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New sensors for pork quality control
use in slaughterhouses and processing to measure pig carcass composition and characterise technological quality of meat

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Slaughterhouses hold a strategic position in the center of the pork industry as they are the technological and economic link between market expectations and livestock production. New technologies, proven in other industries, have appeared in the meat industry and are being tested. X-ray tomography determines accurately and nondestructively in pig carcass, the proportion of three main tissues, fat, lean and bones. X-ray is already used to perform virtual dissections to calibrate grading devices. This X-ray technology is experienced on deboning lines to program deboning robots according to the individual conformation of pieces.
Visible light cameras are now installed in slaughterhouses to classify carcasses according to thickness of lean and fat to allow the distribution of gain payments to farmers.
The infrared spectra (NIRS) of reflection or refraction are quite widely used to measure the composition of mixed fat and lean. Their use is being validated for substitution to pH to predict, at the slaughterhouse stage, the technological quality of hams. Hyperspectral analysis (including visible and infrared rays) becomes possible thanks to the speed of computers available today. It should enhance the accuracy of the NIRS analysis and improve the characterization of pig meat.

De nouveaux capteurs pour maîtriser la qualité des viandes de porc utilisables en abattoir et en transformation pour mieux mesurer la composition des carcasses de porc et caractériser la qualité technologique des viandes

Les abattoirs font le lien technologique et économique entre les attentes des marchés et la production de l'élevage. Les technologies nouvelles apparaissent dans l'industrie de la viande et sont expérimentées dans plusieurs directions.
La tomographie X détermine la composition d'une carcasse dans ses trois tissus principaux, le maigre le gras et l'os. Elle est déjà utilisée pour réaliser des dissections virtuelles afin de calibrer les appareils de classement. Cette technologie RX est expérimentée en ligne sur des chaines de désossage. Où elle sert à programmer les robots selon la conformation individuelle des pièces.
Des caméras en lumière visible installées dans les abattoirs pour classer les carcasses selon des épaisseurs de maigre et de gras permettent la répartition des plus-values aux éleveurs.
Les spectres NIRS (Near Infra red spectroscopy) de réflexion ou de réfraction sont utilisés pour mesurer la composition de mêlées en gras et en maigre. Leur utilisation est en cours de validation en substitution du pH pour prédire au stade abattoir la qualité technologique des jambons et des longes. L'analyse hyperspectrale (incluant les ondes visibles et infra rouge) devient possible grâce aux vitesses des calculateurs aujourd'hui disponibles. Elle devrait renforcer la précision de l'analyse NIRS et améliorer la qualité de caractérisation des viandes porcines.

Keywords: sensor, pork, composition, quality, slaughterhouse, processing
Mots clés : capteur, porc, composition, qualité, abattoir, transformation

Introduction

The pork industry now has new tools to measure carcass composition and control the technological quality of products at various stages in their processing. Here we examine the maturity of this technology in the light of tests performed at pilot and industrial scales.

Context of the pork industry

Pork is sold for consumption in two main forms, as fresh or cooked meat, and as cured and salted products. For best performance, the pork industry must encourage producers to rear pigs whose meat best fits this pattern of demand.
Slaughterhouses hold a strategic place at the heart of the pork industry, where they form an economic and quality-control link between market expectations and livestock production.
The economic link with pig farmers is made through a distribution of incentive gains based on the fat and lean composition and weight of carcasses. The quality-control link is made with the processing stage through predictive measurements of meat quality for cooking and processing. In both cases, the ability for a slaughterhouse to make an objective assessment of meat composition and quality is crucial. This ability makes it possible to connect downstream needs to French pig production, and to integrate these needs into genetic improvement efforts. New technologies, proven in other industrial sectors, have now appeared in the meat industry and are being experimented in several directions.

Sensors in the meat industry for better characterisation of carcass composition to fix payments to farmers

