Shelf-Life Evaluation of Pork Meat Stored Under Different Packaging Atmospheres

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Abstract— **The objective of this study is to evaluate the possibility of a 4 day shelf-life extension for pork meat, stored at refrigeration temperatures, when stored under modified atmosphere packaging (MAP). Three batches of fresh pork meat packed under air or MAP (70% O_2 – 30% $C0_2$) were studied. The evolutions of the pH, the water activity and the gas composition of the batches during storage were monitored and the evolutions of the spoilage microflora (lactic acid bacteria, enterobacteriacae and *Pseudomonas*) were also evaluated. The collected data were fitted using predictive microbiology models to estimate the growth parameters of the spoilage microflora using the software Sym'Previus (http://www.symprevius.net). Simulations were then performed to evaluate the evolution of *Pseudomonas* in pork meat stored under the two packaging atmospheres for several realistic time temperature scenarios, reflecting poor storage profiles with temperature abuses. At the end of all the evaluated storage scenarios, microbial concentrations obtained under MAP packaging (shelf life of 11 days) were systematically lower than those obtained under air (shelf life of 7 days) and reflected satisfactory microbiological quality according to the thresholds recommended in the GHP thus proving that a 4 days extend in fresh pork meat shelf life was possible when packed under the studied modified atmosphere (70% O_2 and 30% CO_2).**

Keywords— **Modified atmosphere packaging, pork meat, predictive microbiology.**

I. INTRODUCTION

Modified atmosphere retail packaging with a high level of oxygen (70-80%) is increasingly used for fresh oxygen concentrations preserve the bright red colour of the meat and increase shelf-life by reducing microbial growth [1]. Moreover, in the last ten years the development of self-service refrigerated fresh meat displays have contributed to the continuous increase in MAP meat presentations in the stores, especially for pork meat. In France, latest estimates showed that 25% of the fresh pork meat sold in fresh markets is packed under MAP [2]. However, few studies quantitatively evaluated the evolution of the microbial behaviour under MAP and the subsequent possible extension of shelf-life for pork meat. The aim of this study is to optimize the extended shelf-life of pork meat packed under MAP, based on microbiological and physico-chemical data and predictive microbiology models.

II. MATERIALS AND METHODS

Three batches of fresh pork meat packed under air (Packaging P1) or modified atmosphere (Packaging P2) (70% O_2 – 30% $C0_2$) were used to assess the inter-batch variability. The products were stored at 8°C in order to reach the maximum population densities of the spoilage microflora. The pH and water activity of the products were monitored at three different dates during storage, using an Orion 210A pH meter CG 818 combined with a 90413 flat probe and an Aqualab Aw-meter, respectively. Gas analysis (% O_2 and % CO_2) was also performed using a PBI Dansensor gaz analyzer, Checkmate 9900.

At pre-established times, bacterial counts were performed on three samples for each batch and the microbiological evolutions of lactic acid bacteria (NF ISO 15214), enterobacteriacae (NF V08-054) and *Pseudomonas* (NF V04-504) were monitored during storage. The collected data were fitted to the primary model of Rosso (1996) using the software Sym'Previus to estimate the growth parameters of the studied flora under both packaging atmospheres. These parameters were: the initial contamination (N_0) and maximum contamination (N_{max}) levels, the maximum growth rate (μ_{max}), and the lag phase (*lag*) as shown in Figure 1.

To describe the effects of the environmental factors (temperature, pH and aw) on the maximum growth rate μ_{max}, the secondary cardinal model [3], implemented in the software Sym'Previus is used. This model makes it possible to simulate the maximum growth rate of a micro-organism in any

product, knowing the optimum growth rate μ_{opt} of the product (obtained in optimal environmental conditions) and its cardinal values which are the minimum, optimum and maximum values for temperature, pH and aw for which micro-organism growth remains possible.

