Evaluation of the impact of the refrigerated transport of pig carcasses loaded above 7°C on their microbial quality and safety

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Abstract— **According to the European Regulation (EC) No 853/2004, carcasses must be chilled in the slaughterhouse along a continuous decreasing chilling curve, to ensure a maximal core temperature of 7 °C before transport. However, higher temperatures can be authorized by national competent authorities, and the French Ministry of Agriculture has already allowed 2 hours duration transports for pig carcasses loaded at a maximum core temperature of 12°C. The aim of this study was to further investigate alternative core temperatures and transport durations while guarantying an acceptable microbiological quality of the transported pig carcasses.**

Data on the core and surface temperature evolution during cooling and transportation were collected in 5 French slaughterhouses from 183 different carcasses, standardized in terms of weight and lean meat percentage. A total of 908 temperature kinetics was generated and predictive microbiology models were used to simulate the growth of *E. coli, Pseudomonas, Salmonella* and *Listeria monocytogenes* on the carcasses. These simulations based on the surface temperature took also into account the variability related to the pH and water activity of the carcasses as well as the strain variability related to the microbial behavior.

The results of the 80 0000 simulations showed that the increases in the microbial population caused by the transport of carcasses experimentally loaded at a core temperature above 12°C remained lower than the microbial variability of pig carcass contamination measured in France after slaughter. Complementary investigations are conducted to identify acceptable maximal temperature at loading and maximal transport duration for pig carcasses.

Keywords— **Pig carcasses, temperature, transport.**

I. INTRODUCTION

Since 1964, carcases must be chilled in the European Union immediately after the post mortem inspection and kept at a constant core temperature, not exceeding 7ºC, even when transported [1]. Some studies have been conducted to assess the impact of the transport of pig carcasses with an internal temperature above 7°C. Moerman [2,3] showed in The Netherlands, with temperature measurements and bacteriological counts, that this kind of transport had no adverse effect on the hygienic condition of the meat. The Belgium Scientific Committee of the FASFC recently used predictive microbiology to conclude that the transport of slaughter warm carcasses was acceptable for 2 hours maximum if they were previously cooled to a maximum of 9°C at the surface and 16°C in the core, or for 3 hours with temperatures of 7°C at surface and 12°C in the core [4,5].

In France, the transport during 2 hours maximum for pig carcasses loaded at a maximum core temperature of 12°C was allowed in 2009 [6]. The present study was conducted to further investigate alternative loading temperatures and transport durations with respect to acceptable microbiological quality of the carcasses. Core and surface temperature kinetics of carcasses were collected in slaughterhouses during cooling and transportation and were used along with predictive microbiology models to simulate the growth of relevant bacteria on the carcasses. Simulations took also into account the variability related to the pH and water activity of the carcasses as well as the strain variability related to the microbial behavior.

II. MATERIALS AND METHODS

A. Temperature kinetics

Data on the temperature evolution during cooling and transportation of 183 pig carcasses, standardized in terms of weight and lean meat percentage, were

collected in 5 slaughterhouses, with different cooling technologies, representative of the slaughtering activity in France. The temperatures were measured from the chilling step through the carcass cooling and storage at the slaughterhouse cold room, or during the loading and transport, on the ham, the carcass anatomic site where the cooling is the slowest. The core temperature (used in regulation) as well as the surface temperature (where contamination occurs) were thus monitored using data loggers (Testo, France ; Oceasoft, France) during the cooling process at the slaughterhouse and during the carcasses transport. Transports were organized in several campaigns with a targeted carcasses core temperature at loading of 18°C, 15°C or 12°C. 908 surface temperature kinetics, representing the natural variability during the carcass cooling and transport were thus obtained. A re-sampling procedure was then realised on this set of kinetics to obtain 2 000 kinetics representative of each slaughterhouse practises. A total of 10 000 kinetics were thus generated.

B. Simulation of microbial behaviour for alternative transport conditions

Listeria monocytogenes and *Salmonella* are the major hazards in the pork meat industry and were therefore chosen to simulate the behaviour of the pathogenic micro-organisms on the pig carcasses. The behaviour of alteration micro-organisms was also studied using a psychrotrophic micro-organism: *Pseudomonas* and a representative of the enterobacteriacae : *E. coli*.

