71st ICoMST
GIRONA - CATALONIA - SPAIN
3rd-8th August - 2025

CHARACTERISATION AND NUMERICAL MODELLING OF WATER AND SALT TRANSFERS IN LOW-FAT DRY-FERMENTED SAUSAGES

N'Gatta K. C. A.[1*], Favier R.[1], Sicard J.[1], Mirade P.-S.[1]

[1] INRAE, UR370 Qualité des Produits Animaux (QuaPA), Saint-Genès-Champanelle, France.

*Corresponding author email: charles.ngatta@inrae.fr

I. INTRODUCTION

Low-fat dry-fermented sausages are increasingly popular among consumers who prefer lower calorie deli meats; however, this fat reduction can affect moisture retention. The drying-ripening process is part of the dry fermented sausages production. During this operation, the products can be affected by several negative developments, in particular by surface microflora growth defects, texture defects with products that are excessively tough and excessive deformation, which can result in losses for the meat industry. These problems are attributable to various physico-chemical reactions, which are often interlinked, leading to difficulties in understanding and controlling the physico-chemical phenomena involved. In this study, we experimentally explored the time-course evolution of moisture and salt contents, water activity (Aw) in a model lean fermented sausage over the entire curing process that lasted 3 weeks.

II. MATERIALS AND METHODS

Model low-fat dry-fermented sausages were produced from pork meat and back fat (resulting in 5% of fat in meat mixture), minced, seasoned (pickling salt, sugars, spices, ripening culture mix) and formed in a collagen casing. This raw product was soaked with a starter culture and drained. Products were subjected to variations in ambient temperature and humidity, which were measured continuously during the experiment. The temperature setup was initially high (about 20°C), for a rapid development of microorganisms, lowered for the drying and maturation period, and were kept under 15°C at the end of the 20 days long process. Three production runs were performed to evaluate inter-assay variability. For each run, three sausages were sampled at multiple key times of the process (days 0, 4, 6, 13, and 20). Samples extremities were removed and three central slices were each divided into 6 concentric zones by distance to the surface, in order to assess the differences between core and surface. Water activity (Novasina® LabMaster Neo), water content (lab oven drying for 48 hr at 105°C) and salt content (ionic chromatograph Metrohm 850 Professional IC) were measured for each sample. The dataset was then used to design a numerical model of heat and mass transfer for low-fat dry-fermented sausages, implemented in COMSOL Multiphysics® v6.2 finite element simulation software. The thermal portion incorporates surface heat transfer by convection from measured ambient temperatures, evaporative heat loss and internal heat conduction, which is affected by water content. In terms of mass transfers, the diffusion of water and salt are key factors alongside their interaction with water activity and evaporation, which relates to measured ambient humidity. The water boundary flux, loss by evaporation, was considered proportional to the difference between the Aw at the surface and the ambient relative humidity, and modulated by differences in product temperature versus ambient temperature through vapour pressure, based on water activity definition (Merai, 2018). The initial performance evaluation was performed for a simplified product geometry, consisting of a radius-changing 1D-axisymmetric shape, for the purpose of rapid resolution. This high-speed approach offers the advantage of optimal compatibility with control systems for the development of prospective digital twin applications.

III. RESULTS AND DISCUSSION

Profiles of Aw, water and salt content as a function of depth and time were obtained. Over the 20 days, Aw decreased progressively from ~0.96 to ~0.86, with lower values close to the surface. This heterogeneity remained pronounced after 20 days. Water content likewise decreased progressively, with an intense gradient over depth. This decrease in water content causes a conjugate increase in average salt content relative to product mass. Absolute salt content does not change over time. However, from an initially homogeneous situation, a profile is created over time, with lower salt content close to the surface (3–4 g/100g) than at the core (6–7 g/100g) of the product.