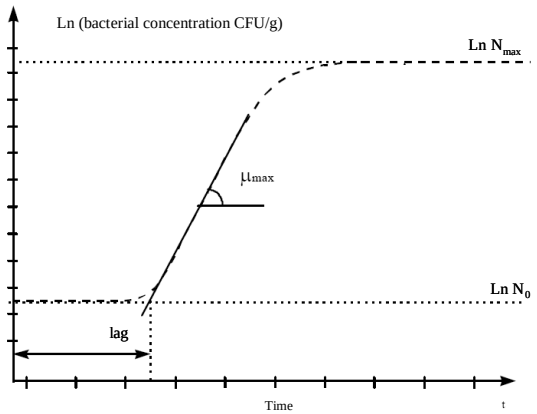

Fig. 1 Microbial growth kinetic and its parameters

Given the physico-chemical characterization of the products, the observed maximum growth rates values, and the cardinal values of *Pseudomonas* [4], it was possible to calculate the optimum growth rate μ_{opt} in pork meat packed under air or under MAP.

Simulations were then performed for *Pseudomonas* on both packaging environments and three different storage scenarios; as shown in Table 2. S1 and S2 correspond to storage scenarios typically used in shelf-life (SL) validation studies. The former consists in a storage at 4°C for 1/3 shelf-life (SL) followed by a storage at 8°C for the remaining SL, while the latter consisted in a storage at 4°C for 2/3 SL followed by a storage at 8°C for the remaining 1/3 SL. S3 correspond to a real storage profile where the evolution of the temperatures of pork meat products with time was monitored from the packaging step at the plant to consumption. This profile was obtained from a specific study [5] and showed poor temperature control conditions throughout the cold chain.

The results of the simulations were expressed as increases in the microbial populations obtained for each packaging environment and were used to evaluate whether a 4 days increase in the pork meat SL was acceptable when using modified atmosphere packaging instead of air packaging.

III. RESULTS AND DISCUSSION

A. pH, aw and gaz analysis results

The average pH of the three batches under air or modified atmosphere packaging (MAP) increased slightly during storage from 5.48 (± 0.2) to 5.83 (±0.5). However, an important variability was observed in the initial pH average value between the batches : 5.62 ; 5.33 and 5.49 for batches 1, 2 and 3, respectively. Based on these observations, the microbial simulations for MAP or air packaging were performed using these three pH values.

No significant evolution of the aw was observed under air or MAP in the three batches between the first (0.993±0.003) and the final day of storage (0.991±0.003 for air and 0.990±0.003 for MAP). No significant difference was observed between the aw values of the three batches. The aw value used in the simulations was therefore fixed for the three batches and the two packaging environments to 0.993.

Finally, the CO_2 measurements showed that the concentration increased during storage. The inhibitory effect was not modelled but simulated through the optimum growth rate for MAP and air.

B. Microbiological fitting results

The products were maintained at a constant temperature of 8°C which is not the conventional scenario used in commercial SL validations (ie 2/3 of SL at 4°C and then 1/3 SL at 8°C). However, storage at a constant temperature was necessary to estimate the growth characteristics of the spoilage flora and then simulate its behavior for other storage scenarios. Figure 2 shows the observed evolution of *Pseudomonas* at 8°C during storage when using MAP or air packaging as well as the fitting results (lines) with their confidence intervals (dashed lines).

The same procedure was applied for lactic acid bacteria and enterobacteriacae, as depicted in Table 1. In which you can see a very low initial contamination level N0 of 1 log cfu/g, corresponding to the quantification threshold of the methods used to enumerate the spoilage microflora. Table 1 also shows that the *lag time* is variable for each of the three studied floras and depends on both the studied batch and the packaging environment.

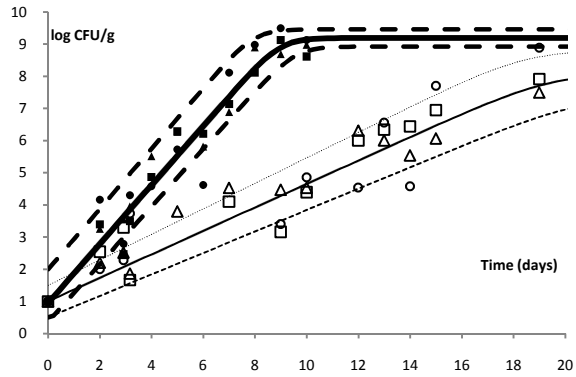

Fig. 2 Fitting results (lines) with their confidence intervals (dashed lines) compared to the observed evolution of *Pseudomonas* under air (closed signs) or MAP packaging (open signs) for batches 1 (circles), 2 (squares) and 3 (triangles).

