flavour (Clark, 1998). Hence, food manufacturers have to achieve satisfactory sensory quality in reduced salt and fat products, to assure any long-term commercial success. This task is challenging for the industry as salt and fat performs numerous roles in many processed foods and beverages (Brady, 2002; Hoog, Ruijschop, Kok, Pyett, & NIZO Food Research, 2011). Salt imparts not only a salty taste, rather it enhances the effect of other flavour components within the food product and inhibits bitterness (Lindsay, 2007). Furthermore, for many products, salt plays a functional role in processing (e.g. cheese, meat products, ambient-stable emulsified sauces, baking goods) (Man, 2007) and in preserving foods(Hutton, 2002). Fat, on the other hand, contributes to food texture which is highly product specific (McClements, 2004), plays a role in process lubrication (Giasson, Israelachvili, & Yoshizawa, 1997; Luengo, Tsuchiya, Heuberger, & Israelachvili, 1997) and in carrying aroma (Hansch, Leo, & Hoekman, 1995). Reducing salt and fat by stealth or through the use of replacers are means by which salt and fat have already been successfully reduced in processed food and beverage products. However, companies with a clean label mandate (usage of natural ingredients only) do not advocate the addition of replacers which contravenes this policy. Furthermore, the use of replacers and higher quality products generally increases processing costs substantially (Kilcast & Ridder, 2007). Nevertheless, the food industry has already and successfully started to implement the manufacture of low in salt and fat products. Nevertheless, a conflict appears to exist between innovation and the concept of traditional foods. The stronger interest in health by consumers might result in a lower consumption of traditional food products in the future (Jordana, 2000), and is one which must be overcome. Furthermore, some food manufacturers are reluctant to reduce salt content, as it makes unpalatable, cheap food, edible at virtually no cost (Nestle, 2002). Another aspect to consider is that salt causes thirst and any reduction in salt intake will reduce liquid consumption with a significant sale reduction in beverage consumption. It is known, that some of the largest snack companies are also part of the soft drink industry (He, Markandu, Sagnella, & MacGregor, 2001). However, a dietary reduction in salt and fat intake can also be obtained by raising consumers' awareness and education through public health campaigns (via television, radio, newspapers, brochures, internet, social media and press releases) focusing on the health risks, thereby leading consumers to purchase healthier food products, encouraging convenience-style cooking but using healthy raw ingredients that require less salt and fat utilization (He & MacGregor, 2007).

Many countries have commenced campaigns to reduce the dietary salt and fat consumption in their native populations. The demand for healthier food has already increased. Hence, consumers demand for healthier and more naturalness from foods is also confronted with the need for convenience food (Barcellos, Grunert, & Scholderer, 2011).

Framework of the present study

Many food manufacturers are currently reformulating recipes in a bid to reduce fat and salt levels in their products and be seen to mirror what is being endorsed by public health campaigns around the consumption of healthier foods. The following survey presents findings from Irish consumers in relation to how well they have adopted and implemented the message of consuming healthier foods, including reduced salt and fat levels from their diets.

It is of great interest to determine how aware consumers are of the health risks caused from a diet rich in salt and fat, and furthermore, to ascertain if they implement strategies to achieve a balanced diet and integrate measures to reduce dietary salt and fat intake. The present study was carried out to clarify if a conflict exists between innovation and traditional food manufacture, especially with respect to processed meat manufacture.

Furthermore, product development of salt and fat reduced foods involves the use of higher quality ingredients and/or replacers which leads to cost increases. This survey was also carried out to determine what the economic implications were for consumers interested in purchasing products that could be generally termed as ‘healthier food products’.

3.2 Methods

3.2.1 Participants and procedure

In September 2014, 1045 consumers took part on the online survey titled “Salt- and fat-reduced foods”. The survey was distributed to a broad range of individuals living on the island of Ireland; the specific demographics of which are explained in great detail later in this paper. The survey was conducted in English and was constructed to take approximately 10 minutes to complete. To attain maximum participation in the survey, a total of 16 questions were constructed.

3.2.2 Questionnaire

The questionnaire was divided into four sections. The first section pertained to consumer socio-demographic details while the second section set about ascertaining financial details from consumers. The third section of the survey dealt with food consumption patterns, with a particular focus on reduced salt and fat food consumption and the final section of the survey explored the inherent knowledge and beliefs held by consumers.

3.2.2.1 Socio-demographic-based survey questions

Survey participants were asked four socio-demographic-based questions, namely; age, gender, nationality and level of education. Age was class-divided as follows; < 20, 20-29, 30-39, 40-49, 50-59 and ≥ 60 and level of education was subdivided into five categories and listed from lowest to highest education level; no school certificate, leaving certificate, primary degree and diploma, postgraduate degree and higher degree. The chosen educational categories were based on the Irish national framework of qualification (Quality and Qualifications Ireland, 2003). In Ireland “the leaving certificate” is gained by successfully passing secondary- or high-school exams. Therefore, the ‘No school certificate’ category refers to individuals who never received this level of education for one reason or another. The category “primary and diploma” covers higher and advanced certificates, bachelor and diploma degrees. Furthermore, education level “postgraduate” comprises Master degree and postgraduate diploma. The highest education category “higher degree” contents Doctoral degree and higher doctorate.

3.2.2.2 Financial-based survey questions

Since the level of available or spending money influences consumer purchase of food products, the second section of the questionnaire included two questions based on income and food purchase and these were; “What percentage of your income do you spend on food per month?” and followed by “Would you spend more money on food, if you had more money available?”

3.2.2.3 Consumption-based survey questions

To explore the food consuming habits of participants, a total of three questions were generated and these were; “Do you consume a balanced diet (vegetables, fruits, fibres, bread, meat, dairy products)?”, “Do you purchase salt-reduced food?” and

"Do you purchase fat-reduced food?". It was assumed that the participants had a basic knowledge about what a balanced diet was, nevertheless, in an attempt to assist panellists with this question, the components of a balanced diet were listed in brackets within the questionnaire.

Questions on specific consumption of products then followed using black and white puddings as specific traditional product examples, beginning with; "Would you eat salt- and fat-reduced white and black pudding sausages?". Three answer choices were provided for panellists as followed: "Yes, even the taste is different to conventional white and black pudding sausages", Yes, if the taste is similar to conventional white and black pudding sausages" or "Not at all". White and black pudding products are popular in Ireland and in the United Kingdom and contribute particularly as a special feature of the traditional Irish and English breakfast. They constitute traditional-type products which are targeted for potential salt and fat reduction. The second question was a decision question: "Would you purchase salt and fat reduced food even when the food is more expensive?" Only if the participants responded to this question with "Yes", were they asked about how much more money, in percentage terms, would each panellist spend on salt- and fat-reduced foods?".

3.2.2.4 Knowledge and belief-based survey questions

In the last section of the questionnaire, participants were asked about their knowledge and beliefs. Therefore, they were asked the following questions; "Do you know that high sodium levels in food can cause hypertension, cardiovascular diseases and stroke?", "Do you know that high saturated fatty acids level in food can cause obesity, diabetes and stroke?", "Do you think there is a greater need in informing people about the impact of sodium and saturated fatty acids in food on body health?" and "Do you think there is a greater need for salt and fat reduced products on the market?".

3.2.3 Data analyses

IBM SPSS Statistics 20 software package (SPSS, Chicago, IL, USA) was used to carry out statistical analyses of data responses received. Assuming that there was a normal distribution of values, comparing column proportion test (using z-test) and Bonferroni correction was applied in order to evaluate the presence of significant differences between factors such as age and level of education (Hochberg, 1988). Furthermore, Pearson Chi-Square analyses and Bonferroni correction were used in order to evaluate significant differences in gender (Beasley & Schumacker, 1995).

3.3 Results

3.3.1 Demographic - results

The survey ”Salt- and fat-reduced foods” was undertaken and completed by 1045 participants and was comprised of 71% female and 29% male participants (Table 1). In total, 96% of the participants were European, of these 88% Irish, 3% British, 2% German, 1% French and other nationality less than 1% (Table 1). The greatest percentage of respondents (34.5%) were aged between 20-29, followed by those aged under 20 (19.6%), 40-49 (16.4%) and 30-39 (14.5%). Adults aged 50 to 59 and aged 60 and over also took part in the survey accounting for 10.2% and 4.8% of participants, respectively (Table 1). From an educational perspective, participants claiming to have “No school certificate” accounted for only 0.8% of participants. A total of 39.1% of participants were educated to “leaving certificate” and 23.3% to “primary degree and diploma”. The higher levels “postgraduate” and “higher degree” were evenly distributed at 19.7% and 17.1%, respectively (Table 1).

3.3.2 Financial situation - results

As shown in Table 2, two-thirds of participants claimed to spend between 15% and 30% of their income on food. The majority of responses (at 23%) reported a 20% spend of income on foods. No significant differences were found between age, gender and level of education in relation to this issue. Furthermore, only 5% of income was spent by 4% of participants on groceries. In general, data analysis revealed that no significant differences existed in gender, though for different levels of education and across the various age groups but without observing a trend. A total of 15% of participants claimed to spend 40% and more of their income on food. No statistical differences in age and gender were found and no definitive pattern was shown for different educational levels.

Fifty percent of the participants responded to the question “Would you spend more money on food, if you had more money available?” with “yes” and 50% with “no” (Table 2). With increasing age and higher levels of education, significantly less people answered “yes”. Only 33% and 18% of participants aged between 50 to 59 and over 59 years would like to spend more money on food. Again, gender had no impact on responses.

3.3.3 Consumption characteristics - results

When the question was posed “Do you consume a balanced diet (vegetables, fruits, fibres, bread, meat, dairy products)?”, the question was answered 59.2% “Yes, completely”, 38.4% “Just a bit” and only 2.4% “Not at all” (Table 3). With increasing age and level of education, significantly more people responded more positively to “Yes, completely”. Furthermore, significantly more women appear to take care of consuming a balanced diet than men. Interestingly, this interest in diet is also reflected in the composition of participants who chose to take up the offer of participating in this survey. Adults aged under 20, and the age group 20 to 29 accounted for 52% and 44%, respectively, for “Just a bit”. For the response “Not at all” no statistical differences in attitudes between age and gender were determined.

In total, 43% of participants purchased salt-reduced foods and almost two-thirds of participants purchased fat-reduced foods (Table 3). Without exception, more fat-reduced than salt-reduced foods were purchased, independent of age, gender and level of education. Adults aged under 20 were the group least interested (at 29%) in the purchase of salt-reduced foods. Significantly more women purchased salt- (48%) and fat-reduced (70%) foods than men (32% and 50%, respectively). Participants with “primary and diploma” degrees were the largest purchasers and consumers of salt- and fat-reduced foods.

When the question was posed “Would you purchase salt- and fat-reduced white and black pudding”, half of the participants answered the question with “Yes, if the taste is similar to conventional white and black pudding sausages” and one-third with “Not at all” (Table 3). Only 15% would purchase salt- and fat-reduced white and black pudding with a different taste to conventional white and black pudding sausages. In general, age, gender and educational level had no impact on patterns determined.

Data analysis revealed that 56% of participants would purchase salt- and fat-reduced foods, even when products were more expensive to purchase (Table 3). Moreover, significantly more adults aged over 29 years and more women (than men) would spend more money on salt- and fat-reduced foods. However, participants with a school leaving certificate voted significantly not to be willing to pay more money for salt- and fat-reduced foods. In total, 33% and 16% of all participants would spend 5% to 15% and 15% to 30%, respectively, more on salt- and fat-reduced foods (Table 3). Statistical differences were observed across the various age groups, though no definitive patterns were evident.

3.3.4 Knowledge and beliefs – results

Two questions were asked in relation to ascertain the respondents' knowledge with respect to salt and fat impacts upon health. In total, 92% of participants claimed to know that high sodium levels in food can cause hypertension, cardiovascular disease and stroke (Table 4). Women were found to be statistically more informed than men. Age and level of education did not appear to impact on this awareness. When the question "Do you know that high saturated fatty acids level in foods can cause obesity, diabetes and stroke?" was posed, respondents who answered this question with "no" only constituted 3% of participants (Table 4). Age, gender and educational level had no impact on awareness levels determined.

Completion of the survey was concluded by addressing participants' beliefs. In total, 87% of respondents think there is a greater need in informing people about the impact of sodium and saturated fatty acids in food upon health (Table 4). Furthermore, significantly more women supported this view than men. No particular age group was found to advocate statistically more or less than the others. Significant differences in age were recorded, although no pattern became apparent. Finally, 83% of participants believe that there is a greater need for salt- and fat-reduced products on the market (Table 4). Again, significantly more women supported this view than men. Age and educational level had no impact on responses obtained.

3.4 Discussion

The present study addressed current consumer attitudes regarding consumption of healthy foods, especially in relation to food products low in salt and low in fat, and about their knowledge and beliefs in order to clarify how well consumers in Ireland have adopted and transferred the message of consuming healthier (salt and fat reduced) foods into their diet. All responses by participants were classified by age, gender and level of education. For evaluation of the survey it was important to consider that no significant differences were found between the education groups "no school certificate” and the others, “leaving certificate”, “primary degree and diploma”, “postgraduate” and “higher degree “. As only 0.8% of the participants belonged to “no school certificate” category, when a pattern was found within the group of educational level then data for the lowest level was excluded because of the low numbers of participants in this category.

The survey, “Salt- and fat-reduced foods” completed 1045 participants, with 71% female and 29% male. A similar distribution of gender was also found in the study by Tobin, O’Sullivan, Hamill, & Kerry (2014) about consumer attitudes on associated health benefits of processed meats using co-enzyme Q10 as a functional ingredient. Thus it is observed that in these instance females are more likely to complete surveys about consumer attitudes on foods linked with health aspects.

In general, it appears that public health campaigns pertaining to the importance of consuming a balanced diet has been acknowledged and adopted by Irish consumers, with only 2% of the participants declaring not to have adopted consumption of a balanced diet, independent of age, gender and level of education. Of the 97.6% of participants who claimed to consume a healthy and balanced diet, 38.4% partially took care to consume such a diet and 59.2% completely. In the present study significantly more women than men consumed a balanced diet. These findings are consistent with those presented by Purdy & Arrmstrong (2007) who surveyed trends in dietary salt intake from processed food sources and discretionary salt among consumers (n = 360) in Northern Ireland. For this purpose, participants were asked *inter alia* how frequently they consumed a range of popular processed foods. Males significantly consumed more products like sausages, tinned vegetables, meat pies and chips compared to females and more frequently. In general, products consumed frequently contained high quantities of fat and salt. Accordingly, the authors concluded that “men are less aware of good dietary practice and the importance of healthy eating messages” which can be confirmed by the present study. However, in the present study participants aged under 30 take significantly less care of a complete balanced diet. The authors Purdy & Arrmstrong (2007) stated that participants aged 15 to 29 had a significantly higher consumption of pizza and crisps than those aged 30 and over. Warwick (1998) postulated that snack foods are popular among this age group. However, in the present study, more highly educated participants take significantly more care themselves in terms of consuming a complete balanced diet.

In contrast, Purdy & Arrmstrong (2007) reported that the higher educated participants consumed pizza and ready-meals more frequently. It was suggested that these consumers have less time to prepare meals and consequently they purchase convenient-style foods. Furthermore, Bardsley (2000) summarized that consumers with professional occupations have generally higher disposable incomes and consequently, they are more easily able to afford the more expensive convenience-style products (such as ready-meals and pre-prepared products). However, it was apparent from the study by Purdy & Arrmstrong (2007) that many consumers frequently consumed highly salted and fatty processed foods, such as; pizza, ready-meals, bacon and tinned vegetables, irrespective of their educational status. However, these listed products are considered to be highly processed and energy-rich and consequently, are not considered as major contributors to a healthy balanced diet. Based on the results of the present study, it can be implied that participants stating they pay full attention to a balanced diet do not consume these products or at least, very rarely. Consequently, more than half of the participants (59%) maintain a balanced diet. Therefore, it is important to encourage consumers, who have stated in this survey that they partially undertake to maintain a balanced diet, to adopt an exclusively balanced diet through continued promotional messaging in relation to healthier food consumption. For those participants who expressed an indifference to the consumption of a balanced diet (minority with 2%), it is quite possible that no amount of information would convince these participants to adopt the consumption of a balanced diet. This lack of concern may be directly attributable to individual personality or are reluctant to change personal habits. Furthermore, the increasing current trend in the lack of cooking skills (Furey, McIlveen, Strugnell, & Armstrong, 2000) and even the lack of cooking facilities (Caraher & Lang, 1999) might also lead to difficulties in encouraging such consumers to adopt a healthy diet as they may have already lost the ability to prepare proper meals. Hence, it is even more important that food manufacturers produce foods low in salt and low in saturated fatty acids and which are also convenient.

Since the WHO first promoted the introduction of foods which were low in salt and fat, an increased number of food producers have adopted the challenge to manufacture sensory-acceptable salt and saturated fat reduced foods. In the present study significantly more women than men, significantly more participants with “diploma and primary” degree than with a “school leaving certificate” and participants with increasing age nominated to purchase salt- and fat-reduced food. In general, participants purchased more fat-reduced (64%) than salt-reduced foods (43%). Although, only less than half of the participants consumed salt-reduced foods, it is more than double the figure presented in the study by Purdy & Arrmstrong (2007) at 19%. Therefore, the findings of this present study marks the fact that quite satisfactory progress has been made with respect to encouraging consumers to eat more fat- and salt-reduced foods. In the present study most of the panelists (>90%) were aware of the health risks leading by a diet rich in salt and fat. Consequently, the lower acceptance for salt-reduced foods (in comparison to fat-reduced foods) may lie in the fact that consumers are not satisfied with the product range currently available on the market, rather than any being attributable to a lack of consumers knowledge or awareness. For a long time, research was only undertaken on issues such as sugar- and fat-reduction, as the factor of saltiness in food products had been seen to be a comparatively simple mechanism. Due to the wide range of intense sweeteners, sugar-reduced foods are now well-established (Kilcast & Angus, 2007). The product development of fat-reduced foods is already far further advanced than that of salt-reduced foods. Considering the increased purchase rate of salt-reduced foods from 2007 at 19% (Purdy & Arrmstrong, 2007) to 2014 at 43% (present survey), it seems that the food industry are already successfully addressing these difficulties of presenting acceptable reformulated salt-reduced products on the market.

However, the author Jordana (2000) suggested that traditional foods in the future may suffer from a less favourable attitude regarding health and nutritional aspects. The greatest threat is seen in an insufficient adaptation to new requirements demanded by consumers. To clarify if consumers see a conflict between innovation and concept of traditional foods, survey participants in the current survey were asked if they would eat salt- and fat-reduced white and black puddings. It is important to note that white and black puddings hold a very high traditional value for both, Irish and British consumers. Independent of age, gender and level of education, a total 65% of participants claimed that they would eat salt- and fat-reduced white and black puddings, and 15% of participants would eat these products even if product taste was different to conventional white and black pudding products. Similar ratings were achieved with respect to the purchase of fat-reduced conventional foods, however, lower acceptance was recorded with respect to participant willingness to purchase salt-reduced conventional foods. Therefore, based on this result, it appears that consumers do not distinguish between traditional foods and conventional foods regarding salt- and fat-reduction. Consequently, the findings from this survey corroborate the views of Guerrero et al. (2009) that innovations in traditional food products are only accepted by consumers if they provide manifest benefits like safety or health improvements and do not harm the intrinsic traditional character of the food in question. In the present survey, only a minority (15%) of the participants were willing to purchase salt- and fat-reduced white and black pudding, would also tolerate differences in taste, and which again confirms the conclusion of Guerrero et al. (2009).

Additionally, Ronteltap, van Trijp, Renes, & Frewer (2007) stated that besides perceiving health benefits, consumers also responded well to reduced product costs and determined that this was a major determinant of consumers acceptance of food innovations. In general, higher costs for salt- and fat-reduced foods can be expected as salt- and fat-reductions are typically achieved by stealth through increasing other ingredients (higher in quality), using replacers/enhancers or by compensation for the lack of taste using flavour delivery agents (e.g. herbs, spices, lemon, onion/garlic, vinegar, etc.) (Kilcast & Ridder, 2007; Talbot, 2011). It was estimated that a sodium reduction of 20% to 30% increased food costs by 5% to 30% depending on the type of food product being processed (Dötsch, Busch, Batenburg, Liem, Tareilus & Müller, 2009). In the present study, two-thirds of the participants claimed to spend between 15% and 30% of their income on foods. Slightly more than half of participants were willing to pay more money for salt- and fat-reduced foods. A total of 33% of all survey participants would accept food cost increases of 5% to 15%, which still is not fully covering the cost increases for all estimated food types (Dötsch et al., 2009). Sixteen percent of all participants would tolerate product cost increases by 15% to 30% and the minority (7%) would even pay more than 30% for salt- and fat-reduced foods. Therefore, only approximately a quarter of all participants were willing to pay the actual expected increase in product cost. Participants aged < 20 and 20 to 29 represented the largest groupings that would like to spend more money on foods, if more money was available and conversely, these panellists were those that were most unwilling to pay more for salt- and-fat reduced foods. The inverse views to those expressed by younger participants in the survey were observed for participants aged 50 to 59 and over 59. Among these participants, 71% and 84%, respectively, would purchase salt- and fat-reduced foods even it was more expensive. Only 33% and 18%, respectively, would spend more money on foods, if more money was available. A similar pattern was also found for survey participants possessing different grades of education. Apparently the reason that younger participants (< 30 years) and lower educated participants were less willing to pay more money for salt- and fat-reduced foods might simply be due to their financial situation. People with professional occupations generally have higher disposable incomes, which can in turn, be spent on food (Bardsley, 2000). Additionally, elderly people are usually already more often confronted with civilisation diseases, whereby their diet may be under medical supervision, and hence they have a greater willingness to spend more money on salt- and fat-reduced food. Furthermore, significantly more women are willing to spend more money on salt- and fat-reduced foods than men, although more women than men would like to spend more on foods in general, if they had more money available (not significant). Despite women's higher financial deficits, they showed a greater willingness for purchase salt- and fat-reduced foods than men. The higher degree of willingness can be explained by the fact that most of the food shopping is still carried out by women (Murcott, 2000) and additionally, significantly more women were aware of the health risks associated with a diet rich in salt. Messages pertaining to health risks associated with the intake of a diet rich in salt and saturated fatty acids appear to have reached the participants of this survey (92% and 97% respectively), independent of age and educational status. Men were significantly less aware of the consequences of consuming a diet rich in salt than women. However, in comparison to consumers' knowledge, less participants generally took care of maintaining a balanced diet (59%). In the previous study by Purdy and Armstong (2007) consumers of lower-economic status were less aware of the link between health and diet. Therefore, public health campaigns have successfully raised consumers' awareness. Nevertheless, the majority (87%) of survey participants thinks that there is still a greater need in informing people about the impact of sodium and saturated fatty acids in foods on human health. Independent of age, gender and level of education, 83% of participants think that there is a greater need for salt- and fat-reduced food products on the market. Therefore, the majority of respondents are informed, looking for more information and a wider range of salt and fat reduced foods.

To counteract the higher prices associated with low-salt and low-fat foods, taxation of food high in salt, fat and sugar could be used to off-set the higher costs associated with these products. The idea of taxing of foods deemed to be ‘unhealthy’ in nature has caused controversy in recent times. Duffey & Gordon-Larsen (2010) evidenced that food consumption is linked with food prices, which has a direct influence on human health. Furthermore, Niebylski, Redburn, Duhaney, & Campbell (2015) revealed consistent evidence that taxation (of unhealthy food/beverage products) and subsidy (of healthy food/beverage products) intervention positively influenced the dietary behaviour of consumers. These authors further suggested that food taxes and subsidies, preferably used in tandem, have to be at least 10% to 15% in order to successfully exert this effect. The health impact seems to be most profound with consumers from a low-income status, as this consumer grouping, not surprisingly, respond to food price reductions. Consequently, such taxation measures may address consumer inequality (Härkänen et al., 2014). However, launching taxation and subsidies for diverse food and beverage products might highlight the importance of adopting a healthy diet and guide all consumers in distinguishing products high and low in salt, fat and sugar, independent of consumers’ disposable income.

Denmark introduced the world’s first saturated fat tax in 2011. Bødker, Pisinger, Toft, & Jørgensen (2015) revealed that upon the launch of the saturated fat tax, food industry representatives fought against its introduction. Additionally, the saturated fat tax suffered from significant shortcomings, especially because the tax did not reflect the actual saturated fat content in final product and gradually suffered a loss in popularity among politicians, health experts and the general public. Consequently, 15 months later the saturated fat tax was abolished, even when a lower consumption of saturated fat was beginning to appear among the Danish public. Bødker et al. (2015) concluded that the fat tax was more focused on a healthy economy than a healthier population. It was suggested that the public health experts should have had a more proactive role in policy-making. Despite the failure of the fat tax in Denmark, it still serves as a model with generated lessons which can be considered upon launching such taxation again in Denmark, or indeed in other countries.

Relating to Ireland, the supply of food and beverages is subjected to different rates of value added tax (VAT), depending on the type of food and drink, and how they are supplied. Most foods (sold by retailing outlets) are subject to a zero rate, although there are many exceptions. The standard VAT rate at 23% applies to alcohol, bottled water, juice, soft drinks, ice cream, crisps, popcorn, biscuits, all chocolate types, sweets and confectionery (VAT Interpretation Branch, 2015). With the exception of bottled water and juice (depending on the sugar content) categories, the listed taxed foods and beverages belong to the ‘unhealthy’ food product category. Nevertheless, the predominant taxation system does not distinguish between low and high salt, fat and sugar products. Therefore, food manufacturers belonging to the taxed food category might have less inducement to reduce salt, fat and/or sugar levels. Consequently, in order to adopt the idea of taxation and subsidies (Niebylski et al., 2015) in Ireland, a different VAT system would have to be introduced.

Additionally to taxation/subsidies, user-friendly product labelling schemes are generally required as not all consumers take the time to carefully read product labels and furthermore, some have difficulties in interpreting them. Through the EU-Regulation 1169/2011 (article 9 (1) l), declaration of nutrition is mandatory legislation since 13th December 2014. However, an exclusive listing of nutritional values might not be enough to allow consumers to make a mature purchasing decision. Using reference intake (RI) labels, previously employing the term “guideline daily amount” (GDA), might help consumers to evaluate more easily how a particular food product fits into their daily diet, and furthermore to manage their key nutrient (fat, saturated fat, salt, sugars) and calorie intake. Although, RI values are applied to adults, they are based on the requirements for an average healthy female with no special dietary requirements (sport activities, special diet, pregnant and breast feeding mothers) with a calculated energy intake of 2000 kcal. So far, declaration of RI is optional (EU-Regulation 1169/2011, article 32 (4)). The authors recommend mandatory uptake of RI labels, as the average consumer cannot be expected to know about daily nutritional intake rates and therefore, RI labels can be used as a simple and reliable reference.

3.5 Conclusion

Based on the present survey conducted in Ireland, it appears that campaigns launched around the importance of consuming a well-balanced diet have generally been well received and adopted by respondents, as only a minority of the survey participants did not appear to be concerned about their general diet; irrespective of age, gender and educational background. More than half of the participants carefully maintained a balanced diet. Furthermore, an increase in purchasing salt-reduced food was observed, although fat-reduced food products were already better accepted. In general, men, young adults (<30 years) and those with a less well-educated background purchased less salt- and fat-reduced foods and also took less care in maintaining a balanced diet. The purchase of traditional food products with reduced salt and fat content were unaffected as long as the intrinsic sensory character was maintained for each product. The majority of the participants were aware of the health risks associated with the consumption of diets rich in salt and fat, although less participants transferred this knowledge into their dietary selection. From respondents, it was clear that there was, and is, a high demand for salt- and fat-reduced products and that they would like to buy more of these kinds of products if available on the market. Younger and lower income respondents pointed to concerns in relation to unit cost prices for such products, but highlighted that if commodity cost prices were reduced, they would purchase more of these reformulated products over conventional equivalents. Clearly, government initiatives around taxation and subsidies might be avenues by which companies and consumers would be encouraged to produce and consume more of these products, respectively. Additionally, user-friendly product labelling scheme, such as reference intake labels, is required so that consumers are able to make easier food choices.

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3.6 Tables and Figures

Table 1
Socio-demographic characteristics of participants (n = 1045)

Age [%]					
< 20	20-29	30-39	40-49	50-59	≥ 60
19.6	34.5	14.5	16.4	10.2	4.8
Gender [%]					
female	male				
71.1	28.9				
Education [%]					
No school certificate	Leaving certificate	Primary degree + Diploma	Post-graduate	Higher degree	
0.8	39.1	23.3	19.7	17.1	
Nationality [%]					
European		American	Asian	African	Australian
96.4		1.5	1.2	0.7	0.2
Irish	87.7				
UK	2.9				
German	1.5				
French	0.8				
Dutch	0.4				
Spanish	0.4				
other	2.7				

Table 2

Financial aspects of participants (n = 1045), questions and frequency of answers as percentage

Questionnaire		Age						Gender		Education				
N = 1045	Total (%)	< 20	20-29	30-39	40-49	50-59	≥ 60	female	male	No school certificate	Leaving certifi-cate	Primary degree + diploma	Post-graduate	Higher degree
What percentage of your income do you spend on food per month?														
5	3,9	10.2^{a}	2.8^{b}	2.6^{a,b}	2.3^{b}	0.9^{b}	2.0^{a,b}	4.3^{a}	3 .0^{a}	0.0^{a,b}	6.8^{a}	2.5^{a,b}	2.4^{a,b}	1.1^{b}
10	9,5	7.8^{a}	7.5^{a}	11.8^{a}	13.5^{a}	11.2^{a}	6.2^{a}	9.6^{a}	9.3^{a}	28.6^{a,b}	6.1^{a}	7.8^{a,b}	11.7^{a,b}	16.2^{b}
15	15,4	7.3^{a}	13.6^{a,c}	27.0^{b}	16.4^{a,b,c}	18.7^{b,c}	16.3^{a,b,c}	14.9^{a}	16.6^{a}	0.0^{a,b}	7.8^{b}	18.0^{a}	22.8^{a}	21.2^{a}
20	23,0	20.5^{a}	22.2^{a}	25.7^{a}	22.8^{a}	24.3^{a}	28.6^{a}	22.2^{a}	24.8^{a}	14.3^{a}	22.5^{a}	23.4^{a}	23.3^{a}	23.5^{a}
25	12,6	11.7^{a}	14.7^{a}	9.2^{a}	10.5^{a}	15.9^{a}	12.2^{a}	12.5^{a}	12.9^{a}	14.3^{a}	10.8^{a}	15.2^{a}	13.1^{a}	12.8^{a}
30	13,8	13.2^{a}	15.8^{a}	10.5^{a}	15.2^{a}	12.1^{a}	10.2^{a}	13.2^{a}	15.2^{a}	0.0^{a}	14.9^{a}	13.9^{a}	14.1^{a}	11.2^{a}
35	6,6	7.8^{a}	6.4^{a}	5.3^{a}	8.8^{a}	1.9^{a}	10.2^{a}	7.4^{a}	4.6^{a}	14.3^{a}	7.6^{a}	7.0^{a}	5.8^{a}	4.5^{a}
40	9,3	11.7^{a}	11.1^{a}	4.6^{a}	6.4^{a}	11.2^{a}	6.1^{a}	10.1^{a}	7.3^{a}	0.0^{a,b,c}	13.9^{b}	7.4^{a,b,c}	6.3^{a,c}	5.0^{c}
> 40	5,9	9.8^{a}	6.1^{a}	3.3^{a}	4.1^{a}	3.7^{a}	8.2^{a}	5.8^{a}	6.3^{a}	28.6^{b}	9.5^{b}	4.9^{a,b}	0.5^{a}	4.5^{a,b}
Would you spend more money on food, if you had more money available?														
Yes	50,0	53.2^{a}	57.6^{a}	50.7^{a,c}	46.8^{a,c}	32.7^{b,c}	18.4^{b}	51.7^{a}	44.4^{a}	85.7^{a,b,c}	55.7^{b}	52.9^{a,b}	43.2^{a,c}	36.9^{c}
No	50,0	46.8^{a}	42.4^{a}	49.3^{a,c}	53.2^{a,c}	67.3^{b,c}	81.6^{b}	48.3^{a}	55.6^{a}	14.3^{a,b,c}	44.3^{b}	47.1^{a,b}	56.8^{a,c}	63.1^{c}

^{a,b,c} Percentages within question and row sharing different letters are significantly different

Table 3

Consumption characteristics of participants (n = 1045), questions and frequency of answers as percentage

Questionnaire		Age						Gender		Education				
N = 1045	Total (%)	< 20	20-29	30-39	40-49	50-59	≥ 60	female	male	No school certificate	Leaving certifi-cate	Primary degree + diploma	Post-graduate	Higher degree
Do you consume a balanced diet (vegetables, fruits, fibres, bread, meat, dairy products)?														
Yes, completely	59,2	43.4^{a}	53.2^{a}	68.4^{b}	67.8^{b}	72.9^{b}	81.6^{b}	63.0^{a}	50.0^{b}	57.1^{a,b,c}	47.9^{c}	59.5^{a}	67.0^{a,b}	76.0^{b}
Just a bit	38,4	51.7^{a}	44.3^{a,c}	29.6^{b}	31.6^{b,c}	26.2^{b}	16.3^{b}	34.9^{a}	47.0^{b}	28.6^{a,b,c}	48.2^{b}	38.9^{a,b}	31.6^{a,c}	23.4^{c}
Not at all	2,4	4.9^{a}	2.5^{a}	2.0^{a}	0.6^{a}	0.9^{a}	2.0^{a}	2.1^{a}	3.0^{a}	14.3^{a}	3.9^{a,b}	1.6^{a,b}	1.4^{a,b}	0.6^{b}
Do you purchase salt-reduced food?														
Yes	43,3	29.3^{a}	43.5^{b}	46.7^{b}	50.3^{b}	49.5^{b}	53.1^{b}	48.2^{a}	31.5^{b}	71.4^{a,b,c}	36.7^{c}	52.9^{a}	39.3^{b,c}	49.2^{a,b}
No	56,7	70.7^{a}	56.5^{b}	53.3^{b}	49.7^{b}	50.5^{b}	46.9^{b}	51.8^{a}	68.5^{b}	28.6^{a,b,c}	63.3^{c}	47.1^{a}	60.7^{b,c}	50.8^{a,b}
Do you purchase fat-reduced food?														
Yes	64,3	52.7^{a}	62.3^{a}	67.8^{a,b}	67.2^{a,b}	78.5^{b}	75.5^{a,b}	70.3^{a}	49.7^{b}	71.4^{a,b}	58.2^{b}	71.7^{a}	65.5^{a,b}	66.5^{a,b}
No	35,7	47.3^{a}	37.7^{a}	32.2^{a,b}	32.7^{a,b}	21.5^{b}	24.5^{a,b}	29.7^{a}	50.3^{b}	28.6^{a,b}	41.8^{b}	28.3^{a}	34.5^{a,b}	33.5^{a,b}
Would you eat salt- and fat-reduced white and black pudding sausages?														
Yes, if the taste is similar to conventional white and black pudding sausages	50,2	49.8^{a}	50.1^{a}	49.3^{a}	51.5^{a}	52.3^{a}	46.9^{a}	50.5^{a}	49.7^{a}	0.0^{b}	49.6^{a,b}	57.0^{a}	49.6^{a,b}	45.3^{a,b}
Yes, even the taste is different to conventional white and black pudding sausages	14,6	18.5^{a}	12.7^{a}	14.5^{a}	11.7^{a}	16.8^{a}	18.4^{a}	14.3^{a}	15.5^{a}	14.3^{a}	15.6^{a}	12.3^{a}	15.0^{a}	15.1^{a}
Not at all	35,1	31.7^{a}	37.1^{a}	36.2^{a}	36.8^{a}	30.8^{a}	34.7^{a}	35.2^{a}	34.8^{a}	85.7^{b}	34.7^{a,b}	30.7^{a}	35.4^{a,b}	39.6^{a,b}
Would you purchase salt- and fat-reduced food even when the product is more expensive?														
Yes	56,0	41.5^{a}	47.9^{a}	66.4^{b}	63.7^{b}	71.0^{b}	83.7^{b}	59.0^{a}	48.7^{b}	71.4^{a,b}	42.1^{b}	63.9^{a}	64.1^{a}	66.5^{a}
No	44,0	58.5^{a}	52.1^{a}	33.6^{b}	36.3^{b}	29.0^{b}	16.3^{b}	41.0^{a}	51.3^{b}	28.6^{a,b}	57.9^{b}	36.1^{a}	35.9^{a}	33.5^{a}
If yes, how much more money in percentage would you spend on salt- and fat-reduced food?														
5 - 15%	33,1	23.9^{a}	26.3^{b}	44.7^{b}	39.8^{b}	42.1^{b}	42.9^{a,b}	34.9^{a}	28.8^{a}	42.9^{a,b}	24.0^{b}	39.8^{a}	41.3^{a}	35.2^{a}
15 - 30%	16,0	11.2^{a}	15.8^{a}	14.5^{a}	18.7^{a}	21.5^{a}	20.4^{a}	17.0^{a}	13.6^{a}	14.3^{a}	11.7^{a}	18.9^{a}	17.5^{a}	20.1^{a}
30 - 50%	3,1	3.4^{a}	1.7^{a}	3.9^{a}	3.5^{a}	2.8^{a}	8.2^{a}	3.0^{a}	3.3^{a}	0.0^{a}	2.7^{a}	2.5^{a}	3.4^{a}	4.5^{a}
50 - 75%	1,7	0.5^{a}	3.0^{a}	2.0^{a}	1.2^{a}	0.9^{a}	0.0^{a}	2.4^{a}	0.0^{a}	14.3^{b}	2.0^{a,b}	1.6^{a,b}	0.5^{a}	2.2^{a,b}
75 - 100%	1,2	1.0^{a}	0.8^{a}	0.7^{a,b}	0.6^{a}	1.9^{a,b}	8.2^{b}	1.0^{a}	2.0^{a}	0.0^{a}	1.2^{a}	0.8^{a}	1.0^{a}	2.2^{a}
> 100%	0,9	1.5^{a}	0.1^{a}	0.7^{a}	0.0^{a}	1.9^{a}	4.1^{a}	0.8^{a}	1.0^{a}	0.0^{a}	0.7^{a}	0.4^{a}	0.5^{a}	2.2^{a}

^{a,b,c} Percentages within question and row sharing different letters are significantly different.

Table 4
Knowledge and beliefs of participants (n = 1045), questions and frequency of answers as percentage

Questionnaire		Age						Gender		Education				
N = 1045	Total (%)	< 20	20-29	30-39	40-49	50-59	≥ 60	female	male	No school certificate	Leaving certifi-cate	Primary degree + diploma	Post-graduate	Higher degree
Do you know that high sodium levels in food can cause hypertension, cardiovascular diseases and stroke?														
Yes	92,1	88.8^{a}	91.4^{a}	92.8^{a}	94.7^{a}	96.3^{a}	89.8^{a}	93.9^{a}	87.4^{b}	85.7^{a}	91.0^{a}	91.0^{a}	93.7^{a}	94.4^{a}
No	7,9	11.2^{a}	8.6^{a}	7.2^{a}	5.3^{a}	3.7^{a}	10.2^{a}	6.1^{a}	12.6^{b}	14.3^{a}	9.0^{a}	9.0^{a}	6.3^{a}	5.6^{a}
Do you know that high saturated fatty acids level in food can cause obesity, diabetes and stroke?														
Yes	97,3	98.0^{a}	96.4^{a}	97.4^{a}	98.8^{a}	99.1^{a}	91.8^{a}	98.1^{a}	95.4^{a}	85.7^{a}	97.8^{a}	98.4^{a}	96.1^{a}	96.6^{a}
No	2,7	2.0^{a}	3.6^{a}	2.6^{a}	1.2^{a}	0.9^{a}	8.2^{a}	1.9^{a}	4.6^{a}	14.3^{a}	2.2^{a}	1.6^{a}	3.9^{a}	3.4^{a}
Do you think there is a greater need in informing people about the impact of sodium and saturated fatty acids in food on body health?														
Yes	87,4	85.9^{a}	86.1^{a}	86.8^{a}	87.1^{a}	93.5^{a}	91.8^{a}	89.8^{a}	81.5^{b}	85.7^{a,b}	84.8^{b}	89.3^{a,b}	93.7^{a}	83.2^{b}
No	12,6	14.1^{a}	13.9^{a}	13.2^{a}	12.9^{a}	6.5^{a}	8.2^{a}	10.2^{a}	18.5^{b}	14.3^{a,b}	15.2^{b}	10.7^{a,b}	6.3^{a}	16.8^{b}
Do you think there is a greater need for salt and fat reduced products on the market?														
Yes	82,7	82.4^{a}	80.3^{a}	85.5^{a}	82.5^{a}	84.1^{a}	89.8^{a}	84.4^{a}	78.5^{a}	57.1^{a}	82.2^{a}	87.3^{a}	80.1^{a}	81.6^{a}
No	17,3	17.6^{a}	19.7^{a}	14.5^{a}	17.5^{a}	15.9^{a}	10.2^{a}	15.6^{a}	21.5^{a}	42.9^{a}	17.8^{a}	12.7^{a}	19.9^{a}	18.4^{a}

[a,b,c] Percentages within question and row sharing different letters are significantly different

References

Barcellos, de M. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: consumer trends and emerging markets. In J. P. Kerry & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Woodhead Publishing Limited, Cambridge, New Delhi.

Bardsley, N. (2000). *Ready meals: Market Report Plus 2000* (5th ed.). Key Note Publications.

Beasley, T. M., & Schumacker, R. E. (1995). Multiple Regression Approach to Analyzing Contingency Tables: Post Hoc and Planned Comparison Procedures. *The Journal of Experimental Education*, *64*(1), 79–93.

Bødker, M., Pisinger, C., Toft, U., & Jørgensen, T. (2015). The rise and fall of the world's first fat tax. *Health Policy*, *119*(6), 737–742.

Booth, D., & Shepherd, R. (1988). Sensory influences on food acceptance - the neglected approach to nutrition promotion. *British Nutrition Foundation Bulletin*, *13*, 39–54.

Brady, M. (2002). Sodium - Survey of the usage and functionality of salt as an ingredient in UK manufactured food products. *British Food Journal*, *104*(2), 84–125.

Branch, V. I. (2015). http://www.revenue.ie/en/tax/vat/leaflets/food-and-drink.html. Last access August 2015.

Caraher, M., & Lang, T. (1999). Can't cook, won't cook: A review of cooking skills and their relevance to health promotion. *International Journal of Health Promotion and Education*, *37*(3), 89.

Chobanian, A. V., Bakris, G. L., Black, H. R., Cushman, W. C., Green, L. A., & Izzo, J. L. (2003). *National High Blood Pressure Education Program Coordinating Committee. Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure.*

Clark, J. (1998). Taste and flavour: their importancein food choice and acceptance. *Proceedings of the Nutrition Society*, *57*(4), 639–643.

Davies, D. (2001). Review of the UK marketplace for convenience foods. *Nutrition and Food Science*, *31*(6), 322–323.

Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Müller, R., & Meijer, G. (2009). Strategies to reduce sodium consumption: a food industry perspective. *Food Science & Nutrition*, *49*(10), 841–851.

Duffey, K., & Gordon-Larsen, P. (2010). Food price and diet and health outcomes: 20 years of the CARDIA Study. *Archives of Internal*, *170*(5), 420–427.

Eaton, S., & Konner, M. (1985). Paleolithic nutrition. A consideration of its nature and current implications. *The New England Journal of Medicine*, *312*(5), 283–289.

Furey, S., McIlveen, H., Strugnell, C., & Armstrong, G. (2000). Cooking skills: a diminishing art? *Nutrition and Food Science*, *30*(5), 263–266.

Giasson, S., Israelachvili, J., & Yoshizawa, H. (1997). Thin film morphology and tribology study of mayonnaise. *Journal of Food Science*, *62*, 640.

Guerrero, L., Guàrdia, M. D., Xicola, J., Verbeke, W., Vanhonacker, F., Zakowska-Biemans, S., Hersleth, M. (2009). Consumer-driven definition of traditional food products and innovation in traditional foods. A qualitative cross-cultural study. *Appetite*, *52*(2), 345–354.

Hansch, C., Leo, A. J., & Hoekman, D. (1995). *Exploring QSAR. Hydrophobic, Electronic, and Steric Constants.* Washington, American Chemical Society.

Härkänen, T., Kotakorpi, K., Pietinen, P., Pirttilä, J., Reinivuo, H., & Suoniemi, I. (2014). The welfare effects of health-based food tax policy. *Food Policy*, *49*, 196–206.

Harrison, M. (2001). Working wives lead to big chill. *Food Processing*, *70*(8), 17.

He, F. J., & MacGregor, G. A. (2007). Dietary salt, igh blood pressure and other harmful effects on health. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 18–54). Woodhead Publishing Limited, Cambridge, England.

He, F. J., Markandu, N. D., Sagnella, G. a, & MacGregor, G. a. (2001). Effect of salt intake on renal excretion of water in humans. *Hypertension*, *38*(3), 317–320.

Henderson, L., Irving, K., Gregory, J., Bates, C., Prentice, A., Perks, J., Farren, M. (2003). *National Diet & Nutrition Survey: Adults aged 19 to 64. Vitamin and mineral intake and urinary analytes*.

Hitchman, C., Christie, I., Harrison, M., & Lang, T. (Eds.). (2002). *Inconvenience food. The struggle to eat well on a low income*. DEMOS, London.

Hochberg, Y. (1988). A sharper Bonferroni test for multiple tests of significance. *Biometrika*, *75*(4), 800–802.

Hoog, E., Ruijschop, R. A., Kok, S., Pyett, P., & NIZO Food Research, B. (2011). The functional attributes that fats bring to food. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 29–46). Woodhead Publishing Limited, Oxford, Cambridge, Philadelphia, New Delhi.

Hutton, T. (2002). Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

James, W., Nelson, M., Ralph, A., & Leather, S. (1997). Socio-economic determinants of health: the contribution of nutrition to inequalities in health. *British Medical Journal*, *314*(7093), 1545–1550.

Joossens, J. V, Hill, M. J., Elliott, P., Stamler, R., Lesaffre, E., Dyer, Kesteloot, H. (1996). Dietary salt, nitrate and stomach cancer mortality in 24 countries. European Cancer Prevention (ECP) and the INTERSALT Cooperative Research Group. *International Journal of Epidemiology*, *25*(3), 494–504.

Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, *33*(3-4), 147–152.

Keys, A. (1970). Coronary heart disease in seven countries. *Circulation*, *41*(1), 186–195.

Kilcast, D., & Angus, F. (2007). Introduction. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. XV–XVI). Woodhead Publishing Limited, Cambridge, England.

Kilcast, D., & Ridder, den C. (2007). Sensory issues in reducing salt in food products. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 201–220). Woodhead Publishing Limited, Cambridge, England.

Kilcast, D., & Ridder, C. (2007). Sensory issues in reducing salt in food products. In D. Kilgast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 201–220). Woodhead Publishing Limited, Cambridge, England.

Lewington, S., Clarke, R., Qizilbash, N., Peto, R., & Collins, R. (2002). Age-specific relevance of usual blood pressure to vascular mortality: A Meta-analysis of individual data for one million adults in 61 prospective studies. *Lancet*, *360*(9349), 1903–1913.

Lindsay, R. (2007). Flavours. In S. Damodaran, K. L. Parkin, & O. R. Fennema (Eds.), *Fennema's Food Chemistry* (4th ed.). Taylor and Francis Group.

Lopez, A. D., & Murray, C. C. J. L. (1998). The global burden of disease 1990-2020. *Nature Medicine*, *4*, 1241–1243.

Luengo, G., Tsuchiya, M., Heuberger, M., & Israelachvili, J. (1997). Thin film rheology and tribology of chocolate. *Journal of Food Science*, *62*, 767.

MacMahon, S., Peto, R., Cutler, J., Collins, R., Sorlie, P., Neaton, J., Stamler, J. (1990). Blood pressure, stroke, and coronary heart disease. Part 1, Prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *Lancet*, *335*(8692), 765–774.

Man, C. (2007). Technological functions of salt in food products. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 157–173). Woodhead Publishing Limited, Cambridge, England.

McClements, D. J. (2004). *Food emulsions: Principles, Practice and Techniques.* (2nd ed.). CRC Press, Boca Raton, New York.

Mennell, S., Murcott, A., & Van Otterloo, A. (1993). *The Sociology of Food, Eating, Diet and Culture* (2nd editio). SAGE Publications Ltd.

Murcott, A. (2000). Is it still a pleasure to cook for him? Social changes in the household and the family. *Journal of Consumer Studies and Home Economics*, *24*(2), 78–84.

Nestle, M. (2002). *Food Politics - How the Food Industry Influences Nutrition and Health*. University of California Press., London.

Niebylski, M. L., Redburn, K. a., Duhaney, T., & Campbell, N. R. (2015). Healthy food subsidies and unhealthy food taxation: A systematic review of the evidence. *Nutrition*, *31*(6), 787–795.

Purdy, J., & Arrmstrong, G. (2007). Dietary salt and the consumer: reported consumption and awarness of associated health risks-A consumer perspective. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 106–116). Woodhead Publishing Limited, Cambridge, England.

Quality_and_Qualifications_Ireland. (2003). http://www.qqi.ie/Pages/National-

Framework-of-Qualifications-(NFQ).aspx. Last access August 2015.

Ronteltap, a., van Trijp, J. C. M., Renes, R. J., & Frewer, L. J. (2007). Consumer acceptance of technology-based food innovations: Lessons for the future of nutrigenomics. *Appetite*, *49*(1), 1–17.

Talbot, G. (2011). Saturated fats in foods and strategies for their replacement: an introduction. In G. Talbot (Ed.), *Reducing saturated fats in foods*. Woodhead Publishing Limited, Cambridge, New Delhi.

Tobin, B., O'Sullivan, M., Hamill, R., & Kerry, J. (2014). European consumer attitudes on the associated health benefits of neutraceutical-containing processed meats using Co-enzyme Q10 as a sample functional ingredient. *Meat Science*, *97*(2), 207–213.

Warwick, J. (1998). *Food choices of young people in Northern Ireland - the influences and health implications*. University of Ulster, Northern Ireland.

Whelton, P. K., Perneger, T. V., He, J., & Klag, M. J. (1996). The role of blood pressure as a risk factor for renal disease: A review of the epidemiological evidence. *Journal of Human Hypertension*, *10*(10), 683–689.

WHO. (2000). *Obesity: preventing and managing the global epidemic*. World Health Organization.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2010). *Global status report on noncommunicable diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

Zock, P. (2006). Health problems associated with saturated and trans fatty acids intake. In C. Williams & J. Buttriss (Eds.), *Improving the fat content of foods* (pp. 3 – 24). Woodhead Publishing Ltd , Cambridge.

Chapter 4

Impact of varying salt and fat levels on the physico-chemical properties and sensory quality of white pudding

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Abstract

Twenty-five white pudding formulations were produced with varying fat contents (20%, 15%, 10%, 5%, 2.5% w/w) and varying sodium contents (1.0%, 0.8%, 0.6%, 0.4%, 0.2% w/w). Compositional analysis, cooking loss, colour and texture profile analysis were determined. Sensory acceptance testing using untrained assessors (n = 25 - 30) was performed in duplicate on products for liking of appearance, flavour, texture, colour and overall acceptability, followed by ranking descriptive analysis using the descriptors grain quantity, fatness, spiciness, saltiness, juiciness, toughness and off-flavour. Puddings containing higher sodium levels (1.0%, 0.8%) were the most accepted, with the exception of those with the lowest fat content. Lower fat and salt puddings were tougher, less juicy, less spicy, lighter and had a more intense yellow colour ($P < 0.05$). However, the pudding sample containing 15% fat and 0.6% sodium was highly accepted ($P < 0.05$), thereby satisfying the sodium target (0.6%) set by the Food Safety Authority of Ireland (FSAI, 2011).

4.1 Introduction

White pudding meat products are popular in Ireland and in the United Kingdom and contribute particularly a special feature of the traditional Western European breakfast. In general, it is manufactured from lean pork meat, pork fat, grains, onions, salt and seasonings, and is similar in nature to black pudding products, but lacks the blood component present in the latter form. The fat content of commercial available white puddings range from 6.0% to 22.4% though the majority of the products contain between 12% and 18% fat (unpublished data, 2013). Additionally, the level of sodium concentrations determined in these products has been reported to range from 520 mg/100 g and 1190 mg/100 g, with an average level of 867 mg/100 g (FSAI, 2014).