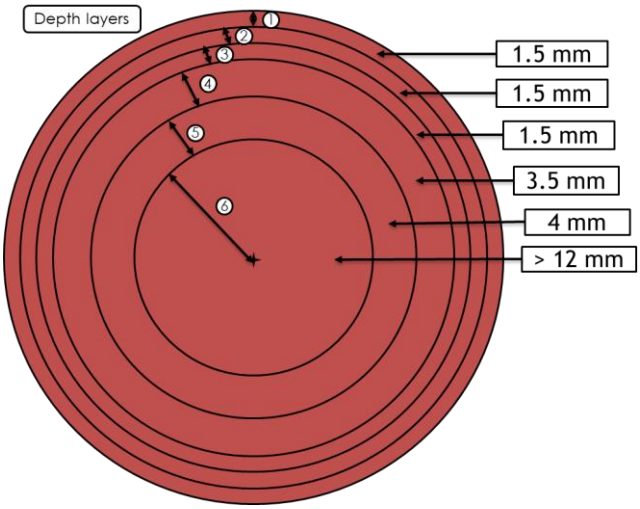


Figure 1. Layer cutting scheme used for the study of depth distribution of water, salt, Aw, pH.
Used as axis for Figure 2.

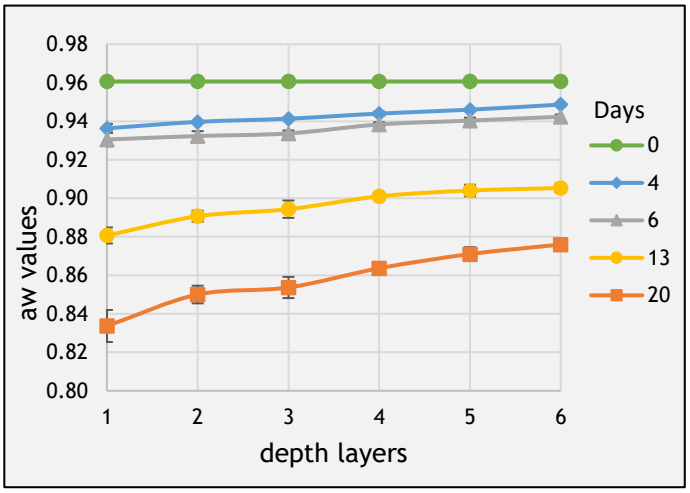


Figure 2. Time evolution of measured water activity within low-fat dry-fermented sausages. Markers are mean values of 9 repetitions (3 different products measured 3 times each). Error bars represents a single positive and negative standard deviation. Lines are visual only

Internal diffusion of water could be described by Fick's second law, albeit with a variable diffusivity which is reduced as water content gets lower. To account for the salt measured behaviour of concentrating towards high water region, the diffusive equation needed to be relative to the remaining water content, in which it is a solute, and not to the global volume as generally considered. Model performance was limited by the coherence between water reduction and the corresponding salt increase, with R^2 in the 0.85 ± 0.08, depending on batch. From the testing of multiple Aw models from literature, it was found to be well predicted by a model combining two elements: a reduction from water salinity and another related to the ratio of fat to proteins (Rougier et al., 2007).
The impact on performance of the design choices, in particular the geometrical limitations, are yet to be evaluated in terms of the speed benefit/risk ratio when compared to more complex, realistic geometries. In addition, the impact of incorporating complementary attenuation strategies based on localised behaviours should be considered.

IV. CONCLUSION

Physico-chemical properties were characterized in detail for the production of low-fat dry-fermented sausages. Those results were put in perspective with mechanistic modelling in order to create a numerical model. The outputs from this numerical model are water and salt content and Aw. Those are key input parameters in secondary models regarding food quality and, in addition to measured pH and lactic acid, could serve for a fungal model of growth at the product surface. The developed numerical model is to be employed for the purpose of examining scenarios, with a view to optimizing processing conditions, thus ensuring greater consistency in the productions. In terms of broader implications, this could provide a foundation for real-time control of ventilation and mechanical systems, based on temperature and humidity fluctuations, with the objective of achieving enhanced eco-efficiency in processing.

REFERENCES

Merai, M. (2018). Modelling of temperature, water activity and microbial growth on the surface of a pork leg during refrigerated transportation. *FOODSIM'2018*, 5 p. https://hal.science/hal-01872589

Rougier, T., Bonazzi, C., & Daudin, J.-D. (2007). Modeling incidence of lipid and sodium chloride contents on sorption curves of gelatin in the high humidity range. *LWT - Food Science and Technology*, *40*(10), 1798-1807. https://doi.org/10.1016/j.lwt.2006.11.004