The composition of pig carcasses is currently estimated in the pork industry during the weighing and grading operation. This is performed on the slaughterhouse lines, generally just before the refrigeration step. Grading is done using devices that use one of the following three technologies: reflectance, ultrasound, and machine vision.
The principle of reflectance consists in analysing a visible light beam emitted by a penetrating probe and reflected by the meat. According to whether the probe enters fat or lean tissue, the spectrum of the reflected light is different. This probe is coupled to a penetration sensor that measures the thickness of each tissue. This principle has been applied since the 1990s in grading devices such as SFK's Fat-O-Meater, and Sydel's CGM.
Ultrasound has been used since the 1980s to predict the lean content of carcasses. An automatic version was devised by the Danish company SFK, today Carometec. The idea is to scan the back of the pig to recover information on backfat and loin eye depth. The device, called AutoFom, is installed in the hot area of the slaughterhouse, after the de-hairing machine at the sampling table stage, before singeing.
The measuring device, which consists of a yoke equipped with a row of 16 ultrasound heads, is placed across the floor of a channel fitted after the pig reception table. The gambrel conveyer draws the whole carcass, non-eviscerated, along the channel and over the yoke, the weight of the carcass pressing it down on the row of sensors. The frequency of measurement is synchronised with the line speed so that a signal is emitted every half-centimetre of travel. The system then analyses images of several longitudinal profiles, from which it extracts a large number of variables, called IP parameters. Among these variables are the backfat and loin muscle depths.
Machine vision, a technology used in beef grading, entered the pig industry more recently. It offers an important advantage, namely its possible automation and therefore low operating cost. In France, Uniporc Ouest has opted to equip the large slaughterhouses in its area with a machine vision device, the CSB-Image-Meater®. Since June 2013, some three-quarters of all French pigs, i.e. about 17 million per year, have been graded and valued according to the lean content of pieces (TMP) predicted by this device.

All methods of carcass grading must be authorised by a decision of the European Commission after analysis of performance by a group of experts following EU rules. The CSB-Image-Meater® method offers a prediction error of 2.4% in TMP (Blum *et al.*, 2014), i.e. lower than the EU acceptability threshold of 2.5%. The prediction equation comprises two thicknesses of subcutaneous fat (G3 and G4) and two thicknesses of muscle (M3 and M4), measured on the carcass split plane at the junction of loin and ham:

$$TMP = 60.12 - 0.487\,G3 - 0.133\,G4 + 0.111\,M3 + 0.036\,M4$$

With the following definition of the four thicknesses, all expressed in mm, and measured by acquired image analysis at the split (Figure 1):

- G3 = minimal fat thickness (rind included) on the gluteus medius,
- G4 = mean fat thickness (rind included) on four lumbar vertebrae,
- M3 = minimal muscle thickness between the anterior end of the gluteus medius and the dorsal part of the spinal channel,
- M4 = mean thickness of the muscle covering four lumbar vertebrae.

This grading device was calibrated using an X-ray scanner (Figure 2) to obviate long, costly manual dissection, the reproducibility of which is difficult to ensure. The four main pieces of the standardized European cut were scanned, and the images analysed using an algorithm developed by Ifip. This procedure enabled us to achieve a prediction error of 0.5% in TMP (Daumas & Monziols, 2011), one of the lowest figures in Europe.

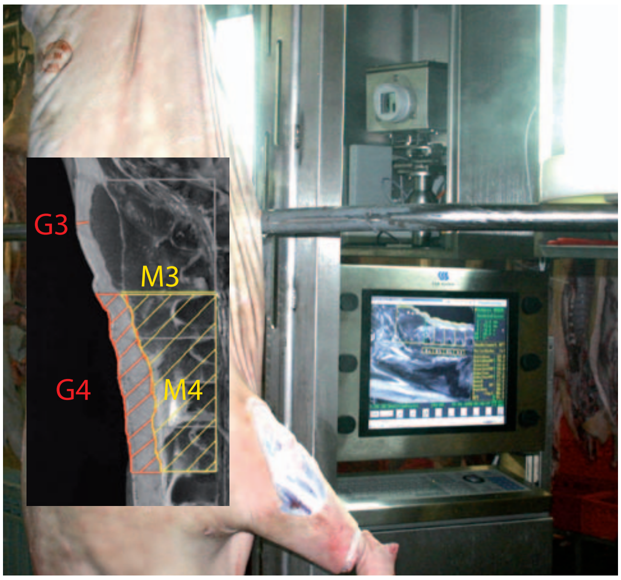


***Figure 1:** The four areas of thickness measurement using the CSB-Image-Meater® method*

The X-ray scanner, a technology under development for research and production applications in slaughterhouses

Work is under way to bring X-ray scanners into slaughterhouses, but to date most instrumentation is still experimental (Pomar *et al.*, 2009). A European scientific network (Action COST FAIM) is working on the imaging of livestock animals, and scanners are central to this work. Through exchange of results, the aim is to develop a European benchmark for percentage muscle measurement using a scanner that would serve as a basis for pig grading (Daumas *et al.*, 2013).