Meat and meat products play an important role in the human diet providing a great source of minerals like iron and zinc, B-vitamins and proteins which contain all nine essential amino acids. Conversely, over-consumption of meat and meat products has been linked with obesity, cancer and cardiovascular diseases primarily due to the high amounts of sodium chloride and saturated fat present in processed products (Cross et al., 2007; Halkjaer, Tjønneland, Overvad, & Sørensen, 2009; Li, Siriamornpun, Wahlqvist, Mann, & Sinclair, 2005; Micha, Wallace, & Mozaffarian, 2010). Generally, 75% to 80% of salt is added during product manufacture, 5% of the dietary salt occurs naturally in foods and the remaining percentages (~15%) are added during cooking or at the table by the consumers themselves (Mattes & Donnelly, 1991; OMS, 2002). The demand for healthier food has increased in the last two decades. Consequently, food and regulatory bodies have targeted issues like salt and fat reduction in processed products. Organizations like the World Health Organization (WHO) and Food Safety Authority of Ireland (FSAI) are driving measures to reduce salt and saturated fat content in foods by raising the consumers' awareness and setting guidelines around ingredient usage for companies. Currently WHO recommends a daily salt consumption of less than 5 grams (WHO, 2012) and furthermore they suggest a daily intake of polyunsaturated fatty acids (PUFAs) between 6% and 11% based on daily energy intake (WHO, 2003). Recently, the FSAI agreed a guideline with the Irish meat industry to reduce the sodium level in white and black pudding to 600 mg/100g (FSAI, 2011). However, there are several compromises to achieve this such as using leaner meat, less fat and salt, more water, replacing parts of animal fat with plant oil, or the application of fat and salt replacers. Previous studies have already investigated fat and salt reduced meat products in frankfurters, ground beef and pork patties, cooked bologna type sausages, pork breakfast sausages (Jeong et al., 2007; Ruusunen et al., 2005; Tobin, O'Sullivan, Hamill, & Kerry, 2012a, 2012b, 2013; Ventanas, Puolanne, & Tuorila, 2010). Significant differences in physicochemical properties and sensory qualities were found in all these reports. These effects are caused by the functional roles of salt and fat in processed meat. Fat interacts with other ingredients, induces mouth-feel, texture and lubrication. In turn, salt is important for the water holding capacity and acts as a preservative and flavour enhancer (Chantrapornchai, McClements, & Julian, 2002; Giese, 1996; Gillette, 1985; Hutton, 2002; McCaughey, 2007; Wood & Fisher, 1990).

From research conducted to date, it has become clear that successful salt and fat reduction in processed meats is product specific and no research has been carried out on salt and fat reduction in meat pudding products. Therefore, the objective of this study was to optimize the effects of reducing fat and salt levels on the physicochemical and sensory properties of white pudding products without using fat and salt replacers, to produce highly accepted end products.

4.2 Materials and Methods

4.2.1 Sample preparation

Lean pork trimming (visual lean score of 95%) and pork fat were obtained from a local supplier (Ballyburden Meats Ltd., Ballincollig, Cork, Ireland) and were minced to a particle size of 10 mm and 5 mm, respectively (TALSABELL SA., Valencia, Spain). Afterwards, the minced meat and fat were vacuum packed and stored at – 20 ºC. Required portions of frozen meat and fat were taken out to defrost at 4 ºC for 12 hr before white pudding production commenced. The ingredients were weighed in accordance with formulations shown in Table 1. The required meat, fat, seasoning, salt and three quarters of the water were fed into a bowl chopper (Seydelmann KG, Aalen, Germany) and chopped at high speed (3000 rpm) for 45 sec, followed by the addition of the remaining water and mixed again at high speed for 30 sec. The required pinhead oatmeal and dried onions were then added and chopped at a low speed (1500 rpm) for 15 sec. Finally, added boiled pearl barley and rusk were chopped at low speed for 30 sec. The white pudding batter was transferred into the casing filler (MAINCA, Barcelona, Spain) and loaded into polyamide casings. The white puddings were then cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) using 100% steam at 85 ºC until the internal temperature reached 75 ºC, as measured by a temperature probe (Testo 110, Lenzkirch, Germany). This temperature was held for 15 min. Following the cooking process, the white puddings were immediately put in the chiller to cool down and stored there at 4 ºC. All sausage batches were produced in replicate.

4.2.2 Reheating procedure

Before serving white pudding at home, usually the cut slices are cooked in a frying pan. For experimental purpose the reheating step was standardized with all samples cut into 1.2 cm thick slices, placed on aluminium plates and dry cooked at 100 ºC for 7 min in a Zanussi convection oven (C. Batassi, Conegliano, Italy). The slices were then turned and heated up again at 100 ºC for 7 min to reach a core temperature of 74 ºC.

4.2.3 Sensory evaluation

The sensory acceptance test was conducted using untrained assessors (n = 25 - 30) (Stone, Bleibaum, & Thomas, 2012a; Stone & Sidel, 2004) in the age range of 18 – 60. They were chosen on the basis that they consumed white pudding products regularly. The experiment was conducted in panel booths which conform to the International Standards (ISO, 1988). The sensory test was split into five sessions, whereby five reheated samples (coded and presented in a randomised order) were served cold to the assessors to ensure comparability. The assessors were asked to assess, on a continuous line scale from 1 to 10 cm, the following attributes: liking of appearance, liking of flavour, liking of texture, liking of colour and overall acceptability (hedonic). Samples were presented in duplicate (Stone, Bleibaum, & Thomas, 2012b). The assessors then participated in a ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio, & Benassi, 2010) using the consensus list of sensory descriptors including grain quantity, fatness, spiciness, saltiness, juiciness, toughness and off-flavour, which was also measured on a 10 cm line scale. All samples were again presented in duplicate (Stone et al., 2012b).

4.2.4 Fat and moisture analysis

Approximately 1.0 g of each of the homogenised vacuum packed white pudding samples was measured before and after reheating in triplicate using SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) for analysing moisture and fat, respectively (Bostian, Fish, Webb, & Arey, 1985).

4.2.5 Protein analysis

Protein content was determined before and after reheating (in triplicate) using the Kjeldahl method (Suhre, Corrao, Glover, & Malanoski, 1982). Approximately 1.0 g - 1.5 g of homogenised sample was weighed into a digestion tube to which 2 catalyst tabs (each tab containing 3.5 g potassium sulphate and 3.5 mg selenium), 15 ml concentrated sulphuric acid (nitrogen free) and 10 ml 30% hydrogen peroxide (w/w) were added. Additionally, a blank tube was prepared similarly to serve as a control. Afterwards, the tubes were placed in a digestion block (FOSS, Tecator ^{TM} digestor, Hillerød, Denmark), heated up to 410 ºC and then held for 1hr. After cooling, 50 ml of distilled water were added to each tube, which were then placed into the distillation unit (FOSS, Kjeltec ^{TM} 2100, Hillerød, Denmark) along with a receiver flask containing 50 ml 4% boric acid with bromcresol green and methyl red indicator. Seventy ml of 30% sodium hydroxide (w/w) were added to the tube before the 5 min distillation started. The content of the receiver flask was titrated with 0.1 N hydrochloric acid until the green colour reverted back to red.

4.2.6 Ash analysis

Before and after reheating, ash concentration was carried out on triplicate samples using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of blended sample was weighed into porcelain dishes and placed into the muffle furnace. In stages the furnace was heated up to 600 ºC for 12 hr, and then cooled down. To increase the surface area of the pre-ashed sample, distilled water was added and the sample heated again stepwise to 600 ºC until a white ash was presented.

4.2.7 Salt analysis

Before and after reheating, salt content was obtained using the potentiometric method (Fox, 1963) by utilising a PHM82 Standard pH Meter (Radiometer, Copenhagen) fitted with a combined Ag electrode (M295, Radiometer Analytical SAS, Lyon, France) and a reference electrode Ag/AgCl buffered with KCl (pH C3006, Radiometer Analytical SAS, Lyon, France). Approximately 2.0 g of homogenised samples were weighed in triplicate into a wide-necked flask to which 100 ml of 0.1% nitric acid was added. The solutions were then mixed and covered with aluminium foil. The flasks were placed in a 60 ºC water bath for 15 min. The flasks were then allowed to cool down to room temperature. Employing magnetic stirring, the flasks were potentiometrically titrated with 0.1 N silver nitrate until the endpoint +255 mV was reached.

4.2.8 Cooking loss analysis

Triplicate samples of approximately 150-170 g were cut in 1.2 cm thick slices and placed on aluminum plates. Before reheating (section 2.2), product weights were recorded. After reheating, samples were allowed to cool down at room temperature for 20 min and then weighed again to obtain the cooking loss.

4.2.9 Colour analysis

Triplicate colour analysis was undertaken on the reheated samples by utilising a Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan) with 11 mm aperture and D_{65} illuminant. The tristimulus values were expressed in L (lightness), a (red-green dimension) and b (yellow-blue dimension) (International Commission on Illumination, 1976). After calibration using a white tile, ten readings were then taken per sample.

4.2.10 Texture analysis

After reheating, the texture of white pudding samples was determined in triplicate using texture profile analysis (TPA) (Bourne, 1978) with a Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K). Pudding slices (1.2 cm in thickness) were compressed, in two-cycles using a cross-head speed of 1.5 mm/s, to 40% of their original size using a 35 mm diameter cylindrical probe (SMSP/35Compression plate) attached to a 25 kg load cell. The following parameters were measured: hardness [N], springiness [dimensionless], cohesiveness [dimensionless] and chewiness [N]. The compression of the product in two-cycles reflects two human bites with, the hardness being the required force to compress food at first bite, which represents the peak force of the first cycle. Springiness describes how well the sample springs back to the original size after deformation, calculated as the ratio of length below graph 2 until maximum force 2 divided by length below graph 1 until maximum force 1. How well the internal structure of a sample withstands compression is expressed by the cohesiveness, which is the ratio of work during compression of the second cycle divided by the first one. Chewiness reflects the required work to chew solid food to a state ready for swallowing, calculated as the product of hardness, springiness and cohesiveness.

4.2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 9.7. The X-matrix was designed as 0/1 variables for fat and salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 17% and 13% respectively.

For evaluation the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$). The compositional data were evaluated using t-test, two-tailed and equal variances (software Microsoft Excel 2010, TTest).

4.3 Results and discussion

4.3.1 Sensory evaluation

The results of the sensory evaluation are presented in the APLSR plot in Figure 1 and in conjunction with ANOVA values including significance and correlation factors presented in Table 2 for hedonic and descriptive sensory assessments, respectively. The compositional properties of cooked and reheated white puddings with varying salt and fat levels are shown in Table 3.

From Figure 1, in the upper right hand quadrant, liking of appearance can be seen to be correlated to puddings with higher fat and salt levels. In Table 2, samples with fat levels from 20% to 10% and sodium levels from 1.0% to 0.8% were positively

($P < 0.05$) correlated to liking of appearance. From Figure 1, in the lower left hand quadrant, the 2.5% fat samples showed a negative correlation to liking of appearance for all five sodium concentrations. Therefore, liking of appearance is clearly correlated to product fat content.

For samples high in fat and salt a positive ($P < 0.01$) correlation to liking of colour is presented in Table 2. As can be seen in Table 4, higher fat samples (10% - 20%) were shown to have a lower ($P < 0.05$) lightness (L) values than lower fat samples. Higher salt samples achieved lower ($P < 0.05$) yellowness (b) values. No trend was observed for redness (a) upon variation of fat and salt levels. In summary, assessors preferred darker pudding samples which possessed the lowest hues of yellowness.

Generally, higher fat samples were positively correlated to fat perception and lower fat samples were negatively correlated (Table 2). Samples containing 5% fat and sodium contents of 0.4% and lower, and accordingly samples containing 2.5% fat (independently of the used salt levels) were negatively ($P < 0.05$) correlated to fatness (Table 2). From Table 1, all white pudding formulations contained the same amount of seasoning, however, samples with a fat content of 2.5% were shown to have a negative correlation with respect to saltiness and spiciness, even for samples high in salt (Table 2). In short, salt and fat synergistically effect salt, fat and spiciness perceptions in white pudding products. Saltiness, fatness and spiciness are important attributes which contribute to flavour perception. Previously published data by Wood & Fisher (1990) and Giese (1996) postulated that fats interact with other ingredients within a meat system contributing to overall flavour. Additionally, Hutton (2002) observed that salt improves not only saltiness perception, but also, the flavour of other compounds in processed foods. This assumption, namely that salt and fat play a key role in enhancing flavour, is supported by this study.

From Figure 1, in the upper right hand quadrant, liking of texture can be seen to be correlated to puddings with higher fat and salt levels. Puddings with lower fat levels and with a high salt content (1.0% - 0.8%) tended to be positively correlated to liking of texture and lower salt samples with a variety of fat contents were negatively assessed by assessors (Table 2). It seems that salt had a larger influence of liking of white pudding texture than fat.

Grain quantity, toughness and juiciness are essential attributes when describing the texture of white puddings. The use of grains, oatmeal and barley, are important pudding additives, which are required to achieve the typical texture associated with white pudding products. Assessors found no significant correlation to intensity of graininess, which is consistent with the pudding formulations (Table 1). Thus, salt and fat content in white pudding products did not influence grain sensory perception.

From Table 2 it can be seen that puddings with a varying fat level from 20% to 5% and a high sodium content ranging from 1.0% to 0.6% were scored ($P < 0.05$) lower for toughness and higher for juiciness. High scores for toughness and low scores for juiciness were determined by the panelists for all 2.5% fat samples, which are consistent with previously reported studies (Berry & Leddy, 1984; Ruusunen et al., 2005; Sofos & Allen, 1977). Lower salt white puddings were positively ($P < 0.05$) correlated to toughness and negatively correlated to juiciness. Thus, inverse instrumental results to toughness (hardness) are shown in Table 4. Hamm (1972) explained sodium chloride interaction with meat as follows: chloride ions are bound more strongly to proteins than sodium and consequently the negative charges associated with proteins rise. This induces repulsion between the myofibrillar proteins which causes a partial solubilisation of filaments, and a swelling of myofibrillar proteins. Subsequently, the polar groups of the amino acids bind water by van der Waals forces and the non-polar groups press the polar water molecules to an arched shaped structure encircling the non-polar groups. This combined effect causes a tension which forces the water molecules into the protein network system, thereby causing swelling of myofibrillar proteins which is depending upon pH. Swelling reaches a minimum at pH 5 in meat without salt and at pH 4 in meat with 2% added salt caused by shifting of the isoelectric point of the proteins. Furthermore, Desmond (2006) correlates an increase in water holding capacity of myofibrillar proteins in processed meat (as a result of adding sodium chloride) to a reduction in cooking loss and an increase in tenderness and juiciness. Tobin et al. (2012a, 2012b, 2013) found that higher salt levels resulted in; beef patties with higher sensory scores for toughness and juiciness, in frankfurters with lower scores for toughness and juiciness and in pork breakfast sausages with lower scores for toughness and higher scoring for juiciness. Thus, salt content in meat products is insufficient in explaining the sensory properties of toughness and juiciness entirely. The type and amount of meat and fat, the amount of other added ingredients (e.g. grains, rusk, seasoning, onions, blood, innards and additives), type of meat product, and utilized processes like chopping time, heating time and temperature may also influence the interaction. To understand these other possible complex interactions further studies are necessary. However, in the present study white pudding products showed similar results with respect to toughness and juiciness perception when compared to that study reported by Tobin et al. (2012a) for frankfurters, even if instrumental analyses presented inverse results.

In Table 2, samples with 0.2% sodium and low fat (5% - 2.5%) were determined to be positively ($P < 0.05$) correlated to off-flavour. A negative correlation ($P < 0.05$) to off-flavour was achieved for samples with 20% fat and 1.0% sodium and 15% fat and 0.8% sodium, respectively. For the remaining samples, no significant correlations were found. Therefore perceived off-flavours in white puddings are due to very low salt and fat levels.

From Figure 1, in the lower right hand quadrant of the plot, the hedonic attributes liking of flavour and overall acceptability correlate to white puddings with fat contents from 20% to 5% and sodium levels from 1.0% to 0.8%. For these samples a positive ($P < 0.05$) result to liking of flavour and overall acceptability were achieved (Table 2). Concentrations of 0.2% sodium in puddings for all fat levels had negative ($P < 0.05$) correlations to liking of flavour and overall acceptability. Therefore, sodium affects, to a greater extent, the attributes of flavour liking and overall acceptability than fat. Only one of the 25 samples examined in this study, which possessed 15% fat, showed a positive ($P < 0.01$) correlation to flavour liking/overall acceptability with the recommended sodium level of 0.6% (FSAI, 2011) which makes it difficult to achieve assessor accepted fat reductions below this level for white pudding products. However, for the sodium concentration of 0.6% a positive direction to correlation (not significant), to liking of flavour and acceptance is presented for the 10% fat sample, and liking of flavour for the 5% fat sample. Thus, there is potential for using salt and fat replacers to reach significant results. Hence, further studies are necessary in order to establish solutions.

4.3.2 Characterization of white pudding samples

The compositional properties of cooked and reheated white pudding products with varying salt and fat levels are presented (Table 3). Fat and salt levels in cooked white puddings were close to the designed model. In general, cooked puddings had ($P < 0.05$) lower fat and ($P < 0.05$) higher water concentrations than those observed in reheated samples. Tobin et al. (2012a) reported a decrease in fat and moisture levels after cooking frankfurters high in fat (25%, 20%) and for all salt levels (3% - 1%). In contrast, lower fat frankfurters (15%, 10%) showed an increase in fat and a decrease in moisture, which is similar to that observed in the present study. Additionally, Jeong et al. (2007) postulated a decrease of fat in higher fat (20%) ground pork patties and an increase of fat in lower fat (10%) patties after cooking. Due to cooking effects in lower fat meat products, fat loss may be overlaid by the water loss resulting in higher fat concentrations in the final product. Furthermore, decreasing the fat content in the recipe resulted in increasing the water content. As shown (Table 1) less fat usage in recipes was balanced with meat. Lean pork meat contains more water than pure pork fat (Souci, Fachmann, & Kraut, 2004). Similar findings were observed by Keeton (1983). Additionally, meat is a protein source, therefore, protein content increased with decreasing fat level. Ash contains inorganic substances like sodium chloride. As expected, ash content in white pudding samples increased with increasing salt content.

Varying fat levels in pudding products have shown differences ($P < 0.05$) in cooking losses (Table 4). With decreasing fat content, cooking loss increased from 8% to 13%. In contrast, Ruusunen et al. (2005) reported increased cooking losses in higher fat ground meat patties. No significant effect was determined in terms of cooking loss through varying salt levels. This is contrary to that reported in previous studies (Puolanne & Ruusunen, 1980; Ruusunen et al., 2005).

As seen in Table 4, higher fat samples (10% -20%) were shown to have lower ($P < 0.05$) lightness (L) values than lower fat samples, which is similar to the study undertaken by Tobin et al. (2013). In contrast, Youssef & Barbut (2011) reported no significant differences in lightness values owing to fat variations in processed meat products. Contrary to Tobin et al. (2013) higher salt samples had lower ($P < 0.05$) yellowness (b) values than those determined in the present study. Additionally, it seems that different fat and salt levels did not affect redness (a) values.

Results from texture profile analysis are presented in Table 4. Differences ($P < 0.05$) in hardness, cohesiveness and chewiness were observed by varying salt and fat levels, though no significant differences in springiness. Samples with decreasing fat levels showed increases in hardness and chewiness. Previous studies have presented both, similar (Hand, Hollingsworth, Calkins, & Mandigo, 1987; Tobin et al., 2012b, 2013) and contrasting results (Claus, Hunt, & Kastner, 1990; Hensley & Hand, 1995; Youssef & Barbut, 2011). Furthermore, in the present study no impact on cohesiveness was observed for these samples, which means the amount of fat in white pudding does not influence the strength of internal bounds. However, samples with reduced salt levels had decreased hardness, chewiness and cohesiveness values. Hence, salt reduced white pudding samples are supposed to need less force to bite, less work to chew and have less strength of internal bonds compared to samples higher in salt. Differences in hardness were also observed by the assessors, although these differences in hardness are not consistent with the instrumental results. For instance, white pudding samples containing 5% fat and 0.8% sodium exhibited a hardness value of 80.5 ± 3.2 N and were scored ($P < 0.001$) lower for toughness by the consumer. Samples containing 15% fat and 0.2% sodium were rated ($P < 0.01$) higher for toughness, although less force with 31.4 ± 3.5 N was needed to compress. However, in the previous study by Tobin et al. (2012a) salt reduced frankfurters also had lower hardness values, additionally showing that sensory results differed to TPA. This indicates in this case, TPA was not able to reflect human masticatory movements.

4.4 Conclusion

Varying salt and fat levels in white pudding products showed a range of effects on sensory quality and physicochemical properties. For pudding samples with varying salt levels, the texture analyzer did not compare favorably with the sensory evaluation data. However, samples low in fat and salt were significantly lighter and more intensive yellow in colour. Additionally, the sensory assessed samples containing 0.4% and 0.2% sodium content were tougher, lower in juiciness, spiciness, saltiness and fatness, even for the higher fat samples. Moreover, all samples with 2.5% fat were scored similarly for all salt levels. These samples were not accepted by the assessors. Therefore, the critical acceptable limits in reducing sodium and fat were achieved at 0.6% sodium and at 5% fat level, respectively. Salt and fat have shown a synergistic effect in developing flavour and this is why samples with 15% fat and 0.6% sodium and with 5% fat and 0.8% sodium were the most significantly acceptable pudding variants. Hence, only one of 25 assessed pudding samples (15% fat, 0.6% sodium) achieved the recommended sodium target level of 0.6% by the FSAI (2011) and was accepted by assessors. However, a trend in liking of flavour and overall acceptability was shown for white puddings containing 10% fat and 0.6% sodium, and liking of flavour for the sample containing 5% fat and 0.6% sodium. Thus, there is potential for further optimization of low salt and low fat white pudding products using salt and fat replacers.

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4.5 Tables and Figures

Table 1

White pudding formulations.

Sample [a]	Formulation [%]								
	Meat	Fat	Salt	Water	Seasoning	Oatmeal	Onion	Boiled barley	Rusk
F 20 Na 1.0	18.44	30.77	2.54	27.00	1.00	11.00	2.50	4.35	2.40
F 20 Na 0.8	18.95	30.77	2.03	27.00	1.00	11.00	2.50	4.35	2.40
F 20 Na 0.6	19.46	30.77	1.52	27.00	1.00	11.00	2.50	4.35	2.40
F 20 Na 0.4	19.96	30.77	1.02	27.00	1.00	11.00	2.50	4.35	2.40
F 20 Na 0.2	20.47	30.77	0.51	27.00	1.00	11.00	2.50	4.35	2.40
F 15 Na 1.0	26.13	23.08	2.54	27.00	1.00	11.00	2.50	4.35	2.40
F 15 Na 0.8 [b]	26.64	23.08	2.03	27.00	1.00	11.00	2.50	4.35	2.40
F 15 Na 0.6	27.15	23.08	1.52	27.00	1.00	11.00	2.50	4.35	2.40
F 15 Na 0.4	27.66	23.08	1.02	27.00	1.00	11.00	2.50	4.35	2.40
F 15 Na 0.2	28.17	23.08	0.51	27.00	1.00	11.00	2.50	4.35	2.40
F 10 Na 1.0	33.83	15.38	2.54	27.00	1.00	11.00	2.50	4.35	2.40
F 10 Na 0.8	34.33	15.38	2.03	27.00	1.00	11.00	2.50	4.35	2.40
F 10 Na 0.6	34.84	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40
F 10 Na 0.4	35.35	15.38	1.02	27.00	1.00	11.00	2.50	4.35	2.40
F 10 Na 0.2	35.86	15.38	0.51	27.00	1.00	11.00	2.50	4.35	2.40
F 5 Na 1.0	41.52	7.69	2.54	27.00	1.00	11.00	2.50	4.35	2.40
F 5 Na 0.8	42.03	7.69	2.03	27.00	1.00	11.00	2.50	4.35	2.40
F 5 Na 0.6	42.53	7.69	1.52	27.00	1.00	11.00	2.50	4.35	2.40
F 5 Na 0.4	43.04	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40
F 5 Na 0.2	43.55	7.69	0.51	27.00	1.00	11.00	2.50	4.35	2.40
F 2.5 Na 1.0	45.36	3.85	2.54	27.00	1.00	11.00	2.50	4.35	2.40
F 2.5 Na 0.8	45.87	3.85	2.03	27.00	1.00	11.00	2.50	4.35	2.40
F 2.5 Na 0.6	46.38	3.85	1.52	27.00	1.00	11.00	2.50	4.35	2.40
F 2.5 Na 0.4	46.89	3.85	1.02	27.00	1.00	11.00	2.50	4.35	2.40
F 2.5 Na 0.2	47.40	3.85	0.51	27.00	1.00	11.00	2.50	4.35	2.40

[a] Sample code: F = fat, Na = sodium.

[b] Salt and fat content of sample is comparable to the average salt and fat content of commercial white puddings.

Table 2

P-values of regression coefficients from ANOVA values of regression coefficients from APLSR for the hedonic and intensity sensory terms of reheated white puddings, including significance and correlation

Sample [a]	Hedonic part [b]					Intensity part						
	Appearance	Flavour	Texture	Colour	Acceptability	Grains	Fatness	Spiciness	Saltiness	Juiciness	Toughness	Off-flavour
F 20 Na 1.0	4.4E-05 ***	0.0005 ***	4.2E-0.5 ***	0.0001 ***	0.0002 ***	0.1166 ns	0.0001 ***	0.7374 ns	0.0067 **	4.1E-06 ***	-1.4E-05 ***	-0.0348 *
F 20 Na 0.8	0.0404 *	0.3149 ns	0.0782 ns	0.0693 ns	0.1975 ns	0.2151 ns	0.0149 *	0.4974 ns	0.5476 ns	0.0155 *	-0.0145 *	-0.0901 ns
F 20 Na 0.6	0.134 ns	0.2764 ns	0.4262 ns	0.3295 ns	0.6682 ns	0.4418 ns	0.0021 **	0.0019 **	0.0709 ns	0.0040 **	-0.0006 ***	-0.3119 ns
F 20 Na 0.4	-0.3770 ns	-0.1454 ns	-0.8448 ns	-0.7013 ns	-0.3636 ns	-0.5739 ns	-0.0049 **	-0.0017 **	-0.0427 *	-0.0122 *	0.0017 **	0.4289 ns
F 20 Na 0.2	-0.4834 ns	-0.0008 ***	-0.1231 ns	-0.2132 ns	-0.0046 **	-0.9825 ns	-0.0185 *	-3.5E-05 ***	-0.0001 ***	-0.1032 ns	0.0009 ***	0.9703 ns
F 15 Na 1.0	0.0001 ***	0.0001 ***	0.0001 ***	0.0001 ***	0.0001 ***	0.1131 ns	0.0006 ***	0.1119 ns	0.0003 ***	0.0001 ***	-0.0037 **	-0.0586 ns
F 15 Na 0.8	0.0004 ***	0.0012 **	0.003 ***	0.0006 ***	0.0005 ***	0.1071 ns	0.0019 **	0.3101 ns	0.0059 **	0.0005 ***	-0.0123 *	-0.0396 *
F 15 Na 0.6	0.0012 **	0.0035 **	0.0009 ***	0.0017 **	0.0018 **	0.1079 ns	0.0010 ***	0.2988 ns	0.0053 **	0.0005 ***	-0.0087 **	-0.0566 ns
F 15 Na 0.4	0.0099 **	0.1614 ns	0.0189 *	0.0186 *	0.0815 ns	0.1683 ns	0.0005 ***	0.2091 ns	0.4019 ns	0.0007 ***	-0.0003 ***	-0.0818 ns
F 15 Na 0.2	-0.2869 ns	-0.0025 **	-0.0639 ns	-0.1111 ns	-0.0062 **	-0.8442 ns	-0.0788 ns	-0.0002 ***	-0.0008 ***	-0.3380 ns	0.0057 **	0.8522 ns
F 10 Na 1.0	0.0142 *	0.0001 ***	0.0033 **	0.0096 **	0.0003 ***	0.4706 ns	0.5747 ns	4.4E-05 ***	0.0001 ***	0.3940 ns	-0.0584 ns	-0.3884 ns
F 10 Na 0.8	0.0004 ***	0.0001 ***	0.0002 ***	0.0006 ***	0.0001 ***	0.1804 ns	0.0209 *	0.0005 ***	4.3E-05 ***	0.0020 **	-0.1751 ns	-0.0966 ns
F 10 Na 0.6	0.2042 ns	0.1856 ns	0.1794 ns	0.1916 ns	0.1743 ns	0.3221 ns	0.4567 ns	0.4046 ns	0.1996 ns	0.3247 ns	-0.6538 ns	-0.3049 ns
F 10 Na 0.4	-0.8821 ns	-0.1254 ns	-0.5272 ns	-0.6284 ns	-0.2035 ns	-0.9126 ns	-0.1288 ns	-0.0206 *	-0.0676 ns	-0.2850 ns	0.0634 ns	0.8506 ns
F 10 Na 0.2	-0.0267 *	-0.0001 ***	-0.0031 **	-0.0128 *	-0.0002 ***	-0.6168 ns	-0.1803 ns	-0.0001 ***	-0.0001 ***	-0.9047 ns	0.0180 *	0.5704 ns
F 5 Na 1.0	0.5891 ns	0.0041 **	0.1834 ns	0.3015 ns	0.0147 *	0.9925 ns	0.0612 ns	0.0003 ***	0.0017 **	0.2167 ns	-0.0179 *	-0.9600 ns
F 5 Na 0.8	0.8763 ns	0.0009 ***	0.1818 ns	0.3903 ns	0.0039 **	0.8633 ns	0.0029 **	9.6E-06 ***	0.0001 ***	0.0073 **	-0.0003 ***	-0.7625 ns
F 5 Na 0.6	0.4645 ns	0.1507 ns	0.9771 ns	0.8179 ns	0.3233 ns	0.6215 ns	0.0100 **	0.0107 *	0.0672 ns	0.0228 *	-0.0048 **	-0.4944 ns
F 5 Na 0.4	-0.0158 *	-0.0307 *	-0.0137 *	-0.0168 *	-0.0232 *	-0.1432 ns	-0.0164 *	-0.6661 ns	-0.0558 ns	-0.0141 *	0.0316 *	0.0992 ns
F 5 Na 0.2	-4.5E-0.5 ***	-0.0001 ***	-3.7E-05 ***	-0.0001 ***	-2.4E-05 ***	-0.1447 ns	-0.0013 **	-0.0189 *	-0.0002 ***	-0.0002 ***	0.0043 **	0.0376 *
F 2.5 Na 1.0	-0.0781 ns	-0.1399 ns	0.2281 ns	-0.1891 ns	-0.7039 ns	-0.4173 ns	-0.0002 ***	-0.0001 ***	-0.0201 *	-0.0003 ***	0.0001 ***	0.2529 ns
F 2.5 Na 0.8	-0.0078 **	-0.7628 ns	-0.0390 *	-0.0227 *	-0.2690 ns	-0.1845 ns	-0.0003 ***	-0.0036 **	-0.4180 ns	-0.0005 ***	0.0005 ***	0.1439 ns
F 2.5 Na 0.6	-0.1421 ns	-0.8491 ns	-0.2143 ns	-0.2674 ns	-0.8220 ns	-0.3809 ns	-0.0057 **	-0.0338 *	-0.4653 ns	-0.0103 *	0.0017 **	0.2195 ns
F 2.5 Na 0.4	-0.0011 **	-0.0252 *	-0.0033 **	-0.0021 **	-0.0098 **	-0.1082 ns	-0.0004 ***	-0.6327 ns	-0.0899 ns	-0.0003 ***	0.0009 ***	0.0617 ns
F 2.5 Na 0.2	-0.0003 ***	-0.0001 ***	-2.7E-05 ***	-0.0003 ***	-0.0001 ***	-0.1359 ns	-3.7E-05 ***	-0.2381 ns	-0.0001 ***	-1.2E-06 ***	0.0001 ***	0.0310 *

[a] Sample code: F = fat, Na = sodium.

[b] Significance of regression coefficients: ns = not significant, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

Table 3

Compositional properties of cooked and reheated white pudding samples containing different fat and salt levels

Sample [c]	Fat [%] [d]		Moisture [%]		Protein [%]		Ash [%]		Sodium [%]	
	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated
F 20 Na 1.0	20.1 ± 0.3 ^{a}	23.0 ± 0.5 ^{b}	53.4 ± 0.7 ^{a}	48.3 ± 0.3 ^{b}	8.1 ± 0.1 ^{a}	9.1 ± 0.1 ^{b}	2.8 ± 0.1 ^{a}	3.3 ± 0.0 ^{b}	1.0 ± 0.0 ^{a}	1.1 ± 0.0 ^{b}
F 20 Na 0.8	19.4 ± 0.6 ^{a}	21.8 ± 0.3 ^{b}	55.0 ± 0.7 ^{a}	49.0 ± 0.1 ^{b}	8.1 ± 0.1 ^{a}	9.2 ± 0.1 ^{b}	2.4 ± 0.1 ^{a}	2.8 ± 0.0 ^{b}	0.8 ± 0.0 ^{a}	0.9 ± 0.0 ^{b}
F 20 Na 0.6	20.8 ± 0.3 ^{a}	23.4 ± 0.6 ^{b}	53.9 ± 0.3 ^{a}	47.0 ± 0.3 ^{b}	8.4 ± 0.1 ^{a}	9.4 ± 0.2 ^{b}	2.2 ± 0.0 ^{a}	2.3 ± 0.0 ^{b}	0.6 ± 0.0 ^{a}	0.7 ± 0.0 ^{b}
F 20 Na 0.4	20.5 ± 0.5 ^{a}	23.0 ± 0.8 ^{b}	54.9 ± 0.6 ^{a}	49.4 ± 0.8 ^{b}	8.8 ± 0.2 ^{a}	9.7 ± 0.1 ^{b}	1.5 ± 0.1 ^{a}	1.7 ± 0.0 ^{b}	0.4 ± 0.0 ^{a}	0.5 ± 0.0 ^{b}
F 20 Na 0.2	20.5 ± 0.2 ^{a}	21.4 ± 0.6 ^{a}	55.1 ± 0.2 ^{a}	50.4 ± 0.3 ^{b}	9.0 ± 0.1 ^{a}	10.3 ± 0.1 ^{b}	1.1 ± 0.0 ^{a}	1.1 ± 0.0 ^{b}	0.2 ± 0.0 ^{a}	0.3 ± 0.0 ^{b}
F 15 Na 1.0	16.8 ± 0.1 ^{a}	18.5 ± 0.5 ^{b}	56.8 ± 0.9 ^{a}	51.4 ± 0.9 ^{b}	9.3 ± 0.1 ^{a}	10.7 ± 0.1 ^{b}	3.0 ± 0.1 ^{a}	3.3 ± 0.1 ^{b}	1.0 ± 0.0 ^{a}	1.2 ± 0.0 ^{b}
F 15 Na 0.8	15.9 ± 0.1 ^{a}	17.3 ± 0.5 ^{b}	57.8 ± 0.5 ^{a}	53.6 ± 0.5 ^{b}	9.2 ± 0.1 ^{a}	10.5 ± 0.2 ^{b}	2.5 ± 0.0 ^{a}	2.9 ± 0.0 ^{b}	0.8 ± 0.0 ^{a}	1.0 ± 0.0 ^{b}
F 15 Na 0.6	16.0 ± 0.4 ^{a}	17.6 ± 0.5 ^{b}	58.3 ± 0.2 ^{a}	53.4 ± 0.7 ^{b}	9.4 ± 0.1 ^{a}	11.3 ± 0.2 ^{b}	2.0 ± 0.0 ^{a}	2.3 ± 0.1 ^{b}	0.6 ± 0.0 ^{a}	0.7 ± 0.0 ^{b}
F 15 Na 0.4	16.2 ± 0.2 ^{a}	17.4 ± 0.3 ^{b}	58.5 ± 0.6 ^{a}	54.6 ± 0.3 ^{b}	9.7 ± 0.1 ^{a}	11.2 ± 0.2 ^{b}	1.5 ± 0.1 ^{a}	1.8 ± 0.0 ^{b}	0.4 ± 0.1 ^{a}	0.5 ± 0.0 ^{b}
F 15 Na 0.2	15.4 ± 0.7 ^{a}	16.7 ± 0.2 ^{a}	60.1 ± 0.2 ^{a}	55.3 ± 0.5 ^{b}	9.8 ± 0.2 ^{a}	11.3 ± 0.3 ^{b}	1.1 ± 0.1 ^{a}	1.2 ± 0.0 ^{b}	0.2 ± 0.0 ^{a}	0.3 ± 0.0 ^{b}
F 10 Na 1.0	11.3 ± 0.3 ^{a}	13.2 ± 0.2 ^{b}	60.7 ± 0.2 ^{a}	55.9 ± 0.4 ^{b}	10.4 ± 0.1 ^{a}	11.6 ± 0.2 ^{b}	3.0 ± 0.0 ^{a}	3.4 ± 0.0 ^{b}	1.0 ± 0.0 ^{a}	1.2 ± 0.0 ^{b}
F 10 Na 0.8	11.3 ± 0.1 ^{a}	13.5 ± 0.1 ^{b}	61.6 ± 0.4 ^{a}	55.8 ± 0.2 ^{b}	10.5 ± 0.1 ^{a}	11.9 ± 0.1 ^{b}	2.6 ± 0.0 ^{a}	2.9 ± 0.0 ^{b}	0.8 ± 0.0 ^{a}	1.0 ± 0.0 ^{b}
F 10 Na 0.6	10.8 ± 0.2 ^{a}	12.5 ± 0.2 ^{b}	62.7 ± 0.3 ^{a}	56.9 ± 0.0 ^{b}	11.2 ± 0.2 ^{a}	12.2 ± 0.1 ^{b}	2.2 ± 0.1 ^{a}	2.4 ± 0.1 ^{b}	0.6 ± 0.0 ^{a}	0.7 ± 0.0 ^{b}
F 10 Na 0.4	11.0 ± 0.2 ^{a}	12.1 ± 0.1 ^{b}	63.0 ± 0.3 ^{a}	57.8 ± 0.5 ^{b}	10.8 ± 0.1 ^{a}	12.3 ± 0.2 ^{b}	1.6 ± 0.1 ^{a}	1.9 ± 0.1 ^{b}	0.4 ± 0.0 ^{a}	0.5 ± 0.0 ^{b}
F 10 Na 0.2	11.5 ± 0.3 ^{a}	12.8 ± 0.4 ^{b}	62.2 ± 0.3 ^{a}	58.2 ± 0.6 ^{b}	10.8 ± 0.2 ^{a}	12.4 ± 0.1 ^{b}	1.1 ± 0.1 ^{a}	1.2 ± 0.1 ^{a}	0.2 ± 0.0 ^{a}	0.3 ± 0.0 ^{b}
F 5 Na 1.0	5.9 ± 0.1 ^{a}	6.3 ± 0.1 ^{b}	65.0 ± 0.1 ^{a}	61.4 ± 0.2 ^{b}	11.6 ± 0.1 ^{a}	13.1 ± 0.3 ^{b}	3.2 ± 0.0 ^{a}	3.4 ± 0.1 ^{b}	1.0 ± 0.0 ^{a}	1.2 ± 0.0 ^{b}
F 5 Na 0.8	6.2 ± 0.2 ^{a}	6.8 ± 0.2 ^{a}	65.3 ± 0.3 ^{a}	61.0 ± 0.1 ^{b}	11.9 ± 0.1 ^{a}	13.5 ± 0.2 ^{b}	2.7 ± 0.0 ^{a}	3.0 ± 0.1 ^{b}	0.8 ± 0.0 ^{a}	1.0 ± 0.0 ^{b}
F 5 Na 0.6	5.7 ± 0.2 ^{a}	6.8 ± 0.2 ^{b}	65.7 ± 0.1 ^{a}	61.4 ± 0.7 ^{b}	11.9 ± 0.1 ^{a}	13.1 ± 0.2 ^{b}	2.2 ± 0.0 ^{a}	2.3 ± 0.1 ^{b}	0.6 ± 0.0 ^{a}	0.7 ± 0.0 ^{b}
F 5 Na 0.4	5.8 ± 0.2 ^{a}	6.8 ± 0.1 ^{b}	66.1 ± 0.4 ^{a}	62.1 ± 0.2 ^{b}	11.6 ± 0.2 ^{a}	13.4 ± 0.2 ^{b}	1.7 ± 0.0 ^{a}	1.9 ± 0.0 ^{b}	0.4 ± 0.0 ^{a}	0.5 ± 0.0 ^{b}
F 5 Na 0.2	5.0 ± 0.2 ^{a}	6.5 ± 0.2 ^{b}	67.9 ± 0.5 ^{a}	63.3 ± 0.3 ^{b}	12.5 ± 0.1 ^{a}	14.2 ± 0.1 ^{b}	1.1 ± 0.0 ^{a}	1.3 ± 0.0 ^{b}	0.2 ± 0.0 ^{a}	0.3 ± 0.0 ^{b}
F 2.5 Na 1.0	2.6 ± 0.1 ^{a}	3.0 ± 0.2 ^{b}	68.4 ± 0.2 ^{a}	64.1 ± 0.3 ^{b}	12.3 ± 0.2 ^{a}	13.9 ± 0.1 ^{b}	3.2 ± 0.1 ^{a}	3.6 ± 0.1 ^{b}	1.0 ± 0.0 ^{a}	1.1 ± 0.0 ^{b}
F 2.5 Na 0.8	2.6 ± 0.1 ^{a}	3.7 ± 0.2 ^{b}	68.4 ± 0.3 ^{a}	63.4 ± 0.6 ^{b}	13.1 ± 0.2 ^{a}	14.4 ± 0.1 ^{b}	2.7 ± 0.0 ^{a}	3.1 ± 0.0 ^{b}	0.8 ± 0.0 ^{a}	1.0 ± 0.0 ^{b}
F 2.5 Na 0.6	2.6 ± 0.1 ^{a}	3.4 ± 0.1 ^{b}	69.2 ± 0.1 ^{a}	63.9 ± 0.5 ^{b}	12.1 ± 0.2 ^{a}	14.0 ± 0.1 ^{b}	2.1 ± 0.1 ^{a}	2.5 ± 0.0 ^{b}	0.6 ± 0.0 ^{a}	0.7 ± 0.0 ^{b}
F 2.5 Na 0.4	2.7 ± 0.1 ^{a}	3.7 ± 0.1 ^{b}	68.0 ± 0.3 ^{a}	63.8 ± 0.2 ^{b}	13.2 ± 0.3 ^{a}	14.6 ± 0.1 ^{b}	1.7 ± 0.0 ^{a}	2.0 ± 0.0 ^{b}	0.4 ± 0.0 ^{a}	0.5 ± 0.0 ^{b}
F 2.5 Na 0.2	2.9 ± 0.1 ^{a}	3.8 ± 0.1 ^{b}	68.7 ± 0.3 ^{a}	64.1 ± 0.2 ^{b}	13.3 ± 0.1 ^{a}	14.8 ± 0.2 ^{b}	1.2 ± 0.0 ^{a}	1.5 ± 0.0 ^{b}	0.2 ± 0.0 ^{a}	0.3 ± 0.0 ^{b}

[a-b] Averages of each composition analyses sharing different letters are significantly different (two tailed t-test, $p < 0.05$).

[c] Sample code: F = fat, Na = sodium.

[d] All values are averages ± standard errors.

Table 4

Colour, texture profile and cooking loss values of reheated white pudding samples containing different fat and salt levels

Sample [o]	Colour [p]			Texture profile analysis				Cooking loss
	L*	a*	b*	Hardness [N]	Springiness	Cohesivness	Chewiness [N]	[%]
F 20 Na 1.0	50.3 ± 0.3^{jkl}	3.9 ± 0.1^{abcdef}	17.8 ± 0.2^{de}	40.7 ± 1.9^{fg}	0.77 ± 0.02^{a}	0.47 ± 0.01^{ab}	14.9 ± 1.2^{ghijk}	8.5 ± 0.3^{gh}
F 20 Na 0.8	51.6 ± 0.4^{fghij}	3.6 ± 0.1^{fghi}	17.7 ± 0.3^{de}	39.8 ± 2.4^{g}	0.76 ± 0.02^{a}	0.47 ± 0.01^{ab}	14.2 ± 1.0^{hijk}	8.5 ± 0.2^{fgh}
F 20 Na 0.6	50.6 ± 0.4^{jkl}	3.9 ± 0.1^{cdef}	17.5 ± 0.3^{ef}	43.4 ± 1.8^{fg}	0.78 ± 0.02^{a}	0.44 ± 0.01^{abcdef}	15.0 ± 1.0^{ghij}	8.6 ± 0.2^{fgh}
F 20 Na 0.4	49.5 ± 0.4^{lm}	4.1 ± 0.1^{abcd}	19.0 ± 0.2^{bc}	29.2 ± 1.8^{h}	0.75 ± 0.03^{a}	0.41 ± 0.02^{efg}	9.0 ± 0.8^{n}	8.3 ± 0.1^{h}
F 20 Na 0.2	49.6 ± 0.4^{lm}	4.3 ± 0.1^{a}	19.1 ± 0.2^{bc}	31.5 ± 2.3^{h}	0.77 ± 0.02^{a}	0.39 ± 0.01^{g}	9.5 ± 0.8^{lmn}	9.1 ± 0.2^{efgh}
F 15 Na 1.0	51.9 ± 0.5^{efghi}	3.2 ± 0.1^{jk}	16.6 ± 0.3^{g}	44.4 ± 1.5^{fg}	0.76 ± 0.01^{a}	0.47 ± 0.01^{abc}	15.8 ± 0.7^{ghi}	10.0 ± 0.1^{defg}
F 15 Na 0.8	49.8 ± 0.4^{klm}	3.9 ± 0.1^{bcdef}	18.5 ± 0.3^{cd}	39.6 ± 1.4^{g}	0.76 ± 0.02^{a}	0.43 ± 0.02^{cdefg}	12.9 ± 0.8^{ijk}	10.1 ± 0.5^{def}
F 15 Na 0.6	49.9 ± 0.4^{klm}	4.0 ± 0.1^{abcd}	18.4 ± 0.2^{cd}	39.2 ± 2.0^{g}	0.73 ± 0.06^{a}	0.42 ± 0.03^{defg}	11.9 ± 0.9^{klm}	10.6 ± 0.1^{d}
F 15 Na 0.4	51.3 ± 0.4^{ghij}	3.7 ± 0.1^{efgh}	18.6 ± 0.3^{cd}	39.5 ± 1.7^{g}	0.75 ± 0.04^{a}	0.40 ± 0.03^{fg}	11.8 ± 0.6^{jklmn}	10.2 ± 0.3^{de}
F 15 Na 0.2	51.9 ± 0.4^{efgh}	3.9 ± 0.1^{bcdef}	19.1 ± 0.3^{bc}	31.4 ± 2.0^{h}	0.73 ± 0.03^{a}	0.40 ± 0.02^{efg}	9.3 ± 1.0^{mn}	10.3 ± 0.6^{de}
F 10 Na 1.0	49.0 ± 0.2^{m}	3.8 ± 0.1^{cdef}	18.3 ± 0.2^{cde}	65.1 ± 3.8^{de}	0.80 ± 0.02^{a}	0.45 ± 0.01^{abcde}	22.9 ± 1.4^{d}	11.2 ± 0.1^{cd}
F 10 Na 0.8	52.5 ± 0.3^{defg}	3.4 ± 0.1^{hijk}	16.8 ± 0.2^{fg}	66.0 ± 2.0^{de}	0.79 ± 0.02^{a}	0.46 ± 0.01^{abcd}	23.9 ± 1.1^{cd}	11.1 ± 0.1^{bcd}
F 10 Na 0.6	53.5 ± 0.3^{abcd}	3.5 ± 0.1^{ghij}	17.9 ± 0.2^{de}	47.1 ± 1.5^{f}	0.74 ± 0.02^{a}	0.42 ± 0.02^{defg}	14.4 ± 0.6^{hijk}	11.3 ± 0.2^{bcd}
F 10 Na 0.4	50.9 ± 0.3^{hijk}	4.1 ± 0.1^{abc}	19.7 ± 0.3^{ab}	42.0 ± 1.8^{fg}	0.75 ± 0.02^{a}	0.40 ± 0.01^{fg}	12.5 ± 0.6^{jkl}	11.7 ± 0.3^{abcd}
F 10 Na 0.2	52.6 ± 0.3^{cdef}	4.2 ± 0.1^{ab}	20.0 ± 0.2^{a}	42.4 ± 1.5^{fg}	0.74 ± 0.02^{a}	0.39 ± 0.01^{g}	12.4 ± 0.8^{jkl}	11.4 ± 0.3^{bcd}
F 5 Na 1.0	53.8 ± 0.3^{abc}	3.2 ± 0.1^{jk}	16.6 ± 0.2^{g}	78.7 ± 2.5^{bc}	0.79 ± 0.02^{a}	0.47 ± 0.02^{ab}	29.3 ± 1.7^{b}	12.2 ± 0.2^{abc}
F 5 Na 0.8	50.6 ± 0.3^{ijkl}	3.6 ± 0.1^{efgh}	17.7 ± 0.2^{de}	80.5 ± 1.0^{b}	0.76 ± 0.02^{a}	0.43 ± 0.01^{bcdefg}	26.5 ± 1.2^{bc}	12.6 ± 0.3^{abc}
F 5 Na 0.6	53.9 ± 0.4^{ab}	3.4 ± 0.1^{hijk}	18.3 ± 0.3^{cde}	62.8 ± 1.1^{e}	0.76 ± 0.03^{a}	0.42 ± 0.02^{defg}	19.7 ± 0.9^{ef}	12.5 ± 0.2^{abc}
F 5 Na 0.4	54.0 ± 0.3^{ab}	4.1 ± 0.1^{abcd}	19.5 ± 0.3^{ab}	60.2 ± 0.8^{e}	0.74 ± 0.01^{a}	0.40 ± 0.02^{efg}	18.0 ± 0.6^{efg}	12.8 ± 0.2^{ab}
F 5 Na 0.2	54.0 ± 0.3^{ab}	4.1 ± 0.1^{abcd}	19.5 ± 0.3^{ab}	59.9 ± 2.8^{e}	0.72 ± 0.03^{a}	0.40 ± 0.02^{efg}	17.2 ± 0.9^{fgh}	13.0 ± 0.2^{a}
F 2.5 Na 1.0	52.6 ± 0.3^{cdef}	3.2 ± 0.1^{ijk}	16.64 ± 0.2^{g}	100.3 ± 3.2^{a}	0.81 ± 0.04^{a}	0.47 ± 0.01^{abcd}	38.2 ± 1.7^{a}	12.5 ± 0.4^{abc}
F 2.5 Na 0.8	53.1 ± 0.3^{bcde}	3.1 ± 0.1^{k}	16.3 ± 0.2^{g}	99.6 ± 4.0^{a}	0.79 ± 0.03^{a}	0.48 ± 0.02^{a}	37.5 ± 1.3^{a}	12.7 ± 0.2^{abc}
F 2.5 Na 0.6	53.0 ± 0.3^{bcde}	3.9 ± 0.1^{bcdef}	18.1 ± 0.2^{de}	72.6 ± 1.6^{bcd}	0.73 ± 0.02^{a}	0.41 ± 0.01^{defg}	21.8 ± 0.8^{de}	12.7 ± 0.2^{abc}
F 2.5 Na 0.4	53.6 ± 0.3^{abcd}	3.7 ± 0.1^{defg}	18.6 ± 0.2^{cd}	72.8 ± 1.7^{c}	0.76 ± 0.02^{a}	0.39 ± 0.02^{g}	21.7 ± 0.9^{de}	12.9 ± 0.2^{a}
F 2.5 Na 0.2	54.7 ± 0.3^{a}	3.6 ± 0.1^{efgh}	18.2 ± 0.2^{cde}	74.1 ± 4.3^{bc}	0.73 ± 0.05^{a}	0.40 ± 0.02^{fg}	21.6 ± 2.3^{de}	13.1 ± 0.4^{a}

[a-n] Averages sharing different letters in the same column are significantly different ($P < 0.05$).