Thus, the mean lag time of the Enterobacteriacae obtained during storage under air is estimated to 92h ± 33, reflecting an important batch variability. This lag time increases to 133h ± 36 when the products are packed under MAP, reflecting a significant effect of the packaging on the initiation of growth. This variability related to the batch and packaging environments is also observed for lactic acid bacteria but with shorter lag phases (mean lag time of 28 hours under air and 80 hours for MAP). As for *Pseudomonas*, the observed lag times were not significantly different from 0h and it was therefore not possible to identify potential sources of variability.

Table 1. Growth parameters of spoilage microflora in the pork meat

		Under air (P1)				Under modified atmosphere (P2)			
		N0 (log UFC/g)	*Lag* (h)	*μmax* (h^{-1})	*Nmax* (log UFC/g)	*N0* (log UFC/g)	*Lag* (h)	*μmax* (h^{-1})	*Nmax* (log UFC/g)
Lactic acid bacteria	Batch 1	1	38 ± 10	0.059	6,55	1	110 ± 10	0.035	5,54
	Batch 2	1	19 ± 7	0.056	5.84	1	96 ± 8	0.032	6.64
	Batch 3	1	28 ± 9	0.062	6.71	1	34 ± 11	0.040	5.42
	Mean	**na**	**28.33**	**0.059**	**6.37**	**na**	**80.00**	**0.036**	**5.87**
	Std dev	**na**	**9.50**	**0.003**	**0.46**	**na**	**40.45**	**0.004**	**0.67**
Entero-bacteriacae	Batch 1	1	120 ± 9	0.16	7.56	1	170 ± 12	0.056	8.36
	Batch 2	1	100 ± 5	0.12	7.26	1	130 ± 6	0.053	7.31
	Batch 3	1	55 ± 9	0.081	7.27	1	99 ± 10	0.056	6.6
	Mean	**na**	**91.67**	**0.120**	**7.36**	**na**	**133.00**	**0.055**	**7.42**
	Std dev	**na**	**33.29**	**0.040**	**0.17**	**na**	**35.59**	**0.002**	**0.89**
Pseudo-monas	Batch 1	1	0 ± 4	0.088	9.49	1	0 ± 12	0.030	8.88
	Batch 2	1	4 ± 4	0.089	9.12	1	0 ± 7	0.035	7.9
	Batch 3	1	0 ± 3	0.086	8.97	1	0 ± 6	0.033	7.49
	Mean	**na**	**1.33**	**0.088**	**9.19**	**na**	**0.00**	**0.033**	**8.09**
	Std dev	**na**	**2.31**	**0.002**	**0.27**	**na**	**na**	**0.003**	**0.71**

Finally, it remains difficult to evaluate the effect of packaging environment on the maximum population density Nmax. Thus, for the lactic acid bacteria, and Pseudomonas, the values of the observed Nmax obtained under air packaging are larger on average than those obtained under MAP, whereas, this difference remains not significant for the Enterobacteriacae.

C. Pseudomonas simulation results

The growth parameters given in Table 1 were used to simulate the growth of *Pseudomonas* in the three scenarios S1-S3. The results of the microbial increases obtained are given in Table 2. For all the studied scenarios, the increase in *Pseudomonas* was consistently more important under air, compared with MAP, which confirms the inhibitory effect of carbon dioxide on this spoilage flora.