X-ray technology has been successfully used experimentally to visualise the changes in ham when it is dry-cured (Fulladosa *et al.*, 2010). The X-ray scanner differentiates muscles according to their density, and thereby visualises the penetration of salt and the progress of drying.
This non-destructive method is very useful for monitoring the changes in ham throughout processing, and for assessing the efficacy of salting variables without waiting for the whole process cycle to reach completion (Figure 3).

The installation of X-ray scanners in production lines has begun: X-ray technology is used in-line on the Mayaekawa Mycom ham deboning machine. An X-ray beam makes a radiograph of each ham to determine its conformation, and the shape and position of the leg and aitch bones in two dimensions. This radiographic picture is interpreted with an image-processing algorithm to yield digital information that is then used to program in-line deboning robots.
This technology is being scaled-up for industrial use by the Danish Meat Research Institute for the purpose of measuring, at entry to the deboning line, the composition of pieces to optimise work-up and establish material balance in pig slaughterhouses. Obtaining precise knowledge of the morphology and the lean and fat composition of pieces before cutting is a major issue throughout the pork industry.

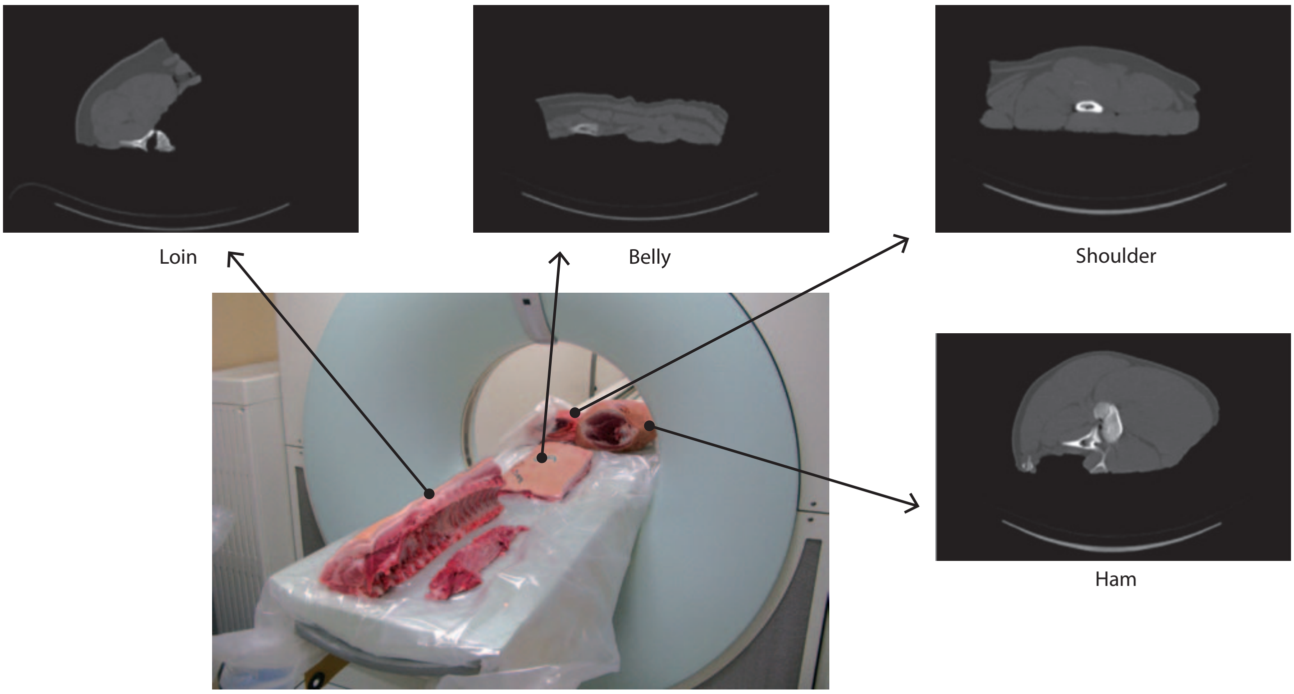


***Figure 2:** An X-ray scanner differentiates three tissues, i.e. muscle, fat and bone, in whole carcasses and pork pieces*