Predictive microbiology models were used to simulate the growth of these bacteria on the surface of the carcasses both on the meat and rind parts. The primary model of Rosso [7] was used to simulate the microbial concentration with time.
A secondary cardinal model, based on the gamma concept [8], was used to simulate the effect of the environmental conditions on the growth rate of the micro-organisms according to equation below:

$$\mu_{\max} = \mu_{opt}.\gamma(T).\gamma(pH).\gamma(aw)$$

where μ_{opt} is the optimum growth rate obtained in environmental optimal conditions. The effect of each environmental factor is simulated according to Rosso [9], with cardinal values representing the minimum, optimum and maximal environmental factor values (for T, pH, or aw) allowing the growth of the micro-organism. The values of the parameters used in the simulations are either fixed values or sampled among normal distributions as presented in Table 1 ; pH values of the rind surface (pH_r) and the meat surface of carcasses (pH_m) as well as their *aw* were obtained from a previous study.

Table 1 Parameters values for microbial growth simulations.

Parameter	*Pseudom.*	*E. coli*	*Salmonella*	*L. mono.*
lag (h)	0	0	0	0
N_0 (log cfu)	0	0	0	0
N_{max} (log cfu)	N(10.4;0.1)	N(8.0;0.1)	N(8.5;0.1)	N(9.0;0.1)
μ_{opt} (h^{-1})	N(1.1;0.1)	N(3.3;0.4)	N(1.7;0.2)	N(1.2;0.2)
T_{min} (°C)	N(-6.4;2.3)	N(5.9;1.4)	N(4.7;0.6)	N(-1.3;1.1)
T_{opt} (°C)	N(27.5;1.0)	N(41.2;1.3)	N(39.6;0.7)	N(38.2;0.7)
T_{max} (°C)	N(31.8;2.8)	N(46.7;2.3)	N(45.9;0.5)	N(43.3;1.1)
pH_{min}	N(5.0;0.4)	N(3.8;0.1)	N(3.2;0.3)	N(4.2;0.1)
pH_{opt}	7	7	7	7
pH_{max}	14-pH_{min}	14-pH_{min}	14-pH_{min}	14-pH_{min}
aw_{min}	N(0.94;0.01)	N(0.96;0.01)	N(0.94;0.01)	N(0.92;0.01)
aw_{opt}	0.997	0.997	0.997	0.997
aw_{max}	1.000	1.000	1.000	1.000
pH_r	N(8.6;0.1)	N(8.6;0.1)	N(8.6;0.1)	N(8.6;0.1)
pH_m	N(6.3;0.5)	N(6.3;0.5)	N(6.3;0.5)	N(6.3;0.5)
aw	0.995	0.995	0.995	0.995

N(*m*;*s*) Normal distribution with its mean *m* and standard deviation *s*

For each micro-organism, 10^4 simulations were performed using the parameters presented in table 1, taking into account the natural variability of the microbial parameters sampled in their respective normal distributions as well as the variability of the temperature kinetics on the surface of the carcasses, during the cooling at the slaughterhouse and during the carcasses transport. Simulations were performed on both type of carcass surface (rind and meat) characterized by different mean pH values (8.6 vs 6.3). Finally, to evaluate the acceptability of alternative transport practises, the increases in the microbial population obtained for transported carcasses loaded at different core temperatures for several transport durations were compared to those obtained for equivalent carcasses that were cooled in the same conditions and then maintained at the cold room of the slaughterhouse during the transport time.

III. RESULTS AND DISCUSSION

The 908 collected kinetics, for which loading core temperatures of 12, 15 or 18°C were targeted, showed a much dispersed distribution since the measured core temperatures at loading ranged from 9 to 29°C.

Table 2 presents a summary of the characteristics of the collected core and surface temperature kinetics for the different slaughterhouses. This table reflects the variability for the surface temperatures, the core temperature, the cooling and the transport times, as well as the important difference between the numbers of eligible kinetics for the 5 slaughterhouses.

Table 2 Presentation of the temperature kinetics characteristics

Slaughterhouse	A	B	C	D	E	Total
Number of kinetics	145	195	56	260	252	908
Mean loading core T°	14.7	19.9	13.4	14.6	18.1	17.2
Mean loading surface T°	9.5	13.0	9.6	10.0	11.0	11.0
Mean cooling time	11.4	5.8	7.4	2.7	5.1	5.7
Mean transport time	13.6	10.4	22.0	15.1	12.1	12.9
Mean kinetic time	25.0	16.2	29.4	17.7	17.3	19.7

A re-sampling procedure among the set of the kinetics obtained for each slaughterhouse was performed to equilibrate their contribution to 2.10^3 kinetics each, to have a total set of 10^4 kinetics.

Figure 1 depicts an example of the evolution of the surface temperature with time (bold line) during the cooling of a carcass and its storage in the cold room (Reference), as well as the evolution of the surface temperature with time (dashed line) during cooling (in the same conditions) and then loading (surface temperature 13°C, core temperature 18°C) and transport for an equivalent carcass.

