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Towards models for the prediction of beef meat quality during cooking

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ABSTRACT

Heating of beef muscles modifies the water content, the micronutrient content and the colour of beef meat. Juice expelling and loss of water soluble micronutrients were predicted by combined transfer-kinetics models. Kinetics modeling and crust formation are needed to progress toward a reliable prediction of HAAs formation. HAAs formation in uniformly heated beef meat slices was compared with the values issued from the kinetic models developed in literature in liquid systems. The models of literature were adapted to meat slices but the parameter values were different from those determined in liquid systems. Results in meat slices were confronted to the HAAs formation at the surface of bigger meat pieces subjected to air roasting conditions. The transposition of the results from the meat slices towards the bigger meat pieces was not direct because the formation of HAAs was affected by the thickening of the crust and the migration of precursors.

1. Introduction

Today, most meat and meat-based products are cooked before being eaten. The cooking process not only destroys pathogenic or spoilage microorganisms but develops also sensorial properties which are specific of the cooked product. Cooking has an important effect on the nutritional properties of the meat product and at the same time on its possible toxicity. This paper deals with: the juiciness, the nutriments content, the colour of cooked meat and the formation of Heterocyclic, Aromatic Amines (HAAs) during grilling and roasting. Discussion on the prediction of meat tenderness which would have required mechanical modeling is beyond the scope of this study. Colour and juiciness are with tenderness the main sensorial properties of beef meat. Juiciness is related with the variation of the water content in the meat during cooking which also determined the cooking yield which is a critical factor for industry. Meat is rich in bioavailable micronutrients (vitamins B, iron, zinc, selenium). A lot of these micronutrients, as the B vitamins, are water-soluble, and are expelled with meat juice during cooking. Some of the B vitamins are also temperature-sensitive as thiamin (B1), pyridoxin (B6) and cobalamin (B12), while other as niacin (B3) are known to be more heat-resistant. Despite its importance for the quality of beef meat, vitamin B12 is seldom studied due to difficulties in its quantification, Szterk, Roszko, Malek, Czerwonka, and Waszkiewicz-Robak (2012). In this paper only the B3 and B6 vitamins have been studied to validate a combined-modeling approach. It will be possible to extend afterwards this approach to other vitamins as the B12.

This paper overviews the work performed during the ProsafeBeef project to improve the quality of the cooked beef meat as it is ingested by consumers. To reach this objective it is necessary to know how the variations in the process conditions and in the quality of the raw meat will affect the quality of the cooked meat. In practice consumer habits, types of heating equipment and raw meat quality vary a lot. Moreover, quality is most often analyzed averagely while its evolution is local and depends on the complex thermal and water gradients generated in the meat during heating. This can explain why the results of literature are sometimes contradictory, and often difficult to transpose from one case to another. This leads scientists and engineers to repeat experiments as soon as the type of meat, the size of the meat cut, the type of equipment, or the cooking conditions are changed. Combined transfer to quality modeling is appropriate to respond to this situation.

This paper describes how the combined modeling approach was used to progress in the project. Text is separated into three parts: (1) the analysis of the evolution of meat water content and colour during cooking linked to protein denaturation and contraction, (2) An example of how the combined models can be used to predict the cooking loss and the B vitamin content in cooked beef meat, and (3) the analysis of the formation of heterocyclic aromatic amines during the roasting and the grilling of beef meat. At the beginning of each part the literature is shortly reviewed to analyze the basic phenomena which are involved in

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List of abbreviations

Muscle types

IS	*Infraspinatus*
LT	*Longissimus thoracis*
MA	*Masseter*
SM	*Semimembranosus*
ST	*Semitendinosus*

Heterocyclic aromatic amines (HAAs)

IQ	2-amino-3-methyl-3*H*-imidazo [4,5-*f*]quinoline
MeIQ	2-amino-3,4-dimethyl-3*H*-imidazo[4,5-*f*]quinoline
IQx	2-amino-3-methyl-3*H*-imidazo[4,5-*f*] quinoxaline
MeIQx	2-amino-3,8-dimethyl-3*H*-imidazo[4,5-*f*] quinoxaline
DiMeIQx	2-amino-3,4,8-trimethyl-3*H*-imidazo[4,5-*f*]quinoxaline
PhIP	2-amino-1-methyl-6-phenyl-imidazo-[4,5-*b*]pyridine

Other abbreviations

DM	Dry Matter
FTIR	Fourier Transform InfraRed
LC-APCI-MS/MS	Liquid Chromatography–Atmospheric Pressure Chemical Ionization Tandem Mass Spectrometry
$MgSO_4$	Magnesium Sulfate
MRI	Magnetic Resonance Imaging
MW	Microwave
NaCl	Sodium Chloride
NMR	Nuclear Magnetic Resonance
SE	Standard Error
STPP	Phosphates Sodium triPolyphosphate
W	Watt

the development of the studied quality. When possible, the results obtained at lab-scale are confronted with what can be observed in household equipment. Combined transfer to quality models require the knowledge of the time-evolution of the target quality at a given temperature and at given water content. Thus, quality kinetics were measured in slices of meat uniformly heated. These kinetics have been combined to a transfer model to predict the evolution of the weight loss and the B vitamin content during the roasting of SM muscle by air convection. The new results and the need for future research are discussed in the paper.