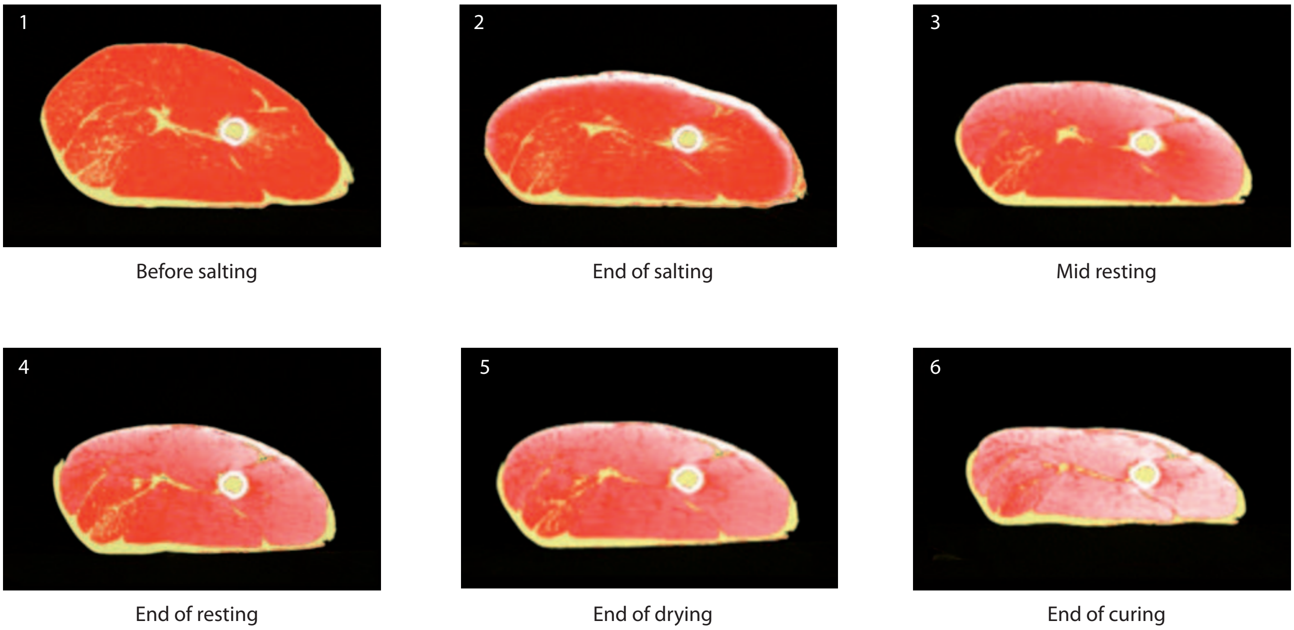


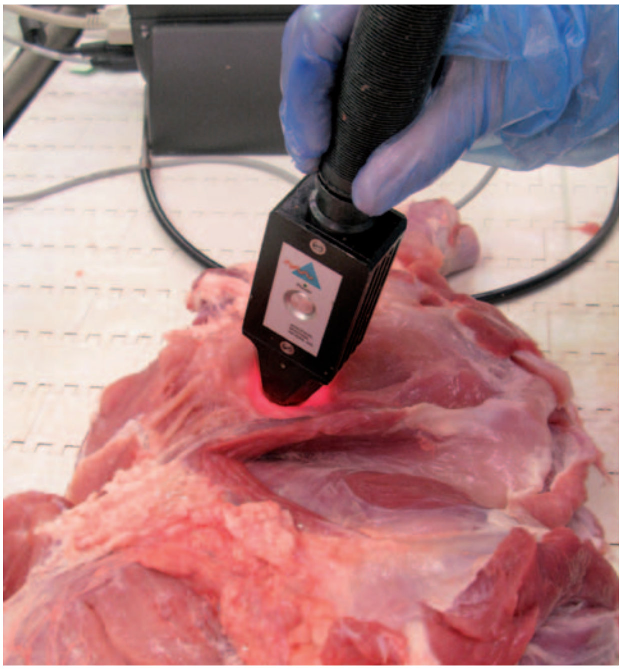
Figure 3: Penetration of salt seen by X-ray tomography (light areas) during the processing of cured ham

With this knowledge, optimal use could be made of each individual piece according to its conformation and its lean/fat composition.
Objective measurement of the composition of each piece by the slaughterhouse is a first step in fixing the value of a pig according to the selling price of its pieces rather than by its overall carcass composition. The use of this technology is thus expected to incentivise producers to produce pieces that meet market demand.