[o] Sample code: F = fat, Na = sodium

[p] All values are averages ± standard errors.

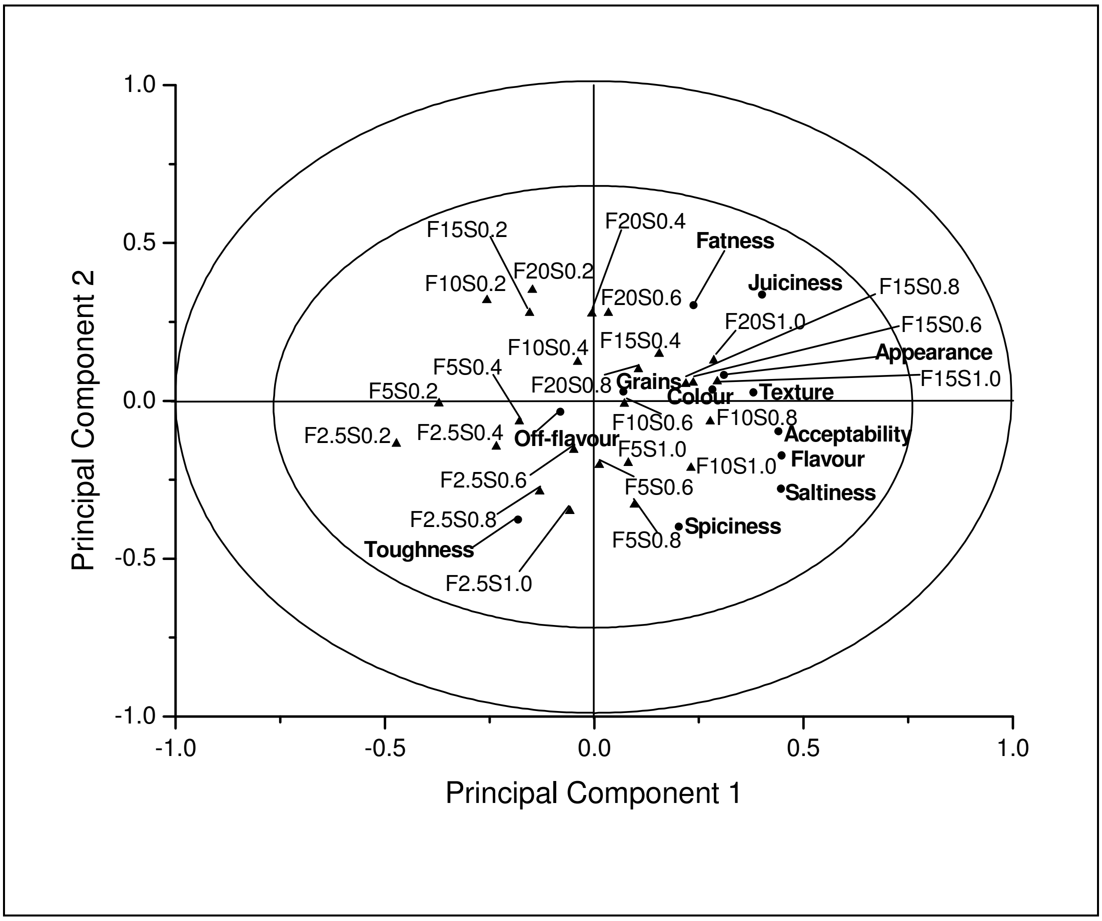

Figure 1:

ANOVA-Partial Least Squares regression (APLSR) for the 25 post-cooked white pudding formulations. ▲ = Samples (code: F = fat, S = sodium), ● = sensory attributes.

References

AOAC. (1923). Determination of ash. *Journal of the Association of Official Analytical Chemists*, *7*, 132. Association of Official Agricultural Chemists.

Berry, B. W., & Leddy, K. F. (1984). Effects of fat level and cooking method on sensory and textural properties of ground beef patties. *Journal of Food Science*, *49*, 870 – 875.

Bostian, M. L., Fish, D. L., Webb, N. B., & Arey, J. J. (1985). Automated methods for determination of fat and moisture in meat and poultry products: collaborative study. *Journal of the Association of Official Analytical Chemists*, *68*(5), 876–880.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, *32* , 62–66.

Chantrapornchai, W., McClements, D. J., & Julian, D. (2002). Influence of NaCl on optical properties, large-strain rheology and water holding capacity of heat-induced whey protein isolate gels. *Food Hydrocolloids*, *16*(5), 467–476.

Claus, J. R., Hunt, M. C., & Kastner, C. L. (1990). Effects of substituting added water for fat on the textural, sensory, and processing characteristics of bologna. *Journal of Muscle Foods*, *1*(1), 1–21.

Cross, A. J., Leitzmann, M. F., Gail, M. H., Hollenbeck, A. R., Schatzkin, A., & Sinha, R. (2007). A Prospective Study of Red and Processed Meat Intake in Relation to Cancer Risk. *PLOS Medicine*, *4*(12), 1973 – 1984.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Fox, P. F. (1963). Potentiometric determination of salt in cheese. *Journal of Dairy Science*, *46*, 744 – 745.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period : September 2003 to July 2014*. The Food Safety Authority of Ireland.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Gillette, M. (1985). Flavor effects of sodium chloride. *Food Technology*, *39*, 47–56.

Halkjaer, J., Tjønneland, A., Overvad, K., & Sørensen, T. I. a. (2009). Dietary predictors of 5-year changes in waist circumference. *Journal of the American Dietetic Association*, *109*(8), 1356–66.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

Hand, L. W., Hollingsworth, C. a., Calkins, C. R., & Mandigo, R. W. (1987). Effects of Preblending, Reduced Fat and Salt Levels on Frankfurter Characteristics. *Journal of Food Science*, *52*(5), 1149–1151.

Hensley, J. & Hand, L. (1995). Formulation and Copping Temperature Effects on Beef Frankfurters. *Journal of Food Science*, *60*(1), 55–57.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

International Commission on Illumination. (1976). ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space.

ISO. (1988). Sensory analysis. General guidance for the design of test rooms. Ref. no. *International Organization for Standardization, Genève, Switzerland*, ISO 8589:1988. International Organization for Standardization.

Jeong, J. Y., Lee, E. S., Choi, J. H., Lee, J. Y., Kim, J. M., Min, S. G., Kim, C. J. (2007). Variability in temperature distribution and cooking properties of ground pork patties containing different fat level and with/without salt cooked by microwave energy. *Meat Science*, *75*(3), 415–22.

Keeton, J. T. (1983). Effects of Fat and NaCl/Phosphate Levels on the Chemical and Sensory Properties of Pork Patties. *Journal of Food Science*, *48*(3), 878–881.

Li, D., Siriamornpun, S., Wahlqvist, M. L., Mann, N. J., & Sinclair, A. J. (2005). Lean meat and heart health. *Asia Pacific Journal of Clinical Nutrition*, *14*(2), 113–119.

Martens, H., & Martens, M. (2001). *Multivariate Analysis of Quality. An Introduction. Measurement Science and Technology* (2nd ed., Vol. 12). John Wiley & Sons Ltd.

Mattes, R. D., & Donnelly, D. (1991). Relative contributions of dietary sodium sources. *Journal of the American College of Nutrition*, *10*(4), 383–393.

McCaughey, S. (2007). Salt and Flavor: Mechanisms of Taste Perception and Physiological Controls. In K. D. & A. F. (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 78–99). Boca Raton Boston, New york, Washington-DC: Woodhead Publishing Ltd.

Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus. A systematic review and meta-analysis. *Circulation*, *121*(21), 2271–2283.

OMS. (2002). Rapport sur la santé dans le monde 2002 : réduire les risques et promouvoir une vie saine. *Organisation Mondiale de La Santé*, 262.

Puolanne, E., & Ruusunen, M. (1980). Kochsalz und Phosphat in ihrer Wirkung auf das Wasserbindungsvermögen von Brühwurst. *Fleischwirtschaft*, *60*, 1359–1362.

Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, *21*(6), 611–620.

Ruusunen, M., Vainionpää, J., Lyly, M., Lähteenmäki, L., Niemistö, M., Ahvenainen, R., & Puolanne, E. (2005). Reducing the sodium content in meat products: The effect of the formulation in low-sodium ground meat patties. *Meat Science*, *69*(1), 53–60.

Sofos, J. N., & Allen, C. E. (1977). Effects of lean meat source and levels of fat soy protein on the properties of wiener-type products. *Journal of Food Science*, *42*(4), 875–878.

Souci, S.W., Fachmann, W., & Kraut, H. (2004). *Der kleine Souci Fachmann Kraut. Lebensmitteltabelle fuer die Praxis. Wissenschaftliche Verlagsgesellschaft mbH Stuttgart* (3rd ed.). Wissenschaftliche Verlagsgesellschaft.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, B. R.N., & H. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 291 – 325). USA: Elsevier Academic Press.

Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, Bleibaum R.N., & H. A. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 117 – 157). USA: Elsevier Academic Press.

Stone, H., & Sidel, J. L. (2004). Affective testing. *In: H. Stone and J. L. Sidel (Eds.), Sensory Evaluation Practices. Food Science and Technology, International Series. USA: Academic Press/Elsevier.*, *3rd ed.*, 247–277.

Suhre, F. B., Corrao, P. A., Glover, A., & Malanoski, A. J. (1982). Comparison of three methods for determination of crude protein in meat: collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*(6), 1339–1345.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, *85*(3), 410–419.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

Wood, J. D., & Fisher, A. V. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). Elsevier Applied Science, London.

Youssef, M. K., & Barbut, S. (2011). Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil. *Meat Science*, *87*(4), 356–360.

Chapter 5

Effect of using ingredient replacers on the physico-chemical properties and sensory quality of low salt and low fat white puddings

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Keywords: White pudding, Salt and fat reduction, Ingredient replacers, Sensory test, Texture profile analysis

Abstract

White pudding, popular in Europe and America, is a processed meat product containing generally pork meat, fat, seasonings, bread, oatmeal and other cereal grains. To achieve highly accepted low sodium and low fat white puddings, 22 formulations comprised of two different fat (10%, 5%) and sodium (0.6%, 0.4%) levels and containing 11 different ingredient replacers were produced. Compositional, texture and sensory analysis were conducted. Adding replacers to low sodium and low fat white puddings showed a range of effects on sensory and physicochemical properties. Two formulations containing 10% fat and 0.6% sodium formulated with sodium citrate, as well as the combination of potassium chloride and glycine (KClG), were found to have overall acceptance ($P < 0.05$) by assessors. These samples showed higher ($P < 0.05$) hardness values, scored lower ($P < 0.05$) in fatness perception and higher ($P < 0.05$) in spiciness perception. Hence, the recommended sodium target level of 0.6% set by the Food Safety Authority of Ireland (FSAI) 2011 was achieved for white pudding products, in addition to a significant reduction in fat level from commercial levels, without causing negative sensory attributes.

5.1 Introduction

Oatmeal pudding (white pudding), popular in Europe and America, is a processed meat product containing generally pork meat, fat, seasonings, bread, oatmeal and other cereal grains. These puddings can be filled into large sausage casings, formed into a semi-solid congealed loaf or encased in an animals' stomach and cooked whole, cut into slices, fried or grilled. Recipes and servings differ dramatically from country to country. "White pudding", known in Ireland and Great Britain is a special feature of the traditional Irish and British breakfast (Ayto, 1990).

Across the years numerous researchers have increasingly postulated that sodium chloride and saturated fatty acids in food are related to particular diseases (Cross et al., 2007; Halkjaer, Tjønneland, Overvad, & Sørensen, 2009; Li, Siriamornpun, Wahlqvist, Mann, & Sinclair, 2005; Micha, Wallace, & Mozaffarian, 2010). Consequently, the World Health Organization (WHO) has recommended the consumption of foods low in saturated fatty acids and sodium chloride (WHO, 2003, 2012). Sodium chloride occurs in processed meat products, not only present for flavour enhancement, but also for myofibrillar protein extraction, texture improvement and microbial stability. Additionally, meat contains high levels of saturated fatty acids and consequently, advances in current meat processing is directed to producing healthier, low saturated fat-containing processed meat products (Aaslyng, 2009). For these reasons, fat and sodium reductions in processed meats have received considerable recent research focus (Aaslyng, Vestergaard, & Koch, 2014; Cofrades, Hughes, & Troy, 2000; Desmond, Troy, & Buckley, 1998; Fellendorf, O'Sullivan, & Kerry, 2015; Shand, 2000; Tobin, O'Sullivan, Hamill, & Kerry, 2012a, 2012b, 2013).

A small gradual reduction of salt from the recipe can be unnoticed by assessors as the palatability is adjusted to the modified sensory profile (Bertino, Beauchamp, & Engleman, 1982; Puolanne, 2010). Larger reductions can be achieved with a gradual salt reduction over a period of years allowing consumers to get used to lower salt concentrations in food. For instance, to reduce the sodium chloride content in cooked sausages from (2.3 - 2.4%) to (1.5 - 1.7%) took 20 years to achieve in Finland. In several other countries, similar experiences were determined (Ruusunen & Puolanne, 2005). However, international governments and regulatory agencies are now looking for significant salt reduction in foods in the short-term and cannot afford to wait for decades to achieve this overall goal. Therefore, the use of salt replacers and salt enhancers in food products may play essential roles in achieving this. The basis of using salt replacers is to reduce sodium cations with, for example; potassium, magnesium, calcium or to reduce the chloride anions with ingredients such as glutamates, phosphates, etc. as a means of providing salty tastes or flavours (Wheelock & Hobbiss, 1999). The most common choice of salt replacer is potassium chloride, though it is limited in usefulness due to a bitterness attribute associated with it (Dzendolet & Meiselman, 1967). A second approach is the use of salt enhancers. These are substances which possess no salty taste themselves, but with the correct combination of sodium chloride, they enhance the salty flavour (Desmond, 2006). Known salt enhancers include amino acids, lactates, yeast extracts and monosodium glutamate. Researchers have already published successful treatments for salt-reduced processed meat products with added salt replacers. For example, in bologna-type sausages, salt reductions of 20% - 25% were achieved by adding sodium citrate, carrageenan or carboxlmethylcellulose (Ruusunen et al., 2003a). Lopez-Lopez, Cofrades & Jimenez-Colmenero (2009) obtained 50% to 75% salt reduction in frankfurters using KCl, seaweed and olive oil.

Similar approaches were also utilized to reduce the fat content in processed meat. Successful saturated fatty acid reductions were achieved by decreasing the total amount of fat, changing the fat profile using plant, fish and algal oils and applying fat replacers (Weiss, Gibis, Schuh, & Salminen, 2010). Fat replacers are categorized into two groups; fat substitutes and fat mimetics. Fat substitutes display a chemical structure close to fats, have similar physicochemical properties, and are either low in calorie or indigestible, such as; Olestra, Caprenin and Salatrim (Kosmark, 1996; Peters, Lawson, Middleton, & Triebwasser, 1997). By contrast, fat mimetics show distinctly different chemical structures from fat (usually protein and/or carbohydrate based), though some of the physicochemical attributes and eating qualities of fat can be simulated, like; mouth feel, appearance and viscosity (Duflot, 1996; Harrigan & Breene, 1989). The use of fat mimetics in foods is generally more common. For example, Chevance et al. (2000) achieved a fat reduction of 46% in salami, 60% – 83% in frankfurters and 55% in beef patties with tapioca starch and oat fibre or maltodextrin or milk protein.

In the present study, the research focus was directed at white pudding production, typical of those consumed in the United Kingdom and Ireland, which contain lean pork meat, pork fat, grains, onions, salt and seasonings. Commercially-available white pudding products contain fat levels which range from 6.0% to 22.4%, although the majority of products possess between 12% and 18% fat (unpublished data, 2013). The sodium concentrations determined for white pudding samples ranged between 520 mg/100g sample and 1190 mg/100g sample with an average of 867 mg/100g sample (FSAI, 2014). The FSAI have set a guideline for the industry to decrease the sodium level in white pudding to 600 mg/100g (FSAI, 2011). Furthermore, the WHO recommends the dietary consumption of a higher polyunsaturated fatty acids-containing diet (WHO, 2003).

In a previous study conducted by Fellendorf, O'Sullivan & Kerry (2015), white pudding products containing 15% fat and 0.6% sodium were found to be accepted ($P < 0.05$) by assessors without using ingredient replacers. Furthermore, fat reduced white pudding samples containing 10% fat and 0.6% sodium indicated a trend in liking of flavour. Therefore, in the present study, these levels of fat and salt were used to determine if salt and fat replacers could be used to further optimise these formulations in order to achieve significant levels of sensory acceptability. Therefore, the objective of this study was to investigate the interactive effects of varying replacers on the physicochemical and sensory properties of fat and salt reduced white puddings with the target to achieve a highly sensory accepted end product.

5.2 Materials and Methods

5.2.1 Sample preparation

Pork trimming lean (visual lean score of 95%) and pork fat were purchased from a local supplier (Ballyburden Meats Ltd., Ballincollig, Cork, Ireland). The meat and fat were minced to a particle size of 10 mm and 5 mm, respectively (TALSABELL SA., Valencia, Spain), vacuum packed and stored at -20 ºC. Approximately 12 hr before commencing production, required portions of meat and fat were defrosted at 4 ºC. In the present study the impact of 11 different replacer combinations were investigated for white puddings containing either 10% fat and 0.6% sodium or 5% fat and 0.4% sodium (Table 1). The replacers chosen included; wheat bran, sodium citrate, carrageen, pectin, potassium chloride (KCl), a combination of potassium chloride and glycine (KClG), carboxymethylcellulose (CMC), PuraQ®Arome NA4 (PuraQ), seaweed wakame (seaweed), a mixture of potassium citrate, potassium phosphate and potassium chloride (KCPCl) and waxy maize starch (WMS). PuraQ®Arome NA4 (Corbion Purac, Barcelona, Spain) is a product designed for use in savory food products and is a product derived from the fermentation of sugar resulting in a mixture of sugars, salts of organic acids and aromas. The used quantities of the replacers and the detailed formulations of white puddings are listed in Table 1. As the seaweed ingredients (wakame) already contained sodium, a lower amount of salt was required during production in order to achieve target levels (Table 1). The required ingredients were then weighed in accordance with the formulations. In the bowl chopper (Seydelmann KG, Aalen, Germany) the required meat, fat, seasoning, salt, replacer and three-fourths of the required water were chopped at high speed (3000 rpm) for 45 sec, followed by addition and mixing the remaining water at high speed for 30 sec. The required pinhead oatmeal and dried onions were then chopped at low speed (1500 rpm) for 15 sec and finally the required boiled pearl barley and rusk were chopped at low speed for 30 sec. The batter was afterwards loaded into a casing filler (MAINCA, Barcelona, Spain) and filled into polyamide casings and cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) with 100% steam at 85 ºC until the internal temperature reached 75 ºC, and then held for 15 min. The heating process was controlled by using a temperature probe (Testo 110, Lenzkirch, Germany). Subsequently, the white pudding samples were immediately placed in the chiller to cool down and stored there at 4 ºC. All sausage batches were manufactured in replicate.

5.2.2 Reheating procedure

Before serving white pudding at home, usually the cut slices are cooked in a frying pan. For experimental purpose the reheating step was standardized with all samples cut into 1.2 cm thick slices, placed on aluminium plates and dry cooked at 100 ºC for 7 min in a Zanussi convection oven (C. Batassi, Conegliano, Italy). The slices were then turned and heated again at 100 ºC for 7 min to reach a core temperature of 74 ºC.

5.2.3 Sensory evaluation

The sensory acceptance test was conducted using untrained assessors (n = 25 - 28) (Stone, Bleibaum, & Thomas, 2012a; Stone & Sidel, 2004) in the age range of 20 – 60. They were chosen on the basis that they consumed white pudding products regularly. The experiment was conducted in panel booths which conformed to International Standards (ISO, 1988). The sensory test was split into five sessions, whereby five reheated samples (coded and presented in a randomised order) were served cold to the assessors to ensure comparability. All samples were presented in duplicate (Stone, Bleibaum, & Thomas, 2012b). The assessors were asked to assess, on a continuous line scale from 1 to 10 cm, the following attributes: liking of appearance, liking of flavour, liking of texture, liking of colour and overall acceptability (hedonic). The assessors then participated in a ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio, & Benassi, 2010) using the consensus list of sensory descriptors including grain quantity, fatness, spiciness, saltiness, juiciness, toughness and off-flavour (intensity), which was also measured on a 10 cm line scale. All samples were again presented in duplicate (Stone et al., 2012b).

5.2.4 Fat and moisture analysis

Approximately 1.0 g of each of the homogenised vacuum-packed white pudding samples was measured, both before and after reheating in triplicate using the SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) for analysing moisture and fat, respectively (Bostian, Fish, Webb, & Arey, 1985).

5.2.5 Protein analysis

Protein content was determined, both before and after reheating, in triplicate using the Kjeldahl method (Suhre, Corrao, Glover, & Malanoski, 1982). Approximately 1.0 g - 1.5 g of homogenised sample was weighed into a digestion tube to which 2 catalyst tabs (3.5 g potassium sulphate and 3.5 mg selenium per tab), 15 ml concentrated sulphuric acid and 10 ml 30% hydrogen peroxide (w/w) were added. Additionally, a blank tube was prepared similarly to serve as a control. The tubes were then placed in a digestion block (FOSS, Tecator ^{TM} digestor, Hillerød, Denmark), heated up to 410 ºC and held for 1 hr. After cooling, 50 ml of distilled water were added to each tube, which were then placed into the distillation unit (FOSS, Kjeltec ^{TM} 2100, Hillerød, Denmark) along with a receiver flask containing

50 ml 4% boric acid with indicator (bromcresol green and methyl red). A total of 70 ml of 30% sodium hydroxide (w/w) was added to the tube before the 5 min distillation commenced. The content of the receiver flask was titrated with 0.1 N hydrochloric acid until the green colour reverted back to red.

5.2.6 Ash analysis

Both before and after reheating, ash content was determined in triplicate using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of homogenized sample was weighed into crucibles and placed into the muffle furnace. For pre-ashing the samples were heated up to 600 ºC in stages for 12 hr and then cooled down. Distilled water was added to the pre-ashed samples and after it heated up again stepwise to 600 ºC until a white ash was presented.

5.2.7 Salt analysis

5.2.7.1 Potentiometer – Measuring chloride concentration

Both before and after reheating, salt (NaCl) content of white puddings samples containing chloride ions bound only to sodium was obtained using the potentiometric method (Fox, 1963) by utilising a chloride sensitive electrode (Ag electrode in combination with a reference electrode Ag/AgCl buffered with KCl (M295 and pH C3006, Radiometer Analytical SAS, Lyon, France)). Approximately 2.0 g of blended samples were weighed into a flask to which 100 ml of 0.1% nitric acid was added. The solutions were mixed, covered and placed in a 60 ºC water bath for 15 min. After cooling down to room temperature, the flask's contents were potentiometrically titrated with 0.1 N silver nitrate until reaching +255 mV. By means of the ratio to chloride, sodium chloride concentrations were calculated in order to determine sodium content.

5.2.7.2 Flame photometer – Measuring sodium concentration

Sodium content was determined, both before and after reheating (triplicate), using the flame photometer for samples containing chloride ions bound not only to sodium (AOAC, 1988). Firstly, 5.0 g of homogenized sample was ashed (section 2.6). The obtained ash was dissolved with 40 ml concentrated HCl/water (1:3), heated until boiling, then transferred to a 50 ml volumetric flask and filled to the mark.

Subsequently, this solution was filtered. Then the filtrate was diluted within the range of the sodium standard concentrations. Sodium content of the diluted filtrate was then measured using the flame photometer (Jenway PFP7, Essex, England).

5.2.8 Cooking loss analysis

Before reheating (section 2.2), sample weights were recorded. After reheating, samples were allowed to cool down at room temperature for 20 min and then weighed again to obtain the cooking loss. Cooking loss was calculated according to the following equation:

$$\text{Cooking loss [\%]} = \frac{(\text{sample raw} - \text{sample cooked}) \times 100}{\text{sample raw}}$$

5.2.9 Colour analysis

Triplicate colour analysis was undertaken on reheated samples by utilising a Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan), using 2 degree observer with a 11 mm aperture and D_{65} illuminant. Tristimulus values were expressed in L (lightness), a (red-green dimension) and b (yellow-blue dimension) (International Commission on Illumination, 1976). Firstly, a white tile (Y=93.6, x=0.3130, y=0.3193) was applied for calibration the colorimeter, afterwards 10 readings were taken per sample.

5.2.10 Texture analysis

In triplicate the texture parameters hardness, springiness, cohesiveness and chewiness for reheated samples were measured using texture profile analysis (Bourne, 1978) by utilizing the Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K). Pudding slices of 1.2 cm were compressed in two-cycles using a cross-head speed of 1.5 mm/s to 40% of their original size by using a 35 mm diameter cylindrical probe (SMSP/35Compression plate) attached to a 25 kg load cell. The following parameters were measured: hardness [N], springiness [dimensionless], cohesiveness [dimensionless] and chewiness [N]. The compression of the product in two-cycles reflects two human bites with, the hardness being the required force to compress food at first bite, which represents the peak force of the first cycle. Springiness describes how well the sample springs back to the original size after deformation, calculated as the ratio of length below graph 2 until maximum force 2 divided by length below graph 1 until maximum force 1. How well the internal structure of a sample withstands compression is expressed by the cohesiveness, which is the ratio of work during compression of the second cycle divided by the first one. Chewiness reflects the required work to chew solid food to a state ready for swallowing, calculated as the product of hardness, springiness and cohesiveness.

5.2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 10.3. The X-matrix was designed as 0/1 variables for fat and salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 4% and 8% respectively.

For evaluation the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$). The compositional data were evaluated using t-test, two-tailed and equal variances (software Microsoft Excel 2010, TTest).

5.3 Results and discussion

5.3.1 Sensory evaluation

In a previous study by Fellendorf et al. (2015) white pudding samples containing 15% fat and 0.6% sodium were found to be acceptable ($P < 0.05$) by assessors ($n = 25$) without using ingredient replacers. This result satisfied the sodium target (0.6%) set by the Food Safety Authority of Ireland (FSAI, 2011), although a significant fat reduction compared to commercial white puddings was not achieved. Furthermore, fat reduced white pudding samples containing 10% fat and 0.6% sodium showed a non-significant trend in liking of flavour. Therefore, in the present study, these levels of fat and salt were used to determine if salt and fat replacers can be used to further optimise these formulations in order to achieve significant levels of sensory acceptability. Additionally, white pudding samples containing 5% fat and 0.4% sodium were also used as a base formulation for the use of ingredient replacers to determine if further sensory optimised sequential reductions of salt and fat could be achieved. The results of the sensory evaluation of white puddings containing ingredient replacers are displayed in the APLSR plot in Figure 1. This plot gives an overview of the correlation of the attributes and samples. Here, the x-axis of the plot is separated by the y-axis. A positive correlation is presented if the attribute and sample are located on the same side of the x-axis and in close proximity and a negative correlation exists in the inverse case. Table 2 presents the corresponding ANOVA values for Figure 1 and includes significance and correlation factors. A significant difference exists, if the p-value is ≤ 0.05. The direction of the correlation (positive or negative) is represented by a + or - algebraic sign before the p-value.

Liking of appearance and colour

Major meat quality cues such as colour, visible fat and drip are important attributes at point of sale, as an appealing appearance raises consumers' interest (Acebrón & Dopico, 2000; Grunert, Bredahl, & Brunsø, 2004; Steenkamp & Trijp, 1996). From Figure 1, in the right hand quadrant of the plot, liking of appearance correlates mostly to the samples containing 10% fat and 0.6% sodium, with the exception being that for white pudding formulations containing seaweed, PuraQ and KCPCl. As shown in Table 2, these formulations containing seaweed and KCPCl (10% fat and 0.6% sodium) scored negatively ($P < 0.05$) for liking of colour (which might account for the non-correlation to appearance). Additionally, the white pudding formulation containing 5% fat and 0.4% sodium and formulated with seaweed was also determined to be negatively correlated ($P < 0.05$) to liking of colour. As shown in Table 4 samples containing seaweed showed differences in colour as they possessed darker, less-red and less-yellow ($P < 0.05$) hues. However, for all white pudding formulations assessed during this study, no significant positive or negative scores were determined for liking of appearance (Table 2).

Summarized, the white pudding samples formulated with seaweed and KCPCl (10% fat, 0.6% sodium) had lower sensory acceptance for colour. Although, the naïve assessors did not significantly reduce their acceptance of any white pudding sample formulated with replacers because of appearance.

Texture attributes (graininess, juiciness, toughness)

Besides the taste, the texture of food determines if the product will be accepted by the consumer and therefore purchased again (Acebrón & Dopico, 2000; Grunert et al., 2004; Steenkamp & Trijp, 1996). Salt and fat are crucial ingredients which influence texture properties (lubrication, water holding, mouth-feel) in processed meat (Chantrapornchai, McClements, & Julian, 2002; Giese, 1996; Gillette, 1985; Hutton, 2002; McCaughey, 2007; Wood & Fisher, 1990). Hence, it is of interest how the added replacer combinations alter the texture of white pudding. Grain intensity, toughness and juiciness are essential attributes for describing the texture of white pudding.

As shown in Table 2 assessors found no significant correlation to intensity of graininess which is in agreement to the pudding formulations shown in Table 1. For both salt and fat levels, sample formulations containing seaweed and KCPCl were rated to be juicier ($P < 0.05$). Additionally, samples containing 10% fat and 0.6% sodium and formulated with PuraQ, as well as the samples containing 5% fat and 0.4% sodium and formulated with WMS were rated to be juicier ($P < 0.05$), though it was not consistent with respect to the two salt and fat formulations. Negative scores ($P < 0.01$) to juiciness were reached for samples containing 10% fat and 0.6% sodium and formulated with carrageen. Furthermore, both pudding formulations containing CMC were negatively correlated ($P < 0.05$) to juiciness and toughness. No other ingredient replacer produced significant results for toughness.

According to Ruusunen et al. (2003a), added carrageen in low fat and low salt bologna-type sausages were found to be harder and less juicy by assessors. Furthermore, added CMC also decreased the juiciness of bologna-type sausages at all salt concentrations (1.1%, 1.35%, 1.6%), which was also seen in the present study. Additionally, Yang, Keeton, Beilken & Trout (2001) reported that when added fat substitutes, such as WMS, were incorporated into low fat frankfurters, products were scored as being less juicy. In contrast to this study, López-López et al. (2010) found no significant effect on juiciness following the addition of seaweed wakame to low salt and low fat beef patties.

However, in the present study, no significant positive correlations to liking of texture were achieved. Though, assessors disliked ($P < 0.05$) the texture of pudding samples containing 10% fat and 0.6% sodium and formulated with KCPCl, and those samples containing 5% fat and 0.4% sodium and formulated with WMS. These two sample formulations were rated to be juicier ($P < 0.05$) with no significant results obtained for graininess and toughness. White pudding samples formulated with seaweed, PuraQ (10% fat, 0.6% sodium) and KCPCl (5% fat, 0.4% sodium) were also significantly scored to be juicier, though no significant results for disliking the texture were obtained. Therefore, lower sensory ratings in juiciness did not additionally correlate to disliking in the texture of white puddings and subsequently to unacceptability (Table 2).

Taste attributes (fatness, spiciness, saltiness)

After purchase, consumers experience the sensory qualities of products which determine whether the food will be re-purchased. Fatness, spiciness and saltiness are important attributes to describe flavour of white pudding.

In the present study, when compared to spiciness, the attributes of fatness and saltiness are located on the opposite of the quadrant (Figure 1). Most of the pudding samples containing 10% fat and 0.6% sodium correlated to spiciness and samples containing 5% fat and 0.4% sodium correlated to fatness and saltiness (Figure 1).

As shown in Table 2, white pudding formulations containing 10% fat and 0.6% sodium and formulated with wheat bran, sodium citrate, KCl and KClG scored lower ($P < 0.05$) for fatness and higher ($P < 0.01$, $P < 0.001$) for spiciness by assessors. Furthermore, control puddings for the same fat and salt level equivalents showed similar results for fatness and spiciness, though a lower significant level for spiciness was reached. However, most pudding samples containing 10% fat and replacers had enhanced spicy flavours and this may have resulted in masking or overlaying the fatty taste itself. This result corroborates findings previously published by Giese (1996) and Wood & Fisher (1990) who postulated that fats interact with further ingredients within a meat system, thereby contributing to, and enhancing flavour.

Furthermore, in the present study, both seaweed formulations were determined to be negatively correlated ($P < 0.05$) to spiciness. Additionally, no significant positive correlation to fatness and saltiness were obtained. Therefore, the seaweed ingredients used in this study failed to enhance flavour perception in white pudding products.

However, the use of carrageen had a positive effect on spiciness in pudding formulations containing 10% fat and 0.6% sodium. This observation is in agreement with Ruusunen et al. (2003a) who added carrageen in low salt and low fat bologna-type sausages and increased flavour intensity in this product type when formulated using three different salt levels (1.1%, 1.35% and 1.6%).

As can be seen in Table 2, only puddings containing 5% fat and 0.4% sodium and formulated with wheat bran and KCPCl reached positive scores ($P < 0.05$) for fatness. No significant effect on saltiness perception was determined for either of these two formulations. Although, white pudding samples (5% fat and 0.4% sodium) containing wheat bran was determined to be less spicy ($P < 0.05$), samples formulated with KCPCl positively correlated ($P < 0.05$) to off-flavour. Either because of reduced spiciness or off-flavour development, assessors showed no liking of flavour or/and overall acceptance for these pudding samples, even when products had significantly higher scores for fatness.

In the present study, no significant negative correlation to saltiness was observed for all white pudding formulations (Table 2). The samples containing 10% fat and 0.6% sodium and formulated with PuraQ and KCPCl, and the white pudding samples containing 5% fat and 0.4% sodium and formulated with WMS exhibited an increase ($P < 0.05$) in saltiness perception. The replacer PuraQ enhances taste, salty taste and imparts meaty and spicy flavour, which can be confirmed partly by this study (Corbion purac, 2013). However, as displayed in Figure 1, these three sample formulations do not correlate to liking of flavour and/ or overall acceptability, presumably because of the existing correlation to off-flavour. Vadlamani, Friday, Broska & Miller (2012) displayed an increase in overall flavour, sweetness and saltiness in all of nine chicken broths containing different combinations of KCPCl, although, significant increases to negative overall aftertaste were also recorded. Furthermore, Ruusunen et al. (2003b) observed, in low salt frankfurters, that adding wheat bran enhanced saltiness perception in this product. This finding cannot be confirmed in the present study.

For both formulations, the replacer pectin did not show any significant impact either on flavour attributes or on texture attributes. In contrast, Desmond, Troy & Buckley (1998) reported a significant increase in juiciness using Slendid ^{TM}, a commercially available replacer containing pectin, in low fat beef burgers, which in turn showed a positive impact on liking of texture and overall acceptability. However, adding pectin to white pudding products did not demonstrate a similar effect.

Summarized, no ultimate replacer combination was found which increased all the three sensory attributes saltiness, fatness and spiciness in white pudding. Nevertheless, the majority of the added replacers showed an enhancement in at least one taste or flavour attribute.

Liking of flavour and overall acceptability

The objective of this study was to achieve highly sensory accepted white puddings low in sodium and fat by adding replacers.

For both seaweed formulations, negative results ($P < 0.001$) for liking of flavour and overall acceptability were observed for pudding products (Table 2). Assessors disliked ($P < 0.05$) the darker colour (Table 4) and the lower ($P < 0.05$, $P < 0.01$) spiciness perception determined in white pudding samples that employed seaweed replacement ingredients. In contrast to this study, López-López et al. (2010) reported that their assessors found low salt and low fat beef patties with seaweed wakame more palatable than the control, even though assessors detected a distinctly different flavour in wakame-treated patties to that of the control.

The white pudding formulations containing 10% fat and 0.6% sodium and formulated with sodium citrate and KClG were accepted ($P < 0.05$) by assessors in this study. These samples scored lower ($P < 0.05$) for fatness perception, higher ($P < 0.05$) in spiciness perception and furthermore, no off-flavours were detected ($P < 0.05$) by assessors. Hence, the recommended sodium target level of 0.6% set by the FSAI (2011) and additionally, a reduction in fat level when compared to the major commercial white puddings were achieved. A positive effect, through the addition of sodium citrate, was also observed by Ruusunen et al. (2003a) which was exhibited through an increase in flavour perception in low salt and low fat bologna-type sausages. In contrast to the present study, Gelabert, Gou, Guerrero & Arnau (2003) postulated that in fermented meat, the addition of KClG (used in the same ratio as employed in this present study) showed no positive significant sensory impacts, although a decrease ($P < 0.05$) in saltiness perception was recorded.

Furthermore, in the present study, a trend in acceptance and liking of flavour was observed for pudding samples containing 10% fat and 0.6% sodium and formulated with wheat bran. A higher concentration of added wheat bran might result in a significantly more accepted product.

Summarized, both white pudding formulations with seaweed were not accepted by the assessors and therefore the recipe cannot be recommended to the industry. Though the white pudding formulations with sodium citrate and KClG (10% fat, 0.6% sodium) were accepted ($P < 0.05$). Wheat bran also presents potential opportunities to further optimize reduced fat white pudding.

5.3.2 Characterization of white pudding samples containing replacers

The compositional properties of cooked and reheated white pudding products containing the experimental replacers are shown in Table 3. The measured fat and salt levels in cooked white puddings were close to the designed model. Cooked puddings had lower fat, sodium, protein and ash concentrations, but higher water concentrations, than those observed in reheated pudding samples. In the previous study by Fellendorf et al. (2015) the same effect in white pudding containing different sodium (1.0%, 0.8%, 0.6%, 0.4%, 0.2%) and fat (20%, 15%, 10%, 5%, 2.5%) levels, were observed both before and after reheating. The differences between cooked and reheated pudding composition was most likely due to evaporative losses from pudding products during the cooking process.

Varying replacers in white pudding products have shown differences in cooking losses compared to the control (Table 4). Most of the samples containing replacers showed a trend (not significant) in decreasing cooking loss due to the use of a hydrocolloid or water-binding agent. Additionally, the use of the added replacer sodium citrate, which does not function as a thickener, reduced significantly ($P < 0.05$) the cooking loss in white pudding with 10% fat and 0.6% sodium. Furthermore, the use of WMS in puddings significantly ($P < 0.05$) decreased cooking losses. In general, lower cooking losses were achieved for samples containing 10% fat and 0.6% sodium compared to samples containing 5% fat and 0.4% sodium. Following the recipe (Table 1) less fat was balanced with meat. Lean pork meat contains more water than pure pork fat (Souci, Fachmann, & Kraut, 2004),therefore, the lower the meat content and the higher the fat content in pudding samples, the lower the cooking loss. Similar findings were observed by Mittal & Barbut (1994) and Fellendorf et al. (2015) for pork frankfurters and white puddings, respectively.

As seen in Table 4, white pudding samples formulated with seaweed recorded the lowest ($P < 0.05$) lightness (L) and redness (a) values. These samples displayed a grey colour, untypical for white pudding. Assessors clearly noticed this distinctive colour. As shown in Table 2, these both pudding samples were disliked ($P < 0.05$) by assessors for colour. The addition of seaweed wakame in a low salt gel/emulsion meat system was shown to change colour by darkening the product, reducing redness values and increasing yellowness values (Cofrades et al., 2008). However, the colour of pudding samples containing 10% fat and 0.6% sodium and formulated with KCPCl were also not accepted by the assessors, though no colour abnormalities were determined (Table 4).

The lowest measured values of hardness, springiness, cohesiveness and chewiness was achieved for white pudding samples formulated with CMC (Table 4). Hence, white pudding samples containing CMC are supposed to need less force to bite, less work to chew and show a low spring back and less strength of internal bonds. These results are consistent with sensory results as assessors scored these samples lower ($P < 0.05$, $P < 0.001$) in terms of toughness. According to Lin, Keeton, Gilchrist & Cross (1988), low fat frankfurters containing CMC also had lower hardness values. However, in the present study, the accepted pudding sample formulated with KClG produced the highest hardness values. The second accepted pudding sample containing sodium citrate also had higher hardness values. Therefore, a harder white pudding texture was preferred by assessors.

5.4 Conclusion

Adding ingredient replacers in white pudding formulations produced a range of effects on the sensory quality and physicochemical properties of these products. Compared to the control, most pudding samples containing replacers showed decreased cooking losses. Ten of the eleven replacer combinations (with the exception of pectin) used showed either an effect on texture or on flavour, although these were often not consistent with respect to the two salt and fat formulations used throughout the study.

Summarized, the white pudding samples formulated with seaweed and KCPCl (10% fat, 0.6% sodium) had lower sensory acceptance for colour. Although, the naïve assessors did not significantly reduce their acceptance of any white pudding sample formulated with replacers because of appearance.

No ultimate replacer combination was found which increased all the three flavour sensory saltiness, fatness and spiciness in white pudding. Nevertheless, the majority of the added replacers showed an enhancement in one taste attribute.

Both seaweed formulations were determined to be negatively correlated ($P < 0.05$) to spiciness. Additionally, no significant positive correlation to fatness and saltiness were obtained. Therefore, seaweed-based ingredients were not deemed suitable to increase the flavour perception in white pudding. Additionally, seaweed ingredient usage in white pudding displayed an untypical grey colour and was assessed as being negatively correlated ($P < 0.05$) to liking of colour. Assessors also did not like ($P < 0.001$) the impact that seaweed-based ingredients had on pudding flavour.

White puddings containing 10% fat and 0.6% sodium and formulated with sodium citrate and KClG were found to score highly for overall acceptability ($P < 0.05$) by assessors which also displayed higher hardness values Furthermore, the recommended sodium target level of 0.6% set by the FSAI (2011) and additionally, a fat reduction compared to the major commercial white puddings was achieved.

Summarized, both white pudding formulations with seaweed were not accepted by the assessors and therefore the recipe cannot be recommended to the industry. Though the white pudding formulations with sodium citrate and KClG (10% fat, 0.6% sodium) were accepted ($P < 0.05$). Furthermore, a trend in acceptance and liking of flavour was observed for pudding samples containing 10% fat and 0.6% sodium and formulated with 1% wheat bran. A higher concentration of added wheat bran might result in a significantly more accepted product.

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5.5 Tables and Figures

Table 1

White pudding formulations containing differnt replacers

Sample[a]	Formulation [%]									
	Meat	Fat	Salt	Water	Season-ing	Oatmeal	Onion	Boiled barley	Rusk	Replacer(s)
Control 1	34.85	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	-
Control 2	43.04	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	-
Wheat bran 1	33.85	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	1.00
Wheat bran 2	42.04	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	1.00
Sodium citrate 1	34.40	15.38	1.47	27.00	1.00	11.00	2.50	4.35	2.40	0.50
Sodium citrate 2	42.59	7.69	0.97	27.00	1.00	11.00	2.50	4.35	2.40	0.50
Carrageen 1	34.35	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	0.50
Carrageen 2	42.54	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.50
Pectin 1	34.45	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	0.40
Pectin 2	42.64	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.40
KCl 1	33.83	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	1.02
KCl 2	42.36	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.68
KClG 1	33.83	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	0.91/0.61[b]
KClG 2	42.02	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.61/0.41[b]
CMC 1	34.35	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	0.50
CMC 2	42.54	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.50
Seaweed 1	31.85	15.38	1.22	27.00	1.00	11.00	2.50	4.35	2.40	3.30
Seaweed 2	40.04	7.69	0.72	27.00	1.00	11.00	2.50	4.35	2.40	3.30
PuraQ 1	31.85	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	3.00
PuraQ 2	40.04	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	3.00
KCPCl 1	33.35	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	0.5/0.5/0.5[c]
KCPCl 2	41.54	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	0.5/0.5/0.5[c]
WMS 1	31.85	15.38	1.52	27.00	1.00	11.00	2.50	4.35	2.40	3.00
WMS 2	40.04	7.69	1.02	27.00	1.00	11.00	2.50	4.35	2.40	3.00

[a] Sample code: 1 = 10% fat and 0.6% sodium, 2 = 5% fat and 0.4% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[b] Added replacers, combination of potassium chloride/glycine in percent

[c] Added replacers, combination of potassium citrate/potassium phosphate/potassium chloride in percent

Table 2

P-values of regression coefficients from ANOVA values of regression coefficients from APLSR for the hedonic and intensity sensory terms of reheated white pudding containing replacers, including significance and correlation

Sample [a]	Hedonic term [b]					Intensity term						
	Appearance	Flavour	Texture	Colour	Acceptability	Grains	Fatness	Spiciness	Saltiness	Juiciness	Toughness	Off-flavour
Control 1	0.7696 ns	0.9060 ns	0.8115 ns	0.9831 ns	0.7060 ns	-0.0858 ns	-0.0098**	0.0168*	-0.4316 ns	-0.8918 ns	-0.9348 ns	-0.0009***
Control 2	-0.7485 ns	-0.9746 ns	-0.6198 ns	-0.7233 ns	-0.9548 ns	0.1342 ns	0.1825 ns	-0.0319*	0.3280 ns	0.6660 ns	0.0811 ns	0.0052**
Wheat bran 1	0.8174 ns	0.1689 ns	0.1196 ns	0.1730 ns	0.0809 ns	-0.9698 ns	-0.0438*	0.0062**	-0.8114 ns	-0.9816 ns	-0.7507 ns	-0.0129*
Wheat bran 2	-0.9266 ns	-0.8589 ns	-0.2339 ns	-0.5477 ns	-0.9862 ns	0.5604 ns	0.0508*	-0.0496*	0.3192 ns	0.0693 ns	0.7993 ns	0.0359*
Sodium citrate 1	0.7669 ns	0.0675 ns	0.4929 ns	0.1948 ns	0.0288*	-0.5331 ns	-0.0131*	0.0004***	-0.1417 ns	-0.2809 ns	-0.3885 ns	-0.0004***
Sodium citrate 2	-0.6753 ns	-0.3747 ns	-0.7514 ns	-0.8831 ns	-0.3710 ns	0.09495 ns	0.1532 ns	-0.2339 ns	0.9031 ns	0.1237 ns	0.1522 ns	0.0144*
Carrageen 1	0.8978 ns	0.6966 ns	0.9672 ns	0.9839 ns	0.4692 ns	-0.7961 ns	-0.1146 ns	0.0117 *	-0.2773 ns	-0.0081**	-0.5361 ns	-0.1242 ns
Carrageen 2	-0.7171 ns	-0.8509 ns	-0.1034 ns	-0.6905 ns	-0.7560 ns	0.4884 ns	0.1052 ns	-0.0115*	0.3692 ns	0.2168 ns	0.5348 ns	0.0081**
Pectin 1	0.7758 ns	0.9873 ns	0.6736 ns	0.9426 ns	0.8659 ns	-0.2244 ns	-0.1177 ns	0.1226 ns	-0.1756 ns	-0.8266 ns	-0.3982 ns	-0.0350*
Pectin 2	-0.8982 ns	-0.4102 ns	-0.75380 ns	-0.2194 ns	-0.4541 ns	0.8356 ns	0.8970 ns	-0.1291 ns	0.8902 ns	0.2557 ns	0.0916 ns	0.3851 ns
KCl 1	0.9956 ns	0.6042 ns	0.2028 ns	0.5464 ns	0.3205 ns	-0.8068 ns	-0.0054**	0.0045**	-0.8103 ns	-0.7442 ns	-0.5668 ns	-0.0108*
KCl 2	-0.8228 ns	-0.3122 ns	-0.5688 ns	-0.3104 ns	-0.2470 ns	0.9315 ns	0.2788 ns	-0.0550 ns	0.5264 ns	0.6746 ns	0.6141 ns	0.1476 ns
KClG 1	0.8081 ns	0.1822 ns	0.1948 ns	0.4221 ns	0.0525*	-0.7001 ns	-0.0124*	0.0064**	-0.9654 ns	-0.7197 ns	-0.4237 ns	-0.0074**
KClG 2	-0.8573 ns	-0.5162 ns	-0.8800 ns	-0.3426 ns	-0.4692 ns	0.4520 ns	0.2463 ns	-0.0816 ns	0.4912 ns	0.7502 ns	0.2206 ns	0.0791 ns
CMC 1	0.6369 ns	0.4927 ns	0.3923 ns	0.1522 ns	0.8800 ns	-0.0773 ns	-0.7646 ns	0.1311 ns	-0.2769 ns	-0.0001***	-0.0001***	-0.0237*
CMC 2	0.8637 ns	0.1245 ns	0.5561 ns	0.1342 ns	0.2748 ns	-0.6151 ns	-0.0435*	0.9009 ns	-0.4192 ns	-0.0184*	-0.0266 *	-0.1836 ns
Seaweed 1	-0.7227 ns	-0.0003***	-0.1520 ns	-0.0526*	-0.0003***	0.0719 ns	0.4253 ns	-0.0031**	0.4195 ns	0.0067**	0.5188 ns	0.2619 ns
Seaweed 2	-0.7491 ns	-0.0008***	-0.2188 ns	-0.0210*	-0.0005***	0.1058 ns	0.9675 ns	-0.0190*	0.2986 ns	0.0093**	0.3837 ns	0.43334 ns
PuraQ 1	-0.8980 ns	-0.8691 ns	-0.2006 ns	-0.4851 ns	-0.5964 ns	0.3386 ns	0.3145 ns	-0.2935 ns	0.0142*	0.0146*	0.7698 ns	0.0897 ns
PuraQ 2	0.7350 ns	0.5494 ns	0.2897 ns	0.8465 ns	0.4657 ns	-0.1681 ns	-0.8753 ns	0.9649 ns	-0.4456 ns	-0.3191 ns	-0.0617 ns	-0.3063 ns
KCPCl 1	-0.8599 ns	-0.0582 ns	-0.0222*	-0.0498*	-0.2168 ns	0.0758 ns	0.0898 ns	-0.4312 ns	0.0009***	0.0001***	0.4829 ns	0.0048**
KCPCl 2	-0.8513 ns	-0.2405 ns	-0.4034 ns	-0.1786 ns	-0.6217 ns	0.1703 ns	0.0161*	-0.0616 ns	0.0799 ns	0.0169*	0.2412 ns	0.0035**
WMS 1	0.7356 ns	0.4179 ns	0.5235 ns	0.9072 ns	0.4853 ns	-0.6850 ns	-0.3167 ns	0.6258 ns	-0.2234 ns	-0.1136 ns	-0.8004 ns	-0.3795 ns
WMS 2	-0.9260 ns	-0.8145 ns	-0.0395*	-0.6365 ns	-0.9330 ns	0.5624 ns	0.0750 ns	-0.0956 ns	0.0323*	0.0058**	0.1046 ns	0.2115 ns

[a] Sample code: 1 = 10% fat and 0.6% sodium; 2 = 5% fat and 0.4% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: seaweed wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[b] Significance of regression coefficients: ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Table 3

Compositional properties of cooked and reheated white pudding samples containing different replacers