The effect of this difference in the surface temperatures on the microbial behavior was assessed for the 10^4 temperature kinetics, both on the meat and rind parts of the carcasses, taking into account their physic-chemical variability as well as the microbial variability, for each bacteria. The difference obtained for *L. monocytogenes* concentration between the reference scenarios and the transport scenarios are presented in Figure 2.

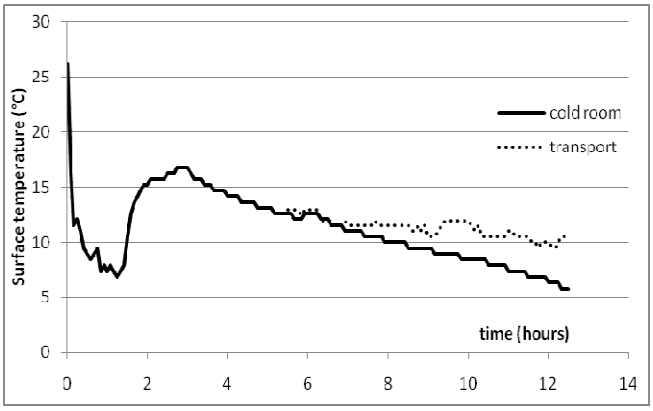

Fig. 1 Evolution of the surface temperature of the carcasses during cooling in the cold room and during the transport.

The kind of peaked distribution presented in Figure 2 shows that the behaviours of this in the reference scenarios and in the transport scenarios remain very close and reflect a minor increase in the microbial population. Thus, for *L. monocytogenes*, the median increase observed between the reference scenario and the transport scenario is estimated to 0.07 log CFU on the rind and to 0.10 log CFU on the meat surface.

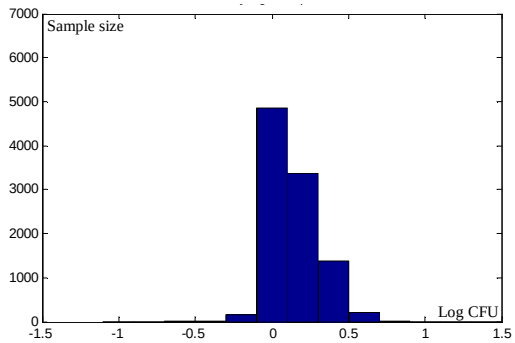

Fig. 2 Distributions of the differences in the microbial contamination between reference and transport scenarios for *L. monocytogenes* on the meat surface of the carcass.

Table 3 summarises the 8.10^4 simulations, performed for *L. monocytogenes*, *Salmonella*, *Pseudomonas* and *E. coli*, presenting the 5th, 50th and 95th centiles of the distributions obtained for the four micro-organisms on both rind and meat surfaces of the carcasses. Table 3 shows similar results for *Salmonella*, *Pseudomonas* and *E. coli* which indicates that the increases in the microbial population caused by the transport of carcasses experimentally loaded at

a core temperature ranging from 9 to 29°C for the several studied durations remained acceptable.

Table 3 Presentation of the centiles of the distributions of the differences in the microbial contamination obtained between reference scenarios and transport scenarios for the four micro-organisms on the both surfaces of the carcasses.

	Centiles	*L. mono.*	*Salmonella*	*E. coli*	*Pseudom.*
	5	-0.06	-0.04	-0.05	-0.10
Meat side	50	0.10	0.07	0.06	0.15
	95	0.43	0.32	0.44	0.75
	5	-0.04	-0.04	-0.04	-0.04
Rind side	50	0.07	0.06	0.05	0.04
	95	0.31	0.27	0.35	0.36

The obtained values remain lower than the standard deviation of 0.9 log CFU observed for the natural contamination of pig carcasses and cuts [10], which is well above the maximum values of the 95th centiles presented in Table 3.

An analysis of variance was ultimately conducted to identify the most important factors influencing the difference between the reference scenario and the transport scenario. Two categories of important factors were identified: factors on which the operator cannot act such as the microbial characteristics, the pH or the slaughterhouse; and factors on which the operator can act such as the core temperature at loading and the transport duration, the latter one being the most important (results not shown).

IV. CONCLUSIONS

The results of the 80 0000 simulations indicate that the increases in the microbial population caused by the transport of carcasses experimentally loaded at a core temperature ranging from 9 to 29°C for the several studied durations remains low compared to the corresponding storage in cold rooms, with a maximum median difference of 0.15 log. The calculated differences are thus much lower than the natural microbial variability of pig carcass contamination usually monitored after slaughter in French slaughterhouses.

Complementary investigations are now conducted to evaluate and propose acceptable maximal transport durations for pig carcasses for different maximum temperatures at loading.

ACKNOWLEDGMENT

This study was financially supported by INAPORC, the French Interprofessional Pork Council.

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