Characterising meat quality to measure suitability for different processing

The second objective of a slaughterhouse is to characterise meat on criteria that are important for processors.
Technological quality is defined as the capacity of ham or loin to retain water during cooking (cooking yield) and to form a protein gel to permit clean slicing (slicing yield). Today this technological quality is predicted on fresh ham using two variables, the pH measured on the outside surface of the semimembranosus muscle, and the visualisation of inner destructuring defect of the ham.
Several recent studies conducted by Ifip have evaluated the ability of visible and near infrared spectroscopy (NIRS) to predict these two technological yield variables in ham and loin.

A first exploratory study (Vautier *et al.*, 2011) saw the development of a calibration method from visible-range spectra to predict the technological yield of cooked ham. The performance of calibration obtained by cross validation gave encouraging results for both ham ($R^2 = 0.70$, RMSEC = 2.1) and loin ($R^2 = 0.45$, RMSEC = 2.0). This performance is comparable to that of pH. The pH taken in ideal conditions has a similar predictivity (correlation between pHu and technological yield of ham: r = 0.58–0.84 according to the study).
In another study of the prediction of technological yield of cooked ham, Vautier *et al.* (2013) confirmed the good performance of spectroscopy as a prediction tool. Spectral measurement in the visible + NIR range (350–1800 nm) at 24 h *post mortem* on the gluteus medius, using a commercially available contact probe provided a calibration that performed well for the prediction of technological yield ($R^2 = 0.75$, RMSEC = 2.8). The external validation of this prediction equation on a sample of n = 36 hams from outside the calibration population gave a close correlation between predicted and observed yields (r = 0.82) with an error of 1.78, less than half the standard deviation of the sample.
Lastly, a study on loin (Vautier *et al.*, 2014) predicted the technological yield of loin during its processing into superior roast pork. The result obtained with an invasive visible + NIR probe depended closely on the measurement site, but gave a correlation of r = 0.65 and RMSEC = 2.9 in external validation on one of the nine sites tested.
The prediction error in the work of Vautier *et al.* (2013 and 2014) and in Table 1, noted RMSEP, corresponds to the standard error in yield relative to the observed yield (the method performs favourably when the RMSEP is less than half the standard error in the sample).



Near infrared spectroscopy on ham (NIRS)

On ham, these results are encouraging, as they show that measurement by NIRS can predict cooking yield and destructuring defect on unopened fresh ham 18 h after slaughter. NIRS, including acquisition and analysis of the spectrum, is fast (1 s) and mostly independent of the operator and measuring environment, unlike pH measurement. NIRS instruments designed for use in an industrial environment already exist. Their integration into process lines to make in-line measurements is now being considered in order to obtain systematic characterisation of hams and even loins. This would make it possible to sort pieces, according to their predicted quality, for either superior cooked products or less demanding processing.

Hyperspectral analysis is very probably the next technological step for optical sensors in the meat industry. The aim will be to analyse images in which every pixel contains a spectrum. Optical technology is useful in that it facilitates automated sorting in pork processing lines by making continuous measurements without contact with the meat or involvement of an operator. Routinely obtaining such information automatically can thus help generalise technological quality prediction in pork.

Expected advances in optical measurements carried out on meat concern measurement tools: probes better suited to measurements on meat (accessibility and measurement surface area) and to the industrial environment (humidity, temperature and ease of cleaning), reduction in cost of instrumentation, measurement surface area of optical probes, power of light sources, processing algorithms for shorter response times, and miniaturisation. In parallel, further knowledge is needed to identify measurement sites that give better predictivity of technological yield of meat and are readily accessible in a slaughterhouse.

***Table 1:** Prediction of technological yield of loin processed by salting. Sites for pH measurement and NIRS*

Site :	Calibration (n = 56)		Cross validation (n = 56/3)	External validation (n = 24)	
	R^2	No. PLS factors	RMSEC min.	r	RMSEP
C	0.26	3	3.8	0.28	3.7
D	0.09	1	3.8	-	-
E	0.66	6	3.5	0.26	3.7
F	0.05	1	3.8	-	-
G	0.08	1	3.8	-	-
H	0.02	1	3.9	-	-
I	0.29	3	3.9	0.31	3.6
J	0.78	9	3.8	0.65	2.9
K	0.15	4	3.9	0.49	3.3

Conclusion

Optical and imaging technologies are being deployed in the meat industry, in particular where obtaining objective quality and composition data is crucial for industrial performance. Optical and X-ray technologies are advantageous because they permit very rapid measurements that are largely independent of an operator and are easy to automate. These are among the new sensors that the meat industry needs to assess quality objectively and monitor material balance.

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