Sample ^{c}	Moisture [%] ^{d}		Fat [%]		Protein [%]		Ash [%]		Sodium [%]	
	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated
Control 1	62.3 ± 0.3^{a}	54.8 ± 0.2^{b}	10.9 ± 0.1^{a}	11.9 ± 0.2^{b}	12.1 ± 0.1^{a}	14.1 ± 0.2^{b}	2.2 ± 0.0^{a}	2.5 ± 0.0^{b}	0.63 ± 0.01^{a}	0.75 ± 0.01^{b}
Control 2	63.1 ± 0.9^{a}	57.8 ± 0.2^{b}	6.4 ± 0.2^{a}	7.2 ± 0.1^{b}	12.2 ± 0.1^{a}	15.3 ± 0.0^{b}	1.6 ± 0.0^{a}	1.8 ± 0.0^{b}	0.43 ± 0.00^{a}	0.51 ± 0.00^{b}
Wheat bran 1	60.6 ± 0.4^{a}	54.7 ± 0.8^{b}	10.2 ± 0.3^{a}	11.5 ± 0.1^{b}	12.0 ± 0.1^{a}	13.9 ± 0.1^{b}	2.1 ± 0.1^{a}	2.5 ± 0.1^{b}	0.62 ± 0.01^{a}	0.73 ± 0.02^{b}
Wheat bran 2	62.7 ± 0.8^{a}	58.5 ± 0.5^{b}	6.4 ± 0.1^{a}	7.1 ± 0.2^{b}	12.3 ± 0.1^{a}	14.5 ± 0.1^{b}	1.8 ± 0.0^{a}	2.0 ± 0.0^{b}	0.41 ± 0.01^{a}	0.51 ± 0.01^{b}
Sodium citrate 1	59.9 ± 0.5^{a}	55.5 ± 0.3^{b}	10.4 ± 0.2^{a}	11.4 ± 0.1^{b}	12.5 ± 0.1^{a}	13.8 ± 0.0^{b}	2.2 ± 0.0^{a}	2.6 ± 0.1^{b}	0.59 ± 0.04^{a}	0.70 ± 0.01^{b}
Sodium citrate 2	64.0 ± 0.2^{a}	57.9 ± 1.0^{b}	6.4 ± 0.1^{a}	7.5 ± 0.2^{b}	12.3 ± 0.1^{a}	14.5 ± 0.2^{b}	1.9 ± 0.1^{a}	2.0 ± 0.1^{a}	0.43 ± 0.03^{a}	0.52 ± 0.02^{b}
Carrageen 1	61.2 ± 0.3^{a}	55.1 ± 0.2^{b}	10.3 ± 0.1^{a}	11.1 ± 0.1^{b}	12.0 ± 0.1^{a}	14.6 ± 0.0^{b}	2.1 ± 0.1^{a}	2.6 ± 0.1^{b}	0.62 ± 0.01^{a}	0.73 ± 0.01^{b}
Carrageen 2	64.3 ± 0.5^{a}	58.3 ± 1.0^{b}	6.3 ± 0.1^{a}	7.7 ± 0.4^{b}	13.0 ± 0.1^{a}	15.3 ± 0.2^{b}	1.8 ± 0.0^{a}	2.0 ± 0.1^{b}	0.42 ± 0.01^{a}	0.50 ± 0.01^{b}
Pectin 1	60.8 ± 0.2^{a}	54.2 ± 0.7^{b}	10.3 ± 0.1^{a}	11.0 ± 0.3^{b}	12.3 ± 0.1^{a}	14.9 ± 0.2^{b}	2.1 ± 0.1^{a}	2.4 ± 0.1^{b}	0.62 ± 0.01^{a}	0.76 ± 0.01^{b}
Pectin 2	63.5 ± 0.6^{a}	56.1 ± 0.5^{b}	5.8 ± 0.1^{a}	8.1 ± 0.5^{b}	13.0 ± 0.1^{a}	14.9 ± 0.1^{b}	1.7 ± 0.0^{a}	1.9 ± 0.1^{b}	0.41 ± 0.01^{a}	0.54 ± 0.01^{b}
KCl 1	60.8 ± 0.3^{a}	55.3 ± 0.2^{b}	10.0 ± 0.3^{a}	10.8 ± 0.2^{a}	11.7 ± 0.1^{a}	14.0 ± 0.3^{b}	2.9 ± 0.1^{a}	3.5 ± 0.1^{b}	0.61 ± 0.01^{a}	0.72 ± 0.01^{b}
KCl 2	61.9 ± 0.2^{a}	56.7 ± 0.4^{b}	6.1 ± 0.3^{a}	7.8 ± 0.1^{b}	13.2 ± 0.2^{a}	15.2 ± 0.2^{b}	2.4 ± 0.1^{a}	2.6 ± 0.1^{a}	0.42 ± 0.01^{a}	0.51 ± 0.02^{b}
KClG 1	59.4 ± 0.3^{a}	53.2 ± 0.4^{b}	10.2 ± 0.1^{a}	11.5 ± 0.2^{b}	13.0 ± 0.1^{a}	14.8 ± 0.2^{b}	2.9 ± 0.1^{a}	3.4 ± 0.0^{b}	0.62 ± 0.02^{a}	0.73 ± 0.01^{b}
KClG 2	63.0 ± 0.2^{a}	56.2 ± 0.2^{b}	6.8 ± 0.1^{a}	7.8 ± 0.2^{b}	12.9 ± 0.1^{a}	15.3 ± 0.2^{b}	2.3 ± 0.0^{a}	2.6 ± 0.0^{b}	0.42 ± 0.00^{a}	0.53 ± 0.01^{b}
CMC 1	60.4 ± 0.6^{a}	54.6 ± 1.6^{b}	10.8 ± 0.5^{a}	11.6 ± 0.6^{b}	12.1 ± 0.1^{a}	14.3 ± 0.0^{b}	2.1 ± 0.0^{a}	2.4 ± 0.1^{b}	0.59 ± 0.02^{a}	0.70 ± 0.03^{b}
CMC 2	62.1 ± 0.6^{a}	55.9 ± 0.8^{b}	6.3 ± 0.3^{a}	8.0 ± 0.1^{b}	12.7 ± 0.1^{a}	15.5 ± 0.1^{b}	1.9 ± 0.0^{a}	2.0 ± 0.1^{a}	0.40 ± 0.01^{a}	0.51 ± 0.00^{b}
Seaweed 1	60.6 ± 0.3^{a}	54.3 ± 0.4^{b}	10.2 ± 0.2^{a}	11.0 ± 0.2^{b}	11.8 ± 0.1^{a}	14.0 ± 0.1^{b}	3.4 ± 0.0^{a}	4.0 ± 0.1^{b}	0.60 ± 0.04^{a}	0.70 ± 0.03^{b}
Seaweed 2	62.2 ± 0.6^{a}	55.6 ± 0.2^{b}	6.3 ± 0.3^{a}	7.3 ± 0.2^{b}	12.1 ± 0.1^{a}	14.9 ± 0.2^{b}	3.0 ± 0.0^{a}	3.5 ± 0.1^{b}	0.42 ± 0.01^{a}	0.54 ± 0.02^{b}
PuraQ 1	61.3 ± 0.2^{a}	56.8 ± 0.6^{b}	10.1 ± 0.1^{a}	11.0 ± 0.2^{b}	11.8 ± 0.1^{a}	14.1 ± 0.3^{b}	2.2 ± 0.1^{a}	2.5 ± 0.1^{b}	0.63 ± 0.01^{a}	0.75 ± 0.00^{b}
PuraQ 2	63.1 ± 0.3^{a}	57.5 ± 0.6^{b}	6.2 ± 0.2^{a}	7.0 ± 0.0^{b}	12.0 ± 0.1^{a}	14.8 ± 0.2^{b}	2.4 ± 0.1^{a}	2.6 ± 0.0^{b}	0.43 ± 0.01^{a}	0.54 ± 0.02^{b}
KCPCl 1	59.6 ± 0.6^{a}	55.2 ± 0.7^{b}	10.2 ± 0.2^{a}	11.5 ± 0.4^{b}	12.0 ± 0.1^{a}	13.6 ± 0.1^{b}	3.0 ± 0.0^{a}	3.4 ± 0.0^{b}	0.61 ± 0.02^{a}	0.71 ± 0.01^{b}
KCPCl 2	62.3 ± 0.3^{a}	57.0 ± 0.1^{b}	6.4 ± 0.1^{a}	7.9 ± 0.1^{b}	12.5 ± 0.1^{a}	14.1 ± 0.2^{b}	2.7 ± 0.0^{a}	3.3 ± 0.0^{b}	0.43 ± 0.01^{a}	0.53 ± 0.01^{b}
WMS 1	59.6 ± 0.8^{a}	55.1 ± 0.5^{b}	10.2 ± 0.2^{a}	11.2 ± 0.1^{b}	11.3 ± 0.1^{a}	13.2 ± 0.1^{b}	1.7 ± 0.1^{a}	2.0 ± 0.1^{b}	0.64 ± 0.00^{a}	0.71 ± 0.00^{b}
WMS 2	62.6 ± 0.2^{a}	57.3 ± 0.9^{b}	5.9 ± 0.1^{a}	7.1 ± 0.4^{b}	11.9 ± 0.1^{a}	14.0 ± 0.3^{b}	1.3 ± 0.1^{a}	1.6 ± 0.1^{b}	0.43 ± 0.01^{a}	0.48 ± 0.01^{b}

$^{a\text{-}b}$ Averages of each cooked and reheated sample of each composition analysis sharing different letters are significantly different (two tailed t-test, $p < 0.05$).

^{c} Sample code: 1 = 10% fat and 0.6% sodium; 2 = 5% fat and 0.4% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: seaweed wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

^{d} All values are averages ± standard errors.

Table 4

Colour, texture profile and cooking loss values of reheated white pudding samples containing replacers

Sample [n]	Colour [o]			Texture Analyzer				Cooking loss
	L*	a*	b*	Hardness [N]	Springiness	Cohesivness	Chewiness [N]	[%]
Control 1	$49.9 \pm 0.2^{k, l}$	$3.6 \pm 0.1^{b, c, d}$	18.4 ± 0.3^{a}	$85.6 \pm 2.6^{e, f, g}$	$0.76 \pm 0.01^{a,b, c}$	$0.44 \pm 0.02^{a,b,c,d}$	$27.2 \pm 1.1^{e, f, g, h, i}$	$14.6 \pm 0.8^{a, b, c}$
Control 2	$52.5 \pm 0.3^{b, c, d, e, f}$	$3.7 \pm 0.1^{a, b}$	$17.8 \pm 0.2^{a, b, c}$	$85.7 \pm 1.4^{e, f, g}$	$0.77 \pm 0.02^{a, b, c}$	$0.41 \pm 0.01^{c, d}$	$27.0 \pm 1.0^{e, f, g, h, i}$	$15.1 \pm 0.6^{a, b}$
Wheat bran 1	$50.6 \pm 0.5^{h, i, j, k}$	$3.4 \pm 0.1^{c, d, e, f}$	$16.8 \pm 0.3^{d, e, f}$	$86.4 \pm 1.8^{e, f, g}$	$0.81 \pm 0.02^{a, b}$	$0.43 \pm 0.01^{a,b,c,d}$	$30.5 \pm 1.0^{d, e, f, g, h}$	$11.8 \pm 0.7^{c, d, e, f, g, h, i, j}$
Wheat bran 2	53.9 ± 0.6^{a}	$3.6 \pm 0.1^{b, c, d}$	$16.3 \pm 0.3^{e, f, g, h}$	$75.8 \pm 3.1^{f, g, h}$	$0.78 \pm 0.03^{a, b}$	$0.44 \pm 0.01^{a,b,c,d}$	$25.6 \pm 1.4^{g, h, i}$	$12.1 \pm 0.8^{c, d, e, f, g, h, i, j}$
Sodium citrate 1	$52.1 \pm 0.6^{c, d, e, f, g}$	2.6 ± 0.1^{j}	$16.0 \pm 0.3^{g, h}$	$96.5 \pm 3.9^{c, d, e}$	$0.81 \pm 0.02^{a, b}$	$0.43 \pm 0.01^{a,b,c,d}$	$33.5 \pm 1.6^{c, d, e, f}$	8.8 ± 1.4^{j}
Sodium citrate 2	$53.5 \pm 0.7^{a, b}$	$3.0 \pm 0.1^{h, i}$	15.1 ± 0.3^{i}	$102.5 \pm 4.7^{b, c, d}$	0.82 ± 0.01^{a}	$0.42 \pm 0.01^{b,c,d}$	$35.8 \pm 2.3^{b, c, d}$	$12.7 \pm 0.8^{b, c, d, e, f, g, h, i}$
Carrageen 1	$50.1 \pm 0.4^{j, k, l}$	$2.8 \pm 0.1^{i, j}$	$17.8 \pm 0.3^{a, b}$	$117.5 \pm 3.7^{a, b}$	$0.78 \pm 0.01^{a, b}$	$0.47 \pm 0.01^{a,b,c}$	$43.3 \pm 2.1^{a, b}$	$10.9 \pm 0.8^{e, f, g, h, i, j}$
Carrageen 2	$53.4 \pm 0.4^{a, b}$	$2.8 \pm 0.1^{i, j}$	$16.8 \pm 0.3^{d, e, f}$	120.9 ± 6.3^{a}	$0.78 \pm 0.01^{a, b}$	$0.45 \pm 0.01^{a,b,c,d}$	$43.0 \pm 3.3^{a, b}$	$12.5 \pm 0.9^{b, c, d, e, f, g, h, i, j}$
Pectin 1	$50.2 \pm 0.3^{j, k, l}$	$3.3 \pm 0.1^{d, e, f, g}$	18.4 ± 0.2^{a}	$83.2 \pm 1.9^{e, f, g}$	$0.73 \pm 0.02^{b, c}$	$0.41 \pm 0.01^{b,c,d}$	$25.3 \pm 1.2^{g, h, i}$	$13.5 \pm 0.8^{c, d, e}$
Pectin 2	$53.0 \pm 0.4^{a, b, c, d}$	$3.2 \pm 0.1^{e,f, g, h}$	$17.7 \pm 0.2^{a, b, c}$	$88.7 \pm 2.0^{e, f, g}$	0.72 ± 0.02^{c}	0.40 ± 0.01^{d}	$25.4 \pm 1.1^{g, h, i}$	$14.3 \pm 0.6^{a, b, c, d}$
KCl 1	$52.2 \pm 0.7^{b, c, d, e, f, g}$	$2.8 \pm 0.1^{i, j}$	$16.3 \pm 0.4^{e, f, g, h}$	$107.9 \pm 3.5^{a, b, c}$	0.84 ± 0.02^{a}	$0.45 \pm 0.01^{a,b,c,d}$	$40.5 \pm 1.2^{a, b, c}$	$12.1 \pm 0.5^{c, d, e, f, g, h, i, j}$
KCl 2	$53.3 \pm 0.6^{a, b, c}$	$3.2 \pm 0.1^{g, h}$	$16.3 \pm 0.3^{e, f, g, h}$	$83.2 \pm 1.8^{e, f, g}$	$0.78 \pm 0.01^{a, b}$	$0.48 \pm 0.01^{a, b}$	$30.9 \pm 0.9^{d, e, f, g, h}$	$12.7 \pm 0.5^{b, c, d, e, f, g, h, i}$
KClG 1	$50.9 \pm 0.2^{g, h, i, j, k}$	$3.0 \pm 0.1^{h, i}$	$16.4 \pm 0.3^{d, e, f, g, h}$	123.3 ± 2.8^{a}	$0.80 \pm 0.01^{a, b}$	0.49 ± 0.01^{a}	48.1 ± 1.5^{a}	$13.1 \pm 0.5^{d, e}$
KClG 2	$52.6 \pm 0.3^{a, b, c, d, e}$	$3.5 \pm 0.1^{b, c, d, e}$	$16.5 \pm 0.2^{d, e, f, g, h}$	$93.0 \pm 4.0^{c, d, e}$	$0.81 \pm 0.02^{a, b}$	$0.45 \pm 0.01^{a,b,c,d}$	$33.9 \pm 1.9^{c, d, e, f}$	15.6 ± 0.6^{a}
CMC 1	$50.5 \pm 0.6^{i, j, k}$	$3.2 \pm 0.1^{f, g, h}$	$16.7 \pm 0.4^{d, e, f, g}$	29.9 ± 1.5^{i}	0.60 ± 0.01^{d}	0.28 ± 0.02^{e}	5.1 ± 0.6^{j}	$10.8 \pm 2.1^{e, f, g, h, i, j}$
CMC 2	$52.4 \pm 0.6^{b, c, d, e, f}$	$3.5 \pm 0.1^{c, d, e}$	$16.1 \pm 0.3^{g, h}$	34.1 ± 0.6^{i}	0.56 ± 0.02^{d}	0.33 ± 0.00^{e}	5.5 ± 0.2^{j}	$14.9 \pm 1.0^{a, b, c, d}$
Seaweed 1	46.3 ± 0.3^{m}	0.1 ± 0.1^{k}	$16.4 \pm 0.3^{e, f, g, h}$	$96.9 \pm 2.1^{c, d, e}$	$0.75 \pm 0.01^{a, b, c}$	$0.42 \pm 0.00^{a,b,c,d}$	$30.8 \pm 1.1^{d, e, f, g, h}$	$12.3 \pm 0.3^{b, c, d, e, f, g, h, i, j}$
Seaweed 2	45.4 ± 0.3^{m}	0.1 ± 0.1^{k}	$16.3 \pm 0.2^{e, f, g, h}$	$96.0 \pm 2.3^{c, d, e}$	$0.75 \pm 0.01^{a, b, c}$	0.40 ± 0.01^{d}	$28.7 \pm 1.3^{d, e, f, g, h}$	$13.7 \pm 0.5^{a, b, c, d, e, f}$
PuraQ 1	$51.9 \pm 0.4^{d, e, f, g, h}$	2.6 ± 0.1^{j}	$15.9 \pm 0.2^{h, i}$	$97.7 \pm 4.4^{c, d, e}$	$0.80 \pm 0.01^{a, b}$	$0.45 \pm 0.01^{a,b,c,d}$	$34.8 \pm 1.7^{c, d, e}$	$10.0 \pm 0.9^{f, i, j}$
PuraQ 2	$53.1 \pm 0.5^{a, b, c, d}$	$2.8 \pm 0.1^{i, j}$	$16.1 \pm 0.2^{f, g, h}$	$94.1 \pm 3.6^{c, d, e}$	$0.79 \pm 0.01^{a, b}$	$0.45 \pm 0.01^{a,b,c,d}$	$33.0 \pm 1.7^{c, d, e, f, g}$	$13.3 \pm 0.8^{a, b, c, d, e, f, g, h, i}$
KCPCl 1	$52.1 \pm 0.3^{c, d, e, f, g}$	$2.8 \pm 0.1^{i, j}$	$17.2 \pm 0.2^{b, c, d}$	$86.4 \pm 2.3^{e, f, g}$	$0.80 \pm 0.01^{a, b}$	$0.45 \pm 0.01^{a,b,c,d}$	$31.0 \pm 1.1^{d, e, f, g, h}$	$9.8 \pm 1.0^{g, h, i, j}$
KCPCl 2	$51.5 \pm 0.3^{e, f, g, h, i}$	$3.0 \pm 0.1^{h, i}$	$16.9 \pm 0.2^{c, d, e}$	$91.5 \pm 1.9^{d, e, f}$	$0.79 \pm 0.02^{a, b}$	$0.48 \pm 0.01^{a, b}$	$34.8 \pm 1.2^{c, d, e}$	$12.0 \pm 0.3^{c, d, e, f, g, h, i, j}$
WMS 1	48.9 ± 0.3^{l}	$3.7 \pm 0.1^{a, b, c}$	$17.8 \pm 0.2^{a, b}$	$74.2 \pm 1.5^{g, h}$	$0.81 \pm 0.01^{a, b}$	$0.44 \pm 0.01^{a,b,c,d}$	$26.3 \pm 1.0^{f, g, h, i}$	$9.9 \pm 0.3^{h, i, j}$
WMS 2	$51.2 \pm 0.4^{f, g, h, i, j}$	3.9 ± 0.1^{a}	18.1 ± 0.2^{a}	63.2 ± 1.7^{h}	$0.76 \pm 0.02^{a, b, c}$	$0.41 \pm 0.01^{c, d}$	19.6 ± 0.7^{i}	$11.0 \pm 0.3^{e, f, g, h, i, j}$

[a-m] Averages sharing different letters in the same column are significantly different ($P < 0.05$).

[n] Sample code: 1 = 10% fat and 0.6% sodium; 2 = 5% fat and 0.4% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: seaweed wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[o] All values are averages ± standard errors.

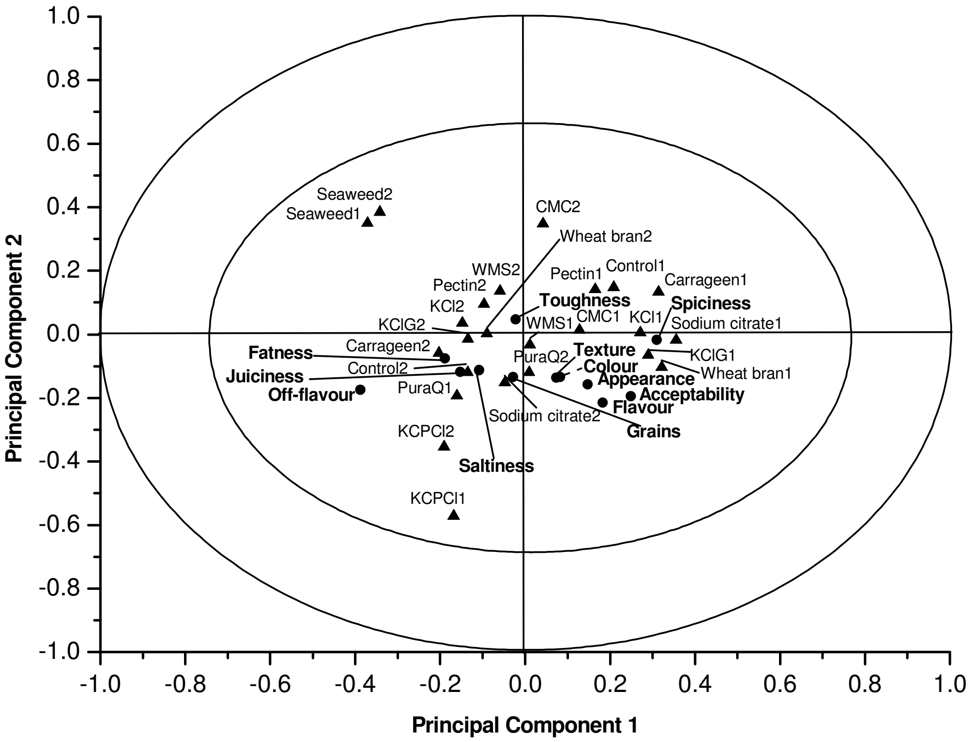

Figure 1:

ANOVA-Partial Least Squares regression (APLSR) for white pudding formulations with different replacers. Presented is PC1 versus PC 2 for sensory data. The inner ellipse indicates 50% explained variance and the outer ellipse indicates 100% explained variance. ▲ = Samples (code: 1 = 10% fat and 0.6% sodium, 2 = 5% fat and 0.4% sodium). KCl = potassium chloride, KClG = potassium chloride and glycine. CMC = carboxymethyl-cellulose. PuraQ = PuraQ®Arome NA4. Seaweed = seaweed wakame. ● = sensory attributes.

References

Aaslyng, M. D. (2009). Trends in meat consumption and the need for fresh meat and meat products of improved quality. In J. P. Kerry & D. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh meat* (pp. 3–18). Cambridge, New Dehli, Boca Raton: Woodhead Publishing Ltd.

Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, *96*(1), 47–55.

Acebrón, B. L., & Dopico, C. D. (2000). The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. *Food Quality and Preference*, *11*(3), 229–238.

AOAC. (1923). Determination of ash. *Journal of the Association of Official Analytical Chemists*, *7*, 132. Association of Official Agricultural Chemists.

AOAC. (1988). Minerals in ready-to-feed milk-based infant formula. *Official Methods of Analysis of AOAC International. AOAC Official Method 985.35.*, *Chapter 50*, 13–14. Association of Official Agricultural Chemists.

Ayto, J. (1990). *The Glutton's Glossary: A Dictionary of Food and Drink Terms*. (J. Ayto, Ed.) (1st ed.). Routledge.

Bertino, M., Beauchamp, G. K., & Engleman, K. (1982). Long term reduction in dietary sodium alter the taste of salt. *The American Journal of Clinical Nutrition*, *36*, 1134–1144.

Bostian, M. L., Fish, D. L., Webb, N. B., & Arey, J. J. (1985). Automated methods for determination of fat and moisture in meat and poultry products: collaborative study. *Journal of the Association of Official Analytical Chemists*, *68*(5), 876–880.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, *32* , 62–66.

Chantrapornchai, W., McClements, D. J., & Julian, D. (2002). Influence of NaCl on optical properties, large-strain rheology and water holding capacity of heat-induced whey protein isolate gels. *Food Hydrocolloids*, *16*(5), 467–476.

Chevance, F. F., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *Journal of Agricultural and Food Chemistry.*, *48*(8), 3476 – 3484.

Cofrades, S., Hughes, E., & Troy, D. J. (2000). Effects of oat fibre and carrageenan on the texture of frankfurters formulated with low and high fat. *European Food Research and Technology*, *211*(1), 19–26.

Cofrades, S., López-López, I., Solas, M. T., Bravo, L., & Jiménez-Colmenero, F. (2008). Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems. *Meat Science*, *79*(4), 767–76.

Corbion_purac. (2013). Sodium Reduction "Meat, Poultry & Fish." http://www.corbion.com/media/97267/thms-food-sodium-reduction-meat-useng-1013-web.pdf

Cross, A. J., Leitzmann, M. F., Gail, M. H., Hollenbeck, A. R., Schatzkin, A., & Sinha, R. (2007). A Prospective Study of Red and Processed Meat Intake in Relation to Cancer Risk. *PLOS Medicine*, *4*(12), 1973 – 1984.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Desmond, E. M., Troy, D. J., & Buckley, D. J. (1998). Comparative Studies of Nonmeat Adjuncts Used in the Manufacture of Low-Fat Beef Burgers. *Journal of Muscle Foods*, *9*(3), 221–241.

Duflot, P. (1996). Starches and Sugars Glucose polymers as sugar/fat substitutes. *Trends in Food Science & Technology.*, *7*, 206.

Dzendolet, E., & Meiselman, H. L. (1967). Gustatory quality changes as a function of solution concentration. *Perception & Psychophysics.*, *2*, 29–33.

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82.

Fox, P. F. (1963). Potentiometric determination of salt in cheese. *Journal of Dairy Science*, *46*, 744 – 745.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period : September 2003 to July 2014*. The Food Safety Authority of Ireland.

Gelabert, J., Gou, P., Guerrero, L., & Arnau, J. (2003). Effect of sodium chloride replacement on some characteristics of fermented sausages. *Meat Science*, *65*(2), 833–9.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Gillette, M. (1985). Flavor effects of sodium chloride. *Food Technology*, *39*, 47–56.

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat Science*, *66*(2), 259–272.

Halkjaer, J., Tjønneland, A., Overvad, K., & Sørensen, T. I. a. (2009). Dietary predictors of 5-year changes in waist circumference. *Journal of the American Dietetic Association*, *109*(8), 1356–66.

Harrigan, K. A., & Breene, W. M. (1989). Fat substitutes: Sucrose esters and simplesse. *Cereal Foods World.*, *34*, 261–267.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

International Commission on Illumination. (1976). ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space.

ISO. (1988). Sensory analysis. General guidance for the design of test rooms. Ref.

no. *International Organization for Standardization, Genève, Switzerland*, ISO 8589:1988. International Organization for Standardization.

Kosmark, R. (1996). Salatrim: Properties and applications. *Food Technol.*, *50*, 98–101.

Li, D., Siriamornpun, S., Wahlqvist, M. L., Mann, N. J., & Sinclair, A. J. (2005). Lean meat and heart health. *Asia Pacific Journal of Clinical Nutrition*, *14*(2), 113–119.

Lin, K. C., Keeton, J. T., Gilchrist, C. L., & Cross, H. R. (1988). Comparisons of Carboxymethyl Cellulose with Differing Molecular Features in Low-Fat Frankfurters. *Journal of Food Science*, *53*, 1592–1595.

Lopez-Lopez, I., Cofrades, S., & Jimenez-Colmenero, F. (2009). Low-fat frankfurters enriched with n-3 PUFA and edible seaweed: Effects of olive oil and chilled storage on physicochemical, sensory and microbial characteristics. *Meat Science*, *83*(1), 148–154.

López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International.*, *43*(5), 1244 – 1254.

Martens, H., & Martens, M. (2001). *Multivariate Analysis of Quality. An Introduction*. *Measurement Science and Technology* (2nd ed., Vol. 12). John Wiley & Sons Ltd.

McCaughey, S. (2007). Salt and Flavor: Mechanisms of Taste Perception and Physiological Controls. In K. D. & A. F. (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 78–99). Boca Raton Boston, New york, Washington-DC: Woodhead Publishing Ltd.

Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus. A systematic review and meta-analysis. *Circulation*, *121*(21), 2271–2283.

Mittal, G. S., & Barbut, S. (1994). Effects of fat reduction on frankfurters ' physical and sensory characteristics. *Food Research International*, *27*, 425 – 431.

Peters, J. C., Lawson, K. D., Middleton, S. J., & Triebwasser, K. C. (1997). The Nutritional Effects of Olestra Assessment of the Nutritional Effects of Olestra , a Nonabsorbed Fat Replacement. *American Society for Nutritional Sciences*, 1539–1546.

Puolanne, E. (2010). Cooked Sausages. In F. Toldrá (Ed.), *Handbook of meat processing* (First, pp. 313–377). WILEY- Blackwell Publishing, John Wiley & Sons Publication.

Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, *21*(6), 611–620.

Ruusunen, M., & Puolanne, E. (2005). Reducing sodium intake from meat products. *Meat Science*, *70*(3), 531–541.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003a). Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. *Meat Science*, *64*, 371–381.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003b). Physical and sensory properties of low-salt phosphate-free frankfurters composed with various ingredients. *Meat Science*, *63*(1), 9–16.

Shand, P. (2000). Textural, Water Holding, and Sensory Properties of Low-fat Pork Bologna with Normal or Waxy Starch Hull-less Barley. *Journal of Food Science*, *65*(1), 101 – 107.

Souci, S.W., Fachmann, W., & Kraut, H. (2004). *Der kleine Souci Fachmann Kraut. Lebensmitteltabelle fuer die Praxis. Wissenschaftliche Verlagsgesellschaft mbH Stuttgart* (3rd ed.). Wissenschaftliche Verlagsgesellschaft.

Steenkamp, J.-B. E. M., & Trijp, H. C. M. (1996). Quality guidance: A consumer-based approach to food quality improvement using partial least squares. *European Review of Agricultural Economics*, *23*, 195–215.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, B. R.N., & H. . Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 291 – 325). USA: Elsevier Academic Press.

Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, Bleibaum R.N., & H. A. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 117 – 157). USA: Elsevier Academic Press.

Stone, H., & Sidel, J. L. (2004). Affective testing. *In: H. Stone and J. L. Sidel (Eds.), Sensory Evaluation Practices. Food Science and Technology, International Series. USA: Academic Press/Elsevier.*, *3rd ed.*, 247–277.

Suhre, F. B., Corrao, P. A., Glover, A., & Malanoski, A. J. (1982). Comparison of three methods for determination of crude protein in meat: collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*(6), 1339–1345.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Vadlamani, K., Friday, D., Broska, A., & Miller, J. (2012). Methods and compositions for reducing sodium content in food products. *US Patent App. 12/ 0003358A1*. United States Patent Application Publication.

Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, *86*(1), 196–213.

Wheelock, V., & Hobbiss, A. (1999). *All you ever wanted to know about salt but were afraid to ask. Skipton, Yorkshire. Verner Wheelock Associates.* Skipton. Yorkshire. Verner Wheelock Associates.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

Wood, J. D., & Fisher, A. V. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). Elsevier Applied Science, London.

Yang, A., Keeton, J. T., Beilken, S. L., & Trout, G. R. (2001). Evaluation of Some Binders and Fat Substitutes in Low-fat Frankfurters. *Journal of Food Science*, *66*(7), 1039 – 1046.

Chapter 6

Effect of different salt and fat levels on the physico-chemical properties and sensory quality of black pudding

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Abstract

Black pudding, also known as blood sausages or blood pudding, is a kind of meat product made by blood, popular in Asia, Europe and America. Twenty-five black pudding formulations with varying fat contents of 2.5%, 5%, 10%, 15%, 20% (w/w) and sodium contents of 0.2%, 0.4%, 0.6%, 0.8%, 1.0% (w/w) were manufactured. Sensory acceptance and ranking descriptive analyses, compositional and physicochemical analyses were conducted. Samples high in sodium (0.6% - 1.0%) were scored higher in juiciness, toughness, saltiness, fatness and spiciness. These samples were the most accepted, whereas samples containing 0.2% sodium were the least accepted. Black pudding samples containing 0.6% sodium and 10% fat displayed a positive ($P < 0.05$) correlation to liking of flavour and overall acceptability. This meets the sodium target level set by the Food Safety Authority of Ireland and shows additionally, that a fat reduction in black pudding products is more than achievable.

6.1 Introduction

In the past, food quality was correlated with safety, shelf-life and sensory quality. Nowadays food quality, like consumer perception, is difficult to specify as it is permanently dynamic and difficult to measure. Furthermore, it is associated with health and nutrition (Grunert, Larsen, Madson, & Baadsgaard, 1996; Peri, 2006). Major meat quality cues such as colour, visible fat and drip are important attributes at point of sale, whereas, tenderness, flavour and juiciness play a key role at point of consumption. Additionally, the major background cues for assessors are safety, nutrition, sustainability and ethics (Acebrón & Dopico, 2000; Grunert, Bredahl, & Brunsø, 2004; Steenkamp & Trijp, 1996). All these factors make it necessary for the meat industry to completely understand these cues to satisfy and enhance consumer perceptions. On one hand, meat and meat products are subjected to a negative image which is due in part to issues relating to high saturated fat and salt content due to their association with health issues such as obesity, cardiovascular diseases and cancer (Cross et al., 2007; Halkjaer, Tjønneland, Overvad, & Sørensen, 2009; Li, Siriamornpun, Wahlqvist, Mann, & Sinclair, 2005; Micha, Wallace, & Mozaffarian, 2010). On the other hand, meat contains high amounts of proteins, essential minerals and vitamins such as iron, zinc, selenium, vitamins A, B12 and folic acid (Biesalski & Nohr, 2009; Souci, Fachmann, & Kraut, 2004; Williams, 2007). Therefore, muscle-based food products present something of a conundrum in food product compositional terms. Consumers increasingly reject products containing additives, even when they are deemed to be healthier. Though, the demand for food high in nutritional value has increased dramatically over the last two decades. Furthermore, the World Health Organization (WHO) have recommended a daily intake of polyunsaturated fatty acids (PUFAs) between 6% and 11% based on daily energy intake (WHO, 2003) and have suggested an intake of sodium which is less than 5 grams per day (WHO, 2012). A guideline for the Irish meat industry was agreed by the Food Safety Authority of Ireland (FSAI) with the target to decrease the sodium content in black and white puddings to 600 mg/100g of product (FSAI, 2011).

Recipes of black pudding and servings differ dramatically from country to country. In Estonia and Italy for example, blood sausages are mostly eaten in winter. Black pudding-style products can contain fillings such as breadcrumbs, pine nuts, rice, mashed potatoes, apples, oatmeal, barley, buckwheat, onions, rice, milk, and salt, but also chocolate, raisins, sugar or butter. Blood sausages are spread on bread, served on sticks as a snack or in slices eaten together with mashed potatoes, fried bacon, beans, eggs, loganberry jam, butter or sour cream (Adesiyun & Balbirsingh, 1996; Marianski & Marianski, 2011; Predika, 1983; Santos, González-Fernández, Jaime, & Rovira, 2003; Stiebing, 1990). However, all black pudding-style products are unified in composition owing to the presence of blood or blood by-product as an ingredient, thereby providing a unique source of proteins and iron.

In the present study the focus was directed at black pudding typical of those consumed in Ireland and the United Kingdom, which contains lean pork meat, pork fat, pork blood powder, grains, onions, salt and seasonings. Usually slices are fried in a pan and served together with bacon, breakfast sausages, eggs and beans or just with bread. Black puddings have a very high value for the Irish and British since they are particularly a special feature of the traditional Irish and English breakfast. The fat contents of commercially available black puddings range from 7% to 22%, with the majority of products containing between 14% and 16% fat (unpublished data, 2013). The range of sodium contents from commercial product was determined to be between 520 mg and 1190 mg with an average of 867 mg per 100 g of product (FSAI, 2014). On the basis of the recommendation for salt and polyunsaturated fatty acids levels set by the WHO (WHO, 2003, 2012) and the sodium guideline for the Irish meat industry set by the FSAI (FSAI, 2011) and the rising demand for healthier products by the consumers, producers are guided to modify their recipes. The stronger interest in health by consumers is already associated with a lower consumption of traditional food products (Pieniak, Verbeke, Vanhonacker, Guerrero, & Hersleth, 2009). In this food category, there may exists a conflict between innovation and concept of traditional food, (Jordana, 2000), which has to overbear.

Because of health issues relating to higher salt and saturated fat levels in processed meat products and due to the fact that no research has been carried out to date on fat and salt reduction in black pudding products, as determined from extensive review of the scientific literature, the objective of this study was to investigate the interactive effects of varying fat and salt levels on the sensory (sensory acceptance and ranking descriptive analysis (RDA)) and physicochemical properties of black puddings without using additional additives to produce a highly accepted product.

6.2 Materials and Methods

6.2.1 Sample preparation

Pork trimming lean (visual lean score of 95%) and pork fat were purchased from a local supplier (Ballyburden Meats Ltd., Ballincollig, Cork, Ireland). Meat and fat were minced to a particle size of 10 mm and 5 mm, respectively (TALSABELL SA., Valencia, Spain), vacuum packed and stored at -20 ºC. Twelve hours before commencing production required portions of meat and fat were unfrozen at room temperature. The ingredients were then weighed in accordance with formulations shown in Table 1 for the manufacture of replicated sausage batches. In the bowl chopper (Seydelmann KG, Aalen, Germany) the required meat, fat, seasoning, salt and three-quarters of the required water were chopped at high speed (3000 rpm) for 45 sec, followed by adding and mixing the remaining water and blood powder at high speed for 30 sec. The required pinhead oatmeal and dried onions were then chopped at low speed (1500 rpm) for 15 sec and finally, required boiled pearl barley and rusk were chopped at low speed for 30 sec. The black pudding batter was afterwards placed into a casing filler (MAINCA, Barcelona, Spain), filled into polyamide casings and cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) using 100% steam at 85 ºC until the internal product core temperature reached 75 ºC, as ascertained by a temperature probe (Testo 110, Lenzkirch, Germany). The temperature was held for 15 min and subsequently, the black pudding products were immediately placed in the chill to cool down and stored there at 4 ºC.

6.2.2 Reheating procedure

Before serving black pudding at home, usually the cut slices are cooked in a frying pan. For experimental purpose the reheating step was standardized with all samples cut into 1.2 cm thick slices, placed on aluminium plates and dry cooked at 100 ºC for 7 min in a Zanussi convection oven (C. Batassi, Conegliano, Italy) and afterwards turned and heated up again at 100 ºC for an additional 7 min.

6.2.3 Sensory evaluation

The sensory acceptance test was conducted using untrained assessors (n = 25 - 28) (Stone, Bleibaum, & Thomas, 2012a; Stone & Sidel, 2004) in the age range of 21 – 60. They were chosen on the basis that they consumed black pudding products regularly. The experiment was conducted in panel booths which conform to the

International Standards (ISO, 1988). The sensory test was split into five sessions, whereby five reheated samples (coded and presented in a randomised order) were served cold to the assessors to ensure comparability. The assessors were asked to assess, on a continuous line scale from 1 to 10 cm, the following attributes: liking of appearance, liking of flavour, liking of texture, liking of colour and overall acceptability (hedonic). Black pudding samples were presented in duplicate (Stone, Bleibaum, & Thomas, 2012b). The assessors then participated in a ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio, & Benassi, 2010) using the consensus list of sensory descriptors including grain quantity, fatness, spiciness, saltiness, juiciness, toughness and off-flavour (intensity), which was also measured on a 10 cm line scale. All samples were again presented in duplicate (Stone et al., 2012b) at ambient temperature.

6.2.4 Fat and moisture analysis

Moisture and fat content were obtained using the SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) (Bostian, Fish, Webb, & Arey, 1985). Before measuring samples, a reference meat sample with a known fat and moisture content was analysed to ensure the functionality of the system. Afterwards approximately 1.0 g of the homogenised sample was measured in triplicate, both before and after reheating.

6.2.5 Protein analysis

Before and after reheating, protein content was also determined using the Kjeldahl method (Suhre, Corrao, Glover, & Malanoski, 1982). Approximately 1.0 g - 1.5 g of homogenised sample, in triplicate, was weighed into a digestion tube to which 2 catalyst tabs (each tab containing 3.5 g potassium sulphate and 3.5 mg selenium), 15 ml concentrated sulphuric acid (nitrogen free) and 30% hydrogen peroxide (w/w) were added. In addition, a blank tube was prepared. In the digestion block (FOSS, Tecator ^{TM} digestor, Hillerød, Denmark) the tubes were heated up to 410 ºC and held for 1 hr. After cooling down, 50 ml of distilled water were added to each tube. Before the tubes were placed in the distillation unit (FOSS, Kjeltec ^{TM} 2100, Hillerød, Denmark), along with a receiver flask containing of 50 ml 4% boric acid (with bromcresol green and methyl red indicator), 70 ml of 30% sodium hydroxide (w/w) were added before the 5 min distillation started. The content of the receiver flask was then titrated with 0.1 N hydrochloric acid.

6.2.6 Ash analysis

Before and after reheating, the ash content was determined in triplicate using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of homogenized sample was weighed into porcelain dishes and placed into the muffle furnace. For the pre-ashing step, samples were heated up to 600 ºC in stages for 12 hrs and then cooled down. Distilled water was added to the pre-ashed samples in order to increase the surface area of ash particles and heated up again stepwise to 600 ºC until a white ash was generated.

6.2.7 Salt analysis

Both, before and after reheating, the salt content of black pudding products were carried out, in triplicate, using the potentiometric method (Fox, 1963) which employed a PHM82 Standard pH Meter (Radiometer, Copenhagen) fitted with a combined Ag electrode (M295, Radiometer Analytical SAS, Lyon, France) and a reference electrode Ag/AgCl buffered with KCl (pH C3006, Radiometer Analytical SAS, Lyon, France). Approximately 2.0 g of blended samples were weighed into a flask to which 100 ml of 0.1% nitric acid was added. The solutions were then mixed, covered and placed in a 60 ºC water bath for 15 min. After cooling down to room temperature, the flasks were potentiometrically titrated with 0.1 N silver nitrate until +255 mV.

6.2.8 Cooking loss analysis

Before reheating (section 2.2), sample weights were recorded. After reheating, the samples were allowed to cool down at room temperature for 20 min and then weighed again to achieve the cooking loss.

6.2.9 Colour analysis

The reheated black pudding samples were analysed in triplicate using CIE L* a* b* colour system by utilising the Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan) with 11 mm aperture and D_{65} illuminant (International Commission on Illumination, 1976). After calibrating, ten readings were then conducted per sample.

6.2.10 Texture analysis

The product texture parameters of hardness, springiness, cohesiveness and chewiness of the reheated samples were measured in triplicate with texture profile analysis (Bourne, 1978) by utilizing the Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K). Pudding slices were compressed in two-cycles using a cross-head speed of 1.5 mm/s to 40% of their original size by using a 35 mm diameter cylindrical probe (SMSP/35Compression plate) attached to a 25 kg load cell. The following parameters were measured: hardness [N], springiness [dimensionless], cohesiveness [dimensionless] and chewiness [N]. The compression of the product in two-cycles reflects two human bites with, the hardness being the required force to compress food at first bite, which represents the peak force of the first cycle. Springiness describes how well the sample springs back to the original size after deformation, calculated as the ratio of length below graph 2 until maximum force 2 divided by length below graph 1 until maximum force 1. How well the internal structure of a sample withstands compression is expressed by the cohesiveness, which is the ratio of work during compression of the second cycle divided by the first one. Chewiness reflects the required work to chew solid food to a state ready for swallowing, calculated as the product of hardness, springiness and cohesiveness.

6.2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 9.7. The X-matrix was designed as 0/1 variables for fat and salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 16% and 12% respectively.

For evaluation the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$). The compositional data were evaluated using t-test, two-tailed and equal variances (software Microsoft Excel 2010, TTest).

6.3 Results and Discussion

6.3.1 Sensory evaluation

The sensory evaluation of the 25 black pudding products is presented in the APLSR plot in Figure 1 and in conjunction with the ANOVA values of regression coefficients shown in Table 2 for hedonic and intensity sensory terms. The plot gives an overview of the correlation of the attributes and samples. Here, the x-axis of the plot is separated by the y-axis. A positive correlation is presented if the attribute and sample are located on the same side of the x-axis and in close proximity. Furthermore, a negative correlation exists in the inverse case. Table 2 presents the corresponding ANOVA values for Figure 1 and includes significance and correlation factors. A significant difference exists, if the p-value is ≤ 0.05. The direction of the correlation (positive or negative) is represented by a + or - algebraic sign before the p-value.

As can be seen in Table 2, the assessors liked ($P < 0.05$) the colour of black pudding samples containing high sodium (0.6% - 1.0%) levels. Fat levels, on the other hand, did not affect colour acceptance. Instrumental results (Table 4) showed higher ($P < 0.05$) redness (a) and yellowness values (b) for very low fat and salt containing samples, although, no trend for lightness (L) values was observed. However, assessors preferred black pudding samples which possessed less yellowness.

From Figure 1, as shown in the right hand quadrant of the figure, liking of appearance was seen to be highly correlated to black pudding products high in fat and salt. Additionally, it is also linked to lower fat (2.5%, 5%) samples containing 1.0% sodium. Samples high in salt and fat (10% - 20%) were scored higher ($P < 0.05$) in terms of liking of appearance (Table 2). Therefore, liking of product appearance is strongly correlated to the fat and salt content.

Fatness, saltiness and spiciness are essential attributes for describing flavour. As can be observed in the right-hand side of Figure 1 and Table 2 the perception of fat, salt and spices were not affected by fat levels, but were impacted upon by salt levels. The data in Table 2 shows that black pudding samples with 0.2% sodium content were negatively ($P < 0.05$) correlated to fatness (with the exception of samples containing 10% and 15% fat), saltiness and spiciness. Samples of product all fat levels and with sodium contents of 0.6% - 1.0% were positively correlated to fatness, saltiness and spiciness whereas samples low in sodium (0.2%, 0.4%) were negatively ($P < 0.05$) correlated to these attributes. Wood & Fisher (1990) and Giese (1996) reported that fats interact with other ingredients within a meat system contributing to overall flavour. Moreover, added salt is associated with enhancement of salt perception, flavour perception of further ingredients and/or bitterness reduction (Hutton, 2002; McCaughey, 2007). The theory that salt and fat play a key role in enhancing the flavour, can be confirmed only partly by this study. Fellendorf, O'Sullivan, & Kerry (2015) reported that both, salt and fat, affect fatness, saltiness and spiciness perceptions in white pudding. The main differences in black and white pudding composition are the added blood powder, in addition to grains (30% less in black pudding) and the mixture of spices. Blood, and its derivatives, is known for its ability to improve the sensory quality caused by the fat and water-binding properties of blood proteins and minerals (Pares, Saguer, & Carretero, 2011). In this case, it may be that in addition to fat, ingredients such as salt and spices interact strongly with blood proteins. Seemingly, the lower fat concentration present in black pudding can be compensated by the use of blood powder, therefore both, salt and blood powder, might act together as a flavour enhancer in black pudding.

From Figure 1, in the right hand quadrant of the figure, liking of texture can be seen to be correlated to black pudding products with higher salt levels. As can be seen in Table 2, samples high in sodium (0.6% - 1.0%) and fat (10% - 20%) are positively ($P < 0.05$) correlated to liking of texture while lower fat and salt samples did not achieve significant positive results; with the exception of the black pudding sample containing 5% fat and 1.0% sodium. Samples of all fat levels; with the exception of 15% fat, with 0.2% sodium content were negatively ($P < 0.05$) correlated to liking of texture. Therefore, varying the salt level in black pudding products affects the sensory acceptance of texture stronger than varying the fat content.

Grains are essential to achieve the typical texture of black pudding, even if the consumer prefers fewer amounts of grains in black pudding compared to white pudding (unpublished data, 2013). From Figure 1, in the right hand quadrant of the figure, intensity of graininess can be seen to be non-correlated to the amount of fat in black pudding samples, though it is correlated to salt. Assessors scored samples high in salt positively ($P < 0.05$) to intensity of grains (Table 2). The inverse effect can be observed for samples with the lowest salt concentration (0.2% sodium). These results are not consistent with sample formulations (Table 1) as the amount of added grains is constant. In a previous study by Fellendorf et al. (2015), varying the salt levels in white pudding products was found not to have affected the intensity of graininess. The presence of blood in black puddings may constrict the visual appearance, texture and taste of the grains used in these products.

As displayed in Figure 1, in the right hand quadrant of the figure, the sensory attributes of juiciness and toughness can be seen to be correlated to samples high in sodium, though, no correlation to different fat levels was observed. As seen in Table 2 the majority of the samples high in sodium (0.6% - 1.0%) for all fat levels were positively ($P < 0.05$) correlated to juiciness and toughness, while samples low in sodium (0.2% - 0.4%) were rated negatively ($P < 0.05$). In black pudding products, salt influences the attributes of juiciness and toughness. These results are in agreement with Ruusunen et al. (2003) and Matulis, McKeith, & Brewer (1994) who reported that salt increases juiciness and toughness in frankfurters. Ventanas, Puolanne, & Tuorila (2010) showed that the perception of juiciness in cooked bologna-type sausages was affected by both, salt and fat. Furthermore, Fellendorf et al. (2015) observed for white puddings containing fat contents ranging from 5% to 20% and sodium levels ranging from 0.6% to 1.0% that positive correlations to juiciness and negative correlations to toughness were determined. Inverse results were recorded for white pudding samples containing 2.5% fat for all salt levels. However, Hamm (1972) and Desmond (2006) postulated that the relationship between higher salt contents and juiciness, as well as tenderness, is caused by the greater extraction of myofibrillar proteins, resulting in greater water-binding properties which can be confirmed partly from data generated in the present study.

As can be seen in Table 2, no significant results were achieved for the sensory attribute of off-flavour. Fellendorf et al. (2015) reported positive ($P < 0.05$) correlations to off-flavours for lower fat (2.5% - 5%) white pudding samples containing 0.2% sodium. However, in the present study, varying salt and fat levels in black puddings did not produce any off-flavours. From Figure 1, in the right hand quadrant of the plot, the attributes for liking of flavour and overall acceptability can be seen to be correlated to samples with higher sodium and fat levels, but also to lower fat (2.5% - 5%) samples containing sodium contents of 0.8% and 1.0%. As shown in Table 2, the concentration of 1.0% sodium in black pudding products for all fat levels (with the exception of the 2.5% fat sample in conjunction with the attribute acceptance) were scored positively ($P < 0.05$) to liking of flavour and overall acceptability. The inverse effect was observed for samples containing 0.2% sodium for all fat levels. Indeed, no correlation was observed between different fat levels and it seems that there exists no limit with respect to fat reduction. Salt plays a key role in acceptance and liking of flavour in black puddings. However, the sample with the reduced fat content of 10% and the sodium level of 0.6%, the target level set by the FSAI (2011) achieved positive ($P < 0.05$) correlations to flavour and overall acceptability.

6.3.2 Characterization of black pudding samples

The compositional properties of cooked and reheated black pudding samples with different salt and fat levels are presented in Table 3. The fat levels were slightly higher compared to the designed model (Table 1) as the fat concentration of pure pork fat differs. The marginal higher salt values might be caused by the presence of blood powder, which contains 0.5% salt as a preservative (unpublished data, 2013). In general, reheated black pudding samples had higher ($P < 0.05$) fat, salt, protein and ash contents, as well as lower ($P < 0.05$) water contents with regard to cooked samples (Table 3). Similar findings were observed in white puddings and pork frankfurters by Fellendorf et al. (2015) and Mittal & Barbut (1994), respectively. Ash contains inorganic substances like sodium chloride wherefore the ash concentration in black puddings increased with increasing the salt content as seen in Table 3.

As fat content decreased in black pudding products, a subsequent increase ($P < 0.05$) in cooking loss was observed (Table 4). After reheating, the fat content increased and the water content decreased owing to cooking losses, mainly caused by water losses. Following the recipe for black pudding, less fat was balanced with meat (Table 1). Pure pork fat contains less water than lean pork meats (Souci et al., 2004), consequently, the higher meat content in lower fat black puddings caused higher cooking losses. In previous studies different findings regarding cooking losses are reported. For instance, Mittal & Barbut (1994) and Fellendorf et al. (2015) found similar results for pork frankfurters and white puddings. In contrast, Ruusunen et al. (2005) recorded increased cooking losses in higher fat ground meat patties. No trend, in terms of cooking loss, was observed in black pudding samples through varying salt contents. This finding is similar to that reported by Fellendorf et al. (2015), but contrasts with those reported with Ruusunen et al. (2005) and Puolanne & Ruusunen (1980). It appears that no general statement can be made about cooking loss and varying salt and fat levels in meat products. Cooking loss might also be influenced by production conditions and processing factors such as chopping time, heating time, cooking temperature, meat type, fat composition, meat product type, ingredient mix etc..