2. Protein denaturation and contraction, links with meat juiciness and colour

Basic knowledge gained at lab-scale will be compared to what can be observed in a controlled microwave equipment. Then, the mathematical relations issued from the experiments on the uniformly heated slice are presented and discussed.

2.1. Basic knowledge on protein denaturation and effect on water binding capacity and colour

Denaturation of muscle proteins which is linked to the organoleptic qualities (tenderness, juiciness and colour) of cooked meat has been studied for a long time. Myosin is known to denature at about 54 and 58 °C, whereas actin, actomyosin complex and titin are denatured at around 80 °C and the transition temperature of sarcoplasmic proteins is about 65–67 °C (Tornberg, 2005). Collagen contraction occurs between 58 °C and 65 °C. Protein structural changes in muscle tissue due to thermal changes have been studied using FTIR microspectroscopy which is a versatile spatially resolved technique (Astruc et al., 2012; Bertram, Kohler, Böcker, Ofstad, & Andersen, 2006; Kirschner, Ofstad, Skarpeid, Høst, & Kohler, 2004). Increase in meat temperature, leads to an increase in β-sheet and a decrease in α-helical structures, which is more pronounced for the intracellular proteins than for the connective tissue and is practically independent of the fibre type (Astruc et al., 2012; Kirschner et al., 2004). Salting can also affect the protein structure which is important to consider when marinated products have to be cooked (Böcker et al., 2008; Böcker, Ofstad, Bertram, Andersen, & Kohler, 2006; Carton, Böcker, Ofstad, Sørheim, & Kohler, 2009). Meat salting is known to increase the water holding capacity of the meat. However, sodium is detrimental for human health and thus it can be interesting to replace sodium by other salts. During the ProSafeBeef project, investigations have been focussed on the analysis of the effect of different salt types on protein structures by FTIR microscopy and Raman microscopy (Perisic, Afseth, Ofstad, Hassani, & Kohler, 2013; Perisic, Afseth, Ofstad, & Kohler, 2011). Clear differences in protein structures could be detected for the different salt mixtures. The samples that were treated with mixtures containing $MgSO_4$ hydrated earlier with increasing salt concentration. An increased hydration of the proteins in meat tissue was related to a partial unfolding of the proteins and thereby to their destabilization. This unfolding of the protein may, at moderate salt concentrations lead, to an increase of hydration, since large parts of the proteins were accessible and thus able to bind to water molecules. A further increase of the salt concentration led to a further destabilization of the proteins and consequently to their denaturation. These last results are important to reduce the salt content in cooked meat products.

Colour change due to temperature increase is initially due to myoglobin denaturation, shifting from deep red to pink and then on to a greyish colour before finishing in a light brown. It is recognized that these changes occur near 60 °C, between 60 and 70 °C, and between 70 and 80 °C, respectively (Lawrie, 1985). Beyond the 85 °C threshold, Maillard molecules begin to form along with the melanoid pigments which are associated with the grilled-meat colour.

2.2. Confrontation of previous knowledge with weight losses and colour evolutions measured during microwave cooking

Microwave cooking has been chosen as an example because it is a cooking method widely used at domestic scale. Moreover, there are limited published data about the quality of beef cuts as affected by rapid heating methods including microwave (Tang, Lyng, Cronin, & Durand, 2006).Traditional cooking methods (such as convection, contact, immersion, and infrared radiation) lead to heterogeneities between the product surface and its center. Microwave cooking/reheating is known to lead to more complex patterns of heterogeneity, related to either the geometric shape of the product (overheated corners and angles of parallelepipeds, or in cylindrical products, overheating of the product center) or to its composition (Ryynanen & Ohlsson, 1996). Work was dedicated during the ProSafeBeef project to microwave cooking to evaluate the effect of the difference sources of variations encountered in practice on the quality of cooked beef meat (Perez-juan, Kondjoyan, Picouet, & Realini, 2012). To discuss the results in the light of previous basic knowledge the heterogeneity of thermal treatment and its duration were determined using six or eight optical probes inserted in the roast. The dimensions of the roastbeef and its position in the microwave were also perfectly controlled to ensure repeatable gradients of temperatures in the sample. Meat issued from different muscles (*Semitendinosus* and *Semimembranosus*) coming from animal of different ages (Friesian yearling heifers and mature cows) were cooked using combinations of microwave power (182 W and 654 W power) and final temperature (60 and 80 °C). The gradient of temperature due to microwave heating was mainly along the vertical cross-section of the sample. Underdone areas were observed at the roast surface being more evident in the central section while the edges were overcooked or almost burnt. Maximum temperature depended on the targeted temperature of each treatment, and