MATHEMATICAL MODELLING OF SHELF LIFE IN MAP PACKED MEAT: COUPLING BETWEEN OXYGEN DYNAMICS, COLOUR STABILITY AND BACTERIAL GROWTH

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To understand shelf life determining processes in a modified atmosphere packaging (MAP) environment and enable more accurate predictions, colour stability and bacterial growth were modelled mathematically. This was done by coupling three distinct processes: two-way coupling of CO_2 and O_2 concentrations in the headspace to bacterial growth, transport of O_2 from the headspace into the product and chemical processes within meat. Parameters were set by extrapolation and fitting of available literature data as well as new data from validation experiments. The model reveals the nature of the competition for oxygen between bacteria and chemical oxygen-consuming processes and the different time scales governing shelf life. The model envisioned can be used as a tool for shelf life prediction.

Key Words – Microbial growth, myoglobin oxidation and reduction, oxygen consumption.

I. INTRODUCTION

Extended shelf life is important to i.a. reduce waste. Two aspects are crucial for shelf life of fresh meat: the growth of spoilage bacteria and colour stability. Colour is a very important characteristic in determining if a consumer will accept or reject a piece of fresh meat, and the only quality parameter available for packaged meat in retail. High O_2 MAP is used to provide the meat with a more favourable appearance for stabilizing the red oxymyoglobin (MbO_2) and hindering the growth of aerobic spoilage bacteria. Predicting the time for colour changes and spoilage, and thereby the overall shelf life, is challenging. Mathematical modelling can be a way to make progress, although few examples of modelling of these processes can be found in the literature and none that model colour changes and spoilage interaction. In this work, the myoglobin oxidation and reduction chemistry, diffusion of O_2 into a meat product from the headspace, and bacterial growth are modelled simultaneously. The model allows for investigation of the coupling between the different processes, although estimating relevant parameter values remains a challenge.

II. MATERIALS AND METHODS

Reaction-diffusion partial differential equations governing the dynamics inside the meat were defined. To get parameter values at relevant temperatures and pH for meat storage, the parameters regarding the autoxidation of myoglobin were fitted to parameters and data from [1]. To validate the chemical part of the model, it was validated against data from [2]. The bacterial parameters were fitted to not yet published data from the Danish Meat Research Institute (DMRI). The fitting resulted in almost all parameters being near realistic values, with a notable exception of the dissociation constant between MbO_2 and deoxymyoglobin (Mb), K_d, which needed to be increased by a factor of 100. The primary bacterial growth model is a logistic model, with secondary parameters that take the O_2 and CO_2 concentrations into account [3]. Enzymatic reduction of metmyoglobin (MMb) was modelled using a Michaelis-Menten dependence on nicotinamide adenine dinucleotide reduced form (NADH). The input of the model, other than parameter values, are: Headspace volume, shape of the meat, concentration and distribution of pigment and starting concentrations of gasses and bacteria. Changing kind, cut, temperature and treatments of meat will change the previous mentoned parameters and starting conditions. The output of the model consists of the concentrations of various myoglobin species, O_2 and NADH in the meat as a function of depth and time, as well as the number of bacteria present on the surface and the total amount of O_2 and CO_2 in the headspace.

III. RESULTS AND DISCUSSION

The model goes through five distinct phases, separated by four times (Figure 1). The first is defined to be the time when enough O_2 has diffused into the meat such that a quasi-steady state is reached where the amount of O_2 consumed is the same as the amount O_2 that diffuses in. In this state the only thing that changes inside the meat is the concentration of NADH. At this point, the number of bacteria is still low, so the O_2 concentration in the headspace is more or less constant, and there is still plenty of NADH left to reduce all the MMb. The model denotes the time when this phase ends t_1.