As shown in Table 4, black pudding samples low in fat (2.5% - 10%) and sodium (0.2% - 0.6%) have achieved increases ($P < 0.05$) in yellowness (b) and redness (a) values. Though, varying the fat and salt levels has shown no effect on lightness (L). No significant differences in lightness among fat variation were also found by Youssef & Barbut (2011).

Table 4 displays the results from the texture profile analysis. Black pudding samples with varied salt and fat contents showed differences ($P < 0.05$) in hardness, springiness, cohesiveness and chewiness. Lower fat (2.5% - 10%) samples with 0.2% sodium have shown lower ($P < 0.05$) springiness values. Black pudding samples very low in fat (2.5%) exhibited lower ($P < 0.05$) cohesiveness values which means less strength of internal bonds compared to samples higher in fat. Samples low in salt (0.2%, 0.4%) were softer ($P < 0.05$) and less chewy ($P < 0.05$). The inverse effect was observed for lower fat samples (2.5% - 10%). In previous studies harder and chewier meat products were also reported for samples low in fat (Ahmed, Miller, Lyon, Vaughters, & Reagan, 1990; Tobin, O'Sullivan, Hamill, & Kerry, 2012b, 2013) and high in salt (Fellendorf et al., 2015; Tobin, O'Sullivan, Hamill, & Kerry, 2012a; Tobin et al., 2012b). Samples with varied salt levels achieved consistent instrumental and sensory results for hardness, thus not for samples with varied fat contents (Table 2, 4). The assessors scored samples high in salt independent of their fat level high for toughness, although the texture analyzer recorded lower ($P < 0.05$) shear force values for higher fat samples. Additional, some of the black pudding samples with similar hardness values were scored differently for toughness. For instance, the sample with 10% fat and 0.8% sodium and the sample with 5% fat and 0.4% sodium achieved hardness values of 109 N but they were rated high and accordingly low for toughness by the consumers. However, for frankfurters and white puddings inverse results have also been observed (Fellendorf et al., 2015; Tobin et al., 2012a).

Conclusion

Fat and salt contents in black puddings have a significant effect on physicochemical and sensory properties, but salt plays the key role. Reheated black pudding products had higher fat, salt, protein and ash contents, as well as lower water content compared to cooked samples. Additionally, with decreasing fat contents, an increase ($P < 0.05$) in cooking loss was achieved. Black pudding samples with varied salt and fat contents showed differences ($P < 0.05$) in hardness, springiness, cohesiveness and chewiness. Samples low in salt and samples high in fat were measured softer ($P < 0.05$) and less chewy ($P < 0.05$). Samples with varied salt levels achieved consistent instrumental and sensory results for hardness. Samples low in fat and salt showed higher ($P < 0.05$) yellowness and redness values. No effect on lightness was recorded. However, assessors preferred samples that appeared less yellow and red in hue. Samples high in sodium (0.6% - 1.0%) scored higher for juiciness, toughness, saltiness, fatness and spiciness. These samples were the most accepted by assessors. Samples with 0.2% sodium were found to be unacceptable. Indeed, for liking of flavour, no correlation was observed between different fat levels and it seems that there exists nearly no limit for potential fat reduction. However, one of the twenty-five samples with 0.6% sodium and 10% fat displayed a positive ($P < 0.05$) correlation to liking of flavour and overall acceptability. This meets the sodium target level set by the Salt Reduction Program (SRP) of the Food Safety Authority of Ireland (FSAI, 2011) for this type of product and shows additionally a fat reduction is possible in black pudding products.

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Conflict of interest

None

6.4 Tables and Figures

Table 1

Black pudding formulations

Sample [a]	Formulation [%]									
	Meat	Fat	Salt	Water	Blood powder	Seasoning	Oatmeal	Onion	Boiled barley	Rusk
F 20 Na 1.0	12.76	36.70	2.54	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 20 Na 0.8	13.27	36.70	2.03	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 20 Na 0.6	13.78	36.70	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 20 Na 0.4	14.28	36.70	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 20 Na 0.2	14.79	36.70	0.51	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 15 Na 1.0	21.94	27.52	2.54	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 15 Na 0.8 [b]	22.45	27.52	2.03	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 15 Na 0.6	22.96	27.52	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 15 Na 0.4	23.46	27.52	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 15 Na 0.2	23.97	27.52	0.51	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 10 Na 1.0	31.11	18.35	2.54	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 10 Na 0.8	31.62	18.35	2.03	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 10 Na 0.6	32.13	18.35	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 10 Na 0.4	32.64	18.35	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 10 Na 0.2	33.14	18.35	0.51	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 5 Na 1.0	40.29	9.17	2.54	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 5 Na 0.8	40.80	9.17	2.03	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 5 Na 0.6	41.31	9.17	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 5 Na 0.4	41.81	9.17	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 5 Na 0.2	42.32	9.17	0.51	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 2.5 Na 1.0	44.87	4.59	2.54	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 2.5 Na 0.8	45.38	4.59	2.03	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 2.5 Na 0.6	45.89	4.59	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 2.5 Na 0.4	46.40	4.59	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85
F 2.5 Na 0.2	46.90	4.59	0.51	27.00	3.00	1.10	6.55	2.50	3.00	4.85

[a] Sample code: F = fat, Na = sodium.

[b] Salt and fat content of sample is comparable to the average salt and fat content of commercial black puddings.

Table 2

P-values of regression coefficients from ANOVA values of regression coefficients from APLSR for the hedonic and intensity sensory terms of reheated black pudding, including significance and correlation

Sample [a]	Hedonic term [b]					Intensity term						
	Appearance	Flavour	Texture	Colour	Acceptability	Grains	Fatness	Spiciness	Saltiness	Juiciness	Toughness	Off-flavour
F 20 Na 1.0	0.0014 **	0.0052 **	0.0012 **	0.0022 **	0.0025 **	0.0304 *	0.0081 **	0.0498 *	0.0106 *	0.0021 **	0.2418 ns	-0.7242 ns
F 20 Na 0.8	0.0151 *	0.0957 ns	0.0082 **	0.0145 *	0.0454 *	0.3326 ns	0.0007 ***	0.6170 ns	0.1228 ns	0.0011 **	0.0044 **	-0.9711 ns
F 20 Na 0.6	0.0542 ns	0.5087 ns	0.0225 *	0.0492 *	0.2457 ns	0.8110 ns	0.0008 ***	0.2938 ns	0.5694 ns	0.0008 ***	0.0002 ***	-0.8757 ns
F 20 Na 0.4	-0.4589 ns	-0.3928 ns	-0.2496 ns	-0.4144 ns	-0.7689 ns	-0.1145 ns	-0.0008 ***	-0.0227 *	-0.2899 ns	-0.0020 **	-0.0005 ***	0.7165 ns
F 20 Na 0.2	-0.0041 **	-0.0004 ***	-0.0200 *	-0.0041 **	-0.0015 **	-0.0001 ***	-0.0378 *	-0.0001 ***	-0.0001 ***	-0.0483 *	-0.0001 ***	0.5253 ns
F 15 Na 1.0	0.0001 ***	0.0001 ***	0.0002 ***	0.0001 ***	0.0001 ***	0.0017 **	0.0047 **	0.0012 **	0.0003 ***	0.0011 **	0.2170 ns	-0.7066 ns
F 15 Na 0.8	0.0003 ***	0.0010 ***	0.0003 ***	0.0006 ***	0.0004 ***	0.0030 **	0.0089 **	0.0036 **	0.0003 ***	0.0015 **	0.4736 ns	-0.6651 ns
F 15 Na 0.6	0.4595 ns	0.6617 ns	0.3025 ns	0.4186 ns	0.9821 ns	0.2760 ns	0.0093 **	0.0935 ns	0.5622 ns	0.0116 *	0.0010 ***	-0.7559 ns
F 15 Na 0.4	0.5053 ns	0.4722 ns	0.2987 ns	0.4687 ns	0.8221 ns	0.1779 ns	0.0021 **	0.0553 ns	0.3742 ns	-0.0052 **	0.0016 **	0.7231 ns
F 15 Na 0.2	-0.0260 *	-0.0029 **	-0.0533 ns	-0.0323 *	-0.0055 **	-0.0015 **	-0.1499 ns	-0.0002 ***	-0.0017 **	-0.5646 ns	-0.0003 ***	0.4886 ns
F 10 Na 1.0	0.0263 *	0.0077 **	0.0456 *	0.0304 *	0.0182 *	0.0042 **	0.6154 ns	0.0025 **	0.0051 **	0.8051 ns	0.0056 **	-0.4731 ns
F 10 Na 0.8	0.0029 **	0.0003 ***	0.0048 **	0.0038 **	0.0007 ***	0.0010 **	0.8392 ns	0.0002 ***	0.0003 ***	0.3407 ns	0.0304 *	-0.4727 ns
F 10 Na 0.6	0.0264 *	0.0101 *	0.0422 *	0.0358 *	0.0134 *	0.0078 **	0.6586 ns	0.0041 **	0.0034 **	0.8169 ns	0.0310 *	-0.4968 ns
F 10 Na 0.4	-0.7403 ns	-0.8510 ns	-0.7157 ns	-0.7320 ns	-0.8109 ns	-0.9219 ns	-0.6268 ns	-0.9756 ns	-0.8649 ns	-0.6292 ns	-0.7184 ns	0.9969 ns
F 10 Na 0.2	-0.0013 **	-0.0001 ***	-0.0024 **	-0.0022 **	-0.0002 ***	-0.0003 ***	-0.7793 ns	-0.0001 ***	-0.0001 ***	-0.2123 ns	-0.0092 **	0.4753 ns
F 5 Na 1.0	0.0030 **	0.0004 ***	0.0033 **	0.0048 **	0.0006 ***	0.0001 ***	0.9412 ns	0.0001 ***	0.0004 ***	0.3286 ns	0.0166 *	-0.4901 ns
F 5 Na 0.8	0.9129 ns	0.1708 ns	0.5954 ns	0.8232 ns	0.3506 ns	0.0615 ns	0.0015 **	0.0170 *	0.1231 ns	0.0053 **	0.0022 **	-0.6523 ns
F 5 Na 0.6	0.8134 ns	0.3378 ns	0.5960 ns	0.7501 ns	0.5785 ns	0.1125 ns	0.0301 *	0.0385 *	0.2556 ns	0.0458 *	0.0063 **	-0.6912 ns
F 5 Na 0.4	-0.1441 ns	-0.4879 ns	-0.0789 ns	-0.1278 ns	-0.3185 ns	-0.8955 ns	-0.0069 **	-0.7390 ns	-0.5449 ns	-0.0077 **	-0.0025 **	0.9230 ns
F 5 Na 0.2	-0.0003 ***	-0.0005 ***	-0.0001 ***	-0.0018 **	-0.0005 ***	-0.0014 **	-0.0009 ***	-0.0004 ***	-0.0001 ***	-0.0001 ***	-0.2470 ns	0.6564 ns
F 2.5 Na 1.0	0.3853 ns	0.0136 *	0.6522 ns	0.4670 ns	0.0517 ns	0.0062 **	0.0199 *	0.0020 **	0.0205 *	0.0417 *	0.0006 ***	-0.5883 ns
F 2.5 Na 0.8	0.7642 ns	0.0769 ns	0.8855 ns	0.8625 ns	0.1926 ns	0.0319 *	0.0006 ***	0.0037 **	0.0355 *	0.0013 **	0.0001 ***	-0.6302 ns
F 2.5 Na 0.6	0.9538 ns	0.3701 ns	0.7213 ns	0.8870 ns	0.5369 ns	0.1876 ns	0.0602 ns	0.0961 ns	0.2861 ns	0.0755 ns	0.0260 *	-0.6834 ns
F 2.5 Na 0.4	-0.0063 **	-0.0873 ns	-0.0018 **	-0.0072 **	-0.0269 *	-0.3848 ns	-0.0001 ***	-0.8200 ns	-0.0904 ns	-0.0001 ***	-0.0007 ***	0.9943 ns
F 2.5 Na 0.2	-0.0002 ***	-0.0001 ***	-0.0001 ***	-0.0002 ***	-0.0001 ***	-0.0005 ***	-0.0074 **	-0.0001 ***	-0.0001 ***	-0.0002 ***	-0.7429 ns	0.6169 ns

[a] Sample code: F = fat, Na = sodium.

[b] Significance of regression coefficients: ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Table 3

Compositional properties of cooked and reheated black pudding samples containing different fat and salt levels

Sample^{c}	Fat [%]^{d}		Moisture [%]		Protein [%]		Ash [%]		Sodium [%]	
	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated
F 20 Na 1.0	23.5 ± 0.1^{a}	26.0 ± 0.1^{b}	50.7 ± 0.1^{a}	46.7 ± 0.1^{b}	9.4 ± 0.1^{a}	10.0 ± 0.2^{b}	3.2 ± 0.0^{a}	3.4 ± 0.1^{b}	1.06 ± 0.01^{a}	1.11 ± 0.01^{b}
F 20 Na 0.8	23.0 ± 0.4^{a}	26.0 ± 0.2^{b}	51.2 ± 0.5^{a}	47.3 ± 0.2^{b}	9.7 ± 0.0^{a}	10.0 ± 0.1^{b}	2.6 ± 0.0^{a}	2.9 ± 0.0^{b}	0.87 ± 0.01^{a}	0.91 ± 0.00^{b}
F 20 Na 0.6	23.0 ± 0.2^{a}	25.8 ± 0.3^{b}	51.6 ± 0.2^{a}	47.8 ± 0.1^{b}	10.2 ± 0.2^{a}	10.7 ± 0.2^{b}	2.1 ± 0.0^{a}	2.3 ± 0.0^{b}	0.64 ± 0.01^{a}	0.69 ± 0.01^{b}
F 20 Na 0.4	23.7 ± 0.2^{a}	26.0 ± 0.2^{b}	51.2 ± 0.4^{a}	47.3 ± 0.2^{b}	10.1 ± 0.0^{a}	10.8 ± 0.1^{b}	1.6 ± 0.0^{a}	1.7 ± 0.1^{b}	0.45 ± 0.01^{a}	0.46 ± 0.00^{a}
F 20 Na 0.2	21.9 ± 0.2^{a}	24.8 ± 0.2^{b}	52.1 ± 0.2^{a}	48.0 ± 0.2^{b}	10.0 ± 0.2^{a}	11.0 ± 0.5^{b}	1.1 ± 0.1^{a}	1.2 ± 0.0^{a}	0.23 ± 0.01^{a}	0.26 ± 0.00^{b}
F 15 Na 1.0	17.7 ± 0.4^{a}	19.7 ± 0.3^{b}	54.4 ± 0.3^{a}	50.2 ± 0.2^{b}	11.1 ± 0.1^{a}	11.8 ± 0.5^{b}	3.2 ± 0.1^{a}	3.4 ± 0.0^{b}	1.02 ± 0.01^{a}	1.12 ± 0.01^{b}
F 15 Na 0.8	17.9 ± 0.1^{a}	20.0 ± 0.2^{b}	54.2 ± 0.3^{a}	50.2 ± 0.1^{b}	11.3 ± 0.1^{a}	11.9 ± 0.1^{b}	2.7 ± 0.0^{a}	2.9 ± 0.0^{b}	0.83 ± 0.00^{a}	0.94 ± 0.01^{b}
F 15 Na 0.6	17.7 ± 0.5^{a}	19.2 ± 0.1^{b}	54.8 ± 0.3^{a}	51.3 ± 0.2^{b}	11.2 ± 0.1^{a}	11.8 ± 0.2^{b}	2.2 ± 0.1^{a}	2.4 ± 0.0^{b}	0.65 ± 0.01^{a}	0.74 ± 0.00^{b}
F 15 Na 0.4	16.5 ± 0.4^{a}	18.3 ± 0.2^{b}	56.1 ± 0.4^{a}	52.2 ± 0.3^{b}	11.5 ± 0.0^{a}	12.3 ± 0.0^{b}	1.5 ± 0.1^{a}	1.8 ± 0.1^{b}	0.43 ± 0.00^{a}	0.49 ± 0.00^{b}
F 15 Na 0.2	17.9 ± 0.2^{a}	19.5 ± 0.1^{b}	55.8 ± 0.2^{a}	51.7 ± 0.1^{b}	11.6 ± 0.2^{a}	12.6 ± 0.2^{b}	1.1 ± 0.0^{a}	1.3 ± 0.0^{b}	0.22 ± 0.01^{a}	0.28 ± 0.01^{b}
F 10 Na 1.0	11.7 ± 0.2^{a}	13.4 ± 0.1^{b}	58.0 ± 0.4^{a}	54.0 ± 0.2^{b}	12.2 ± 0.1^{a}	13.5 ± 0.2^{b}	3.2 ± 0.1^{a}	3.5 ± 0.1^{b}	1.04 ± 0.00^{a}	1.16 ± 0.00^{b}
F 10 Na 0.8	11.6 ± 0.2^{a}	13.1 ± 0.1^{b}	58.4 ± 0.3^{a}	54.6 ± 0.3^{b}	12.4 ± 0.5^{a}	13.8 ± 0.1^{b}	2.7 ± 0.0^{a}	3.0 ± 0.1^{b}	0.86 ± 0.01^{a}	0.94 ± 0.01^{b}
F 10 Na 0.6	12.2 ± 0.1^{a}	13.5 ± 0.1^{b}	58.5 ± 0.2^{a}	54.6 ± 0.1^{b}	12.7 ± 0.1^{a}	13.8 ± 0.1^{b}	2.3 ± 0.1^{a}	2.5 ± 0.0^{b}	0.64 ± 0.00^{a}	0.72 ± 0.01^{b}
F 10 Na 0.4	11.9 ± 0.1^{a}	13.7 ± 0.2^{b}	58.9 ± 0.3^{a}	54.8 ± 0.2^{b}	12.6 ± 0.1^{a}	13.7 ± 0.1^{b}	1.7 ± 0.0^{a}	1.9 ± 0.1^{b}	0.43 ± 0.00^{a}	0.51 ± 0.01^{b}
F 10 Na 0.2	11.9 ± 0.1^{a}	13.6 ± 0.1^{b}	58.9 ± 0.3^{a}	54.9 ± 0.2^{b}	12.7 ± 0.1^{a}	14.4 ± 0.2^{b}	1.3 ± 0.0^{a}	1.4 ± 0.0^{b}	0.23 ± 0.00^{a}	0.28 ± 0.01^{b}
F 5 Na 1.0	6.3 ± 0.1^{a}	6.8 ± 0.2^{b}	62.4 ± 0.2^{a}	58.9 ± 0.3^{b}	13.4 ± 0.1^{a}	15.0 ± 0.1^{b}	3.2 ± 0.1^{a}	3.6 ± 0.0^{b}	1.01 ± 0.02^{a}	1.17 ± 0.01^{b}
F 5 Na 0.8	6.7 ± 0.1^{a}	7.5 ± 0.1^{b}	62.3 ± 0.3^{a}	58.7 ± 0.5^{b}	13.8 ± 0.1^{a}	15.2 ± 0.1^{b}	2.9 ± 0.0^{a}	3.1 ± 0.0^{b}	0.85 ± 0.01^{a}	0.93 ± 0.01^{b}
F 5 Na 0.6	6.3 ± 0.2^{a}	7.0 ± 0.1^{b}	62.3 ± 0.3^{a}	58.9 ± 0.2^{b}	14.0 ± 0.2^{a}	15.8 ± 0.1^{b}	2.3 ± 0.0^{a}	2.5 ± 0.0^{b}	0.63 ± 0.00^{a}	0.72 ± 0.01^{b}
F 5 Na 0.4	6.3 ± 0.1^{a}	6.9 ± 0.2^{b}	62.4 ± 0.2^{a}	59.1 ± 0.1^{b}	14.1 ± 0.1^{a}	15.8 ± 0.1^{b}	1.7 ± 0.1^{a}	2.0 ± 0.1^{b}	0.42 ± 0.00^{a}	0.51 ± 0.01^{b}
F 5 Na 0.2	6.7 ± 0.1^{a}	7.2 ± 0.1^{b}	62.3 ± 0.3^{a}	58.9 ± 0.2^{b}	14.5 ± 0.0^{a}	16.0 ± 0.1^{b}	1.3 ± 0.0^{a}	1.5 ± 0.0^{b}	0.22 ± 0.01^{a}	0.27 ± 0.01^{b}
F 2.5 Na 1.0	2.4 ± 0.1^{a}	2.7 ± 0.3^{a}	63.8 ± 0.1^{a}	60.1 ± 0.2^{b}	14.6 ± 0.1^{a}	16.4 ± 0.2^{b}	3.3 ± 0.0^{a}	3.6 ± 0.1^{b}	1.03 ± 0.01^{a}	1.14 ± 0.01^{b}
F 2.5 Na 0.8	2.1 ± 0.1^{a}	2.3 ± 0.2^{a}	63.9 ± 0.3^{a}	59.9 ± 0.1^{b}	14.8 ± 0.1^{a}	16.0 ± 0.2^{b}	2.8 ± 0.0^{a}	3.2 ± 0.0^{b}	0.82 ± 0.01^{a}	0.90 ± 0.01^{b}
F 2.5 Na 0.6	2.7 ± 0.1^{a}	3.2 ± 0.2^{b}	64.6 ± 0.2^{a}	61.1 ± 0.2^{b}	14.7 ± 0.1^{a}	16.3 ± 0.2^{b}	2.4 ± 0.0^{a}	2.6 ± 0.0^{b}	0.61 ± 0.02^{a}	0.72 ± 0.01^{b}
F 2.5 Na 0.4	2.7 ± 0.1^{a}	3.1 ± 0.1^{b}	64.7 ± 0.2^{a}	60.9 ± 0.1^{b}	14.8 ± 0.1^{a}	16.7 ± 0.2^{b}	1.9 ± 0.0^{a}	2.0 ± 0.0^{b}	0.43 ± 0.01^{a}	0.48 ± 0.01^{b}
F 2.5 Na 0.2	2.8 ± 0.1^{a}	3.2 ± 0.1^{b}	65.2 ± 0.1^{a}	61.5 ± 0.2^{b}	15.5 ± 0.1^{a}	17.0 ± 0.2^{b}	1.3 ± 0.1^{a}	1.5 ± 0.0^{b}	0.21 ± 0.00^{a}	0.31 ± 0.01^{b}

[a-b] Averages of each cooked and reheated sample of each composition analysis sharing different letters are significantly different (two tailed t-test, $p < 0.05$).

[c] Sample code: F = fat, Na = sodium.

[d] All values are averages ± standard errors.

Table 4

Colour, texture profile and cooking loss values of reheated black pudding samples containing different fat and salt levels

Sample^{m}	Colour^{n}			Texture analyzer				Cooking loss [%]
	L*	a*	b*	Hardness [N]	Springiness	Cohesivness	Chewiness [N]	
F 20 Na 1.0	24.5 ± 0.3$^{h, i}$	4.4 ± 0.1$^{i, j, k, l}$	5.2 ± 0.2^{l}	50.3 ± 1.5$^{j, k}$	0.82 ± 0.01$^{b, c, d}$	0.51 ± 0.01$^{b, c, d,e, f}$	21.1 ± 0.9$^{f, g}$	5.7 ± 0.2$^{g, h, i}$
F 20 Na 0.8	25.8 ± 0.3$^{b, c, d, e, f, g, h}$	5.7 ± 0.1$^{d, e}$	6.6 ± 0.2$^{g, h, i, j}$	53.4 ± 1.3$^{j, k}$	0.82 ± 0.01$^{b, c, d, e}$	0.48 ± 0.01$^{e, f}$	21.1 ± 0.8$^{f, g}$	5.4 ± 0.1$^{h, i}$
F 20 Na 0.6	27.7 ± 0.4^{a}	6.4 ± 0.1$^{a, b, c}$	7.9 ± 0.2$^{c, d}$	55.6 ± 5.6$^{i, j}$	0.81 ± 0.01$^{c, d, e}$	0.50 ± 0.01$^{d, e, f}$	22.4 ± 0.9^{f}	5.1 ± 0.2^{i}
F 20 Na 0.4	25.4 ± 0.3$^{e, f, g, h}$	4.7 ± 0.1$^{h, i, j}$	5.7 ± 0.2$^{k, l}$	53.8 ± 1.9$^{j, k}$	0.84 ± 0.01$^{a, b , c}$	0.49 ± 0.01$^{e, f}$	21.9 ± 0.6^{f}	5.4 ± 0.2$^{h, i}$
F 20 Na 0.2	25.1 ± 0.4$^{f, g, h}$	4.7 ± 0.1$^{h, i, j}$	6.2 ± 0.3$^{i, j, k}$	35.7 ± 1.0^{l}	0.82 ± 0.01$^{c, d}$	0.45 ± 0.01$^{g, h}$	13.1 ± 0.6^{h}	5.6 ± 0.2$^{h, i}$
F 15 Na 1.0	27.1 ± 0.4$^{a, b, c}$	5.3 ± 0.1$^{e, f}$	7.2 ± 0.2$^{d, e, f, g}$	79.7 ± 2.0$^{e, f}$	0.82 ± 0.01$^{b, c, d, e}$	0.50 ± 0.00$^{d, e, f}$	32.2 ± 0.9$^{d, e}$	6.3 ± 0.1$^{g, h, i}$
F 15 Na 0.8	26.0 ± 0.3$^{b, c, d, e, f, g, h}$	4.1 ± 0.1^{l}	5.9 ± 0.2$^{j, k, l}$	70.0 ± 1.5$^{g, h}$	0.81 ± 0.01$^{b, c, d, e}$	0.49 ± 0.00$^{e, f}$	27.7 ± 0.7^{e}	6.7 ± 0.2$^{g, h}$
F 15 Na 0.6	25.4 ± 0.4$^{e, f, g, h}$	4.5 ± 0.1$^{h, i, j, k}$	6.1 ± 0.3$^{i, j, k}$	71.2 ± 1.6$^{f, g, h}$	0.84 ± 0.01$^{a, b , c}$	0.49 ± 0.01$^{d, e, f}$	29.1 ± 1.0^{d,e}	6.6 ± 0.2$^{g, h}$
F 15 Na 0.4	26.5 ± 0.4$^{a, b, c, d, e, f}$	4.6 ± 0.1$^{h, i, j}$	6.2 ± 0.3$^{h, i, j, k}$	74.9 ± 4.9$^{f, g}$	0.83 ± 0.01$^{b, c, d}$	0.48 ± 0.01$^{f, g}$	29.6 ± 0.9$^{g, h}$	6.7 ± 0.0$^{g, h}$
F 15 Na 0.2	23.4 ± 0.3^{i}	4.8 ± 0.1$^{g, h, i}$	5.5 ± 0.2$^{k, l}$	46.7 ± 1.6^{k}	0.80 ± 0.01$^{c, d, e}$	0.44 ± 0.01$^{h, i}$	16.4 ± 0.5^{c}	7.0 ± 0.1$^{f, g}$
F 10 Na 1.0	26.7 ± 0.4$^{a, b, c, d, e}$	4.5 ± 0.1$^{h, i, j, k}$	6.6 ± 0.2$^{f, g, h, i, j}$	103.9 ± 2.4^{d}	0.85 ± 0.01$^{a, b, c}$	0.51 ± 0.01$^{b, c, d, e}$	45.4 ± 0.4^{c}	8.5 ± 0.2^{e}
F 10 Na 0.8	27.0 ± 0.4$^{a, b, c, d}$	4.9 ± 0.1$^{g, h}$	7.1 ± 0.2$^{e, f, g}$	109.2 ± 2.0^{d}	0.85 ± 0.01$^{a, b, c}$	0.51 ± 0.00$^{b, c, d,e}$	48.0 ± 0.6^{c}	8.3 ± 0.2$^{e, f}$
F 10 Na 0.6	24.6 ± 0.3$^{g, h, i}$	4.0 ± 0.1^{l}	5.8 ± 0.2$^{j, k, l}$	106.0 ± 2.4^{d}	0.84 ± 0.01$^{a, b, c}$	0.50 ± 0.01$^{c, d, e, f}$	44.6 ± 1.0^{c}	8.7 ± 0.4$^{d, e}$
F 10 Na 0.4	25.3 ± 0.3$^{e, f, g, h}$	5.1 ± 0.1$^{f, g}$	7.0 ± 0.2$^{e, f, g, h}$	107.6 ± 1.6^{d}	0.84 ± 0.01$^{a, b, c}$	0.51 ± 0.00$^{b, c, d,e, f}$	45.8 ± 1.0^{c}	8.7 ± 0.2$^{d, e}$
F 10 Na 0.2	26.3 ± 0.3$^{a, b, c, d, e, f}$	6.6 ± 0.1$^{a, b}$	8.2 ± 0.2^{c}	64.2 ± 1.4$^{h, i}$	0.77 ± 0.01^{e}	0.42 ± 0.01^{i}	20.6 ± 0.6$^{f, g}$	8.4 ± 0.4^{e}
F 5 Na 1.0	25.5 ± 0.4$^{d, e, f, g, h}$	4.8 ± 0.1$^{g, h, i}$	7.4 ± 0.3$^{c, d, e, f}$	129.1 ± 2.3^{b}	0.85 ± 0.01$^{a, b, c}$	0.51 ± 0.00$^{b, c, d, e}$	56.1 ± 1.3^{b}	9.4 ± 0.6$^{c, d, e}$
F 5 Na 0.8	25.4 ± 0.5$^{d, e, f, g, h}$	4.3 ± 0.1$^{j, k, l}$	6.9 ± 0.2$^{e, f, g, h, i}$	129.1 ± 2.3^{b}	0.85 ± 0.01$^{a, b, c}$	0.53 ± 0.00$^{a, b, c}$	58.3 ± 1.6^{b}	11.1 ± 0.3$^{a, b}$
F 5 Na 0.6	27.2 ± 0.6$^{a, b}$	4.7 ± 0.1$^{h, i, j}$	7.7 ± 0.2$^{c, d, e}$	131.2 ± 2.4^{b}	0.85 ± 0.02$^{a, b, c}$	0.52 ± 0.01$^{a, b, c, d}$	57.8 ± 1.9^{b}	10.0 ± 0.3$^{b, c, d}$
F 5 Na 0.4	25.1 ± 0.4$^{f, g, h}$	5.8 ± 0.1^{d}	8.2 ± 0.2^{c}	109.9 ± 1.7^{d}	0.84 ± 0.01$^{a, b, c}$	0.49 ± 0.01$^{d, e, f}$	45.6 ± 3.4^{c}	10.5 ± 0.2$^{b, c}$
F 5 Na 0.2	25.6 ± 0.5$^{c, d, e, f, g, h}$	6.3 ± 0.2$^{b, c}$	9.0 ± 0.3^{b}	83.5 ± 2.5^{e}	0.79 ± 0.02$^{d, e}$	0.42 ± 0.01$^{h, i}$	27.8 ± 1.1^{e}	10.5 ± 0.2$^{b, c}$
F 2.5 Na 1.0	26.8 ± 0.5$^{a, b, c, d, e}$	4.2 ± 0.1$^{k, l}$	7.4 ± 0.2$^{c, d, e, f}$	146.5 ± 3.4^{a}	0.86 ± 0.01$^{a, b}$	0.53 ± 0.01$^{a, b}$	66.9 ± 2.1^{a}	10.3 ± 0.3$^{b, c}$
F 2.5 Na 0.8	26.0 ± 0.5$^{b, c, d, e, f, g, h}$	4.3 ± 0.1$^{j, k, l}$	7.2 ± 0.2$^{d, e, f, g}$	119.2 ± 3.0^{c}	0.85 ± 0.01$^{a, b, c}$	0.55 ± 0.00^{a}	55.6 ± 1.3^{b}	10.4 ± 0.2$^{b, c}$
F 2.5 Na 0.6	26.1 ± 0.5$^{b, c, d, e, f, g}$	4.5 ± 0.1$^{h, i, j, k}$	7.5 ± 0.3$^{c, d, e}$	123.8 ± 2.4$^{b, c}$	0.87 ± 0.01^{a}	0.55 ± 0.00^{a}	59.4 ± 1.1^{b}	11.2 ± 0.5^{b}
F 2.5 Na 0.4	25.8 ± 0.5$^{b, c, d, e, f, g, h}$	6.0 ± 0.1$^{c, d}$	9.2 ± 0.3$^{a, b}$	102.7 ± 2.0^{d}	0.83 ± 0.01$^{a, b, c, d}$	0.51 ± 0.01$^{b, c, d, e}$	44.0 ± 1.4^{c}	10.9 ± 0.1^{b}
F 2.5 Na 0.2	26.8 ± 0.5$^{a, b, c, d, e}$	6.8 ± 0.1^{a}	9.8 ± 0.2^{a}	85.9 ± 1.4^{e}	0.80 ± 0.02$^{c, d, e}$	0.48 ± 0.01$^{e, f}$	33.5 ± 1.3^{d}	12.2 ± 0.1^{a}

$^{a-l}$ Averages sharing different letters in the same column are significantly different ($P < 0.05$).

^{m} Sample code: F = fat, Na = sodium.

^{n} All values are averages ± standard errors.

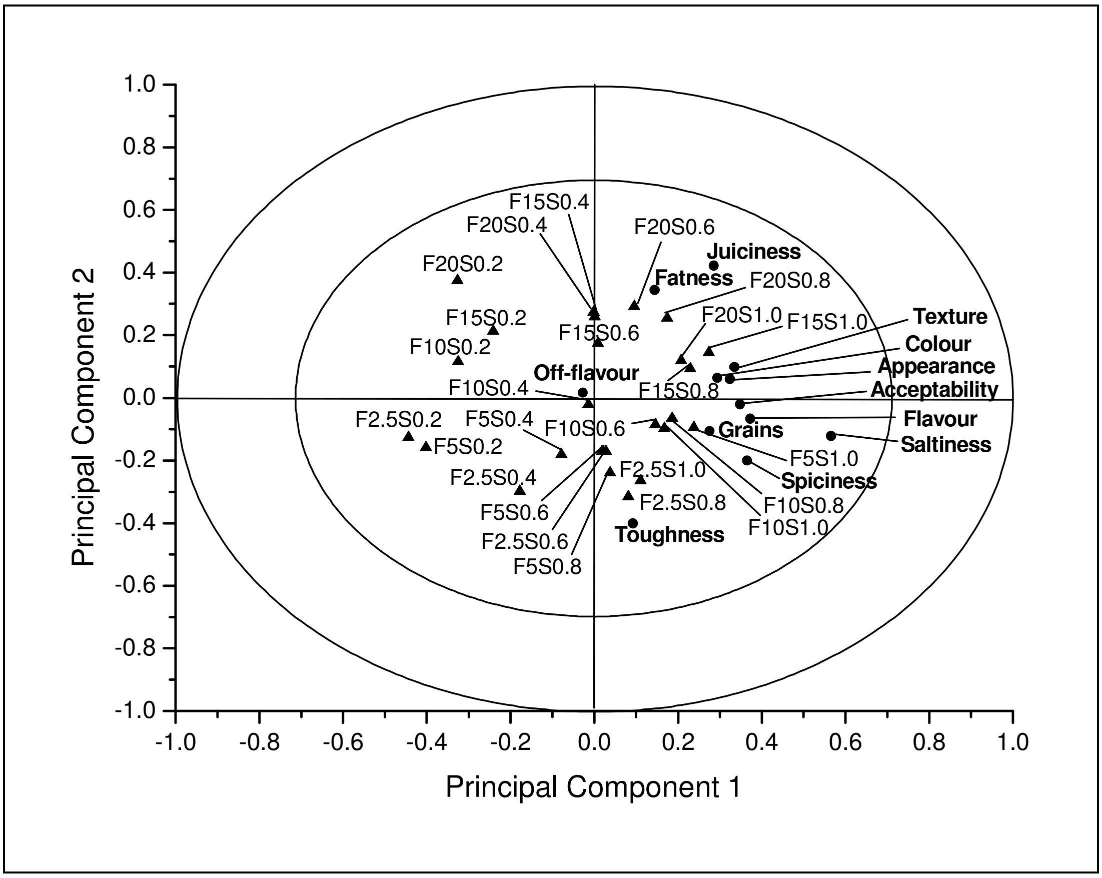

Figure 1:

ANOVA-Partial Least Squares regression (APLSR) for the 25 black pudding formulations. ▲ = Samples (code: F = fat, S = sodium), ● = sensory attributes.

References

Acebrón, B. L., & Dopico, C. D. (2000). The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. *Food Quality and Preference*, *11*(3), 229–238.

Adesiyun, A. A., & Balbirsingh, V. (1996). Microbiological analysis of "black pudding", a Trinidadian delicacy and health risk to consumers. *International Journal of Food Microbiology*, *31*(1–3), 283–299.

Ahmed, P. O., Miller, M. F., Lyon, C. E., Vaughters, H. M., & Reagan, J. O. (1990). Physical and Sensory Characteristics of Low-Fat Fresh Pork Sausage Processed with Various Levels of Added Water. *Journal of Food Science*, *55*(3), 625–628.

AOAC. (1923). Determination of ash. *Journal of the Association of Official Analytical Chemists*, *7*, 132. Association of Official Agricultural Chemists.

Biesalski, H. K., & Nohr, D. (2009). The nutritional quality of meat. In J. P. Kerry & D. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh meat* (pp. 161–177). Cambridge, England:Woodhead Publishing Ltd.

Bostian, M. L., Fish, D. L., Webb, N. B., & Arey, J. J. (1985). Automated methods for determination of fat and moisture in meat and poultry products: collaborative study. *Journal of the Association of Official Analytical Chemists*, *68*(5), 876–880.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, *32* , 62–66.

Cross, A. J., Leitzmann, M. F., Gail, M. H., Hollenbeck, A. R., Schatzkin, A., & Sinha, R. (2007). A Prospective Study of Red and Processed Meat Intake in Relation to Cancer Risk. *PLOS Medicine*, *4*(12), 1973 – 1984.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82.

Fox, P. F. (1963). Potentiometric determination of salt in cheese. *Journal of Dairy Science*, *46*, 744 – 745.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period : September 2003 to July 2014*. The Food Safety Authority of Ireland.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat Science*, *66*(2), 259–272.

Grunert, K. G., Larsen, H. H., Madson, T. K., & Baadsgaard, A. (1996). *Market Orientation in Food and Agriculture*. *Kluwer Academic Publishers*. Boston : Kluwer Academic Publishers.

Halkjaer, J., Tjønneland, A., Overvad, K., & Sørensen, T. I. a. (2009). Dietary predictors of 5-year changes in waist circumference. *Journal of the American*

Dietetic Association, *109*(8), 1356–66.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

International Commission on Illumination. (1976). ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space.

ISO. (1988). Sensory analysis. General guidance for the design of test rooms. Ref. no. *International Organization for Standardization, Genève, Switzerland*, ISO 8589:1988. International Organization for Standardization.

Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, *33*(3-4), 147–152.

Li, D., Siriamornpun, S., Wahlqvist, M. L., Mann, N. J., & Sinclair, A. J. (2005). Lean meat and heart health. *Asia Pacific Journal of Clinical Nutrition*, *14*(2), 113–119.

Marianski, S., & Marianski, A. (2011). *Making Healthy Sausages*. pp. 251-262. Bookmagic, LLC.

Martens, H., & Martens, M. (2001). *Multivariate Analysis of Quality. An Introduction*. *Measurement Science and Technology* (2nd ed., Vol. 12). John Wiley & Sons Ltd.

Matulis, R. J., McKeith, F. K., & Brewer, S. (1994). Physcial and sensory characteristics of commercially available frankfurters. *Journal of Food Quality*, *17*, 263–271.

McCaughey, S. (2007). Salt and Flavor: Mechanisms of Taste Perception and Physiological Controls. In K. D. & A. F. (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 78–99). Boca Raton Boston, New york, Washington-DC: Woodhead Publishing Ltd.

Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus. A systematic review and meta-analysis. *Circulation*, *121*(21), 2271–2283.

Mittal, G. S., & Barbut, S. (1994). Effects of fat reduction on frankfurters ' physical and sensory characteristics. *Food Research International*, *27*, 425 – 431.

Pares, D., Saguer, E., & Carretero, C. (2011). Blood by-products as ingredients in processed meat. In J. P. Kerry & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 218–242). Oxford, Cambridge, Philadelphia, New Dehli: Woodhead Publishing Ltd.

Peri, C. (2006). The universe of food quality. *Food Quality and Preference*, *17*, 3–8.

Pieniak, Z., Verbeke, W., Vanhonacker, F., Guerrero, L., & Hersleth, M. (2009). Association between traditional food consumption and motives for food choice in six European countries. *Appetite*, *53*(1), 101–108.

Predika, J. (1983). *The Sausage-making Cookbook*. Stackpole Books.

Puolanne, E., & Ruusunen, M. (1980). Kochsalz und Phosphat in ihrer Wirkung auf das Wasserbindungsvermögen von Brühwurst. *Fleischwirtschaft*, *60*, 1359–1362.

Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, *21*(6), 611–620.

Ruusunen, M., Vainionpää, J., Lyly, M., Lähteenmäki, L., Niemistö, M., Ahvenainen, R., & Puolanne, E. (2005). Reducing the sodium content in meat products: The effect of the formulation in low-sodium ground meat patties. *Meat Science*, *69*(1), 53–60.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., … Niemisto, M. (2003). Physical and sensory properties of low-salt phosphate-free frankfurters composed with various ingredients. *Meat Science*, *63*(1), 9–16.

Santos, E. M., González-Fernández, C., Jaime, I., & Rovira, J. (2003). Physicochemical and sensory characterisation of Morcilla de Burgos, a traditional Spanish blood sausage. *Meat Science*, *65*(2), 893–898.

Souci, S.W., Fachmann, W., & Kraut, H. (2004). *Der kleine Souci Fachmann Kraut. Lebensmitteltabelle fuer die Praxis. Wissenschaftliche Verlagsgesellschaft mbH Stuttgart* (3rd ed.). Wissenschaftliche Verlagsgesellschaft.

Steenkamp, J.-B. E. M., & Trijp, H. C. M. (1996). Quality guidance: A consumer-based approach to food quality improvement using partial least squares. *European Review of Agricultural Economics*, *23*, 195–215.

Stiebing, A. (1990). Blood sausage technology. *Fleischwirtschaft*, *70* (4), 424–428.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, B. R.N., & H. . Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 291 – 325). USA: Elsevier Academic Press.

Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, Bleibaum R.N., & H. A. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 117 – 157). USA: Elsevier Academic Press.

Stone, H., & Sidel, J. L. (2004). Affective testing. *In: H. Stone and J. L. Sidel (Eds.), Sensory Evaluation Practices. Food Science and Technology, International Series. USA: Academic Press/Elsevier.*, *3rd ed.*, 247–277.

Suhre, F. B., Corrao, P. A., Glover, A., & Malanoski, A. J. (1982). Comparison of three methods for determination of crude protein in meat: collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*(6), 1339–1345.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, *85*(3), 410–419.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

Williams, P. (2007). Nutritional composition of red meat. *Nutrition & Dietetics*, *64*(4), 113–119.

Wood, J. D., & Fisher, A. V. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). Elsevier Applied Science, London.

Youssef, M. K., & Barbut, S. (2011). Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil. *Meat Science*, *87*(4), 356–360.

Chapter 7

Impact of ingredient replacers on the physicochemical properties and sensory quality of reduced salt and fat black puddings

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Abstract

Twenty-two black puddings possessing different fat (10%, 5%) and sodium (0.6%, 0.4%) levels were used as base formulations for 11 different salt and fat replacers. Compositional, physicochemical and sensory analyses were conducted. Black pudding samples with 5% fat and 0.6% sodium containing potassium chloride (KCl), potassium chloride and glycine mixture (KClG), and seaweed, respectively, and 10% fat and 0.4% sodium containing carrageen were rated higher ($P < 0.05$) for spiciness and saltiness. Samples with 10% fat and 0.4% sodium containing KClG were rated positively ($P < 0.05$) to fatness. Samples with 5% fat and 0.6% sodium containing pectin and a combination of potassium citrate, potassium phosphate and potassium chloride (KCPCl), as well as samples containing 10% fat and 0.4% sodium with waxy maize starch (WMS) were liked ($P < 0.05$) for flavour and overall acceptance. The Food Safety Authority of Ireland (FSAI) recommends a sodium target level of 0.6% and an even lower sodium level (0.4%) was achieved.

7.1 Introduction

Processed meats have moved more into public focus over the past 20 years for many reasons, but particularly with respect to health concerns. Irrespective of public opinion, the processing of under-utilized meat is necessary on ethical grounds alone as it is responsible for converting inedible material to a more palatable form, thereby reducing food waste and generating more protein-based food products which also present product diversity in the marketplace. Additionally, and more specifically, processing extends shelf-life, improves texture and enhances overall flavour. However, meat processing inevitably leads to products having higher amounts of salt, saturated fatty acids and preservatives such as nitrates which have health implications (Barcellos, Grunert & Scholderer, 2011), particularly where overconsumption of such products occurs. A higher risk of coronary heart disease, stroke, cancer and obesity has been tenuously linked with their consumption (Demeyer, Honikel & De Smet, 2008; Gilbert & Heiser, 2005; Verbeke, Pérez-Cueto, De Barcellos, Krystallis & Grunert, 2010; WHO, 2003; 2009). In recent years, worldwide healthcare campaigns have attempted to educate consumers with respect to the associated risks of an over-dependency of a fat-, sugar- and salt rich diet.

Meat product suppliers have already commenced reformulating their recipes, and now offer lower levels of nitrate, salt and fat, or even higher levels of polyunsaturated fatty acids in processed meat products on the market (Verbeke et al., 2010). Additionally, several studies have looked at sensory focused salt and fat reduction in processed meats including beef patties (Tobin, O'Sullivan, Hamill, & Kerry, 2012b), breakfast sausage (Tobin, O'Sullivan, Hamill, & Kerry, 2013), frankfurters (Tobin, O'Sullivan, Hamill, & Kerry, 2012a) and white pudding (Fellendorf, O'Sullivan, & Kerry, 2015) to mention but a few. However, there is still a huge potential to produce even healthier and more sensory accepted products. With regard to achieving such acceptable products, the use of ingredient replacers such as hydrocolloids (a range of polysaccharides and proteins) could be utilized in the meat processing industry, as they have been used in processed meat products for many years to improve properties such as water binding and texture due to their ability to thicken, gel, bind, stabilize emulsions and pH (Andrès, Zaritzky & Califano, 2006). Hydrocolloids, based on animal proteins, include; casein, whey, gelatin and blood-derived protein. Additionally, an enormous range of polysaccharides are available on the market, such as starches (corn, wheat, maize, potato, tapioca, pea), celluloses (carboxymethylcellulose), gums (guar, alginate, pectin, locust bean), fibres (ß-glucan), chitin/chitosan and xanthan derived from microorganisms (Cutter, 2006). Recently, published studies have also presented the use of different types of edible seaweed (Sea Spaghetti, Wakame and Nori) in meat products (Cofrades, López-López, Solas, Bravo & Jiménez-Colmenero, 2008; Jiménez-Colmenero et al., 2010; López-López, Cofrades, Yakan, Sola & Jiménez-Colmenero, 2010). Seaweeds are a rich source of minerals, trace elements, proteinaceous compounds and flavour precursors (reducing sugars) which can act as flavour enhancers, or even as reactants in the flavour developing process (Maillard reaction, caramelisation), within processed meats. Additionally, seaweeds comprise a unique taste profile, which might replenish lost flavour in reduced salt and fat processed meat products (Hotchkiss, 2012). However, the most commonly used salt replacer is potassium chloride, although it is self-limiting due to its bitterness and metallic flavour when used above certain concentrations (Dzendolet & Meiselman, 1967). Nevertheless, Zanardi, Ghidini, Conter, & Ianieri (2010) reduced successfully the sodium content in Cacciatore salami, a typical Italian dry fermented sausage, by using a mixture of KCl, $CaCl_2$, and $MgCl_2$. Recently, the authors dos Santos, Campagnol, Morgano, & Pollonio (2014) reported that fermented cooked sausages containing monosodium glutamate combined with lysine, taurine, disodium inosinate and disodium guanylate masked the unpalatable sensory attributes linked with the replacement of 50% and 75% NaCl with KCl. Following, salt enhancers such as amino acids (glycine, glutamate), lactates and yeast extracts have found applications in processed meat. These substances have no salty taste themselves, although with the combination of sodium chloride, they are able to enhance the salty flavour (Desmond, 2006).

The present study investigated black pudding typically made in the United Kingdom and Ireland, which contains lean pork meat, pork fat, grains, onions, salt, blood powder and seasonings. The majority of commercially available black puddings contain between 14% and 16% fat, whereas the maximum commercial levels determined for products exceed 20% (unpublished data, 2013). The Food Safety Authority of Ireland (FSAI) reported that the levels of sodium concentrations in black and white puddings range between 520 mg and 1190 mg, with an average of

867 mg (FSAI, 2014). Due to health issues pertaining to higher salt and saturated fat levels in meat products, the FSAI have set a guideline for the Irish industry to decrease the sodium level in black pudding to at least 600 mg/100g (FSAI, 2011). Furthermore, the World Health Organization (WHO) recommends a lower intake of saturated fatty acids and additional a daily intake of polyunsaturated fatty acids (PUFAs) between 6% and 11%, based on daily energy intake (WHO, 2003).

In a previous study by Fellendorf, O'Sullivan & Kerry (unpublished, 2014) black pudding samples with 10% fat and 0.6% sodium was found to be accepted ($P < 0.05$) by consumers without the requirement for replacer usage at all. Consequently there is an enormous potential to achieve lower salt and fat levels in black puddings through the use of ingredient replacers. Therefore the objective of this work was to investigate the impact of using different salt and fat replacers on the physicochemical properties and sensory quality of low fat and low salt black puddings with the primary focus of producing a more highly accepted end product with further reductions in fat and salt levels.

7.2 Materials and Methods

7.2.1 Sample preparation

Pork trimming lean (visual lean score of 95%) and pork fat were purchased from a local meat supplier (Ballyburden Meats Ltd., Ballincollig, Cork, Ireland). Meat and fat were minced to a particle size of 10 mm and 5 mm, respectively (TALSABELL SA., Valencia, Spain), vacuum packed and stored at -20 ºC. Twelve hours before commencing production, required portions of meat and fat were defrosted at room temperature. Eleven different replacers were investigated for black puddings containing either 10% fat and 0.4% sodium or 5% fat and 0.6% sodium. Replacers chosen for investigation were as follows; wheat bran , sodium citrate, carrageen, pectin, potassium chloride (KCl), a mixture of potassium chloride and glycine (KClG), carboxymethylcellulose (CMC), PuraQ®Arome NA4 (PuraQ) (Corbion Purac, Barcelona, Spain), seaweed wakame (seaweed), a combination of tripotassium citrate, monopotassium phosphate and potassium chloride (KCPCl) and waxy maize starch (WMS). PuraQ is a product from the fermentation of sugar resulting in a mixture of sugars, salts of organic acids and aromas. The used quantities of the replacers and the detailed formulations of black puddings are listed in Table 1. As the ingredient seaweed (wakame) already contained sodium, a lower amount of salt was required during production in order to achieve target levels. The required ingredients were then weighed according to the recipe. Meat, fat, seasoning, salt, replacer and three-quarters of the water were added into the bowl chopper (Seydelmann KG, Aalen, Germany) and chopped at high speed (3000 rpm) for 45 sec, followed by addition and mixing of the remaining water and blood powder at high speed for 30 sec. The required pinhead oatmeal and dried onions were then chopped at low speed (1500 rpm) for 15 sec and finally, the required boiled pearl barley and rusk were chopped at low speed for 30 sec. The batter was afterwards placed into a casing filler (MAINCA, Barcelona, Spain), filled into polyamide casings and cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) using 100% steam at 85 ºC until the internal product core temperature reached 75 ºC, as ascertained by a temperature probe (Testo 110, Lenzkirch, Germany) placed in a pudding situated in the centre of the oven. The temperature was held for 15 min and subsequently, the black pudding products were immediately placed in the chill to cool down and stored there at 4 ºC**.** All sausage batches were produced in replicate.

