HOW COMBINED MODELS CAN BE USED TO PREDICT THE QUALITY OF PROCESSED FOODS

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Abstract – In literature experimental results on the transformation of meat products are often contradictory or difficult to compare from one case to another. This is because they have been obtained in different equipment. Moreover, they are often a lack of data to predict the effect of new process conditions on the evolution of the quality of process foods. Mathematical modelling which combines transfers phenomena to chemical reactions is appropriate to respond to this situation. This approach is applied here on two types of processes: meat cooking and the dry-curing of ham. It illustrates how combined modelling can be used to find out the best scenarios to obtain a targeted food quality.

Key Words – Modelling, transfer, reactions, meat, processing.

I. INTRODUCTION

Quantitative literature results are often contradictory and always difficult to transpose from one case to another. This leads scientists and engineers to repeat experiments as soon as the type or size of the products, the types of equipment or the processing conditions is changed. Mathematical modelling which couples transfers phenomena to chemical reactions is appropriate to respond to this situation. This paper illustrates how this approach was used in the case of two types of meat products. It is divided into three parts, dealing successively with the modelling of heat and mass transfers, then with the modelling of chemical reactions and finally with the predictions issued from their combination.

II. TRANSFER MODELLING

Temperature and concentration of chemical compounds are not homogeneous in solid foods. The local concentration values determine the rate of the reactions responsible for the development of food quality. Thus, the development of quality is locally variable which can be most often be visually observed during meat cooking. Transfer modelling aims at calculating the gradients of temperature and concentrations in the food all along the processing. Heat and mass transfers are here modelled during two meat cooking and dry-curing of ham.

Heat and mass transfer modelling during meat cooking

A simple approach has been described by [1] to model the mass heat-mass transfers where water debinding and migration is assimilated to a first order chemical reaction. Under this assumption, the modelling can be divided into two stages. In the first stage, the temperature kinetics are calculated inside the sample. In-product heat transfer can be assumed as purely conductive and energy exchanges at the boundaries can be determined by a Newtonian law. In the second stage, the water concentration is calculated using the first-order kinetic models. The value of the water content in the meat at equilibrium has to be determined experimentally at different temperature. Experiments have been conducted on beef, lamb and horse [2] and more recently on pork salted and unsalted [3]. The shape of the curve which gives the equilibrium water content as a function of temperature is always the same, expect for very special muscles. This transfer modelling approach was validated to predict the water concentration in beef roasts of parallelepiped shapes subjected to oven cooking conditions [1]. The geometrical domain was meshed and finite element methods were used under COMSOL® Multiphysics 3.4 to simulate the evolution of temperature, water concentration and weight loss during meat cooking. The rectangular cuboid geometry of the sample was meshed using between 3,600 and 170,000 tetrahedrons depending on the sample's dimensions. The solver used a conjugate gradient method and an algebraic multigrid preconditioning to solve the equations. The solution took from 2 to

20 min depending on processing conditions, using a PC with a 2.33 GHz Intel Core2Duo Processor and 32 Gb RAM. The results of [3] leads to the conclusion that the results on non-salted meat can be transposed to slightly salted meat under laboratory conditions.

Modelling Transfers during the dry-cured ham process.

Dry-cured ham elaboration is a very long process separated in 4 different stages: salting (duration of about 15 days), post-salting (8 weeks), pre-drying (1 week) and drying (5 to more than 18 months). During the process, heat transfer in the product can considered as purely conductive. Salt diffusion and water migration can be modelled using classical Fick equation, considering that the diffusivity of water depends on water concentration. During post-salting, salt still goes on diffusing from the surface inside the ham while water migrates from inside the ham to the outer zones where evaporation took place. Specific mass flow rate boundary conditions have then to be imposed at the ham-air interface. The quality of the dry-cured ham depends on the type of muscle involved in the biochemical reactions. Thus, muscles internal distribution has to be taken into account in the representation of the product as well as the complex shape of the surface. The process of constructing an accurate 3D ham representation required a series of 2D slices of a fresh ham that can be typically provided by Computed Tomography (CT), which is a rapid and non-destructive X-ray imaging technique. Building the geometry is a complex procedure which shall include: noise reduction, smoothing, re-sampling and rescaling. Finally, the 3D ham model consisting in 202,000 tetrahedral meshes and containing 5 different groups of muscle was imported into Comsol® Multiphysics software. Once implemented solving all these equations lasted about 3.5 h on a 3 GHz Xeon 8-processors PC with 48 Go of RAM to model what happened during the salting and post-salting stages in terms of water and salt transfers, with a time step of 0.1 day.