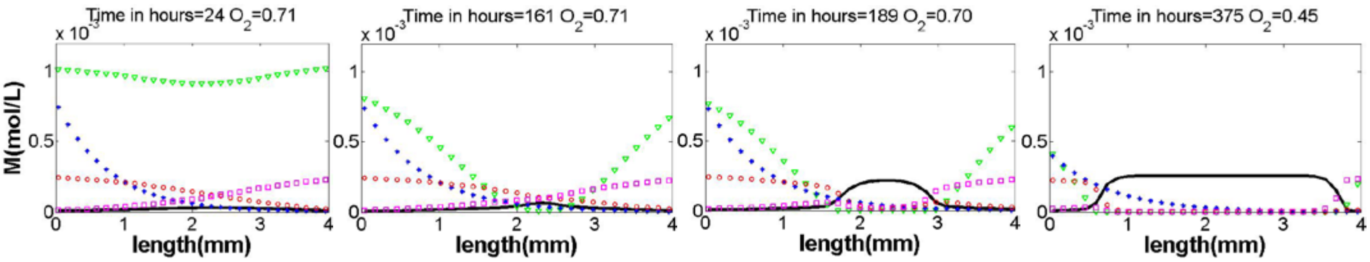
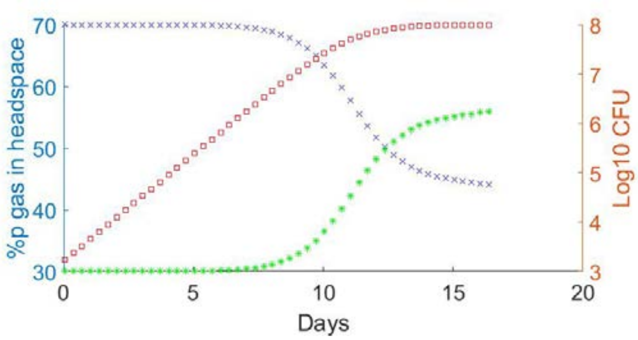


Figure 1. The four times. The triangle is the concentration of NADH, circle is MbO_2, square is Mb, full drawn line is MMb and the filled dot is the concentration of free O_2

The second phase ends when, at the point of maximum oxidation rate, [NADH] << [Mb] + [MbO_2]. At this time, all the Mb and MbO_2 located where the maximum oxidation takes place will be oxidized, spreading outwards as time progresses. This time is called t_2. When enough bacteria have accumulated, and the O_2 consumption of their growth is starting to consume the significant amounts of O_2 in the headspace, the third phase ends. This time is called t_3. It is not necessarily the case that $t_2 < t_3$. Whichever occurs first marks the end of the quasi-steady state, where either the amount of MMb begins to increase or the amount of O_2 in the headspace begins to decrease. The fourth phase ends at the "beginning of the end" of the model. Either the bacteria have consumed all the O_2, or the bacteria have reached the carrying capacity. This happens at t_4. In the fifth and final phase, nothing happens on the time scales that is meaningful for meat storage. For a starting concentration of 70% O_2 and 30% CO_2, t_1 occurs around 24 h, t_2 around 161 h, t_3 around 189 h and t_4 around 375 h.
The result of the model at the end of the first 4 phases is plotted above in Figure 1 and continues below in Figure 2.



End of phase	Time	Characteristic of phase
t_1	24h	Only [NADH] changes
t_2	161h	Somewhere [NADH]=0
t_3	189h	Bacteria start consuming O_2
t_4	375h	"End" of model

Table 1

Figure 2. Gas concentration in headspace as function of time. The X symbol denotes O_2 concentration, the star symbol denotes CO_2 concentration and the square symbol denotes expected psychrotrophic plate count.

IV. CONCLUSION

A model was made capable of showing the effect of different concentrations of O_2 and CO_2 in the headspace, as well as different volumes. As expected, qualitative results were found, for example, for high O_2 concentrations, the MMb is formed inside the meat and spread outwards (as seen in Figure 1). It is concluded that the model will be useful for determining the right MA package for different types and cuts of meat.

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