7.2.2 Reheating procedure

Before serving black pudding at home, usually the cut slices are cooked in a frying pan. For experimental purpose the reheating step was standardized with all samples cut into 1.2 cm thick slices, placed on aluminium plates and dry cooked at 100 ºC for 7 min in a Zanussi convection oven (C. Batassi, Conegliano, Italy) and afterwards turned and heated up again at 100 ºC for an additional 7 min.

7.2.3 Sensory evaluation

The sensory acceptance test was conducted using untrained assessors (n = 25 - 30) (Stone, Bleibaum, & Thomas, 2012a; Stone & Sidel, 2004) in the age range of 21 – 60. They were chosen on the basis that they consumed black pudding products regularly. The experiment was conducted in panel booths at room temperature which conform to the International Standards (ISO, 1988) under artificial light (1000 LUX). The sensory test was split into five sessions, whereby five reheated samples (coded and presented in a randomised order) were served cold to the assessors to ensure comparability. The assessors were asked to assess, on a continuous line scale from 1 to 10 cm, the following attributes: liking of appearance, liking of flavour, liking of texture, liking of colour and overall acceptability (hedonic). Black pudding samples were presented in duplicate (Stone, Bleibaum, & Thomas, 2012b). The assessors then participated in a ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio, & Benassi, 2010) using the consensus list of sensory descriptors including grain quantity, fatness, spiciness, saltiness, juiciness, toughness and off-flavour (intensity), which was also measured on a 10 cm line scale. All samples were again presented in duplicate (Stone et al., 2012b).

7.2.4 Fat and moisture analysis

For investigating moisture and fat, both before and after reheating, 1.0 g of each of the homogenised vacuum packed black pudding samples was measured in triplicate using the SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) (Bostian, Fish, Webb, & Arey, 1985).

7.2.5 Protein analysis

Protein content was determined, in triplicate, both before and after reheating using the Kjeldahl method (Suhre, Corrao, Glover & Malanoski, 1982). Approximately 1.0 g - 1.5 g of homogenised sample was weighed into a digestion tube, to which 2 catalyst tabs (3.5 g potassium sulphate and 3.5 mg selenium per tab), 15 ml concentrated sulphuric acid and 10 ml 30% hydrogen peroxide (w/w) were added. Additionally, a blank tube was prepared similarly to serve as a control. The tubes were then placed in a digestion block (FOSS, Tecator ™ digestor, Hillerød, Denmark), heated up to 410 ºC and held for 1hr. After cooling, 50 ml of distilled water were added to each tube, which were then placed into the distillation unit (FOSS, Kjeltec ™ 2100, Hillerød, Denmark) along with a receiver flask containing 50 ml 4% boric acid with indicator (bromcresol green and methyl red). A total of 70 ml of 30% sodium hydroxide (w/w) was added to the tube before the 5 min distillation commenced. The content of the receiver flask was titrated with 0.1 N hydrochloric acid until the green colour reverted back to red.

7.2.6 Ash analysis

Ash content, both before and after reheating, was determined in triplicate using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of homogenized sample was weighed into crucibles, placed into the muffle furnace and heated in a stepwise manner to 600 ºC until a white ash was generated.

7.2.7 Salt analysis

7.2.7.1 Potentiometer – Measuring chloride concentration

Both before and after reheating, the salt (NaCl) content of black puddings samples containing chloride ions bound only to sodium was obtained using the potentiometric method (Fox, 1963) employing a chloride sensitive electrode (Ag electrode in combination with a reference electrode Ag/AgCl buffered with KCl (M295 and pH C3006, Radiometer Analytical SAS, Lyon, France)). Approximately 2.0 g of blended samples were weighed into flasks to which 100 ml of 0.1% nitric acid were added, mixed and placed into a 60 ºC water bath for 15 min. After cooling down to room temperature, the solutions were titrated with 0.1 N silver nitrate until reaching +255 mV. By means of the ratio to chloride, sodium chloride and sodium content, respectively, were calculated.

7.2.7.2 Flame photometer – Measuring sodium concentration

Both before and after reheating, sodium content was determined in triplicate using the flame photometer for samples containing chloride ions bound not only to sodium (AOAC, 1988). The obtained ash (section 2.6) was dissolved with 40 ml concentrated HCl/water (1+3) and heated until boiling. The solution was then transferred to a 50 ml volumetric flask topped up, filtered and diluted within the range of the sodium standard concentrations. Sodium content of the diluted filtrate was then analysed using the flame photometer (Jenway PFP7, Essex, England).

7.2.8 Cooking loss analysis

Before reheating, pudding sample weights were recorded. After reheating (section 2.2), samples were allowed to cool down to room temperature for 20 min and then weighed again. The difference in both weights represented the cooking loss.

7.2.9 Colour analysis

Colour analysis was undertaken on reheated samples by utilising a Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan) with a 11 mm aperture and D_{65} illuminant. The tristimulus values were expressed in L (lightness), a (red-green dimension) and b (yellow-blue dimension) (International Commission on Illumination, 1976). A white tile was applied for colorimeter calibration, afterwards 10 readings were taken per sample in triplicate.

7.2.10 Texture analysis

Texture of reheated samples were measured in triplicate using texture profile analysis (Bourne, 1978) by utilizing the Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K). Pudding slices 1.2 cm in thickness were compressed in two-cycles with a time interval of 5 seconds. TPA analyses were conducted at 40% strain, a cross-head speed of 1.5 mm/s by utilizing a 35 mm diameter cylindrical probe (SMSP/35Compression plate) attached to a 25 kg load cell. Time-force plot was adopted for evaluating the texture parameters. The following parameters were measured: hardness [N], springiness [dimensionless], cohesiveness [dimensionless] and chewiness [N]. The compression of the product in two-cycles reflects two human bites with, the hardness being the required force to compress food at first bite, which represents the peak force of the first cycle. Springiness describes how well the sample springs back to the original size after deformation, calculated as the ratio of length below graph 2 until maximum force 2 divided by length below graph 1 until maximum force 1. How well the internal structure of a sample withstands compression is expressed by the cohesiveness, which is the ratio of work during compression of the second cycle divided by the first one. Chewiness reflects the required work to chew solid food to a state ready for swallowing, calculated as the product of hardness, springiness and cohesiveness.

7.2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 10.3. The X-matrix was designed as 0/1 variables for fat and salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 2% and 7% respectively.

For evaluation the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$). The compositional data were evaluated using t-test, two-tailed and equal variances (software Microsoft Excel 2010, TTest).

7.3 Results and discussion

7.3.1 Sensory evaluation

In a previous study by Fellendorf et al. (unpublished, 2014) black pudding samples containing 10% fat and 0.6% sodium were found to be acceptable ($P < 0.05$) to naive assessors without the necessity of using replacement ingredients at all. In the present study, 11 different replacer combinations were added to black puddings, with sequentially lower levels of sodium and fat included in the base formulations used, 10% fat and 0.4% sodium and accordingly 5% fat and 0.6% sodium. The principle objective was to achieve sensory accepted products with even lower salt and fat levels through the use of replacement ingredients. The sensory evaluation of these black pudding samples containing replacers is displayed in the APLSR plot presented in Figure 1. This plot gives an overview of the correlation of the attributes and samples. Here, the x-axis of the plot is separated by the y-axis. A positive correlation is presented if the attribute and sample are located on the same side of the x-axis and in close proximity. Furthermore, a negative correlation exists in the inverse case. Table 2 presents the corresponding ANOVA values for Figure 1 and includes significance and correlation factors. A significant difference exists, if the p-value is ≤ 0.05. The direction of the correlation is represented by a positive or negative algebraic sign before the p-value.

Colour and visible fat are important quality cues at point of sale, since an appealing appearance raises consumers' interest. During consumption consumers experience the sensory qualities tenderness, flavour and juiciness of products which conclude whether the food will be re-purchased (Acebrón & Dopico, 2000; Grunert, Bredahl, & Brunsø, 2004; Steenkamp & Trijp, 1996). Fat interacts with other ingredients, induces mouth-feel, texture and lubrication. In turn, salt is important for the water holding capacity and acts as a preservative and flavour enhancer (Chantrapornchai, McClements, & Julian, 2002; Giese, 1996; Gillette, 1985; Hutton, 2002; McCaughey, 2007; Wood & Fisher, 1990). Therefore, the texture and taste of a product are essentially influenced by salt and fat levels. It is of importance how the added replacers modify the texture and flavour of black pudding. Under these aspects, the assessors were asked to rate the sensory of black puddings low in fat and salt formulated with replacers.

Liking of appearance and colour

The attributes liking of appearance and colour are located close to the center of the plot (Figure 1) which indicate that the added replacers to black puddings did not affect appearance and colour. Consequently, no significant results to liking of appearance and colour were achieved (Table 2). In contrast, Cofrades et al. (2008) reported that low salt gel/emulsion meat systems displayed changes in colour through the addition of seaweed. Presumably, the dark red-brown colour of coagulated blood in black puddings masked colour changes in products that were lighter or brighter in appearance.

Texture attributes (graininess, juiciness, toughness)

Grain intensity, toughness and juiciness are essential attributes for describing the texture of black pudding. Grains are a special feature in black and white puddings which are produced in the UK and Ireland. Barley, oatmeal and rusk are important ingredients in pudding manufacture as they are used to bind free water in product formulations as well as in the development of texture. As shown in Table 2, the replacer ingredient CMC decreased ($P < 0.05$) graininess intensity in black pudding products, although no changes were made in the recipe relating to the amount or type of grains used (Table 1). Additionally, assessors scored these samples very low ($P < 0.001$) for toughness. However, black pudding samples containing 10% fat and 0.4% sodium without replacers (control), and formulated with wheat bran and KCLG, respectively, were also rated negatively ($P < 0.05$) to toughness (Table 2), and as can be seen in the plot (Figure 1) negatively correlated to intensity of graininess. It therefore appears that assessors associated a soft texture in pudding samples with lower grain contents.

The inverse effect was observed for the black pudding sample containing 10% fat and 0.4% sodium and formulated with carrageen. This sample was found to be harder ($P < 0.01$), less juicy ($P < 0.05$) and positively ($P < 0.01$) correlated to intensity of graininess, but lower ($P < 0.05$) for liking of texture (Table 2). Ruusunen et al. (2003a) showed similar results where low salt and low fat Bologna-type sausages containing carrageen decreased juiciness and increased hardness. Shand (2000) similarly reported that low fat pork Bologna sausages containing carrageen were found to be harder ($P < 0.05$) in texture by consumers. However, black pudding samples containing 5% fat and 0.6% sodium and individually formulated with wheat bran, carrageen, KCl, PuraQ, and the sample containing 10% fat and 0.4% sodium and formulated with KCPCL were also scored higher ($P < 0.05$) for toughness and additionally correlated positively to intensity of graininess (Table 2).

It is clear from data generated in this study that toughness in black pudding products is linked to graininess intensity. Furthermore, the harder ($P < 0.01$) and dryer ($P < 0.05$) texture of black puddings (10% fat, 0.4% sodium) formulated with carrageen were not liked by assessors. However, black pudding samples with 10% fat and 0.4% sodium containing WMS were accepted in texture, though no significant correlation to juiciness and hardness were observed (Table 2).

Taste attributes (fatness, spiciness, saltiness)

Saltiness, fatness, and spiciness are essential attributes to define the flavour of black pudding. Only the black pudding formulation with 10% fat and 0.4% sodium and containing KCLG had a positive ($P < 0.05$) correlation for fatness (Table 2). Two pudding samples formulated with 10% fat and 0.4% sodium and containing carrageen and KCPCL, respectively, were rated negatively ($P < 0.05$) for fatness. The pudding formulation containing carrageen, while not showing positively for fatness flavour, did show increases ($P < 0.05$) in spiciness and saltiness perceptions (Table 2). Similarly, carrageen usage was previously shown to increase saltiness and flavour intensity in low salt Bologna-type sausages (Ruusunen et al., 2003a). In contrast, Gelabert, Gou, Guerrero & Arnau (2003) found that adding KCLG to fermented sausages caused a less salty taste with respect to the control. Black pudding samples formulated with 5% fat and 0.6% sodium containing the salt replacers KCl, KCLG, and seaweed, respectively, were rated higher ($P < 0.05$) for spiciness and saltiness (Table 2). As fully acknowledged, salt plays a key role in enhancing the flavour of other ingredients within the meat system, in addition to enhancing the saltiness perception (Hutton, 2002). Therefore, for this particular sodium and fat level, the use of the replacers KCL, KCLG and seaweed in black puddings satisfy the requirements for salt replacement as they were shown to have the capacity to increase saltiness and spiciness perceptions, even though the pudding samples containing these replacement ingredients were shown not to be acceptable to consumers.

Black pudding samples formulated with 10% fat and 0.4% sodium and containing wheat bran and PuraQ, respectively, and pudding samples formulated with 5% fat and 0.6% sodium and containing waxy maize starch were scored negatively ($P < 0.05$) for saltiness and spiciness (with the exception of formulations containing PuraQ) (Table 2). PuraQ was manufactured commercially with the specific purpose of being used as a salt replacer. The manufacturer Corbion purac (2013) published data for frankfurters and chicken roll products demonstrating that the use of PuraQ in these products increased saltiness perception, though it cannot be confirmed for low salt and low fat black pudding products. Contrary to this present study, Ruusunen et al. (2003b) postulated that sodium citrate and wheat bran enhanced perceived saltiness in frankfurters at a salt content of less than 1.4%. Added sodium citrate in black pudding showed no significant results in this regard.

In summary, black pudding samples formulated with 5% fat and 0.6% sodium and containing the salt replacers KCl, KCLG, and seaweed, respectively, and pudding samples formulated with 10% fat and 0.4% sodium and containing carrageen were rated higher ($P < 0.05$) for spiciness and saltiness. Only the black pudding formulation with 10% fat and 0.4% sodium and containing KCLG was shown to have a positive ($P < 0.05$) correlation to fatness. Therefore, some added replacers showed an increase with respect to spiciness, saltiness or fatness perceptions, but this was not consistently observed with respect to the two salt and fat formulations used in this study for all black pudding treatments. Furthermore, the use of replacement ingredients and their impact on ultimate product taste depends, not only on the type of replacer used, further on the meat product-type and its formulation.

Liking of flavour and overall acceptability

The target of this study was to produce highly sensory accepted low salt and low fat black puddings by adding respective replacers.

Both black pudding formulations containing carrageen showed a negative ($P < 0.05$) correlation to flavour liking and overall acceptability (Table 2). The pudding formulation containing 10% fat and 0.4% sodium with carrageen, scored positively for off-flavour and additionally, assessors did not accept product texture. Furthermore, the tougher texture ($P < 0.05$) detected by assessors might have also been the reason why the second pudding formulation containing 5% fat and 0.6% sodium with carrageen, was not accepted. In contrast with these findings, Hughes, Cofrades & Troy (1997) found no changes, either on overall acceptability of flavour, or on further flavour attributes like smokiness, spiciness and saltiness following addition of carrageen to low fat frankfurters. Desmond, Troy & Buckley (1998) and Yang, Keeton, Beilken & Trout (2001) reported increased scores (not significant) for overall flavour of low fat beef burgers and low fat frankfurters containing carrageen, respectively.

However, pudding samples formulated with 5% fat and 0.6% sodium and containing pectin and KCPCL, respectively, and the pudding sample formulated with 10% fat and 0.4% sodium and containing WMS were liked ($P < 0.05$) in flavour and overall accepted by assessors (Table 2). All three formulations showed a negative ($P < 0.05$) correlation to off-flavour. In a previous study, low fat frankfurters containing waxy maize starch were also found to score highly for overall palatability compared to controls (Yang et al., 2001). Vadlamani, Friday, Broska & Miller (2012) postulated an increase in overall flavour for all nine chicken broths formulated to contain different combinations of KCPCL, although significant increases with respect to negative overall aftertaste were observed. Furthermore, the use of pectin in the form of Slendid^{TM} was added to low fat beef burgers, which in turn increased scores for overall flavour and acceptability, although no significant results were determined (Desmond et al., 1998).

In summary, both black pudding formulations with carrageen were not accepted by the assessors and therefore these recipes cannot be recommended to the industry. Though the black pudding samples with 5% fat and 0.6% sodium and formulated with pectin and KCPCl, and with 10% fat and 0.4% sodium and formulated with WMS were accepted ($P < 0.05$). Therefore, the sodium target level of 0.6% in black and white puddings set by the FSAI (FSAI, 2011) was achieved. An even lower sodium level in black pudding was accepted by assessors. With the assistance of ingredient replacers, a further sodium and fat reduction in black pudding products has been shown to be possible.

7.3.2 Characterization of black pudding samples containing replacers

The compositional properties of cooked and reheated black pudding products containing varying ingredient replacers are shown in Table 3. The fat and sodium contents in cooked black puddings were slightly higher compared to the designed model as fat contents in pure pork fat differs naturally due to animal variation and blood powder also contains low levels of salt which is used for product preservation. Lower ($P < 0.05$) fat, sodium, protein and ash concentrations and higher ($P < 0.05$) moisture levels were recorded for cooked black pudding samples containing replacers when compared to reheated equivalents. Similar results were reported by Fellendorf et al. (2015) for white puddings. During reheating, water evaporates from products, which in turn increasingly effects the concentration of the remaining ingredients.

The addition of different ingredient replacers to black pudding formulations generally reduced cooking losses compared to controls (Table 4), although no significant differences were determined. The majority of pudding samples containing ingredient replacers generally decreased cooking loss, though no significant results were observed. The lowest cooking losses were obtained for black pudding samples containing the highest levels of fat. Black pudding samples containing the lowest fat levels were formulated to have a higher meat content (as meat in the formulation compensated for fat usage) and consequently, such pudding products contained more water than fat, thereby increasing moisture evaporation during reheating.

Significant differences in instrumental colour were recorded for black pudding samples containing replacement ingredients (Table 4). For instance, both pudding samples containing WMS had lower ($P < 0.05$) L, a, and b values compare to the control. However, it is interesting to note that while such differences in colour were determined instrumentally, no colour differences were determined via sensory assessment (Table 2

Differences ($P < 0.05$) in pudding hardness, springiness, cohesiveness and chewiness were measured instrumentally using the texture analyzer (Table 4). The highest hardness and chewiness values were observed for samples containing carrageen.

Interestingly, assessors also rated these samples higher in hardness (Table 2). In contrast, Yang et al. (2001) and Desmond et al. (1998) recorded lower hardness values for low fat frankfurters and low fat beef burgers containing carrageen compared to controls. Differences in carrageen function in processed meats is dependent upon the concentration of carrageen used, carrageen-type and meat product form influence final product texture. In the present study, black pudding samples containing CMC achieved the lowest hardness, springiness, cohesiveness and chewiness values (Table 4), and again which are consistent with sensory results.

7.4 Conclusion

The use of ingredient replacers in black puddings impacted upon several physicochemical and sensory properties. However, no significant changes in sensory colour were observed through the addition of ingredient replacers from a sensory perspective implying that assessors were unconcerned with such changes. This observation contrasted when compared with instrumental analysis. The majority of pudding samples containing ingredient replacers generally decreased cooking loss, though no significant results were observed.

Black pudding samples formulated with 5% fat and 0.6% sodium and containing the salt replacers KCl, KCLG, and seaweed, respectively, and pudding samples formulated with 10% fat and 0.4% sodium and containing carrageen were rated higher ($P < 0.05$) for spiciness and saltiness. Only the black pudding formulation with 10% fat and 0.4% sodium and containing KCLG was shown to have a positive ($P < 0.05$) correlation to fatness. Therefore, some added replacers showed an increase with respect to spiciness, saltiness or fatness perceptions, but this was not observed consistently with respect to the two salt and fat formulations used in this study for all black pudding treatments. Furthermore, the use of replacement ingredients and their impact on ultimate product taste depends, not only on the type of replacer used, but also on the meat product-type and its formulation.

Assessors rated the samples containing carrageen and CMC higher ($P < 0.05$; $P < 0.01$) and lower ($P < 0.001$) for hardness, respectively, which was in full agreement with instrumental assessment. However, it is clear from data generated in this study that toughness in black pudding products is linked to graininess intensity.

Furthermore, the harder ($P < 0.01$) and dryer ($P < 0.05$) texture of black puddings (10% fat, 0.4% sodium) formulated with carrageen were not liked by assessors.

Both black pudding formulations with carrageen were not accepted by the assessors. Inferential these recipes cannot be recommended to the industry. Black pudding samples formulated with 5% fat and 0.6% sodium and containing pectin and KCPCl, respectively, and the black pudding sample formulated with 10% fat and 0.4% sodium and containing WMS were liked ($P < 0.05$) in terms of flavour and overall acceptance by assessors. All three formulations showed a negative ($P < 0.05$) correlation to off-flavour. The FSAI recommend a sodium target level of 0.6% in black and white puddings (FSAI, 2011). In this study, an even lower sodium level (0.4%) was accepted by assessors of black pudding. With the assistance of ingredient replacers, a further sodium and fat reduction in black pudding products has been shown to be possible.

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7.5 Tables and Figures

Table 1

Black pudding formulations with different replacers

Sample [c]	Formulation [%]										
	Meat	Fat	Salt	Water	Blood powder	Season-ing	Oatmeal	Onion	Boiled barley	Rusk	Replacer(s)
Control 1	35.60	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	-
Control 2	42.79	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	-
Wheat bran 1	34.60	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	1.00
Wheat bran 2	41.79	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	1.00
Sodium citrate 1	35.15	15.38	0.97	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
Sodium citrate 2	42.34	7.69	1.47	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
Carrageen 1	35.10	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
Carrageen 2	42.29	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
Pectin 1	35.20	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.40
Pectin 2	42.39	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.40
KCl 1	34.58	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	1.02
KCl 2	42.11	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.68
KClG 1	34.08	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.91/0.61 [a]
KClG 2	41.77	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.61/0.41 [a]
CMC 1	35.10	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
CMC 2	42.29	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.50
Seaweed 1	32.30	15.38	0.72	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.30
Seaweed 2	39.49	7.69	1.22	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.30
PuraQ 1	32.60	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.00
PuraQ 2	39.79	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.00
KCPCl 1	34.10	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.5/0.5/0.5 [b]
KCPCl 2	41.29	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	0.5/0.5/0.5 [b]
WMS 1	32.60	15.38	1.02	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.00
WMS 2	39.79	7.69	1.52	27.00	3.00	1.10	6.55	2.50	3.00	4.85	3.00

[a] Added replacers, combination of potassium chloride/glycine in percent

[b] Added replacers, combination of potassium citrate/potassium phosphate/potassium chloride in percent

[c] Sample code: 1 = 10% fat and 0.4% sodium, 2 = 5% fat and 0.6% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: seaweed wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

Table 2

P-values of regression coefficients from ANOVA values of regression coefficients from APLSR for the hedonic and intensity sensory terms of reheated black pudding containing replacers, including significance and correlation

Sample [a]	Hedonic term [b]					Intensity term						
	Appearance	Flavour	Texture	Colour	Acceptability	Grains	Fatness	Spiciness	Saltiness	Juiciness	Toughness	Off-flavour
Control 1	-0.7790 ns	0.7103 ns	0.3218 ns	-0.9829 ns	0.4562 ns	-0.1001ns	0.7283 ns	-0.0362*	-0.0013**	0.0036**	-0.0030**	-0.4126 ns
Control 2	0.8427 ns	-0.4376 ns	-0.2884 ns	0.6175 ns	-0.3443 ns	0.3137 ns	-0.9614 ns	0.2030 ns	0.0902 ns	-0.1706 ns	0.1433 ns	0.3406 ns
Wheat bran 1	-0.5086 ns	0.4939 ns	0.9683 ns	-0.5142 ns	0.8058 ns	-0.2855 ns	0.5150 ns	-0.0246*	-0.0014**	0.1297 ns	-0.0350*	-0.9746 ns
Wheat bran 2	0.7282 ns	-0.9436 ns	-0.9453 ns	0.8664 ns	-0.9445 ns	0.0607 ns	-0.1608 ns	0.0258*	0.0173*	-0.3589 ns	0.0035**	0.4016 ns
Sodium citrate 1	0.4393 ns	-0.4337 ns	-0.7440 ns	0.6458 ns	-0.5517 ns	0.2724 ns	-0.1095ns	0.6942 ns	0.2733 ns	-0.8907 ns	0.5067 ns	0.3737 ns
Sodium citrate 2	0.6020 ns	-0.9189 ns	-0.8903 ns	0.7997 ns	-0.9961 ns	0.8939 ns	0.5367 ns	0.2494 ns	0.3670 ns	-0.4095 ns	0.7795 ns	0.3927 ns
Carrageen 1	0.5417 ns	-0.0059**	-0.0335*	0.3436 ns	-0.0206*	0.01330*	-0.0362*	0.0511*	0.0430*	-0.0424*	0.0091**	0.0491*
Carrageen 2	0.9185 ns	-0.0143*	-0.0708 ns	0.3097 ns	-0.0117*	0.4002 ns	-0.6421 ns	0.3741 ns	0.7393 ns	-0.1377 ns	0.0301*	0.1900 ns
Pectin 1	-0.6787 ns	0.2500 ns	0.3638 ns	-0.3281 ns	0.3097 ns	-0.2494 ns	0.9753 ns	-0.1011 ns	-0.0408*	0.4486 ns	-0.1015 ns	-0.6421 ns
Pectin 2	-0.3350 ns	0.0533*	0.0627 ns	-0.1725 ns	0.0526 *	-0.3083 ns	0.5580 ns	-0.7973 ns	-0.8164 ns	0.1094 ns	-0.1402 ns	-0.0340*
KCl 1	0.2826 ns	-0.5388 ns	-0.5855 ns	0.3523 ns	-0.5087 ns	0.4029 ns	-0.6609 ns	0.7894 ns	0.8068 ns	-0.3267 ns	0.2553 ns	0.3080 ns
KCl 2	0.7006 ns	-0.7554 ns	-0.1747 ns	0.8929 ns	-0.2689 ns	0.3157 ns	-0.0907 ns	0.0050**	0.0002***	-0.0279*	0.0127*	0.3558 ns
KClG 1	-0.3789 ns	0.8013 ns	0.3331 ns	-0.8250 ns	0.5556 ns	-0.4568 ns	0.03013*	-0.8683 ns	-0.1865 ns	0.0715 ns	-0.0082**	-0.5686 ns
KClG 2	0.5630 ns	-0.5629 ns	-0.9497 ns	0.9520 ns	-0.8780ns	0.4680 ns	-0.3496 ns	0.0029**	0.0027**	-0.9386 ns	0.3065 ns	0.2711 ns
CMC 1	-0.3839 ns	0.1063 ns	0.0968 ns	-0.1263 ns	0.0837 ns	-0.0005***	0.9801 ns	-0.0686 ns	-0.0037**	0.1048 ns	-0.0001***	-0.1337 ns
CMC 2	-0.5349 ns	0.6673 ns	0.4713 ns	-0.3790 ns	0.4238 ns	-0.0054**	0.3493 ns	-0.4095 ns	-0.7176 ns	0.1253 ns	-0.0001***	-0.3388 ns
Seaweed 1	-0.76265 ns	0.6570 ns	0.6329 ns	-0.5182 ns	0.6294 ns	-0.4106 ns	0.9047 ns	-0.9138 ns	-0.7561 ns	0.6663 ns	-0.3687 ns	-0.6742 ns
Seaweed 2	0.5087 ns	-0.8241 ns	-0.4760 ns	0.6014 ns	-0.5314 ns	0.9891 ns	-0.9504 ns	0.0243*	0.0279*	-0.8094 ns	0.6200 ns	0.2524 ns
PuraQ 1	-0.9632ns	0.3608 ns	0.0738 ns	-0.4998 ns	0.1559 ns	-0.7595 ns	0.4701 ns	-0.1738 ns	-0.0416*	0.1138 ns	-0.0776 ns	-0.2286 ns
PuraQ 2	0.8001 ns	-0.7377 ns	-0.6005 ns	0.9575 ns	-0.6230 ns	0.0702 ns	-0.5635 ns	0.2271 ns	0.1276 ns	-0.1830 ns	0.0315*	0.3930 ns
KCPCl 1	0.1343 ns	-0.1338 ns	-0.6697 ns	0.2486 ns	-0.2844 ns	0.3586 ns	-0.0040**	0.1078 ns	0.0014**	-0.1004 ns	0.0058**	0.1211 ns
KCPCl 2	-0.0624 ns	0.0243*	0.0342*	-0.0578 ns	0.0183*	-0.9482 ns	0.0982 ns	-0.9236 ns	-0.4330 ns	0.9379 ns	-0.7138 ns	-0.0149*
WMS 1	-0.0915 ns	0.0042**	0.0064**	-0.0600 ns	0.0037**	-0.6648 ns	0.0783 ns	-0.3133 ns	-0.7888 ns	0.6738 ns	-0.8046 ns	-0.0024**
WMS 2	-0.2590 ns	0.3934 ns	0.1520 ns	-0.3029 ns	0.1323 ns	-0.7532 ns	0.3685 ns	-0.0005***	-0.0004***	0.8857 ns	-0.5837 ns	-0.0055**

[a] Sample code: 1 = 10% fat and 0.4% sodium, 2 = 5% fat and 0.6% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, PuraQ: PuraQ®Arome NA4, seaweed: seaweed wakame, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[b] Significance of regression coefficients: ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Table 3

Compositional properties of cooked and reheated black pudding samples containing replacers

Sample [c]	Moisture [%] [d]		Fat [%]		Protein [%]		Ash [%]		Sodium [%]	
	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated
Control 1	57.5 ± 0.4^{a}	51.3 ± 0.5^{b}	11.5 ± 0.1^{a}	12.7 ± 0.3^{b}	13.2 ± 0.1^{a}	15.2 ± 0.1^{b}	1.6 ± 0.0^{a}	2.0 ± 0.0^{b}	0.43 ± 0.01^{a}	0.53 ± 0.01^{b}
Control 2	61.2 ± 0.2^{a}	56.6 ± 0.5^{b}	6.5 ± 0.1^{a}	7.3 ± 0.1^{b}	14.3 ± 0.1^{a}	16.2 ± 0.2^{b}	2.2 ± 0.1^{a}	2.6 ± 0.1^{b}	0.63 ± 0.01^{a}	0.72 ± 0.02^{b}
Wheat bran 1	57.6 ± 0.3^{a}	51.5 ± 0.3^{b}	11.5 ± 0.3^{a}	13.1 ± 0.2^{b}	13.6 ± 0.2^{a}	15.0 ± 0.1^{b}	1.5 ± 0.0^{a}	1.9 ± 0.1^{b}	0.45 ± 0.01^{a}	0.51 ± 0.00^{b}
Wheat bran 2	59.8 ± 0.1^{a}	54.5 ± 0.4^{b}	6.9 ± 0.2^{a}	7.9 ± 0.2^{b}	14.8 ± 0.2^{a}	16.4 ± 0.1^{b}	2.1 ± 0.1^{a}	2.2 ± 0.1^{a}	0.61 ± 0.01^{a}	0.73 ± 0.01^{b}
Sodium citrate 1	56.1 ± 0.1^{a}	51.6 ± 1.0^{b}	12.4 ± 0.1^{a}	13.7 ± 0.6^{b}	14.0 ± 0.2^{a}	15.4 ± 0.2^{b}	1.7 ± 0.0^{a}	2.1 ± 0.0^{b}	0.44 ± 0.01^{a}	0.53 ± 0.02^{b}
Sodium citrate 2	59.3 ± 0.5^{a}	53.7 ± 0.3^{b}	7.6 ± 0.3^{a}	8.6 ± 0.1^{b}	15.2 ± 0.0^{a}	17.0 ± 0.2^{b}	2.2 ± 0.1^{a}	2.7 ± 0.1^{b}	0.63 ± 0.01^{a}	0.77 ± 0.01^{b}
Carrageen 1	57.1 ± 0.3^{a}	52.1 ± 0.2^{b}	11.6 ± 0.2^{a}	12.7 ± 0.1^{b}	14.1 ± 0.2^{a}	15.8 ± 0.1^{b}	1.4 ± 0.1^{a}	1.8 ± 0.1^{b}	0.43 ± 0.01^{a}	0.51 ± 0.00^{b}
Carrageen 2	60.1 ± 0.4^{a}	54.0 ± 1.0^{b}	7.1 ± 0.5^{a}	8.0 ± 0.2^{b}	15.2 ± 0.2^{a}	16.8 ± 0.2^{b}	2.0 ± 0.1^{a}	2.4 ± 0.1^{b}	0.62 ± 0.00^{a}	0.72 ± 0.00^{b}
Pectin 1	56.4 ± 0.3^{a}	52.6 ± 0.8^{b}	11.8 ± 0.3^{a}	13.3 ± 0.3^{b}	14.0 ± 0.0^{a}	15.4 ± 0.3^{b}	1.5 ± 0.0^{a}	1.8 ± 0.2^{b}	0.46 ± 0.01^{a}	0.50 ± 0.01^{b}
Pectin 2	61.7 ± 0.2^{a}	54.3 ± 0.4^{b}	6.2 ± 0.0^{a}	8.2 ± 0.3^{b}	14.5 ± 0.2^{a}	17.8 ± 0.2^{b}	2.1 ± 0.0^{a}	2.5 ± 0.1^{b}	0.62 ± 0.01^{a}	0.73 ± 0.02^{b}
KCl 1	57.0 ± 0.5^{a}	50.7 ± 0.2^{b}	12.2 ± 0.4^{a}	13.9 ± 0.3^{b}	12.8 ± 0.2^{a}	15.7 ± 0.1^{b}	2.1 ± 0.1^{a}	2.7 ± 0.1^{b}	0.42 ± 0.01^{a}	0.52 ± 0.01^{b}
KCl 2	60.8 ± 0.2^{a}	54.0 ± 0.4^{b}	6.4 ± 0.1^{a}	7.8 ± 0.1^{b}	14.0 ± 0.1^{a}	17.5 ± 0.3^{b}	2.9 ± 0.1^{a}	3.6 ± 0.1^{b}	0.60 ± 0.01^{a}	0.71 ± 0.02^{b}
KClG 1	55.8 ± 0.5^{a}	50.4 ± 0.2^{b}	12.3 ± 0.3^{a}	13.9 ± 0.3^{b}	13.8 ± 0.2^{a}	16.3 ± 0.1^{b}	2.3 ± 0.0^{a}	2.6 ± 0.1^{b}	0.42 ± 0.01^{a}	0.53 ± 0.02^{b}
KClG 2	59.6 ± 0.4^{a}	55.6 ± 0.8^{b}	7.1 ± 0.1^{a}	7.8 ± 0.3^{b}	14.8 ± 0.2^{a}	17.4 ± 0.2^{b}	2.7 ± 0.1^{a}	3.0 ± 0.1^{b}	0.57 ± 0.02^{a}	0.71 ± 0.03^{b}
CMC 1	57.5 ± 0.4^{a}	52.7 ± 0.2^{b}	11.6 ± 0.1^{a}	12.6 ± 0.2^{b}	13.8 ± 0.2^{a}	15.1 ± 0.1^{b}	1.8 ± 0.1^{a}	2.1 ± 0.0^{b}	0.43 ± 0.01^{a}	0.52 ± 0.01^{b}
CMC 2	60.5 ± 0.2^{a}	54.6 ± 0.4^{b}	7.1 ± 0.2^{a}	8.0 ± 0.2^{b}	14.9 ± 0.2^{a}	16.8 ± 0.2^{b}	2.3 ± 0.0^{a}	2.7 ± 0.0^{b}	0.60 ± 0.01^{a}	0.74 ± 0.02^{b}
Seaweed 1	54.6 ± 0.4^{a}	49.8 ± 0.3^{b}	12.6 ± 0.2^{a}	13.8 ± 0.1^{b}	13.2 ± 0.2^{a}	14.3 ± 0.1^{b}	2.9 ± 0.1^{a}	3.4 ± 0.0^{b}	0.44 ± 0.00^{a}	0.54 ± 0.04^{b}
Seaweed 2	58.1 ± 0.5^{a}	54.2 ± 0.2^{b}	6.4 ± 0.3^{a}	6.7 ± 0.1^{a}	14.5 ± 0.1^{a}	16.4 ± 0.1^{b}	3.4 ± 0.1^{a}	4.2 ± 0.1^{b}	0.63 ± 0.02^{a}	0.74 ± 0.03^{b}
PuraQ 1	55.8 ± 0.9^{a}	51.6 ± 0.2^{b}	12.7 ± 0.3^{a}	13.6 ± 0.1^{b}	13.5 ± 0.2^{a}	14.0 ± 0.1^{b}	2.3 ± 0.1^{a}	2.6 ± 0.0^{b}	0.44 ± 0.01^{a}	0.51 ± 0.02^{b}
PuraQ 2	60.5 ± 0.2^{a}	54.6 ± 0.3^{b}	6.0 ± 0.2^{a}	7.4 ± 0.4^{b}	14.9 ± 0.2^{a}	16.3 ± 0.2^{b}	2.5 ± 0.1^{a}	3.2 ± 0.0^{b}	0.60 ± 0.01^{a}	0.76 ± 0.01^{b}
KCPCl 1	56.4 ± 0.1^{a}	49.6 ± 0.2^{b}	12.4 ± 0.2^{a}	14.3 ± 0.1^{b}	13.1 ± 0.2^{a}	14.4 ± 0.2^{b}	2.9 ± 0.1^{a}	3.1 ± 0.1^{a}	0,45 ± 0.03^{a}	0.55 ± 0.01^{b}
KCPCl 2	61.1 ± 0.1^{a}	53.3 ± 0.3^{b}	6.2 ± 0.2^{a}	8.4 ± 0.2^{b}	14.2 ± 0.1^{a}	16.2 ± 0.4^{b}	3.3 ± 0.0^{a}	3.7 ± 0.0^{b}	0,57 ± 0.01^{a}	0.69 ± 0.02^{b}
WMS 1	57.4 ± 0.1^{a}	50.9 ± 0.1^{b}	11.5 ± 0.2^{a}	13.8 ± 0.1^{b}	13.3 ± 0.2^{a}	13.8 ± 0.3^{a}	1.7 ± 0.1^{a}	2.0 ± 0.1^{b}	0.45 ± 0.00^{a}	0.50 ± 0.01^{b}
WMS 2	61.0 ± 0.2^{a}	54.2 ± 0.3^{b}	6.5 ± 0.3^{a}	8.3 ± 0.1^{b}	14.0 ± 0.1^{a}	15.5 ± 0.1^{b}	2.2 ± 0.0^{a}	2.6 ± 0.1^{b}	0.63 ± 0.00^{a}	0.68 ± 0.02^{b}

[a-b] Averages of each cooked and reheated sample of each composition analysis sharing different letters are significantly different (two tailed t-test, p < 0.05).

[c] Sample code: 1 = 10% fat and 0.4% sodium, 2 = 5% fat and 0.6% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethyl-cellulose, PuraQ: PuraQ®Arome NA4, seaweed: seaweed wakame, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[d] All values are averages ± standard errors.

Table 4

Colour, texture profile and cooking loss values of reheated black pudding samples containing different replacers

Sample ^{m}	Colour ^{n}			Texture profile analyses				Cooking loss [%]
	L	a	b	Hardness [N]	Springiness	Cohesivness	Chewiness [N]	
Control 1	26.2 ± 0.3 $^{g, h, i, j}$	5.5 ± 0.1 ^{c}	8.5 ± 0.2 $^{b, c, d, e, f}$	126.7 ± 1.9 $^{i, j, k}$	0.84 ± 0.02 $^{a, b}$	0.49 ± 0.01 $^{f, g, h, i}$	52.7 ± 1.7 $^{h, i}$	11.6 ± 0.2 $^{a, b, c, d, e, f}$
Control 2	28.3 ± 0.6 $^{a, b, c}$	4.9 ± 0.1 $^{e, f}$	9.0 ± 0.3 $^{a, b}$	148.7 ± 4.8 $^{e, f, g, g, h}$	0.84 ± 0.02 $^{a, b}$	0.53 ± 0.00 $^{a, b, c, d}$	66.1 ± 3.0 $^{e, f, g}$	10.3 ± 0.9 $^{b,c, d, e, f}$
Wheat bran 1	26.8 ± 0.3 $^{c, d, e, f, g, h, i}$	5.4 ± 0.1 $^{c, d}$	8.6 ± 0.2 $^{b, c, d, e}$	147.2 ± 2.9 $^{e, f, g, h}$	0.82 ± 0.01 $^{a ,b}$	0.52 ± 0.01 $^{b, c, d, e, f, g}$	62.1 ± 1.3 $^{g, h}$	12.6 ± 1.7 $^{a, b, c}$
Wheat bran 2	27.9 ± 0.6 $^{a, b, c, d, e, f}$	5.0 ± 0.1 ^{e}	8.9 ± 0.2 $^{a, b, c}$	179.7 ± 1.0 $^{b, c}$	0.83 ± 0.01 $^{a, b}$	0.53 ± 0.00 $^{a, b, c, d}$	78.7 ± 1.2 $^{b, c, d}$	10.3 ± 0.4 $^{b,c, d, e, f}$
Sodium citrate 1	27.1 ± 0.5 $^{b, c, d, e, f, g, h}$	5.0 ± 0.1 ^{e}	7.5 ± 0.2 $^{i, j}$	144.3 ± 3.0 $^{g, h, i}$	0.83 ± 0.01 $^{a, b}$	0.53 ± 0.00 $^{a, b, c, d}$	63.7 ± 1.2 $^{f, g}$	8.7 ± 0.6 $^{e, f}$
Sodium citrate 2	26.8 ± 0.5 $^{c, d, e, f, g, h, h, i}$	4.4 ± 0.1 $^{g, h, i}$	8.3 ± 0.2 $^{c, d, e, f, g, h}$	166.2 ± 4.4 $^{b, c, d, e}$	0.83 ± 0.00 $^{a, b}$	0.55 ± 0.00 $^{a, b}$	75.3 ± 1.7 $^{b, c, d, e}$	11.5 ± 0.4 $^{a, b,c, d, e, f}$
Carrageen 1	27.8 ± 0.6 $^{a, b, c, d, e, f}$	4.7 ± 0.2 $^{f, g}$	7.8 ± 0.3 $^{g, h, i, j}$	183.0 ± 4.4 ^{b}	0.84 ± 0.01 $^{a, b}$	0.53 ± 0.00 $^{a, b, c, d, e}$	80.7 ± 2.0 $^{b, c}$	9.7 ± 0.2 $^{c, d, e, f}$
Carrageen 2	28.1 ± 0.5 $^{a, b, c, d}$	4.6 ± 0.2 $^{f, g, h}$	8.6 ± 0.2 $^{b, c, d, e}$	203.7 ± 2.8 ^{a}	0.85 ± 0.01 $^{a, b}$	0.54 ± 0.00 $^{a, b, c, d}$	92.5 ± 1.5 ^{a}	10.8 ± 0.4 $^{b,c, d, e, f}$
Pectin 1	27.1 ± 0.6 $^{b, c, d, e, f, g, h}$	6.0 ± 0.1 $^{a, b}$	8.7 ± 0.2 $^{a, b, c, d}$	116.1 ± 3.6 $^{j, k}$	0.82 ± 0.01 $^{a, b}$	0.48 ± 0.01 $^{h, i}$	45.3 ± 1.6 ^{i}	8.8 ± 0.8 $^{c, d, e, f}$
Pectin 2	27.8 ± 0.5 $^{a, b, c, d, e, f}$	5.7 ± 0.1 ^{c}	9.3 ± 0.2 ^{a}	147.9 ± 5.5 $^{e, f, g, h}$	0.84 ± 0.01 $^{a, b}$	0.51 ± 0.01 $^{c, d, e, f, g}$	63.5 ± 2.7 $^{f, g}$	12.5 ± 0.5 $^{a, b,c, d, e}$
KCl 1	26.3 ± 0.5 $^{f, g, h, i, j}$	4.4 ± 0.1 $^{g, h, i, j}$	7.6 ± 0.3 $^{i, j}$	146.2 ± 3.1 $^{f, g, h, i}$	0.82 ± 0.01 $^{a, b}$	0.54 ± 0.00 $^{a, b, c}$	64.4 ± 1.8 $^{f, g}$	14.7 ± 1.2 ^{a}
KCl 2	27.9 ± 0.7 $^{a, b, c, d, e}$	4.3 ± 0.1 $^{g, h, i, j}$	7.9 ± 0.2 $^{f, g, h, i, j}$	173.9 ± 5.2 $^{b, c, d}$	0.87 ± 0.01 ^{a}	0.55 ± 0.00 ^{a}	83.2 ± 3.0 $^{a, b}$	12.3 ± 0.4 $^{a, b,c, d, e, f}$
KClG 1	26.4 ± 0.4 $^{e,f, g, h,i, j}$	4.9 ± 0.1 $^{e, f}$	8.0 ± 0.2 $^{e, f, g, h, i, j}$	143.1 ± 2.4 $^{h, i}$	0.83 ± 0.01 $^{a, b}$	0.53 ± 0.00 $^{a, b, c, d, e, f}$	62.6 ± 1.6 $^{f, g, h}$	9.6 ± 0.3 $^{c, d, e, f}$
KClG 2	27.5 ± 0.5 $^{a, b, c, d, e, f, g}$	4.4 ± 0.1 $^{g, h, i}$	8.1 ± 0.3 $^{d, e, f, g, h, i}$	154.3 ± 6.0 $^{d, e, f ,g, h}$	0.85 ± 0.01 $^{a, b}$	0.53 ± 0.01 $^{a, b, c, d, e}$	68.7 ± 3.0 $^{d, e, f, g}$	8.9 ± 0.9 $^{c, d, e, f}$
CMC 1	25.7 ± 0.5 $^{h, i, j}$	5.5 ± 0.1 ^{c}	7.6 ± 0.2 $^{i, j}$	57.8 ± 0.9 ^{l}	0.72 ± 0.01 ^{c}	0.38 ± 0.01 ^{j}	15.7 ± 0.6 ^{j}	12.7 ± 0.1 $^{a, b,c, d, e, f}$
CMC 2	25.0 ± 0.6 ^{j}	6.1 ± 0.1 ^{a}	8.6 ± 0.2 $^{b, c, d, e}$	56.7 ± 5.2 ^{l}	0.71 ± 0.01 ^{c}	0.39 ± 0.01 ^{j}	15.5 ± 0.7 ^{j}	14.5 ± 0.0 $^{a, b}$
Seaweed 1	26.7 ± 0.6 $^{c, d, e, f, g, h, i}$	4.1 ± 0.1 $^{j, k}$	8.1 ± 0.3 $^{d, e, f, g, h, i}$	140.7 ± 1.7 $^{h, i,}$	0.82 ± 0.01 $^{a, b}$	0.46 ± 0.01 ^{i}	53.9 ± 1.5 $^{h, i}$	11.5 ± 0.5 $^{a, b,c, d, e, f}$
Seaweed 2	28.2 ± 0.6 $^{a, b, c}$	4.3 ± 0.1 $^{h, i, j}$	8.9 ± 0.2 $^{a, b, c}$	165.4 ± 1.7 $^{b, c, d, e, f}$	0.84 ± 0.02 $^{a, b}$	0.50 ± 0.00 $^{d, e, f, g, h}$	70.2 ± 1.5 $^{c, d, e, f, g}$	12.3 ± 0.3 $^{a, b,c, d, e, f}$
PuraQ 1	29.1 ± 0.5 ^{a}	5.7 ± 0.1 $^{b, c}$	8.3 ± 0.2 $^{b, c, d, e, f, g}$	114.7 ± 4.1 ^{k}	0.83 ± 0.01 $^{a, b}$	0.50 ± 0.01 $^{d, e, f, g, h}$	47.8 ± 1.8 ^{i}	8.7 ± 1.2 $^{c, d, e, f}$
PuraQ 2	28.5 ± 0.5 $^{a, b}$	5.0 ± 0.2 ^{e}	8,0 ± 0.2 $^{d, e, f, g, h, i}$	163.1 ± 3.7 $^{c, d, e, f, g}$	0.85 ±.0.01 $^{a, b}$	0.53 ± 0.01 $^{a, b, c, d}$	73.1 ± 2.2 $^{b, c, d, e, f}$	13.0 ± 0.2 $^{a, b,c, d, e, f}$
KCPCl 1	26.4 ± 0.7 $^{e, f, g, h, i, j}$	5.1 ± 0.1 $^{d, e}$	8.4 ± 0.2 $^{b, c,d, e, f, g}$	111.3 ± 5.6 ^{k}	0.84 ± 0.01 $^{a, b}$	0.49 ± 0.00 $^{g, h, i}$	45.5 ± 1.2 ^{i}	8.5 ± 0.9 $^{d, f}$
KCPCl 2	26.5 ± 0.7 $^{d, e, f, g, h, i, j}$	4.2 ± 0.1 $^{i, j, k}$	7.7 ± 0.2 $^{g, h, i, j}$	153.0 ± 1.9 $^{e, f, g, h}$	0.85 ± 0.01 $^{a, b}$	0.51 ± 0.01 $^{c, d, e, f, g, h}$	65.9 ± 3.3 $^{e, f, g}$	12.0 ± 0.6 $^{a, b,c, d, e, f}$
WMS 1	25.3 ± 0.4 $^{i, j}$	4.5 ± 0.1 $^{g, h, i}$	7.3 ± 0.2 ^{j}	118.3 ± 2.5 $^{j, k}$	0.83 ± 0.01 $^{a, b}$	0.49 ± 0.01 $^{e, f, g, h, i}$	48.1 ± 1.1 ^{i}	9.9 ± 0.3 $^{c, d, e, f}$
WMS 2	27.1 ± 0.6 $^{b,c, d, e, f, g, h}$	3.9 ± 0.1 ^{k}	7.6 ± 0.2 $^{h, i, j}$	150.8 ± 3.3 $^{e, f, g, h}$	0.85 ± 0.01 $^{a, b}$	0.51 ± 0.00 $^{c, d, e, f, g, h}$	65.0 ± 1.7 $^{f, g}$	10.3 ± 0.1 $^{b,c, d, e, f}$

[a-l] Averages sharing different letters in the same column are significantly different ($P < 0.05$).

[m] Sample code: 1 = 10% fat and 0.4% sodium, 2 = 5% fat and 0.6% sodium. KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, seaweed: seaweed wakame, PuraQ: PuraQ®Arome NA4, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch.

[n] All values are averages ± standard errors.

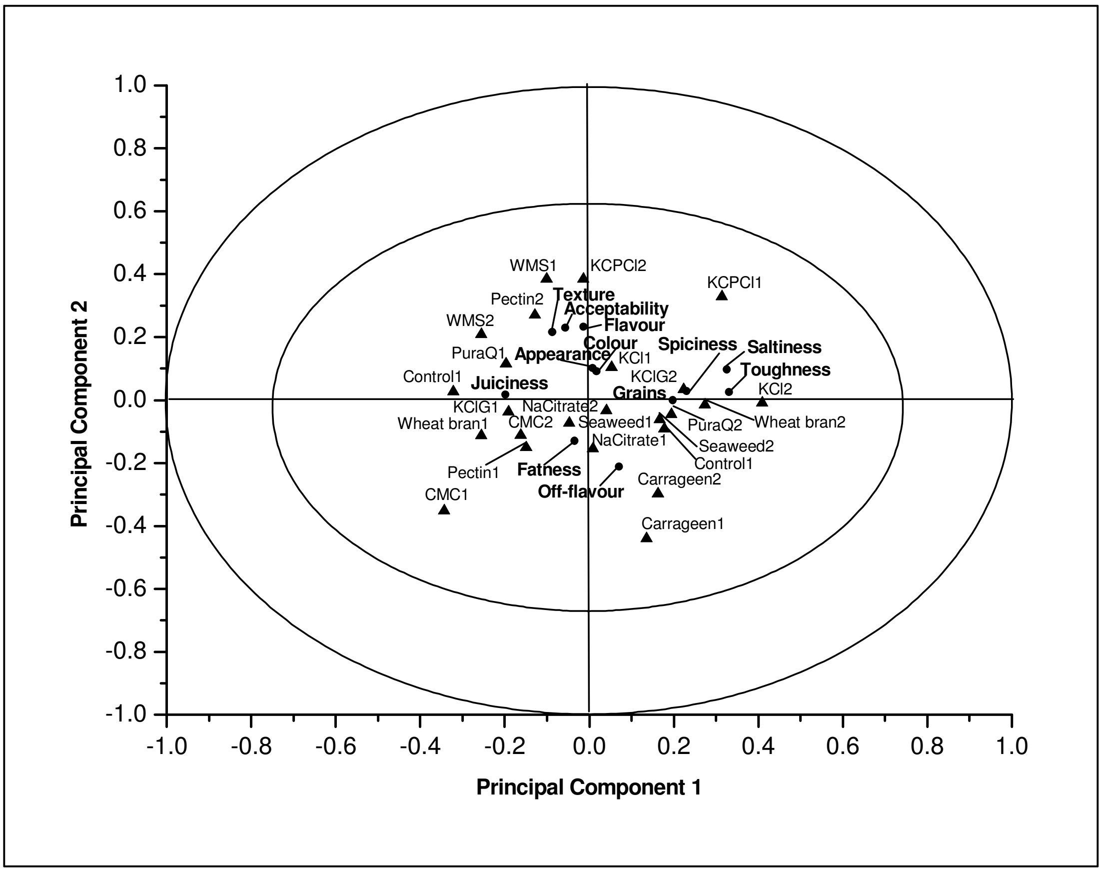

Figure 1:

ANOVA-Partial Least Squares regression (APLSR) for black pudding formulations with different replacers. ▲ = Samples (code: 1 = 10% fat and 0.4% sodium, 2 = 5% fat and 0.6% sodium; NaCitrate: sodium citrate; KCl: potassium chloride, KClG: mixture of potassium chloride and glycine, CMC: carboxymethylcellulose, PuraQ: PuraQ®Arome NA4, seaweed: seaweed wakame, KCPCl: combination of potassium citrate, potassium phosphate and potassium chloride, WMS: waxy maize starch), ● = sensory attributes.