Results of the 3D simulated mass transfer prove that after one week of process, the salt penetration was only visible in the few first centimeters from the salting surface of the ham, leading to a salt concentration of 10% of the total matter (TM) in this area, whereas it was 2-3% TM in the middle part of the ham and negligible near to the rind side of the ham opposite the salting surface (Fig. 1). At the end of salting, salt has more diffused inside in the ham and salt concentration reached 5% TM in the middle part of the ham while it remained relatively low in the deeper zones of the ham (Fig. 2). During the post-salting stage, salt content became more uniform in the product. Also, after six weeks, the simulated value of the salt concentration reached 4-5% TM and 2-3% TM in the middle of the ham and its rind opposite salting zones, respectively (Fig. 2). All along the process, water concentration decreased due to evaporation. This effect was all the more important that the ham muscle was close to the salting surface.

III. REACTION MODELLING

Two different qualities were analyzed depending on the type of process. In the example on meat cooking, the studied quality was the content in micronutrients while it was the texture of the product which was analyzed in the case of the dry-cured ham.

Loss of micronutrient during meat cooking

Meats are rich in micronutrients (B vitamins, iron, zinc and selenium) which can be easily assimilated. The example is focused here on the water soluble vitamins B3 and B6, but the same approach can also be extended to vitamin B12 or to heme iron. During cooking, water soluble micronutrients can be lost both because of thermal denaturing and because of juice expelling. The loss by the juice can be calculated from the previous mass transfer model as soon as the concentration of micronutrient in the juice is known, while thermal degradation can be described using a first order chemical reaction. Concentrations in the juice and parameters of the degradation reaction have been determined using separate experiments and data treatments.

Proteolysis and texture during dry-cured ham processing

A major sensory characteristic to be followed during dry-cured ham processing is texture evolution which can lead to problems, such as softness, pastiness, crusting and impede slicing, or give a mouth-coating sensation. Texture evolution can be linked to the variation of the proteolysis index (PI) which can be rapidly measured by fluorescence using a fluorescamine-specific labelling method [4]. Time evolution of proteolysis index has been measured and modelled on five different types of pork muscle under different accurate temperature and water activity (water and salt contents) laboratory conditions. Statistical analysis of the experimental results showed that the PI was correlated positively with temperature and water content, but negatively with salt content. Applying response surface methodology and multiple linear regressions enabled us to build phenomenological models relating PI to water and salt content, and to temperature [5].

IV. COMBINED TRANSFER- REACTION MODELS

The quality of the product can be predicted thanks to the combination of the transfer and of the reaction models.

During meat cooking, experiments on the thermal degradation of the B vitamins confirm the literature knowledge that B3 Vitamin was thermally resistant while B6 vitamin can be degraded by temperature. Thus, the loss of vitamin B3 was predicted afterwards directly from the calculated quantity of expelled juice while the thermal degradation of the vitamin B6 was added to the quantity of B6 expelled in the juice to determine the total loss of this vitamin. The validated model was used to predict the loss of vitamins B3 and B6 under different heating conditions. Simulated results lead to the conclusion that during grilling or pan frying of steaks, the loss in vitamin B, was only due to juice expelling, and was ranging from 4 to 23% depending on the degree of doneness. During roasting, the loss of vitamin B3 in beef meat was in between 25 and 32% mainly depending on the final core temperature of the meat (50–70 °C), while it was in between 30 and 41% during simmering. The combined model was used to calculate the loss of B vitamins under a lot of practical cooking conditions. The calculated data were gathered in table sheet to be used by industrials and nutritionists (Table 1). A similar approach has been used to simulate the loss of hem iron during cooking [6].

Table 1. Example of calculations of the loss of B3 vitamin for different muscles cooked under different conditions. The actual tables gathered much more different cooking conditions and also the loss of B6 vitamin.

Cooking conditions & weight loss (%)				**Estimated quantity of vit. B3 remaining**
Muscles	**Cooking time (min)**	**Temp. (°C)**	**%**	**µg/g$_{MS}$**
Masseter	60	80	40.0	74.4
Steak LT	4.37	55	17.2	215.4
Roast slice	76	55	29.4	151.8

The quality of the dry-cured ham was determined from the proteolysis indexes (PI) which were compared at the end of post-salting stage with the experimental PI values measured in samples extracted from industrial Bayonne hams. In-ham PI evolution was determined using the local calculated values of the water and salt concentrations. According to the phenomenological model of proteolysis, the predicted PI values were logically lower in areas highly dried and highly salted, as close to the salting surface, than in the wet-low-salted areas. During the two first weeks of the process, the in-ham PI values are increased up to 3-4% (Fig. 1). Proteolysis went on during the post-salting stage leading to local PI values ranging from 7 to 9%. At the end of the post-salting stage, i.e. after 11 weeks of process, the lower mean values of PI were still predicted in the most dried and salted group of muscles, i.e. the “grosse noix” (Fig. 2). The difference in mean PI values exceeded 3% between the “sous-noix” (12.5%) and the “grosse noix” (9%); the mean PI value of the entire ham was intermediate (10.7%). In fact, these calculated mean PI values globally agreed with those measured on samples extracted from two types of muscle (BF and SM) of industrial Bayonne dry-cured hams, at the end of the post-salting stage.