Table 2. Median increases (log cfu / g) of *Pseudomonas* obtained by simulations for three scenarios

Scenarios	S1 SL : 1/3 at 4°C 2/3 at 8°C	S2 SL : 2/3 at 4°C 1/3 at 8°C	S3 Bad T° control
Air	4.00	3.00	0.25
MAP	2.50	2.00	0.10

For the worst case scenario (S1), an increase of 2.5 log was observed for MAP against an increase of 4.0 log for the air packaging, while the shelf-life is more This difference (1.5 log cfu/g) is similar to that obtained between MAP and air for the scenario S3 of poor temperature control (1.8 log cfu/g).

The difference between the increases achieved between the two packaging environments becomes less important when the temperature is controlled well. This difference is estimated to 1 log cfu/g for scenario S2. To evaluate the effect of these scenarios on the microbiological quality of the products, we considered an initial contamination level of 2.5 log cfu/g for *Pseudomonas* and simulated its behavior for scenarios S1-S3. The results are presented in Figure 3.

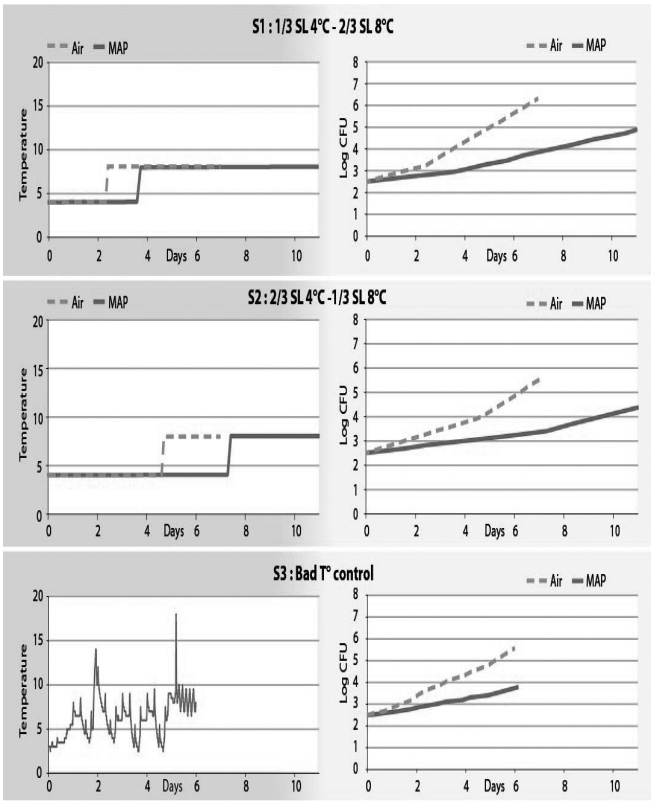

Fig. 3 Effect of different storage scenarios on the microbiological quality of meat pork packed under air or MAP.

Figure 3 shows that when the products are stored under the S2 scenario, the *Pseudomonas* concentrations reached at the end of the storage (11 days under MAP and 7 days under air) are estimated to 4.4 and 5.5 log cfu/g, respectively. This observation means that under the recommended scenario for SL evaluations, the *Pseudomonas* concentration obtained under air packaging at the end of the SL remains acceptable according to the GHP guide criterion (6 log cfu/g). However, in the S1 scenario which is also applied by some food processors to establish the SL of their products, the concentration obtained under air packaging (6.5 log cfu/g) exceeds the GHP guide criterion, which is not observed under MAP (4.8 log cfu/g). In case of realistic storage conditions reflecting when the products are exposed to a bad temperature scenario (S3), the *Pseudomonas* contamination obtained at the end of the SL for the air packaging (5.5 log cfu/g) remains acceptable, and the growth is very similar to the S2 scenario recommend by the GHP guide for SL evaluations.

IV. CONCLUSION

This study used predictive microbiology models to quantify the effect of two packaging environments on the microbiological quality of pork meat in several storage scenarios. It proved that MAP limits the growth of spoilage bacteria and makes a 4 days shelf life extension acceptable for pork meat with reference to the *Pseudomonas* criterion presented in the GHP guide. Complementary experiments would also make it possible to predict the pathogens behavior in this product for both packaging environments.

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