References

Acebrón, B. L., & Dopico, C. D. (2000). The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. *Food Quality and Preference*, *11*(3), 229–238.

Andrès, S., Zaritzky, N., & Califano, A. (2006). The effect of whey protein concentrates and hydrocolloids on the texture and colour characteristics of chicken sausages. *International Journal of Food Science & Technology*, *41*(8), 954 – 961.

AOAC. (1923). Determination of ash. *Journal of the Association of Official Analytical Chemists*, *7*, 132. Association of Official Agricultural Chemists.

AOAC. (1988). Minerals in ready-to-feed milk-based infant formula. *Official Methods of Analysis of AOAC International. AOAC Official Method 985.35.*, *Chapter 50*, 13–14. Association of Official Agricultural Chemists.

Barcellos, de M. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: consumer trends and emerging markets. In J. P. Kerry & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Oxford, Cambridge, Philadelphia, New Dehli: Woodhead Publishing Ltd.

Bostian, M. L., Fish, D. L., Webb, N. B., & Arey, J. J. (1985). Automated methods for determination of fat and moisture in meat and poultry products: collaborative study. *Journal of the Association of Official Analytical Chemists*, *68*(5), 876–880.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, *32* , 62–66.

Chantrapornchai, W., McClements, D. J., & Julian, D. (2002). Influence of NaCl on optical properties, large-strain rheology and water holding capacity of heat-induced whey protein isolate gels. *Food Hydrocolloids*, *16*(5), 467–476.

Cofrades, S., López-López, I., Solas, M. T., Bravo, L., & Jiménez-Colmenero, F. (2008). Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems. *Meat Science*, *79*(4), 767–76.

Corbion_purac. (2013). Sodium Reduction "Meat, Poultry & Fish." http://www.corbion.com/media/97267/thms-food-sodium-reduction-meat-useng-1013-web.pdf

Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, *74*(1), 131–142.

Demeyer, D., Honikel, K., & De Smet, S. (2008). The World Cancer Research Fund report 2007: A challenge for the meat processing industry. *Meat Science*, *80*, 953–959.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Desmond, E. M., Troy, D. J., & Buckley, D. J. (1998). Comparative Studies of Nonmeat Adjuncts Used in the Manufacture of Low-Fat Beef Burgers. *Journal* *of Muscle Foods*, *9*(3), 221–241.

dos Santos, B. A., Campagnol, P. C. B., Morgano, M. A., & Pollonio, M. A. R. (2014). Monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine improve the sensory quality of fermented cooked sausages with 50% and 75% replacement of NaCl with KCl. *Meat Science*, *96*(1), 509–513.

Dzendolet, E., & Meiselman, H. L. (1967). Gustatory quality changes as a function of solution concentration. *Perception & Psychophysics.*, *2*, 29–33.

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82.

Fox, P. F. (1963). Potentiometric determination of salt in cheese. *Journal of Dairy Science*, *46*, 744 – 745.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period : September 2003 to July 2014*. The Food Safety Authority of Ireland.

Gelabert, J., Gou, P., Guerrero, L., & Arnau, J. (2003). Effect of sodium chloride replacement on some characteristics of fermented sausages. *Meat Science*, *65*(2), 833–9.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Gilbert, P. A., & Heiser, G. (2005). Salt and health : the CASH and BPA perspective. *British Nutrition Foundation*, *30*, 62–69.

Gillette, M. (1985). Flavor effects of sodium chloride. *Food Technology*, *39*, 47–56.

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat Science*, *66*(2), 259–272.

Hotchkiss, S. (2012). Edible Seaweeds. A rich source of flavor components for sodium replacement. *Agro FOOD Industry Hi Tech*, *23*(6), 30–32.

Hughes, E., Cofrades, S., & Troy, D. J. (1997). Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 and 30% fat. *Meat Science*, *45*(3), 273–281.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

International Commission on Illumination. (1976). ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space.

ISO. (1988). Sensory analysis. General guidance for the design of test rooms. Ref. no. *International Organization for Standardization, Genève, Switzerland*, ISO 8589:1988. International Organization for Standardization.

Jiménez-Colmenero, F., Cofrades, S., López-López, I., Ruiz-Capillas, C., Pintado, T., & Solas, M. T. (2010). Technological and sensory characteristics of reduced/low-fat, low-salt frankfurters as affected by the addition of konjac and seaweed. *Meat Science*, *84*(3), 356–63.

López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International.*, *43*(5), 1244 – 1254.

Martens, H., & Martens, M. (2001). *Multivariate Analysis of Quality. An Introduction. Measurement Science and Technology* (2nd ed., Vol. 12). John Wiley & Sons Ltd.

McCaughey, S. (2007). Salt and Flavor: Mechanisms of Taste Perception and Physiological Controls. In K. D. & A. F. (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 78–99). Boca Raton Boston, New york, Washington-DC: Woodhead Publishing Ltd.

Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, *21*(6), 611–620.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003a). Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. *Meat Science*, *64*, 371–381.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003b). Physical and sensory properties of low-salt phosphate-free frankfurters composed with various ingredients. *Meat Science*, *63*(1), 9–16.

Shand, P. (2000). Textural, Water Holding, and Sensory Properties of Low-fat Pork Bologna with Normal or Waxy Starch Hull-less Barley. *Journal of Food Science*, *65*(1), 101 – 107.

Steenkamp, J.-B. E. M., & Trijp, H. C. M. (1996). Quality guidance: A consumer-based approach to food quality improvement using partial least squares. *European Review of Agricultural Economics*, *23*, 195–215.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, B. R.N., & H. . Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 291 – 325). USA: Elsevier Academic Press.

Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, Bleibaum R.N., & H. A. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 117 – 157). USA: Elsevier Academic Press.

Stone, H., & Sidel, J. L. (2004). Affective testing. *In: H. Stone and J. L. Sidel (Eds.), Sensory Evaluation Practices. Food Science and Technology, International Series. USA: Academic Press/Elsevier.*, *3rd ed.*, 247–277.

Suhre, F. B., Corrao, P. A., Glover, A., & Malanoski, A. J. (1982). Comparison of three methods for determination of crude protein in meat: collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*(6), 1339–1345.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Vadlamani, K., Friday, D., Broska, A., & Miller, J. (2012). Methods and compositions for reducing sodium content in food products. *US Patent App. 12/ 0003358A1*. United States Patent Application Publication.

Verbeke, W., Pérez-Cueto, F. J. A., De Barcellos, M. D., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, *84*, 284–292.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2009). *Recommendations for preventing cardiovascular diseases. WHO Technical Report Series, No. 916 (TRS 916).*World Health Organization.

Wood, J. D., & Fisher, A. V. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). Elsevier Applied Science, London.

Yang, A., Keeton, J. T., Beilken, S. L., & Trout, G. R. (2001). Evaluation of Some Binders and Fat Substitutes in Low-fat Frankfurters. *Journal of Food Science*, *66*(7), 1039 – 1046.

Zanardi, E., Ghidini, S., Conter, M., & Ianieri, A. (2010). Mineral composition of Italian salami and effect of NaCl partial replacement on compositional, physico-chemical and sensory parameters. *Meat Science*, *86*(3), 742–747.

Chapter 8

Impact on the sensory properties of salt-reduced corned beefs formulated with and without the use of salt replacers

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Abstract

The aim of this study was to investigate the impact of varying sodium levels (0.2% - 1.0%) and salt replacers in corned beef on physicochemical, sensory and microbiological properties. Significant differences in colour, hardness and cooking loss were measured. Corned beef samples low in sodium (0.2%, 0.4%) showed reduced ($P < 0.05$) saltiness perception, but were positively correlated ($P > 0.05$) to liking of flavour and overall acceptability. Samples formulated with $CaCl_2$, $MgCl_2$ and KCl scored higher ($P < 0.01$) in saltiness perceptions, but correlated negatively ($P > 0.05$) to liking of flavour and overall acceptability. However, a sodium reduction of 60% in corned beef was determined to be achievable as assessors liked ($P < 0.05$) the flavour of the sodium reduced corned beef containing 0.4% sodium and formulated with potassium lactate and glycine (KLG), even with the noticeable lower salty taste. Sodium reduction in corned beef (packaged under modified atmosphere) did not negatively impact on the microbiological shelf-life.

8.1 Introduction

Corned beef is a traditional cured meat product from Western Europe and America which is popular in Ireland and the United Kingdom. The term “corned” comes from the treatment with large grained rock salt, which looks like a wheat kernel known as a corn of salt. Corned beef is first mentioned in the old Irish Gaelic poem Aeslinge Meic Conglinne “The *Vision of MacConglinne”* in the 12th century, which describes corned beef as a delicacy given to a king. In the 19th century corned beef was a festive dish in Ireland, served with cabbage and potatoes at Christmas, Halloween, weddings, wakes and on St. Patrick’s Day. This tradition was transferred all over the world, especially to North America, by the emigrants of the 18th /19th centuries (Mahon, 1998). Corned beef in its canned form was an important food source during World War II. Nowadays, corned beef is still available in its two forms: full piece of beef –brisket/round– or canned, though the recipes, and therefore the taste differs extremely. Ingredients employed in corned beef manufacture, besides beef (50% - 95%), sodium chloride and nitrite, can also consist the following: thickeners (starches, flours), stabilisers (phosphate derivate), antioxidants (ascorbate derivate), flavour enhancers (glutamate derivate), dextrose and spices. The sodium content of the available corned beef in Ireland ranges from 0.7% to 1.0% (unpublished data, 2014).

On the basis that the meat industry is responsible for a relevant part of the daily sodium intake by consumers, the meat processing industry is trying to develop low-salt meat products to address consumer concerns and adhere to health recommendations. Already, different strategies have been attempted to achieve these: reducing the total amount of salt or by (partly) substitution of sodium chloride with potassium, magnesium and calcium chloride, glutamate, glycine and potassium lactate (Aaslyng, Vestergaard, & Koch, 2014; Aliño, Grau, Toldrá, & Barat, 2010a; Aliño, Grau, Toldrá, Blesa, et al., 2010b; Fellendorf, O’Sullivan, & Kerry, 2015; Gou, Guerrero, Gelabert, & Arnau, 1996; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Tobin, O’Sullivan, Hamill, & Kerry, 2012b, 2013, 2012a). The most efficient outcome is the substitution of sodium by potassium to simultaneously increase potassium intake.

An excessive sodium intake is linked with mortality and the risk of developing coronary heart diseases (Bibbins-Domingo et al., 2010; Ezzati, Lopez, Rodgers, Vander Hoorn, & Murray, 2002; Qizilbash et al., 1995). Sodium chloride is the main additive used in manufacturing processed meat as it contributes to developing the texture and flavour, and furthermore extension of shelf-life (Toldrá, 2007). A survey in UK calculated that the processed meat sector, with 18%, is the largest contributor of sodium in food, followed by bread and bakery products (13%), dairy products (12%), and sauces and spreads (11%) (Ni et al., 2011). The Irish Universities Nutrition Alliance carried out a national adult nutritional survey and determined that the mean daily salt intake from food (excluding salt added in cooking and at the table) for the Irish population (age of 18 to 64) was estimated as 7.4 g (men 8.5 g salt/day and women 6.2 g salt/day). Elderly people aged 65 years and over, had a lower salt mean daily intake of 6.3 g. Furthermore, breads, and cured and processed meats were the main contributors to the daily salt intake in the Irish population (Irish Universities Nutrition Alliance, 2011). The World Health Organization (WHO) recommends a daily sodium consumption for adults of less than 2 grams (<5 g salt/day) (WHO, 2012b). Furthermore, the WHO suggests for adults an increase in potassium intake from food (3.5 mg potassium/day) to reduce blood pressure, the risk of cardiovascular diseases and stroke (WHO, 2012a). Therefore, a “Salt Reduction Programme” (SRP) set up by the Food Safety Authority of Ireland (FSAI) provides guidelines for maximum sodium levels for uncured cooked meat products, cured uncooked meat products, black & white puddings, sausages and burgers. Although, no regulations are defined for cured cooked meat products like corned beef and cooked ham (FSAI, 2011). The Food Standard Agency (FSA) takes responsibility for protecting the public health associated with food throughout the UK. The FSA, includes in their sodium reduction plan, ham and other cured meats, (which commenced in 2010) a recommended level of 800 mg (FSA, 2010), and since 2012, the sodium target level was set as 650 mg/100g. No further reductions are planned until 2017 (FSA, 2014). It is only a matter of time before the FSAI will also include in their Irish salt reduction program guidelines for cooked cured meat products.

Due to their high contribution of the daily salt intake in the Irish population the salt level of cured meat products, such as corned beef, has to be reduced (Irish Universities Nutrition Alliance, 2011). No research has been carried out to date on salt reduction in corned beef. Therefore, the objective of this study was to investigate the impacts of varying sodium levels (0.2% - 1.0%) and salt replacers in corned beef on physicochemical (colour, hardness, cooking loss), sensory (Affective and Descriptive) and microbiological properties in order that a healthier and more consumer acceptable product might be produced.

8.2 Materials and Methods

8.2.1 Sample preparation

Thirteen test runs (in total 39 muscles used) were conducted using multi-needle injector and hand injector to determine the most suitable manufacturing process. The focus was directed on producing replicable corned beef samples. Corned beef produced by hand injector showed the best results (unpublished data, 2014) and therefore used in the present study.

The beef used in this study was the eye of round (Semitendinosus) and was purchased from a local supplier (Feoil O Criostoir Teo, Ballincollig, Cork, Ireland). Before commencing with injection of the brine, visible fat was removed and the beef was portioned in order that all meat pieces had the same starting weight (2.0kg). Semitendinosus muscles within the pH range from 5.5 ± 0.1 were taken for production. Firstly, five brine solutions with a constant concentration of potassium nitrite and different levels of sodium chloride were prepared using the following calculation:

$$\%\ \text{ingredient in brine} = \frac{\%\ \text{ingredient in final product x}\ (100 + \text{injection rate})}{\text{injection rate}}$$

This ensured a residual potassium nitrite level of 0.0185% and a range of sodium contents from 1.0%, 0.8%, 0.6%, 0.4% to 0.2% in the final product (Table 1). In the second part of this study, salt replacer combinations were added to the brine solution to achieve acceptable low salt (0.4% sodium) corned beef samples (Table 1). The following seven combinations were chosen: potassium chloride and sodium chloride 50/50% (CB_KCl); mixture of potassium lactate, potassium chloride and sodium chloride 10/40/50% (CB_KLCl); mixture of potassium citrate, potassium phosphate, potassium chloride and sodium chloride 20/20/20/40% (CB_KCPCl); mixture of potassium lactate, glycine and sodium chloride 20/20/60% (CB_KLG); mixture of calcium chloride, magnesium chloride, potassium chloride and sodium chloride 15/5/45/35% (CB_CaMgKCl1); mixture of calcium chloride, magnesium chloride, potassium chloride and sodium chloride 15/5/25/55% (CB_CaMgKCl2) and a mixture of potassium chloride, glycine and sodium chloride 30/20/50% (CB_KClG). The brine was mixed for 3 min with 3500 rpm using Silverson AXR mixer (Dartmouth, USA). With the help of the one needle hand injector (4mm needle diameter) (Friedr. Dick GmbH & Co. KG, Deizisau, Germany), the homogenized brine solution was injected into the standardised beef until an injection rate of 20% was reached. Afterwards the beef was vacuum packaged in a bag (made of a two layer laminate of oriented polyamide and polypropylene (OPA/PP), (Fispak, Dublin, Ireland)), stored into the chiller at 4°C for 24 hr. Before commencing cooking, the vaccum bag was cut open to record the weight of the injected beef and afterwards heat sealed. Injected beef samples in bags were then cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) with 100% steam at 85 ºC for 3 hrs. The temperature of the chamber was controlled by a temperature probe (Testo 110, Lenzkirch, Germany). After cooking, the samples (in the bag) were transferred immediately into the chill at 4 °C. On the next day, corned beef samples were taken out of the bag to record the weights for calculating cooking loss. Afterwards the samples were cut into 3 pieces of the same length named A, B and C. Each corned beef piece (A, B, C) was vacuum packaged in a bag (OPA/PP), (Fispak, Dublin, Ireland)) and stored at 4 °C until commencing the analyses. All corned beef samples were produced in duplicate (two independent samples per treatment) and were then analysed in replicates.

8.2.2 Sensory evaluation

For the first production part of this study, 2 days after manufacturing all 5 samples were sensory analysed by assessors (n = 29) in the age range from 20 – 56. Sensory test of the 8 samples belonging to the second production component of this study using the replacers was split into 2 sessions (4 samples per session), conducted after 2 and 3 days of manufacturing. Therefor assessors (n = 25) ranged in the age from 19 – 56. Sensory testing was conducted using untrained assessors (Stone, Bleibaum & Thomas, 2012a; Stone & Sidel, 2004) who consumed corned beef regularly. The experiment was conducted in panel booths, which conformed to International Standards (ISO, 1988). The samples from part B were served cold as 3 mm thick slices, coded in randomised order and presented in duplicate to assessors (Stone, Bleibaum & Thomas, 2012b). The assessors were asked to assess samples using the sensory acceptance test, on a continuous line scale from 1 to 10 cm in relation to the following attributes: liking of appearance, liking of flavour, liking of texture, liking of colour and overall acceptability (hedonic). The assessors then participated in ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio & Benassi, 2010) using the consensus list of sensory descriptors, including; saltiness, juiciness, toughness, corned beef flavour, cured flavour and off-flavour (intensity), which was also measured on a 10 cm line scale. All samples were again presented in duplicate (Stone et al., 2012b).

8.2.3 Fat and moisture analysis

Approximately 1.0 g of each homogenised vacuum packed corned beef sample from part A, B and C was measured using the SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) for analysing moisture and fat, respectively (Bostian, Fish, Webb & Arey, 1985).

8.2.4 Protein analysis

Protein content was determined from part A, B and C using the Kjeldahl method (Suhre, Corrao, Glover & Malanoski, 1982). Approximately 0.8 - 1.0 g of homogenised sample was weighed into a digestion tube to which 2 catalyst tabs (3.5 g potassium sulphate and 3.5 mg selenium per tab), 15 ml concentrated sulphuric acid and 10 ml 30% hydrogen peroxide (w/w) were added. Additionally, a blank tube was prepared similarly to serve as a control. The tubes were then placed in a digestion block (FOSS, Tecator ™ digestor, Hillerød, Denmark), heated up to 410 ºC and held for 1hr. After cooling, 50 ml of distilled water were added to each tube, which were then placed into the distillation unit (FOSS, Kjeltec ™ 2100, Hillerød, Denmark) along with a receiver flask containing 50 ml 4% boric acid with indicator (bromcresol green and methyl red). A total of 70 ml of 30% sodium hydroxide (w/w) was added to the tube before the 5 min distillation started. The content of the receiver flask was titrated with 0.1 N hydrochloric acid until the green colour reverted back to red.

8.2.5 Ash analysis

The ash content was determined from part A, B and C using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of homogenized samples were weighed into crucibles and heated up to 600 ℃ stepwise until a white ash was presented.

8.2.6 Salt analysis

8.2.6.1 Potentiometer

Salt content of corned beef samples, containing chloride ions bound only to sodium, were obtained from part A, B and C using the potentiometric method (Fox, 1963) by utilising a chloride sensitive electrode (Ag electrode in combination with a reference electrode Ag/AgCl buffered with KCl (M295 and pH C3006, Radiometer Analytical SAS, Lyon, France)). Approximately 2.0 g of blended samples were weighed into a flask to which 100 ml of 0.1% nitric acid was added. The solutions were mixed, covered and placed in a 60 ℃ water bath for 15 min. After cooling down, the flasks were potentiometrically titrated with 0.1 N silver nitrate until a current of +255 mV was achieved. By means of the ratio to chloride, sodium chloride concentrations were calculated, as was sodium content.

8.2.6.2 Flame photometer

Sodium content was determined from part A, B and C using the flame photometer for samples containing chloride ions bounding not only to sodium (AOAC, 1988). Firstly, 5.0 g of homogenized sample was ashed (section 2.5.) The obtained ash was dissolved with 40 ml concentrated HCl/water (1+3), heated until boiling, transferred to a 50 ml volumetric flask and then filled up. After this step, the solution was filtered. Subsequently, the filtrate was diluted within the range of the sodium standard concentrations. The diluted filtrate was then measured using the flame photometer (Jenway PFP7, Essex, England).

8.2.7 Cooking loss analysis

Before cooking (section 2.1), sample weights were recorded. After cooking, samples were allowed to cool down overnight and then weighed again to obtain the cooking loss.

8.2.8 Colour analysis

Colour analysis was undertaken on six corned beef slices from part A, B, C of each sample by utilising a Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan), using 2 degree observer with 11 mm aperture and D_{65} illuminant. The tristimulus values were expressed in L* (lightness), a* (red-green dimension) and b* (yellow-blue dimension) (International Commission on Illumination, 1976). Firstly, a white tile (Y=93.6, x=0.3130, y=0.3193) was applied for calibration the colorimeter, afterwards ten readings were taken per slice.

8.2.9 Texture analysis

The instrumental texture of corned beef was evaluated using shear force, which was measured utilizing a Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K) attached with a Warner-Bratzler blade (connected to a 25 kg load cell) (Bratzler, 1932). Each corned beef sample was assessed 15 times. For that, five 12mm diameter core samples from part A, B and C were taken parallel to the muscle fiber orientation and then cut with a test speed of 3.0 mm/s by a Warner-Bratzler blade (pre-test speed 3.0 mm/s; post-test speed 10.0 mm/s). The recorded force peak represents the hardness of the product.

8.2.10 Shelf-life test

Total Viable Counts (TVC) were carried out for corned beef samples containing 1.0% sodium, 0.4% sodium and 0.4% sodium formulated with potassium lactate, glycine and sodium chloride (CB_KLG) (section 2.1). Three slices of corned beef sample from part B (in duplicate) with thicknesses of 3 mm were packed for each shelf-life test run. Two different packaging configurations were utilized: vacuum packaging (VP) and modified atmosphere packaging (MAP) (70% N_2: 30% CO_2). On the day of commencing the shelf-life test, a 10 g sample was placed into a stomacher bag with sterile 90 ml Maximum Recovery Diluent (MRD) and homogenised in a paddle blender (STOMACHER 400, Colworth, UK) for 3 min. Appropriate sample dilutions were prepared as followed: 1 ml aliquot was transferred into sterile screw-capped tubes containing 9 ml MRD and then mixed (Vortex mixer SA 7, Stuart, Staffordshire, UK). Afterwards, 0.1 ml of each dilution were plated in duplicate onto Plate Count Agar (PCA). All plates were aerobically incubated at 37°C for 48 hr. The results were expressed as Colony Forming Unit per g sample (CFU/g). Following the guideline for cooked meat, including cured products, by the International Commission on Microbiological Specifications for Foods (ICMSF)

(ICMSF, 2011), the acceptable limit in this study was defined as < 10^5 CFU/g of sample.

8.2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 10.3. The X-matrix was designed as 0/1 variables for salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 34% and 14% respectively.

For evaluation of the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$). A randomized block design was used for the first and second study. For this purpose, different recipes were chosen for the experimental unit and data were set as response. The following null hypothesis was defined: corned beefs made from different recipes (variation of salt levels and replacers) show no significant differences in hardness, colour and cooking loss. Null hypothesis was rejected when null hypothesis was false (type I error, $\alpha = 0.05$).

8.3 Results and discussion

8.3.1 Sensory evaluation

8.3.1.1 Salt reduction in corned beef

The results of the sensory evaluation of corned beef with varied salt levels are displayed in the APLSR plot in Figure 1 and the corresponding ANOVA values, including significance and correlation factors presented in Table 2 for hedonic and descriptive sensory assessments, respectively.

As can be seen in Table 2 varying the sodium chloride levels in corned beef did not significantly affect either liking of colour or appearance. The curing agent potassium nitrite, amongst others, was responsible for developing the red colour, as it reacts with myoglobin to form the heat-stable NO-myoglobin (Fe^{2+}) (Haldane, 1901;

Kisskalt, 1899; Lehmann, 1899). Potassium nitrite was added at a constant concentration to the brine for all five corned beef formulations (Table 1), therefore no major differences in colour were expected.

From Figure 1, in the right hand quadrant of the plot, liking of texture correlated positively to corned beef samples low in sodium (0.2%, 0.4%). Furthermore, these samples correlated negatively to juiciness and toughness. Samples with higher sodium contents were assessed inversely to this data by assessors. No significant differences were determined between formulations (Table 2). Hamm (1972) and Honikel (2010) postulated the theory that the injected sodium chloride penetrates into the meat cells, which causes a swelling of myofibrillar proteins. Furthermore, more water molecules are able to move between the proteins chains. During heating, the swollen myofibrillar proteins become softer, the added water remains and the meat becomes juicy. This is in agreement with Desmond (2006), who correlated an increase in water holding capacity of myofibrillar proteins in processed meat to an increase in juiciness and tenderness. This theory that salt increases juiciness and tenderness of meat products can be confirmed partly in the present study, as lower salt samples correlated negatively to juiciness, but also to toughness. Aaslyng et al. (2014) similarly reported in a study that very low salted (1.3% NaCl) boiled ham decreased juiciness and firmness, although low salted (1.8% NaCl) boiled ham was rated positively for juiciness and firmness.

Lower sodium corned beef samples (0.4%, 0.2%) were rated lower ($P < 0.05$) for saltiness and corned beef with 1.0% sodium were found to be ($P < 0.001$) more salty (Table 2). Furthermore, samples low in sodium correlated negatively to corned beef flavour and cured flavour. Reverse outcomes were recorded for the higher sodium samples (0.6 - 1.0%), though no significant results were achieved for any of the five formulations assessed. However, these results are in consistent agreement with the theory that salt plays a key role in enhancing the flavour, besides developing the salty taste (Hutton, 2002), which had been well confirmed in previous studies over the last 10 years (Aaslyng et al., 2014; Fellendorf et al., 2015; Ruusunen et al., 2005; Tobin et al., 2012a).

In spite of decreased saltiness ($P < 0.05$), corned beef flavour and cured flavour perceptions, samples containing 0.2% and 0.4% sodium, respectively, correlate positively (although not significantly) to liking of flavour and overall acceptability (Figure 1, Table 2). It is probable that because of the positive correlations to off-flavour, assessors did not accept ($P > 0.05$) corned beef samples high in sodium (0.6% - 1.0%). They detected off-flavours in samples high in sodium. This off-flavour was not caused by rancidity developing over time since all samples were served immediately after production to guarantee freshness. A positive correlation to off-flavour was also noted by Tobin et al. (2012a, 2012b) for higher salt frankfurters (3.0%, 2.5%, 2.0%) and beef patties (1.5%, 1.25%). However, the lower sodium corned beef samples (0.4%, 0.2%) were correlated to be accepted (not significantly) by the assessors, even with decreased flavour perceptions.

8.3.1.2 Salt replacers in corned beef

Seven different salt replacer combinations were added to corned beef samples containing 0.4% sodium with the target of improving the flavour profile (section 3.1.1) and producing significant consumer-acceptable end product. The sensory evaluation of these sodium-reduced corned beef samples are shown in an APLSR plot (Figure 2) in conjunction with the ANOVA values for hedonic and descriptive sensory assessments (Table 2).

As can be seen in Figure 2, corned beef sample containing 0.4% sodium (control) is located on the y-axis. In contrast, samples formulated with replacers (with exception of CB_KLCl) are scattered around the plot (Figure 2), therefore the addition of replacers in corned beef impacted upon sensory properties.

The attributes; liking of appearance and colour are located close to the center of the plot (Figure 2) which indicates that the added replacers to corned beef did not affect appearance or colour. Consequently, no significant results were achieved (Table 2). It is well known that the agent potassium nitrite develops the typical cured meat colour (Haldane, 1901; Kisskalt, 1899; Lehmann, 1899). However, in a previous study by Fellendorf, O'Sullivan, & Kerry et al. (unpublished, 2014) also found no changes in either colour or appearance for low salt and low fat (uncured) black pudding samples formulated with 11 different ingredient replacer combinations.

As can be seen in Figure 2, sodium-reduced corned beef samples formulated with KLG and KClG, respectively, correlate positively to liking of texture and toughness, and negatively for juiciness. However, no significant differences in results for texture attributes, juiciness, toughness and liking of texture were observed across all treatments (Table 2). In summary, adding salt replacers to lower sodium corned beef resulted in unnoticeable effects on product texture by assessors. However, dependent upon the ratio of salt-replacers used, significant changes in texture were reported (Gelabert, Gou, Guerrero & Arnau 2003) through the substitution of sodium chloride in fermented sausages formulated with potassium lactate and glycine, and accordingly, with potassium chloride and glycine.

In the present study, the lower sodium corned beef sample formulated with KClG and KLG were rated even lower ($P < 0.05$) in saltiness perception by assessors. Gelabert et al. (2003) also reported that all five different ratio combinations of potassium chloride and glycine added to fermented sausages were not able to mask the decreased salty taste of products.

Corned beef formulations containing KCl, KLCl and accordingly KCPCl were rated similarly by assessors. These samples were positively correlated to saltiness, and negatively correlated to intensity of corned beef and cured flavour. Furthermore, these samples showed a negative correlation to liking of flavour and overall acceptability. However, no significant results were achieved. Guàrdia et al. (2008) reported on small caliber fermented sausages with a 50% substitution of NaCl with 50% KCl and accordingly, a mixture of KCl/potassium lactate (40/10%), and concluded that these samples scored similarly to the control with respect to overall acceptability. However, Vadlamani, Friday, Broska & Miller (2012) published contradicting data for eight different ratio combinations with KCl, potassium phosphate and potassium citrate in chicken broth, which significantly increased overall flavour scores.

Assessors rated the low sodium samples formulated with CaMgKCl1 and CaMgKCl2 higher ($P < 0.001$) in saltiness (Table 2). Hence, these salt replacers appeared to have the capacity to enhance the saltiness perception in corned beef. No significant results ($P > 0.05$) were obtained for the sensory attributes of corned beef flavour and cured flavour. Furthermore, these samples displayed negative correlations to liking of flavour and overall acceptability (Figure 2), which confirm the results reported in section 3.1.1, where assessors preferred corned beef products with a less salty taste. However, Armenteros, Aristoy, Barat & Toldrá (2009) reported that the addition of CaMgKCl2 to dry-cured loins can be used to reduce the sodium content without negatively affecting product sensory qualities. Two other ratio combinations of sodium, magnesium, calcium and potassium chloride were tested without success. Armenteros, Aristoy, Barat & Toldrá (2012) prepared dry-cured hams with $NaCl/KCl/CaCl_2/MgCl_2$ (55/25/15/5%) which were scored lower in aroma and taste compared to the control and the sample formulated with sodium and potassium chloride (50/50%). All things considered, these results demonstrate that for each meat product, the sodium chloride level and the type and ratio of salt replacer has to be adjusted to reach a highly accepted end product.

Sodium-reduced corned beef samples formulated with KLG achieved positive ($P < 0.05$) correlations to liking of flavour and additionally displayed a positive directional correlation to overall acceptability. This sample was scored very low ($P < 0.001$) in saltiness perception and no off-flavours were detected ($P < 0.05$). Previously, significantly lower scores for saltiness were also reached for fermented sausages formulated with a mixture of sodium chloride, potassium lactate and glycine (60/20/20%) (Gelabert et al., 2003). Nevertheless, in the present study, assessors preferred corned beef samples with the lowest salty taste, which is similar to the results reported in section 8.3.1.1.

In summary, a sodium reduction of 60% in corned beef is achievable based on assessors' feedback. Assessors liked ($P < 0.05$) the flavour of sodium-reduced corned beef containing only 0.4% sodium and formulated with potassium lactate and glycine (CB_KLG), even with the noticeable lower salty taste.

8.3.2 Characterization of corned beef

8.3.2.1 Characterization of salt reduced corned beef

The compositional properties of corned beef samples containing different sodium levels are presented in Table 3. In the present study the average protein content of corned beef was 30 g/100g, which is 20% higher compared to the literature (American corned beef), as the fat was initially removed to standardize the beef pieces used in this study. For this reason, the fat content was one third lower (Souci, Fachmann, & Kraut, 2004). The sodium levels in all final corned beef samples were slightly lower than targeted levels (Table 3), because of the curing process (injection) and the resulting exudative losses.

Average lightness (L) values of 59 ± 3, redness (a) values of 17 ± 1 and yellowness (b) values of 12 ± 1 were measured for the five corned beef samples containing different sodium levels (Table 4). Furthermore, significant differences in colour were recorded. The curing agent potassium nitrite and the protein myoglobin found in muscle tissue react with NO-Myoglobin (Fe^{2+}), which is responsible for the typical red colour of cured meat (Honikel, 2010). Hence, cured colour is dependent upon the amount of curing agent used, resting period employed and on meat quality selected, among other factors. Before curing, differences in meat colour can already be caused by the kind of muscle selected, animal species, age, feeding, pH, stress (before slaughtering) and shelf-life (Potthast, 1987; Renerre, 1990). Added salt affects the pH, water activity and shelf-life of the meat (Barat & Toldrá, 2011; Durack, Alonso-Gomez, & Wilkinson, 2008; Honikel, 2010), although in the present study, no trend was observed between different salt levels employed and colour. Since potassium nitrite was added at a constant level, it is assumed that the meat quality itself caused the observed differences in colour. However, these colour changes did not influence assessors' liking of meat colour (Table 2).

The measured hardness of the salt-reduced corned beef samples ranged from 20 N to 26 N (Table 4). Significant differences in shear force values were noted. However, different salt levels did not account for differences in hardness values obtained in the present study. Similar to the present study, Lee & Chin (2011a) did not achieve higher Allo-Kramer shear values for salt-reduced pork loins. King, Wheeler, Shackelford & Koohmaraie (2009) reported that tenderness is also influenced by complex interactions of multiple ante-mortem and post-mortem factors. Therefore, in the present study the recorded significant differences in shear force might be due to the variability of raw material.

One concern of the meat industry with respect to salt reduction in meat products is the possible decrease in water-holding capacity, thereby adversely affecting processing yields and product sensory qualities (Barat & Toldrá, 2011). In the present study, cooking losses from 38% to 41% were recorded, though no significant differences were achieved between samples (Table 4). Hence, allaying the concerns of the meat industry, different salt levels employed in corned beef manufacture in this study did not negatively alter cooking losses and therefore, processing yields. In contrast, Lee & Chin (2011b) reported significant increases in cooking loss for salt-reduced (0.5 - 1.0%) restructured pork hams.

8.3.2.2 Characterization of sodium reduced corned beef formulated with salt replacers

The measured protein, fat and moisture contents of salt-reduced corned beef samples formulated with salt replacers are comparable to corned beef samples containing different salt levels (Table 3). Again, measured sodium levels were slightly lower than target level.

Physicochemical data (colour, hardness and cooking loss) are presented in Table 4. Average lightness (L) values of 57 ± 2, redness (a) values of 18 ± 0 and yellowness (b) values of 13 ± 1 were recorded for sodium-reduced corned beef samples formulated with salt replacers. The measured shear force of corned beef samples formulated with salt replacers ranged from 19 N to 29 N. Significant differences in colour and hardness values were obtained between each formulation. Aliño et al. (2010b) reported that dry-cured loins containing 30% NaCl, 50% KCl, 15% $CaCl_2$ and 5%$MgCl_2$ had significantly higher hardness values than dry-cured loins containing a salt formulation consisting of 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$. Similar results were found in the present study. The highest shear force was recorded for CB_CaMgKCl1, while the lowest force was determined for CB_CaMgKCl2. Recently, Aliño et al. (2010a) also reported that dry-cured hams salted with NaCl/KCl (50/50%) were significantly harder compared to hams salted with NaCl/KCl/$CaCl_2$/$MgCl_2$ (55/25/15/5%). No significant differences in lightness, redness or yellowness values were determined. In the present study, the corned beef sample CB_KCl also showed higher (not significant) shear force values compared to corned beef sample CB_CaMgKCl2. Furthermore, no significant differences in redness or yellowness were recorded, although sample CB_KCl was darker ($P < 0.05$).

As shown in Table 4, cooking losses for corned beef samples formulated with salt replacers ranged from 37% to 42%. Significant differences compared to the control were observed. The lowest cooking loss was achieved for corned beef sample CB_CaMgKCl1. Guàrdia et al. (2008) recorded for small caliber fermented sausages an average weight loss of 47.4%. The 50% substitution of NaCl by 50% KCl, and accordingly 10% potassium lactate and 40% KCl in small caliber fermented sausages showed no significant differences in weight loss. Similar results were found in the present study for corned beef samples CB_KCl and CB_KLCl when comparing similar salt replacers.

8.3.3 Shelf-life test

The TVC-test was conducted for corned beef samples containing 1.0% sodium, 0.4% sodium and 0.4% sodium formulated with potassium lactate, glycine and sodium chloride (CB_KLG). The vacuum packaged corned beef samples containing 0.4% sodium possessed the shortest shelf-life from all examined samples, as a total viable count of $\geq 10^5$ CFU/ g per sample was recorded after 21 days of storage. After 56 days of storage, vacuum packaged corned beef samples formulated with 1.0% sodium, and accordingly CB_KLG, were also deemed to have expired. Hence, corned beef with the lowest sodium content, not surprisingly, had the shortest shelf-life. It is well known that salt acts as a food preservative by reducing the water activity of food, thereby reducing the growth rate of microorganisms. However, adding salt replacers like potassium lactate and glycine to corned beef with 0.4% sodium (CB_KLG) extended product shelf-life. This result corroborates the theory that glycine and lactate are able to decrease the water activity, and additionally, act as salt enhancer for various types of sausages (Gelabert et al., 2003; Gou et al., 1996; Kilcast & Angus, 2007). All three corned beef samples packaged with MAP recorded no microbial growth until day 82 of chilled storage. No further tests were conducted as the achieved storage life was already 4- to 6-times longer than that currently available for commercial MAP corned beef (unpublished data, 2014). The gas mixture employed in the present study consisted of 70% N_2 : 30% CO_2, which is typical for cooked meats (Smiddy, Papkovskaia, Papkovsky, & Kerry, 2002). As no oxygen was used, the growth of aerobic bacteria was inhibited, which is consistent with the literature (Cutter et al., 2012). Presumably, the shorter shelf-life of commercial corned beef products is caused by sensory deterioration rather than by exceeding the limit of 10^5 CFU/ g per sample for total viable count. However, it is well known that the shelf-life of refrigerated meat can be prolonged by packaging with nitrogen and carbon dioxide (Gill & Molin, 1991).

In summary, sodium reduction in corned beef using MAP did not negatively affect the shelf-life of corned beef samples. Even the shelf-life of vacuum packaged sodium-reduced corned beef samples lasted similarly to commercially-available corned beef.

8.4 Conclusion

Significant differences in colour and hardness were measured for corned beef samples containing different sodium levels (0.2% - 1.0%), although no connection between these quality parameters and sodium level could be determined. Furthermore, no significant differences in cooking losses were recorded. Corned beef samples containing 1.0% sodium were rated higher ($P < 0.001$) in saltiness perception, although a negative correlation ($P > 0.05$) to liking of flavour and overall acceptability was observed. In contrast, corned beef samples low in sodium (0.2%, 0.4%) showed reduced ($P < 0.05$) saltiness perceptions, but were positively correlated ($P > 0.05$) to liking of flavour and overall acceptability. Therefore, assessors preferred (not significant) corned beef samples low in salt.

Sodium reduced corned beef samples formulated with different salt replacer combinations showed significant differences in colour, hardness and cooking loss. Samples CB_CaMgKCl1 and CB_CaMgKCl2 scored higher ($P < 0.01$) in saltiness perception, but correlated negatively ($P > 0.05$) to liking of flavour and overall acceptability. Samples CB_KClG and CB_KLG were rated lower ($P < 0.05$, $P < 0.001$) in saltiness. Furthermore, assessors liked ($P < 0.05$) the flavour of CB_KLG, even a positive directional correlation (not significant) to overall acceptability was observed. Therefore, a sodium reduction of 60% in corned beef was achievable as the assessor liked ($P < 0.05$) the flavour of sodium-reduced corned beef containing 0.4% sodium and formulated with potassium lactate and glycine (CB_KLG), even with the noticeable lower salty taste. Therefore, the sodium target level of 650 mg/100g set by Food Standards Agency (FSA, 2014), and as applied within the UK, was obtained in this study. Furthermore, sodium reduction in corned beef did not negatively affect product shelf-life when combined with MAP.

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products. The authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

8.5 Tables and Figures

Table 1

Corned beef formulations with different sodium contents with and without using salt replacers

	% in final product									
Sample [a]	NaCl	Na	K(nitrite)	KCl	K(phosphate)	K(citrate)	K(lactate)	$CaCl_2$	$MgCl_2$	Glycine
Study I: Salt reduction										
CB_S1.0	2.54	1.00	0.0185	-	-	-	-	-	-	-
CB_S0.8	2.03	0.80	0.0185	-	-	-	-	-	-	-
CB_S0.6	1.52	0.60	0.0185	-	-	-	-	-	-	-
CB_S0.4	1.02	0.40	0.0185	-	-	-	-	-	-	-
CB_S0.2	0.51	0.20	0.0185	-	-	-	-	-	-	-
Study II: Salt replacer										
CB_Control S0.4	1.02	0.40	0.0185	-	-	-	-	-	-	-
CB_KCl	1.02	0.40	0.0185	1.02	-	-	-	-	-	-
CB_KLCl	1.02	0.40	0.0185	0.81	-	-	0.20	-	-	-
CB_KCPCl	1.02	0.40	0.0185	0.51	0.51	0.51	-	-	-	-
CB_KLG	1.02	0.40	0.0185	-	-	-	0.34	-	-	0.34
CB_CaMgKCl 1	1.02	0.40	0.0185	1.31	-	-	-	0.44	0.15	-
CB_CaMgKCl 2	1.02	0.40	0.0185	0.46	-	-	-	0.28	0.09	-
CB_KClG	1.02	0.40	0.0185	0.61	-	-	-	-	-	0.41

[a] Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate,potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

Table 2

P-values of regression coefficients from ANOVA-Partial Least Squares regression (APLSR) for hedonic and intensity sensory terms of corned beef samples with different sodium contents with and without using salt replacers.

Sample [a]	Hedonic term [b]					Intensity term					
	Appearance	Colour	Flavour	Texture	Acceptability	Saltiness	Juiciness	Toughness	CB flavour	Cured flavour	Off-flavour
StudyI: Salt reduction											
CB_S1.0	-0.6192 ns	-0.4784 ns	-0.7595 ns	-0.9116 ns	-0.4384 ns	0.0001 ***	0.2159 ns	0.9653 ns	0.8548 ns	0.0627 ns	0.7792 ns
CB_S0.8	-0.9959 ns	-0.8485 ns	-0.5040 ns	-0.5995 ns	-0.4102 ns	0.6390 ns	0.7557 ns	0.5679 ns	0.7527 ns	0.8209 ns	0.7732 ns
CB_S0.6	-0.4469 ns	-0.4632 ns	-0.4353 ns	-0.3090 ns	-0.8979 ns	0.2684 ns	0.2374 ns	0.3377 ns	0.6520 ns	0.4375 ns	0.4971 ns
CB_S0.4	0.9572 ns	0.5692 ns	0.5048 ns	0.1846 ns	0.7899 ns	-0.0228 *	-0.6258 ns	-0.0596 ns	-0.9043 ns	-0.2533 ns	-0.4289 ns
CB_S0.2	0.7096 ns	0.4637 ns	0.2240 ns	0.5230 ns	0.8615 ns	-0.0003 ***	-0.4770 ns	-0.9070 ns	-0.9670 ns	-0.0666 ns	-0.6279 ns
StudyII: Salt replacer											
CB_Control S0.4	0.6468 ns	0.8080 ns	0.7584 ns	0.5782 ns	0.6930 ns	-0.9137 ns	-0.5498 ns	0.9427 ns	0.9587 ns	-0.8608 ns	-0.7586 ns
CB_KCl	-0.7696 ns	-0.8632 ns	-0.2471 ns	0.6709 ns	-0.3889 ns	0.2839 ns	0.1494 ns	-0.6876 ns	-0.9712 ns	0.5906 ns	0.3352 ns
CB_KLCl	-0.9862 ns	-0.8894 ns	-0.7386 ns	-0.8497 ns	-0.7771 ns	0.8884 ns	0.8586 ns	-0.8705 ns	-0.9596 ns	0.9883 ns	0.8005 ns
CB_KCPCl	-0.1512 ns	-0.5546 ns	-0.2325 ns	-0.2107 ns	-0.0854 ns	0.6127 ns	0.2242 ns	-0.3482 ns	-0.4131 ns	0.3520 ns	0.3925 ns
CB_KLG	0.4990 ns	0.7805 ns	0.0198 *	0.4033 ns	0.0714 ns	-0.0001 ***	-0.7983 ns	0.5719 ns	0.9771 ns	-0.2589 ns	-0.0123 *
CB_CaMgKCl 1	-0.9599 ns	-0.9480 ns	-0.3911 ns	-0.9754 ns	-0.6161 ns	0.0018 **	0.5168 ns	-0.9175 ns	-0.9433 ns	0.2033 ns	0.3330 ns
CB_CaMgKCl 2	-0.8159 ns	-0.7783 ns	-0.9220 ns	-0.7406 ns	-0.8592 ns	0.0033 **	0.7714 ns	-0.4834 ns	-0.5773 ns	0.1156 ns	0.6585 ns
CB_KClG	0.8082 ns	0.9233 ns	0.1322 ns	0.8314 ns	0.3510 ns	-0.0116 *	-0.0791 ns	0.9770 ns	0.7495 ns	-0.3537 ns	-0.2120 ns

[a] Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

[b] Significance of regression coefficients: ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Table 3

Compositional properties of corned beef samples with different sodium contents with and without using salt replacers

Samples [a]	Protein [%] [d]	Fat [%]	Moisture [%]	Sodium [%]	Ash [%]
Salt reduction					
CB_S1.0	30.3 ± 0.5	3.1 ± 0.5	64.9 ± 0.4	0.95 ± 0.06 [b]	3.4 ± 0.1
CB_S0.8	30.6 ± 0.5	3.1 ± 0.2	65.3 ± 0.5	0.70 ± 0.11 [b]	2.8 ± 0.3
CB_S0.6	29.6 ± 0.0	3.8 ± 0.5	65.0 ± 0.4	0.51 ± 0.04 [b]	2.2 ± 0.1
CB_S0.4	29.8 ± 0.5	4.4 ± 0.1	65.4 ± 0.4	0.28 ± 0.00 [b]	1.7 ± 0.0
CB_S0.2	29.9 ± 0.3	4.9 ± 0.2	63.9 ± 1.4	0.09 ± 0.01 [b]	1.1 ± 0.0
Salt replacer					
CB_Control S0.4	31.5 ± 0.4	2.7 ± 0.0	65.6 ± 0.5	0.32 ± 0.01 [b]	1.5 ± 0.2
CB_KCl	30.6 ± 0.5	2.8 ± 0.2	64.9 ± 0.2	0.34 ± 0.00 [c]	2.8 ± 0.3
CB_KLCl	30.1 ± 0.1	4.3 ± 0.5	63.5 ± 0.3	0.33 ± 0.01 [c]	2.5 ± 0.1
CB_KCPCl	31.4 ± 0.2	3.5 ± 0.2	63.5 ± 0.1	0.34 ± 0.01 [c]	3.1 ± 0.1
CB_KLG	31.4 ± 0.5	4.7 ± 0.4	64.4 ± 0.3	0.33 ± 0.01 [c]	1.9 ± 0.2
CB_CaMgKCl 1	30.1 ± 0.4	4.4 ± 0.4	64.4 ± 0.2	0.35 ± 0.01 [c]	3.4 ± 0.1
CB_CaMgKCl 2	29.0 ± 0.1	3.4 ± 0.2	66.5 ± 0.2	0.34 ± 0.01 [c]	2.3 ± 0.0
CB_KClG	30.2 ± 0.1	4.0 ± 0.2	65.3 ± 0.5	0.34 ± 0.01 [c]	2.2 ± 0.1

[a] Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = mixture of potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

[b] Sodium content analysed using potentiometer

[c] Sodium content analysed using flame photometer

[d] All values are averages ± standard errors.

Table 4

Colour, hardness and cooking loss values of corned beef samples with different sodium contents with and without using salt replacers

Sample ^{e}	Colour ^{f} L*	a*	b*	Hardness Shear force [N]	Cooking loss [%]
Salt reduction					
CB_S1.0	60.3 ± 0.0^{b}	16.0 ± 0.0^{b}	12.3 ± 0.0^{b}	23.6 ± 0.1$^{a, b}$	39.2 ± 0.1^{a}
CB_S0.8	64.0 ± 0.1^{a}	15.1 ± 0.0^{c}	12.9 ± 0.0^{a}	19.7 ± 0.1^{c}	38.3 ± 0.6^{a}
CB_S0.6	57.2 ± 0.0^{c}	18.1 ± 0.1^{a}	12.1 ± 0.1^{b}	23.5 ± 0.1$^{a, b, c}$	41.4 ± 0.4^{a}
CB_S0.4	57.9 ± 0.0^{c}	18.2 ± 0.0^{a}	12.6 ± 0.0$^{a, b}$	19.9 ± 0.1$^{b, c}$	40.0 ± 0.4^{a}
CB_S0.2	58.0 ± 0.1^{c}	18.2 ± 0.0^{a}	11.3 ± 0.1^{c}	26.3 ± 0.1^{a}	41.1 ± 0.7^{a}
Salt replacer					
CB_Control S0.4	60.2 ± 0.0^{a}	17.2 ± 0.0$^{b, c}$	12.4 ± 0.0^{c}	21.7 ± 0.1$^{b, c, d}$	42.4 ± 0.5^{a}
CB_KCl	55.9 ± 0.0^{d}	17.7 ± 0.1$^{a. b}$	13.3 ± 0.0^{b}	23.5 ± 0.1$^{a, b, c, d}$	41.9 ± 0.2$^{a, b}$
CB_KLCl	58.4 ± 0.1^{b}	17.1 ± 0.0^{c}	13.8 ± 0.1^{b}	26.8 ± 0.1$^{a, b}$	40.0 ± 0.4$^{a, b}$
CB_KCPCl	56.2 ± 0.2$^{c, d}$	18.0 ± 0.0^{a}	13.7 ± 0.1$^{a, b}$	25.1 ± 0.1$^{a, b, c, d}$	40.1 ± 0.3$^{a, b, c}$
CB_KLG	56.5 ± 0.0$^{c, d}$	17.1 ± 0.1$^{b, c}$	13.3 ± 0.0^{b}	27.9 ± 0.1^{a}	40.1 ± 0.3$^{a, b, c}$
CB_CaMgKCl 1	55.6 ± 0.0^{d}	17.8 ± 0.0^{a}	14.0 ± 0.0^{a}	28.5 ± 0.1^{a}	37.2 ± 0.7^{c}
CB_CaMgKCl 2	58.6 ± 0.0^{b}	17.9 ± 0.0^{a}	13.6 ± 0.0$^{a, b}$	18.6 ± 0.1^{d}	38.9 ± 0.4$^{b, c}$
CB_KClG	57.2 ± 0.1^{c}	18.1 ± 0.0^{a}	12.7 ± 0.1^{c}	20.1 ± 0.1$^{c, d}$	39.4 ± 0.3$^{a, b, c}$

[a-d] Averages sharing different letters in the same column within the same study are significantly different ($P < 0.05$).