Accurate analysis of results reveals that the difference in terms of time course of PI values between the 3 groups of muscles appeared early in the second or third day of salting.

Figure 1. Distribution of proteolysis index (PI), salt and water contents predicted during the salting stage, at mid-salting and at the end of salting.

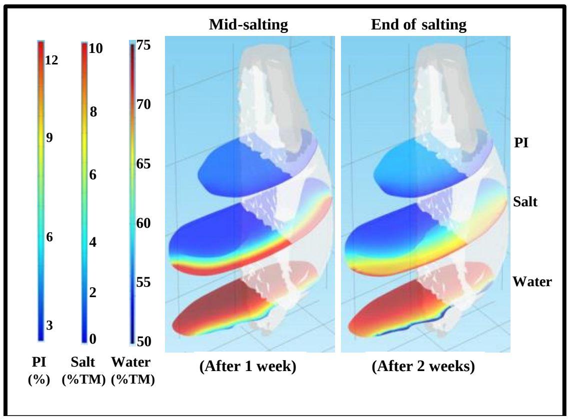
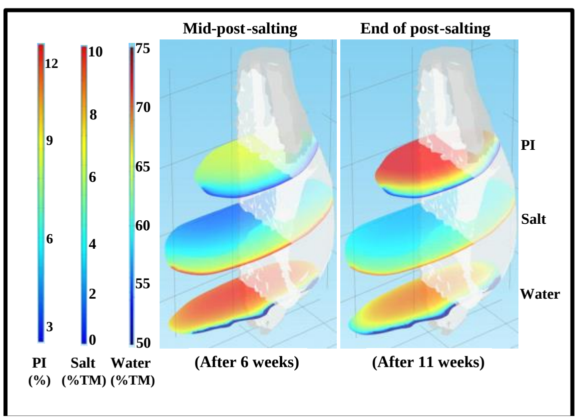


Figure 2. Distribution of PI, salt and water contents predicted during the post-salting stage, at mid-period and at the end of post-salting.



V. CONCLUSION

The way how transfer-reaction models can be built and used has been illustrated in two cases: either cooked meat or dry-cured ham. It has been shown how this approach can help in sparing time and money as in the case of the dry-cured ham which processing last several months and which final product can be costly. Transfer-reaction modelling approach can be generalized to other meat foods and processes to find out the best scenarios to obtain a targeted quality; both the initial food material characteristics and types of industrial equipment can be considered.

ACKNOWLEDGEMENTS

Works on the salted meat products were funded by the Na- integrated program (ANR-09-ALIA-013-01) financed by the French National Research Agency. Authors thank IFIP for providing CT images during the study on the dry-cured ham.

REFERENCES

1. Kondjoyan, A., Oillic, S., Portanguen, S., Gros, J. B. (2013). Combined heat transfer and kinetic models to predict cooking loss during heat treatment of beef meat. Meat Science 95(2): 336-344.
2. Oillic, S., Lemoine, E., Gros, J.-B., Kondjoyan, A. (2011). Kinetic analysis of cooking losses from beef and other animal muscles heated in a water bath — Effect of sample dimensions and prior freezing and ageing. Meat Science 88(3): 338-346.
3. Bombrun, L., Gatellier, P., Portanguen, S., & Kondjoyan, A. (2015). Analysis of the juice and water losses in salted and unsalted pork samples heated in water bath. Consequences for the prediction of weight loss by transfer models. Meat Science 99: 113-122.
4. Harkouss, R., Mirade, P. S., Gatellier, P. (2012). Development of a rapid, specific and efficient procedure for the determination of proteolytic activity in dry-cured ham: definition of a new proteolysis index. Meat Science 92(2): 84-88.
5. Harkouss, R., Safa, H., Gatellier, P., Lebert, A., Mirade, P. S. (2014). Building phenomenological models that relate proteolysis in pork muscles to temperature, water and salt content. Food Chemistry 151: 7-14.
6. Scislowski V., Gandemer G., Kondjoyan A. (2011). Changes in heme iron content in beef meat during wet heating. Consequences for human nutrition. In Proceedings 57th International Congress of Meat Science and Technology (pp. O40), 7-12 August 2011, Ghent, Belgium.