[e] Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = mixture of potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

[f] All values are averages ± standard errors.

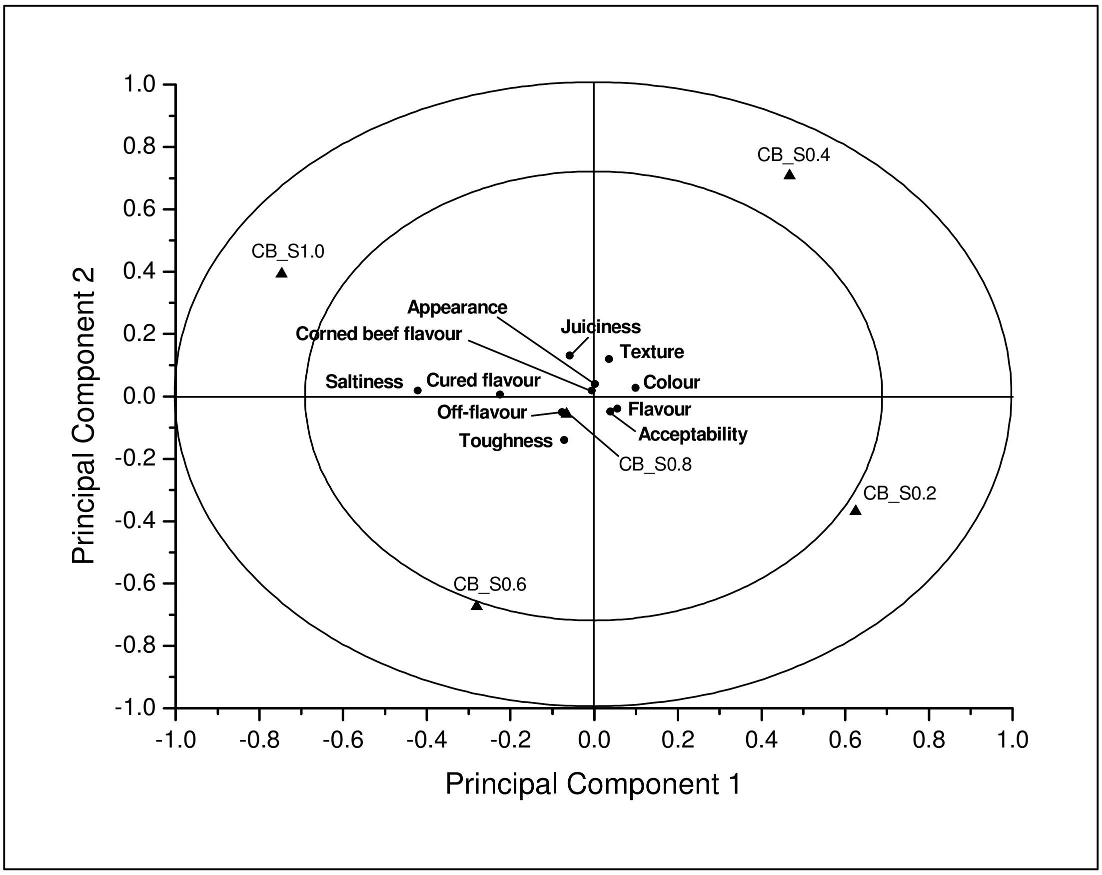

Figure 1:

ANOVA-Partial Least Squares regression (APLSR) for the corned beef formulations. ▲ = Samples (code: CB = corned beef, S = sodium), ● = sensory attributes

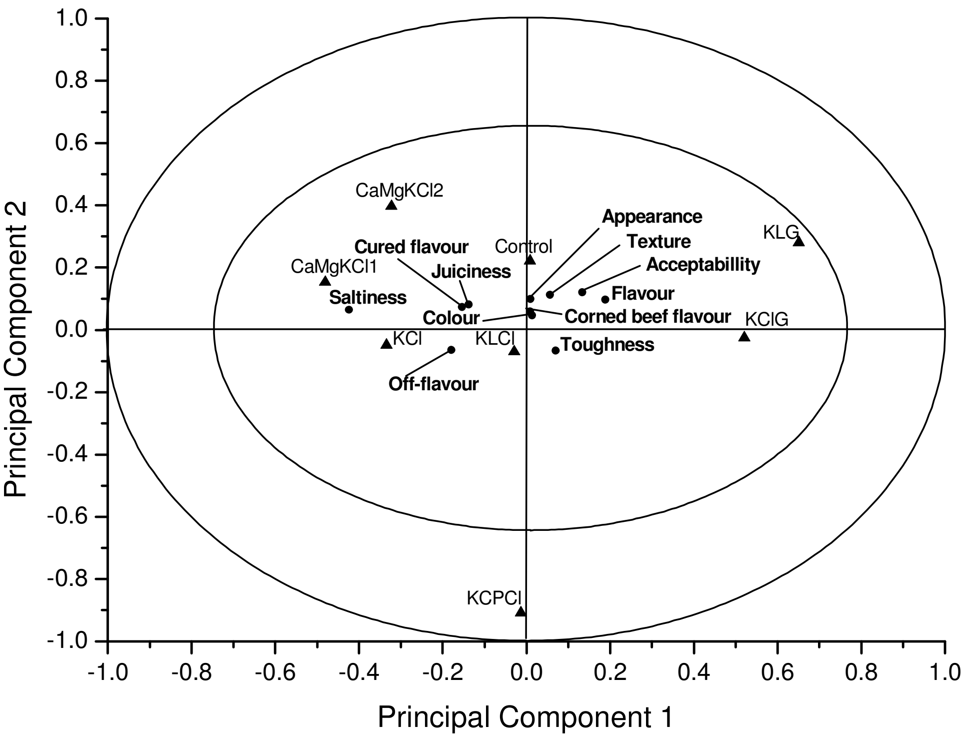

Figure 2:

ANOVA-Partial Least Squares regression (APLSR) for the corned beef formulations. ▲ = Samples (code: Control = corned beef (0.4% sodium); KCl = potassium chloride; KLG = mixture of potassium lactate and glycine; KClG = mixture of potassium chloride and glycine; KLCl = mixture of potassium lactate and potassium chloride; KCPCl = mixture of potassium chloride, potassium phosphate, potassium chloride, CaMgKCl1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45); CaMgKCl2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), ● = sensory attributes

References

Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, *96*(1), 47–55.

Aliño, M., Grau, R., Toldrá, F., & Barat, J. M. (2010). Physicochemical changes in dry-cured hams salted with potassium, calcium and magnesium chloride as a partial replacement for sodium chloride. *Meat Science*, *86*(2), 331–6.

Aliño, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M. J., & Barat, J. M. (2010). Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science*, *85*(3), 580–8.

AOAC. (1923). Determination of ash. *Journal of the Association of Official Analytical Chemists*, *7*, 132. Association of Official Agricultural Chemists.

AOAC. (1988). Minerals in ready-to-feed milk-based infant formula. *Official Methods of Analysis of AOAC International. AOAC Official Method 985.35.*, *Chapter 50*, 13–14. Association of Official Agricultural Chemists.

Armenteros, M., Aristoy, M.-C., Barat, J. M., & Toldrá, F. (2009). Biochemical and sensory properties of dry-cured loins as affected by partial replacement of sodium by potassium, calcium, and magnesium. *Journal of Agricultural and Food Chemistry*, *57*(20), 9699–705.

Armenteros, M., Aristoy, M.-C., Barat, J. M., & Toldrá, F. (2012). Biochemical and sensory changes in dry-cured ham salted with partial replacements of NaCl by other chloride salts. *Meat Science*, *90*(2), 361–7.

Barat, J., & Toldrá, F. (2011). Reducing salt in processed meat products. In J. Kerry & J. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (First, pp. 331 – 345). Woodhead Publishing Limited, Oxford, Cambridge, Philadelphia, New Delhi.

Bibbins-Domingo, K., Chertow, G. M., Coxson, P. G., Moran, A., Lightwood, J. M., Pletcher, M. J., & Goldman, L. (2010). Projected effect of dietary salt reductions on future cardiovascular disease. *New England Journal of Medicine*, 590–599.

Bostian, M. L., Fish, D. L., Webb, N. B., & Arey, J. J. (1985). Automated methods for determination of fat and moisture in meat and poultry products: collaborative study. *Journal of the Association of Official Analytical Chemists*, *68*(5), 876–880.

Bratzler, L. J. (1932). *Measuring the tenderness of meat by means of a mechanical shear*. Kansas State University, Manhattan.

Cutter, C. N., Senevirathne, R. N., Chang, V. P., Cutaia, R. B., Fabrizio, K. A., Geiger, A. M., Yoder, S. F. (2012). Major microbiological hazards associated with packaged fresh and processed meat and poultry. In J. P. Kerry (Ed.), *Advances in meat, poultry and seafood packaging* (First, pp. 4 – 7). Woodhead Publishing Limited, Oxford, Cambridge, Philadelphia, New Delhi.

Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, *74*(1), 188–96.

Durack, E., Alonso-Gomez, M., & Wilkinson, M. G. (2008). Salt: A Review of its Role in Food Science and Public Health. *Current Nutrition & Food Science*, *4*(4), 290–297.

Ezzati, M., Lopez, A. D., Rodgers, A., Vander Hoorn, S., & Murray, C. J. L. (2002). Selected major risk factors and global and regional burden of disease. *Lancet*, *360*, 1347–1360.

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (n.d.-a). Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding. *Submitted.*

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (n.d.-b). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *Submitted.*

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82.

Fellendorf, S., O'Sullivan, M., & Kerry, J. (2016). Impact of using ingredient replacers on the physicochemical properties and sensory quality of reduced salt and fat black puddings. *Meat Science*, *113*, 17–25.

Fox, P. F. (1963). Potentiometric determination of salt in cheese. *Journal of Dairy Science*, *46*, 744 – 745.

FSA. (2010). *Salt reduction targets for 2010 and 2012*. The Food Standards Agency.

FSA. (2014). *2017 UK salt reduction targets*. The Food Standards Agency.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

Gelabert, J., Gou, P., Guerrero, L., & Arnau, J. (2003). Effect of sodium chloride replacement on some characteristics of fermented sausages. *Meat Science*, *65*(2), 833–9.

Gill, C. O., & Molin, G. (1991). Modified atmospheres and vacuum packaging. In N. J. Rusel & G. W. Gould (Eds.), *Food preservatives* (p. 172). Blackie and Sons Ltd, Glasgow.

Gou, P., Guerrero, L., Gelabert, J., & Arnau, J. (1996). Potassium chloride, potassium lactate and glycine as sodium chloride substitutes in fermented sausages and in dry-cured pork loin. *Meat Science*, *42*(1), 37–48.

Guàrdia, M. D., Guerrero, L., Gelabert, J., Gou, P., & Arnau, J. (2008). Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. *Meat Science*, *80*(4), 1225–30.

Haldane, J. (1901). The Red Colour of Salted Meat. *Journal of Hygiene*, *1*(1), 115 – 122.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

Honikel, K. O. (2010). Curing. In F. Toldrá (Ed.), *Handbook of meat processing* (First, pp. 125 – 141). WILEY-Blackwell, A John Wiley & Sons, Inc., Publication, USA.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

ICMSF. (2011). *Microorganisms in Foods 8.Use of Data for Assessing Process Control and Product Acceptance*. (K. M. J. Swanson, Ed.) (1st ed.). Springer.

International Commission on Illumination. (1976). ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space.

Irish_Universities_Nutrition_Alliance. (2011). *National Adult Nutrition Survey–Summary Report on Food and Nutrient Intakes, Physical Measurements, Physical Activity Patterns and Food Choice. Dublin: Irish Universities Nutrition Alliance*.

ISO. (1988). Sensory analysis. General guidance for the design of test rooms. Ref. no. *International Organization for Standardization, Genève, Switzerland*, ISO 8589:1988. International Organization for Standardization.

Kilcast, D., & Angus, F. (2007). *Reducing salt in foods. Practical strategies*. (D. Kilcast & F. Angus, Eds.) (First). Woodhead Publishing Limited, Cambridge, England.

King, D. A., Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (2009). Fresh meat texture and tenderness. In J. Kerry & D. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh meat* (First, pp. 61–88). Woodhead Publishing Limited, Cambridge, New Delhi.

Kisskalt, K. (1899). Beitraege zur Erkenntnis der Ursachen des Rotwerdens des Fleisches beim Kochen nebst einigen Versuchen ueber die Wirkung der schwefeligen Saeure auf der Fleischfarbe. *Archiv für Hygiene Und Bakteriologie.*, *35*, 11–18.

Lee, H. C., & Chin, K. B. (2011a). Effect of the combination of various NaCl levels and soy protein isolate on the quality characteristics of smoked pork loins. *International Journal of Food Science & Technology*, *46*(5), 1038–1043.

Lee, H. C., & Chin, K. B. (2011b). Evaluation of various salt levels and different dairy proteins in combination with microbial transglutaminase on the quality characteristics of restructured pork ham. *International Journal of Food Science & Technology*, *46*(7), 1522–1528.

Lehmann, K. (1899). Ueber das Haemorrhodin. Ein neues weit verbreitetes Blutfarbstoffderivat. *Physisch Medizinische Gesellschaft Wuerzburg*, *4*, 57–61.

Mahon, B. (1998). *Land of Milk and Honey: The Story of Traditional Irish Food and Drink.* (B. Mahon, Ed.) (Second). Irish Amer Book Co.

Martens, H., & Martens, M. (2001). *Multivariate Analysis of Quality. An Introduction. Measurement Science and Technology* (2nd ed., Vol. 12). John Wiley & Sons Ltd.

Ni, M. C., Capelin, C., Dunford, E. K., Webster, J. L., Neal, B. C., & Jebb, S. A. (2011). Sodium content of processed foods in the United Kingdom: analysis of 44,000 foods purchased by 21,000 households. *American Journal of Clinical Nutrition*, *93*(7), 594–600.

Potthast, K. (1987). Fleischfarbe, Farbstabilität und Umrötung. *Fleischwirtschaft*, *67*(1), 50–55.

Qizilbash, N., Lewington, S., Duffy, S., Peto, R., Smith, T., Spiegelhalter, D., Shipley, M. (1995). Cholesterol, diastolic blood pressure, and stroke: 13000 strokes in 450000 people in 45 prospective cohorts. *Lancet*, *346*(8991-2), 1647–1653.

Renerre, M. (1990). Factors involved in the discoloration of beef meat. *International Journal of Food Science & Technology*, *25*, 613–630.

Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, *21*(6), 611–620.

Ruusunen, M., Vainionpää, J., Lyly, M., Lähteenmäki, L., Niemistö, M., Ahvenainen, R., & Puolanne, E. (2005). Reducing the sodium content in meat products: The effect of the formulation in low-sodium ground meat patties. *Meat Science*, *69*(1), 53–60.

Smiddy, M., Papkovskaia, N., Papkovsky, D. B., & Kerry, J. P. (2002). Use of oxygen sensors for the non-destructive measurement of the oxygen content in modified atmosphere and vacuum packs of cooked chicken patties; impact of oxygen content on lipid oxidation. *Food Research International (2002) Volume: 35, Issue: 6, Pages: 577-584*, *35*(6), 577–584.

Souci, S.W., Fachmann, W., & Kraut, H. (2004). *Der kleine Souci Fachmann Kraut. Lebensmitteltabelle fuer die Praxis. Wissenschaftliche Verlagsgesellschaft mbH Stuttgart* (3rd ed.). Wissenschaftliche Verlagsgesellschaft.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, B. R.N., & H. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 291 – 325). USA: Elsevier Academic Press.

Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, Bleibaum R.N., & H. A. Thomas (Eds.), *Sensory evaluation practices* (Fourth, Vol. 4th ed., pp. 117 – 157). USA: Elsevier Academic Press.

Stone, H., & Sidel, J. L. (2004). Affective testing. *In: H. Stone and J. L. Sidel (Eds.), Sensory Evaluation Practices. Food Science and Technology, International Series. USA: Academic Press/Elsevier.*, *3rd ed.*, 247–277.

Suhre, F. B., Corrao, P. A., Glover, A., & Malanoski, A. J. (1982). Comparison of three methods for determination of crude protein in meat: collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*(6), 1339–1345.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659–666.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, *91*(4), 460–465.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, *93*(2), 145–52.

Toldrá, F. (2007). Sodium reduction in foods: a necessity for a growing sector of the population. *Trends Food Science Technology*, *18*, 583.

Vadlamani, K., Friday, D., Broska, A., & Miller, J. (2012). Methods and compositions for reducing sodium content in food products. *US Patent App. 12/0003358A1*. United States Patent Application Publication.

WHO. (2012a). *Guideline: Potassium intake for adults and children*. World Health Organization.

WHO. (2012b). *Guideline: Sodium intake for adults and children*. World Health Organization.

Chapter 9

Overall discussion and conclusion

Overall discussion

Dietary patterns have shifted with increased consumption of energy-dense diets high in saturated fat, sugar and salt. Following on from this, dietary energy intake has increased dramatically, although this change has not taken place equally across regions (FAO, 2012). The excessive consumption of sodium is associated with elevated blood pressure (≥ 140/90 mm Hg), which is estimated to induce 7.5 million deaths annually, equivalent to ~12.8% of all deaths worldwide (Kearney, Whelton, Reynolds, Whelton, & He, 2004; Strazzullo, D'Elia, Kandala, & Cappuccio, 2009; WHO, 2003). Evidence exists that individuals who develop high blood pressure show a defect in the kidneys' ability to excrete sodium. Furthermore, high blood pressure is the major risk factor for developing cardiovascular disease (strokes, heart attacks, heart failure) (Dahl, Heine, & Thompson, 1974; Dahl, Heine, & Thompson, 1972; WHO, 2003). A diet rich in salt is also linked to further serious diseases, such as;left ventricular hypertrophy, progression of renal disease and albuminuria, stomach cancer and bone demineralization (Cianciaruso et al., 1998; Devine, Cridle, Dick, Kerr, & Prince, 1995; Heeg, De Jong, Van Der Hem, & De Zeeuw, 1989; Joossens et al., 1996; Kupari, Koskinen, & Virolainen, 1994; Schmieder & Messerli, 2000; Swift, Markandu, Sagnella, He, F., & Macgregor, 2005; Tsugane, Sasazuki, Kobayashi, & Sasaki, 2004). The excessive intake of saturated fatty acids and cholesterol are linked to increasing the plasma low-density lipoprotein (LDL) level which can lead to plaque build-up in arteries and result in cardiovascular diseases (strokes, heart attacks, heart failure) (Grundy & Denke, 1990). Furthermore, a diet rich in fat can easily lead to excessive weight gain and obesity as fat has one of the highest energy densities (9kcal/g) of all macronutrients. Obesity is also linked to further diseases, such as; respiratory difficulties, chronic musculoskeletal problems, infertility, skin problems, cardiovascular diseases diabetes mellitus, certain types of cancers and gallbladder disease (WHO, 2000).

For that reason, the WHO are driving measures to reduce worldwide populations daily intake of salt and saturated fat by raising consumers' awareness (WHO, 2003, 2012). A consumer survey entitled "Salt- and fat-reduced foods" was conducted using Irish consumers (302 male, 743 female) as the first part of this thesis (Chapter 3). The survey investigated how well the Irish consumer has adopted and implemented the message of consuming healthier foods, including reduced salt and fat levels from their diets. This survey revealed that educational campaigns have generally been well adopted by respondents. Only a minority were not concerned about their diet (irrespective of age, gender or educational background). More than half carefully maintained a balanced diet. Among these individuals, significantly more women than men maintained a balanced diet, which are consistent with the findings presented by Purdy & Arrmstrong (2007). Furthermore, in the present survey, more highly educated participants took significantly more care of themselves in terms of consuming a complete balanced diet. In contrast, Purdy & Arrmstrong (2007) reported that the higher educated participants in their survey consumed pizza and ready-meals more frequently. These authors also stated that many consumers frequently consumed highly salted and fatty processed foods. In the present survey, an increase in purchasing salt-reduced food was observed, although fat-reduced food products were already better accepted. It was suggested by Jordana (2000) that traditional foods in the future may suffer from a less favourable attitude regarding health and nutritional aspects. The greatest threat for the future is seen in an insufficient adaptation to new requirements demanded by consumers. The purchase of traditional food products with reduced salt and fat content were unaffected in the present study, as long as the intrinsic sensory character was maintained for each product. This findings corroborate the views of Guerrero et al. (2009).

Higher costs for salt- and fat-reduced foods can be generally expected as salt- and fat-reductions are typically achieved by stealth through increasing other ingredients (higher in quality), using replacers/enhancers or flavour delivery agents (Kilcast & Ridder, 2007; Talbot, 2011). It was estimated that a sodium reduction of 20% to 30% increased food costs by 5% to 30% (Dötsch, Busch, Batenburg, Liem, Tareilus & Müller, 2009). Slightly more than half of participants were willing to pay more money for salt- and fat-reduced foods, but only approximately a quarter of all participants were willing to pay up to the maximum of the actual expected increase in product cost. The survey revealed that younger participants (< 30 years) and lower educated participants were less willing to pay more money for salt- and fat-reduced foods. This might be simply due to their financial situation. It is assumed that people with professional occupations generally have higher disposable incomes, which can in turn, be spent on food with higher quality (Bardsley, 2000). However, in the present survey women showed a greater willingness to purchase salt- and fat-reduced foods than men, despite their higher financial deficits. This might reside in the fact that more women (than men) were aware of the health risks associated with a diet rich in salt.

Nevertheless, messages regarding to health risks associated with the intake of a diet rich in salt and saturated fatty acids seems to have reached the participants of the present survey (92% and 97%, respectively), independent of their age and educational status. In comparison, less participants appeared to take care of maintaining a balanced diet (59%).

Previously, Purdy and Armstong (2007) reported, contrarily, that consumers of lower-economic status were less aware of the link between health and diet. Consequently, public health campaigns have successfully raised consumers' awareness. Thus, this survey revealed that the majority of respondents are informed, but are also looking for more information about the impact of diet on health. Furthermore, the participants of the survey would appreciate a wider product range of salt- and fat-reduced foods on the markets.

Besides raising consumer awareness, WHO are also setting guidelines for the food processing industry to reduce salt and saturated fat content in food (WHO, 2003, 2012). Processing food generally involves the use of added salt, in fact, 75% to 80%. Only 15% are added during the preparation of food (cooking and at the table) by consumers themselves, the remaining percentages (5%) of the dietary salt occurs naturally in foods (He & MacGregor, 2007). Clearly, the major reduction of salt must be implemented by the food processing industry in order to achieve the target level of 5 g salt/day set by WHO (WHO, 2012). Nevertheless, a reduction of salt and saturated fat levels in foods is challenging for the food producing industry because of their multi-purpose roles in many manufactured foods, such as bread, meat products, sauces, cheese, margarine and spreads (Brady, 2002; Giese, 1996). Attempts to reduce the level of salt and fat in these products can affect flavour, texture, mouth feel and in some cases, the microbiological shelf-live. Consequently, the food producing industry and various researcher groups have focused on developing consumer accepted salt- and fat-reduced foods. The present thesis concentrated on the development of sensory accepted low salt and low fat Irish traditional processed meats, in particular, white pudding (chapters 4, 5), black pudding (chapters 6, 7) and corned beef (chapter 8) with and without the use of additives. At first, salt- and fat-reduction was carried out in these products by simply reducing the total salt and fat content sequentially, both within and outside of current industrial usage, including FSAI target levels. The FSAI launched a salt reduction programme (SRP) in 2011, and have set a maximum sodium level of 600 mg/100g for black & white puddings. No guideline has been agreed for corned beef. Subsequently, to reach an even further reduction of salt and fat levels, various ingredient replacer combinations were added to the recipes with the highest potential of sensory acceptance (previous non-significant trend in liking of flavour and/overall acceptance). The effects of salt- and fat-reduction on sensory and physicochemical properties of white puddings, black puddings and corned beefs were thus investigated. Furthermore, microbiological shelf-life of corned beef samples was determined. Shelf-life test for white and black pudding was not possible to implement. The total viable counts (TVC) test showed spreaders, *B. Cereus*, over the whole surface of the agar plate after incubation. Thus, no further colonies were able to grow. Changes in incubation time and temperature were not successful. *Bacillus Cereus* is ubiquitously present on barley, an ingredient in both black and white puddings, and as it is a thermo-resistant spore-forming bacterium it will not be inactivated by normal cooking regimes. Interestingly, commercial puddings (black and white) also produced this spreader phenomenon on plating. However, normal processing and appropriate cold chain storage will not cause the growth of this organism and it is not considered a health risk. Consequently, the implementation of the microbiological shelf-life test for white and black pudding was not feasible.

In general, recipes for white and black pudding and servings differ dramatically from country to country, even from region to region. Nevertheless, it can be said that the basic ingredients of Irish white pudding and black pudding among themselves differ only slightly (pork meat, pork fat, grains, onions, salt and seasonings), although the taste of both formulations differs extremely. In Ireland, black puddings are made with blood, and contain generally less grains and are less spicy in taste.

With the aim to reduce salt and fat levels in white pudding, 25 formulations were produced with varying fat contents (20%, 15%, 10%, 5%, 2.5% w/w) and sodium contents (1.0%, 0.8%, 0.6%, 0.4%, 0.2% w/w) without using additives (chapter 4). The fat content of commercially-available white puddings ranged from 6.0% to

22.4%, though the majority of the products contained between 12% and 18% fat (unpublished data, 2013) and the level of sodium concentrations ranged from 520 mg/100 g and 1190 mg/100 g, with an average level of 867 mg/100 g (FSAI, 2014).

Varying salt and fat levels in white pudding products showed a range of effects on sensory quality and physicochemical properties. With decreasing fat content, cooking loss increased. No significant effect was determined in terms of cooking loss through varying salt levels. Samples low in fat and salt were significantly lighter and more intensive in yellow colour, which were less preferred in terms of liking of colour by assessors. Salt had a larger influence of liking the white pudding texture than fat. Lower salt white puddings were positively ($P < 0.05$) correlated to toughness and negatively correlated to juiciness. For all 2.5% fat samples, high scores for toughness and low scores for juiciness were determined, which are consistent with previously reported studies (Berry & Leddy, 1984; Ruusunen et al., 2005; Sofos & Allen, 1977). Samples containing 0.4% and 0.2% sodium content were rated to be tougher, lower in juiciness, spiciness, saltiness and fatness, even for the higher fat samples. Moreover, all samples with 2.5% fat were scored similarly for all salt levels and were not accepted by assessors. Thus, the critical acceptable limits in reducing sodium and fat were achieved at 0.6% sodium and at the 5% fat level, respectively. Salt and fat have shown a synergistic effect in developing flavour of white pudding. Samples with 15% fat and 0.6% sodium and with 5% fat and 0.8% sodium were the most significantly acceptable pudding variants. Hence, only one of the 25 assessed pudding samples (15% fat, 0.6% sodium) achieved the recommended sodium target level of 0.6% by the FSAI (2011) and was accepted by assessors, although a significant fat reduction compared to the average fat content of commercial white puddings was not achieved. Nevertheless, a non-significant trend in liking of flavour and overall acceptability was shown for white puddings containing 10% fat and 0.6% sodium, and a non-significant trend in liking of flavour for the sample containing 5% fat and 0.6% sodium.

In a subsequent study, white pudding samples with 10% fat and 0.6% sodium were chosen as the basic recipe to determine if salt and fat replacers can be used to further optimise these formulations in order to achieve significant levels of sensory acceptability (chapter 5). Moreover, white pudding samples containing 5% fat and 0.4% sodium were also used as a base formulation for the use of ingredient replacers to determine if further sensory optimised sequential reductions of salt and fat might be achieved. The replacers chosen included; wheat bran, sodium citrate, carrageen, pectin, potassium chloride (KCl), a combination of potassium chloride and glycine (KClG), carboxymethylcellulose (CMC), PuraQ®Arome NA4 (PuraQ), seaweed wakame (seaweed), a mixture of potassium citrate, potassium phosphate and potassium chloride (KCPCl) and waxy maize starch (WMS). PuraQ®Arome NA4 (Corbion Purac, Barcelona, Spain) is a product designed for use in savory food products and is a product derived from the fermentation of sugar resulting in a mixture of sugars, salts of organic acids and aromas.

Most of the samples formulated with replacers showed a trend (not significant) in decreasing cooking loss due to the use of a hydrocolloid or water-binding agents. The use of WMS in both formulations and the use of sodium citrate in white pudding with 10% fat and 0.6% sodium significantly ($P < 0.05$) decreased cooking losses. The lowest measured values of hardness, springiness, cohesiveness and chewiness were achieved for white pudding formulations containing CMC. Hence, these samples are supposed to need less force to bite, less work to chew and show a low spring back and less strength of internal bonds. According to Lin, Keeton, Gilchrist & Cross (1988) low fat frankfurters containing CMC also had lower hardness values. In addition, these results are consistent with sensory results as assessors scored these samples lower ($P < 0.05$, $P < 0.001$) in terms of toughness. Based on the sensory data set, ten of the eleven replacer combinations (with the exception of pectin) used showed either an effect on texture or on flavour. However, these observed effects were often not consistent with respect to the two salt and fat formulations (with exception of CMC and seaweed) used throughout the study. Furthermore, no ultimate replacer combination was found which increased all of the three flavour sensory attributes of saltiness, fatness and spiciness in white pudding. Nevertheless, the majority of the added replacers showed an enhancement in one taste attribute.

For both seaweed formulations, assessors did not like ($P < 0.001$) the impact that seaweed-based ingredients had on white pudding flavour, and therefore, the recipe cannot be recommended to industry. In contrast, López-López, Cofrades, Yakan, Sola & Jiménez-Colmenero (2010) reported that their assessors found low salt and low fat beef patties with seaweed wakame more palatable, although a distinctly different flavour in wakame-treated patties to that of the control were detected. White puddings containing 10% fat and 0.6% sodium and formulated with sodium citrate and KClG displayed higher hardness values, which were found to score highly for overall acceptability ($P < 0.05$). Thus, the recommended sodium target level of 0.6% set by the (FSAI, 2011) and additionally, a fat reduction compared to the average fat content of commercial white puddings was achieved. Furthermore, a trend in acceptance and liking of flavour was observed for pudding samples containing 10% fat and 0.6% sodium and formulated with 1% wheat bran. A higher concentration of added wheat bran might result in a significantly more accepted product. All investigated white pudding samples containing 5% fat and 0.4% sodium and formulated with 11 different ingredient replacer combinations were neither acceptable nor liked in terms of flavour. Therefore, reducing salt and fat levels in white pudding to a very low level (0.4% sodium, 5% fat) was not successful using the chosen ingredient replacer combinations outlined.

Chapter 6 focused on the reduction of salt and fat levels in black pudding. Consequently, 25 black pudding formulations were produced with varying fat contents (20%, 15%, 10%, 5%, 2.5% w/w) and sodium contents (1.0%, 0.8%, 0.6%, 0.4%, 0.2% w/w). For comparison, the fat contents of commercially-available black puddings range from 7% to 22%, with the majority of products containing between 14% and 16% fat (unpublished data, 2013) and the range of sodium contents determined to be between 520 mg and 1190 mg, with an average of 867 mg per 100 g of product (FSAI, 2014). Salt and fat reduction levels were carried out in these products by simply reducing the total salt and fat content sequentially, both within and outside of current industrial usage, including FSAI target levels.

Fat and salt contents in black puddings showed a significant effect on physicochemical and sensory properties, but salt played the key role. Measuring the colour of black pudding revealed that samples low in fat and salt had higher ($P < 0.05$) yellowness and redness values. However, assessors preferred samples that appeared less yellow and red in hue. As fat content decreased in black pudding products, a subsequent increase ($P < 0.05$) in cooking loss was observed, and no trend was seen through varying salt contents. Similar results regarding cooking loss were also obtained for lower salt and fat white pudding samples (chapter 4) and for lower salt corned beef samples (chapter 8). For lower fat pork frankfurters, an increase in cooking loss was also reported by Mittal & Barbut (1994). In contrast, Ruusunen et al. (2005) and Puolanne & Ruusunen (1980) observed that for varied salt levels in ground meat patties and bologna-type sausage, an impact on cooking loss occurred. Furthermore, these authors observed increased cooking losses in higher fat ground meat patties. Thus, no general statement can be made regarding cooking loss and varying salt and fat levels in meat products. This author suggests that cooking loss might also be influenced by production conditions and processing factors.

The perception of fat, salt and spices were not affected by fat levels, but were impacted upon by salt levels. The theory that salt and fat play a key role in enhancing product flavour (Giese, 1996; Hutton, 2002; McCaughey, 2007; Wood & Fisher, 1990), can be only partly confirmed. In white puddings (chapter 4) both salt and fat affected the perception of fatness, saltiness and spiciness. In black puddings, salt also influenced the attributes of juiciness, toughness and liking of texture to a far greater degree than varying the fat content. Ruusunen et al. (2003) and Matulis, McKeith, & Brewer (1994) reported that salt increases juiciness and toughness in frankfurters, which is in agreement to the results achieved for black pudding. For all 25 black pudding variations, no off-flavours were detected by assessors. In contrast, perceived off-flavours in white puddings (chapter 4) were due to very low salt (0.2% sodium) and fat levels (5% - 2.5%). The formulation with 10% fat and 0.6% sodium achieved positive ($P < 0.05$) correlations to flavour and overall acceptability. Thus, the target level of sodium (0.6%) for black puddings set by the FSAI (2011) and additionally, a significant fat reduction compared to the average fat content of commercial black puddings, was achieved. Therefore, the reduction of sodium and fat content in black pudding was successful.

Subsequent to the previous study, black pudding samples with 10% fat and 0.4% sodium and accordingly 5% fat and 0.6% sodium were chosen as the basic recipes for the investigation of the use of ingredient replacers (chapter 7). The objective was to obtain sensory-acceptable products with even lower salt and fat levels through the use of replacement ingredients. As in chapter 5 for white pudding, 11 different replacer combinations used in the same concentrations were added to black puddings.

The use of ingredient replacers in black puddings impacted upon several physicochemical and sensory properties. The majority of pudding samples containing ingredient replacers generally showed a non-significant trend in decreasing cooking loss. No significant changes in sensory colour were observed through the addition of ingredient replacers from a sensory perspective, thereby implying that assessors were unconcerned with such changes. In contrast, seaweed ingredient usage in white pudding displayed an untypical grey colour and was assessed as being negatively correlated to liking of colour (chapter 5).

Some added replacers showed an increase with respect to spiciness, saltiness or fatness perceptions, but this was not observed consistently with respect to the two salt and fat formulations used in this study for all black pudding treatments; which is consistent to the results gained in the study with white pudding (chapter 5). Therefore, the use of ingredient replacers and their effect on product taste depends, not only on the type of replacer used, but also on the meat product-type and its formulation. Assessors rated both black pudding formulations containing CMC lower ($P < 0.001$) for hardness, which was also in full agreement with instrumental assessment. Added CMC to white pudding (chapter 5) also decreased hardness of the final product. However, in both cases (white and black pudding) the addition of CMC did not lead to a sensory-acceptable product by assessors.

The significant harder and dryer texture of black puddings (10% fat, 0.4% sodium) formulated with carrageen were not liked by assessors. In addition, black pudding samples with 5% fat and 0.6% sodium and formulated with carrageen were rated to be harder and not accepted by assessors. These findings are similar to Ruusunen et al. (2003) and Shand (2000) who reported a harder texture for low salt and low fat Bologna-type sausages, and accordingly for low fat pork Bologna containing carrageen. Ruusunen et al. (2003) also observed lower scores in juiciness. One of the two white pudding formulations (10% fat and 0.6% sodium) containing carrageen were also rated to be less juicy (chapter 5). In contrast to the previous study, Desmond, Troy & Buckley (1998) and Yang, Keeton, Beilken & Trout (2001) reported a non-significant trend in liking of overall flavour of low fat beef burgers and low fat frankfurters containing carrageen, respectively.

Black pudding samples formulated with 5% fat and 0.6% sodium and containing pectin and KCPCl, respectively, and the black pudding sample formulated with 10% fat and 0.4% sodium and containing WMS were liked ($P < 0.05$) in terms of flavour and overall acceptance by assessors. All three formulations showed a negative ($P < 0.05$) correlation to off-flavour. Therefore, with the assistance of ingredient replacers, a further sodium- and fat-reduction in black puddings was achieved. Consequently, it was possible to produce consumer-acceptable black puddings with even a lower sodium level (0.4%) than the target level of sodium (0.6%) set by the FSAI (2011).

Chapter 8 of the present thesis concentrated on salt reduction in corned beef, both with and without the use of ingredient replacers. In addition to examining the impact on sensory and physicochemical properties, microbiological shelf-life studies using two different packaging systems, vacuum packaging and modified atmosphere packaging, were also conducted for particular corned beef samples.

In Ireland the sodium content of commercially-available corned beef ranges from 0.7% to 1.0% (unpublished data, 2014). Corned beef belongs to the category of cured cooked meat products. The national “Salt Reduction Programme” provides guidelines for maximum sodium levels for uncured cooked meat products, cured uncooked meat products, black & white puddings, sausages and burgers, but no regulations are defined for cured cooked meat products (FSAI, 2011). Instead, the Food Standard Agency (FSA) applied within the UK, includes in their sodium reduction plan, ham and other cured meats. Since 2012, the sodium target level was set as 650 mg/100g and no further reductions are planned until 2017 (FSA, 2014).

The study focused on lowering the sodium level in corned beef without the use of additives. For that purpose, corned beef samples with varied sodium levels from 1.0%, 0.8%, 0.6%, 0.4% to 0.2% were produced. Varying sodium chloride levels in corned beef did not significantly affect either liking of colour or appearance. As potassium nitrite (responsible for developing the red colour) was added at a constant concentration to the brine for all five corned beef formulations, no major differences in colour were determined. Different salt levels employed in corned beef manufacture did not negatively alter cooking losses. Hence, concerns by the meat industry that salt reduction in meat products decreases water-holding capacity, thereby adversely affecting processing yields (Barat & Toldrá, 2011) can be allayed for the type of corned beef samples manufactured for our studies.

The theory by Hamm (1972) and Honikel (2010) that salt increases juiciness and tenderness of meat products can be confirmed partly, as lower salt corned beef samples correlated negatively (not significant) to juiciness, but also to toughness. As expected, lower sodium corned beef samples (0.4%, 0.2%) were rated lower for saltiness and corned beef with 1.0% sodium being found to be more salty. Moreover, samples low in sodium correlated negatively (not significant) to corned beef flavour and cured flavour. Reverse outcomes (not significant) were recorded for the higher sodium samples (0.6 - 1.0%). These results are accordance with the theory that salt plays a key role in enhancing flavour, besides developing the salty taste (Hutton, 2002), which had been already well confirmed in previous chapters 4 and 6 concerning salt and fat reduction in white and black puddings.

Assessors did not accept ($P > 0.05$) corned beef samples high in sodium (0.6% - 1.0%); probably because of the positive correlations to off-flavour. Despite scoring corned beef samples low in salt (0.2% and 0.4% sodium) significantly lower for saltiness perception, and (not significant) lower for corned beef and cured flavour perceptions, these samples were positively correlated to be accepted (not significant) by assessors.

In the subsequent study, different salt replacer combinations were added to corned beef samples containing 0.4% sodium, with the target of improving flavour profile and thus, producing significant consumer-acceptable end products. Consequently, the following ingredient replacer combinations were chosen: potassium chloride and sodium chloride (CB_KCl); mixture of potassium lactate, potassium chloride and sodium chloride (CB_KLCl); mixture of potassium citrate, potassium phosphate, potassium chloride and sodium chloride (CB_KCPCl); mixture of potassium lactate, glycine and sodium chloride (CB_KLG); two different mixtures of calcium chloride, magnesium chloride, potassium chloride and sodium chloride (CB_CaMgKCl1, CB_CaMgKCl2) and a mixture of potassium chloride, glycine and sodium chloride (CB_KClG).

The lowest cooking loss was achieved for corned beef sample CB_CaMgKCl1. Significant differences in colour and hardness values were determined between each formulation, although assessors did not notice these changes. Furthermore, no significant correlations to cured flavour and corned beef flavour were achieved through the addition of salt replacers. Samples CB_CaMgKCl1 and CB_CaMgKCl2 scored higher in saltiness perception, but correlated negatively (not significant) to liking of flavour and overall acceptability. Samples CB_KClG and CB_KLG were rated lower in saltiness. However, assessors liked ($P < 0.05$) the flavour of CB_KLG and a positive directional correlation (not significant) to overall acceptability was observed. Therefore, a sodium reduction of 60% in corned beef was achieved through the addition of potassium lactate and glycine and, the sodium target level of 650 mg/100g set by FSA (FSA, 2014) was satisfied.

Subsequent to product development, shelf-life tests (Total Viable Count) were carried out for corned beef samples containing 1.0% sodium, 0.4% sodium and 0.4% sodium formulated with potassium lactate, glycine and sodium chloride (CB_KLG) by using vacuum packaging (VP) and modified atmosphere packaging (MAP) (70% N_2: 30% CO_2). The vacuum packaged corned beef samples containing 0.4% sodium possessed the shortest shelf-life from all examined samples (expired after 21 days), and samples formulated with 1.0% sodium, and accordingly CB_KLG, showed similar shelf-life (expired after 56 days). As salt acts as a food preservative by lowering the water-activity (Betts, Everis, & Betts, 2007), it was not a surprise that corned beef samples, with the lowest sodium content, had the shortest shelf-life. Adding salt replacers like potassium lactate and glycine to corned beef with 0.4% sodium extended product shelf-life. However, all three corned beef samples packaged with MAP recorded no microbial growth (until day 82) during chilled storage. Therefore, sodium reduction in corned beef did not negatively affect product shelf-life when combined with MAP.

Conclusion

The survey component of this thesis revealed that public health campaigns have successfully raised consumers' awareness to the negative health impacts of diets high in salt and fat. The majority of respondents were well informed, nevertheless, less participants transferred this knowledge into their daily dietary habits. However, respondents are looking for more information and a wider range of salt and fat reduced foods. Studies on product development revealed that it is possible to reduce salt and saturated fat contents in Irish traditional meat products, although different products will require different modifications. The reduction of the total amount of salt and fat in black pudding produced a sensory accepted end product. However, even lower salt and fat contents in black pudding were obtained by using ingredient replacers. To achieve sensory accepted salt- and fat-reduced white puddings and salt-reduced corned beefs the use of additives was necessary. Furthermore, salt reduction in corned beef packaged with modified atmosphere did not negatively affect product microbiological shelf-life.

References

Barat, J., & Toldrá, F. (2011). Reducing salt in processed meat products. In J. Kerry & J. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (First, pp. 331 – 345). Woodhead Publishing Limited, Oxford, Cambridge, Philadelphia, New Delhi.

Bardsley, N. (2000). *Ready meals: Market Report Plus 2000* (5th ed.). Key Note Publications.

Berry, B. W., & Leddy, K. F. (1984). Effects of fat level and cooking method on sensory and textural properties of ground beef patties. *Journal of Food Science*, *49*, 870 – 875.

Betts, G., Everis, L., & Betts, R. (2007). Microbial issues in reducing salt in food products. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 174–200). Woodhead Publishing Limited, Cambridge, England.

Brady, M. (2002). Sodium - Survey of the usage and functionality of salt as an ingredient in UK manufactured food products. *British Food Journal*, *104*(2), 84–125.

Cianciaruso, B., Bellizzi, V., Minutolo, R., Tavera, A., Capuano, A., Conte, G., & De Nicola, L. (1998). Salt intake and renal outcome in patients with progressive renal disease. *Mineral and Electrolyte Metabolism*, *24*(4), 296–301.

Dahl, L. K., Heine, M., & Thompson, K. (1972). Genetic influence of renal homografts on the blood pressure of rats from different strains. *Proceedings of the Society for Experimental Biology and Medicine*, *140*(3), 852–856.

Dahl, L. K., Heine, M., & Thompson, K. (1974). Genetic influence of the kidneys on blood pressure. Evidence from chronic renal homografts in rats with opposite predispositions to hypertension. *Circulation Research*, *40*(4), 94–101.

Desmond, E. M., Troy, D. J., & Buckley, D. J. (1998). Comparative Studies of Nonmeat Adjuncts Used in the Manufacture of Low-Fat Beef Burgers. *Journal of Muscle Foods*, *9*(3), 221–241.

Devine, A., Cridle, A. R., Dick, I. M., Kerr, D. A., & Prince, R. L. (1995). A longitudinal study of the effect of sodium and calcium intakes on regional bone density in postmenopausal women. *The American Journal of Clinical Nutrition*, *62*, 740–745.

Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Müller, R., & Meijer, G. (2009). Strategies to reduce sodium consumption: a food industry perspective. *Food Science & Nutrition*, *49*(10), 841–851.

FAO. (2012). World agriculture towards 2030/2050, (12), 146. Food and Agriculture Organization of the United Nations.

FSA. (2014). *2017 UK salt reduction targets*. The Food Standards Agency.

FSAI. (2011). *Salt Reduction Programme (SRP) - 2011 to 2012*. The Food Safety Authority of Ireland.

FSAI. (2014). *Monitoring of Sodium and Potassium in Processed Foods Period: September 2003 to July 2014*. The Food Safety Authority of Ireland.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*, 78–83.

Grundy, S., & Denke, M. (1990). Dietary influences on serum lipids and lipoproteins. *The Journal of Lipid Research*, *31*, 1149–1172.

Guerrero, L., Guàrdia, M. D., Xicola, J., Verbeke, W., Vanhonacker, F., Zakowska-Biemans, S., Hersleth, M. (2009). Consumer-driven definition of traditional food products and innovation in traditional foods. A qualitative cross-cultural study. *Appetite*, *52*(2), 345–354.

Hamm, R. (1972). *Kolloidchemie des Fleisches. Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis.* (R. Hamm, Ed.). Paul-Parey-Verlag, Berlin und Hamburg.

He, F. J., & MacGregor, G. A. (2007). Dietary salt, high blood pressure and other harmful effects on health. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 18–46). Woodhead Publishing Limited, Cambridge, England.

Heeg, J. E., De Jong, P. E., Van Der Hem, G. K., & De Zeeuw, D. (1989). Efficacy and variability of the antiproteinuric effect of ACE inhibition by lisinopril. *Kidney International*, *36*(2), 272.

Honikel, K. O. (2010). Curing. In F. Toldrá (Ed.), *Handbook of meat processing* (First, pp. 125 – 141). WILEY-Blackwell, A John Wiley & Sons, Inc., Publication, USA.

Hutton, T. (2002). Sodium Technological functions of salt in the manufacturing of food and drink products. *British Food Journal*, *104*(2), 126–152.

Joossens, J. V., Hill, M. J., Elliott, P., Stamler, R., Lesaffre, E., Dyer, A., Kesteloot, H. (1996). Dietary salt, nitrate and stomach cancer mortality in 24 countries. European Cancer Prevention (ECP) and the INTERSALT Cooperative Research Group. *International Journal of Epidemiology*, *25*(3), 494–504.

Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, *33*(3-4), 147–152.

Kearney, P. M., Whelton, M., Reynolds, K., Whelton, P. K., & He, J. (2004). Worldwide prevalence of hypertension: a systematic review. *Journal of Hypertension*, *22*(1), 11–19.

Kilcast, D., & Ridder, C. (2007). Sensory issues in reducing salt in food products. In D. Kilgast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 201–220). Woodhead Publishing Limited, Cambridge, England.

Kupari, M., Koskinen, P., & Virolainen, J. (1994). Correlates of left ventricular mass in a population sample aged 36 to 37 years. Focus on lifestyle and salt intake. *Circulation*, *89*(3), 1041–1050.

Lin, K. C., Keeton, J. T., Gilchrist, C. L., & Cross, H. R. (1988). Comparisons of

Carboxymethyl Cellulose with Differing Molecular Features in Low-Fat Frankfurters. *Journal of Food Science* , *53*, 1592–1595.

López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International.*, *43*(5), 1244 – 1254.

Matulis, R. J., McKeith, F. K., & Brewer, S. (1994). Physcial and sensory characteristics of commercially available frankfurters. *Journal of Food Quality*, *17*, 263–271.

McCaughey, S. (2007). Salt and Flavor: Mechanisms of Taste Perception and Physiological Controls. In K. D. & A. F. (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 78–99). Boca Raton Boston, New york, Washington-DC: Woodhead Publishing Ltd.

Mittal, G. S., & Barbut, S. (1994). Effects of fat reduction on frankfurters ’ physical and sensory characteristics. *Food Research International*, *27*, 425 – 431.

Puolanne, E., & Ruusunen, M. (1980). Kochsalz und Phosphat in ihrer Wirkung auf das Wasserbindungsvermögen von Brühwurst. *Fleischwirtschaft*, *60*, 1359–1362.

Purdy, J., & Arrmstrong, G. (2007). Dietary salt and the consumer: reported consumption and awarness of associated health risks-A consumer perspective. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods: Practical Strategies* (pp. 106–116). Woodhead Publishing Limited, Cambridge, England.

Ruusunen, M., Vainionpää, J., Lyly, M., Lähteenmäki, L., Niemistö, M., Ahvenainen, R., & Puolanne, E. (2005). Reducing the sodium content in meat products: The effect of the formulation in low-sodium ground meat patties. *Meat Science*, *69*(1), 53–60.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003a). Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. *Meat Science*, *64*, 371–381.

Ruusunen, M., Vainionpää, J., Puolanne, E., Lyly, M., Lähteenmäki, L., Niemistö, M., Niemisto, M. (2003b). Physical and sensory properties of low-salt phosphate-free frankfurters composed with various ingredients. *Meat Science*, *63*(1), 9–16.

Schmieder, R. E., & Messerli, F. H. (2000). Hypertension and the heart. *Journal of Human Hypertension*, *14*, 597–604.

Shand, P. (2000). Textural, Water Holding, and Sensory Properties of Low-fat Pork Bologna with Normal or Waxy Starch Hull-less Barley. *Journal of Food Science*, *65*(1), 101 – 107.

Sofos, J. N., & Allen, C. E. (1977). Effects of lean meat source and levels of fat soy protein on the properties of wiener-type products. *Journal of Food Science*, *42*(4), 875–878.

Strazzullo, P., D'Elia, L., Kandala, N.-B., & Cappuccio, F. P. (2009). Salt intake, stroke, and cardiovascular disease: meta-analysis of prospective studies. *British Medical Journal*, *339*(nov24 1), b4567–b4567.

Swift, P. A., Markandu, N. D., Sagnella, G. A., He, F., J., & Macgregor, G. A. (2005). Modest salt reduction reduces blood pressure and urine protein excretion in black hyper-tensives. A randomised control trial. *Hypertension*, *46*, 308–312.

Talbot, G. (2011). Saturated fats in foods and strategies for their replacement: an introduction. In G. Talbot (Ed.), *Reducing saturated fats in foods*. Woodhead Publishing Limited, Cambridge, New Delhi.

Tsugane, S., Sasazuki, S., Kobayashi, M., & Sasaki, S. (2004). Salt and salted food intake and subsequent risk of gastric cancer among middle-aged Japanese men and women. *British Journal of Cancer*, *90*(1), 128–134.

WHO. (2000). Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organization Technical Report Series*, *894*, i–xii, 1–253. World Health Organization.

WHO. (2003). *Diet, nutrtition and the prevention of chronic diseases*. World Health Organization.

WHO. (2012). *Guideline: Sodium intake for adults and children*. World Health Organization.

Wood, J. D., & Fisher, A. V. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). Elsevier Applied Science, London.

Yang, A., Keeton, J. T., Beilken, S. L., & Trout, G. R. (2001). Evaluation of Some Binders and Fat Substitutes in Low-fat Frankfurters. *Journal of Food Science*, *66*(7), 1039 – 1046.