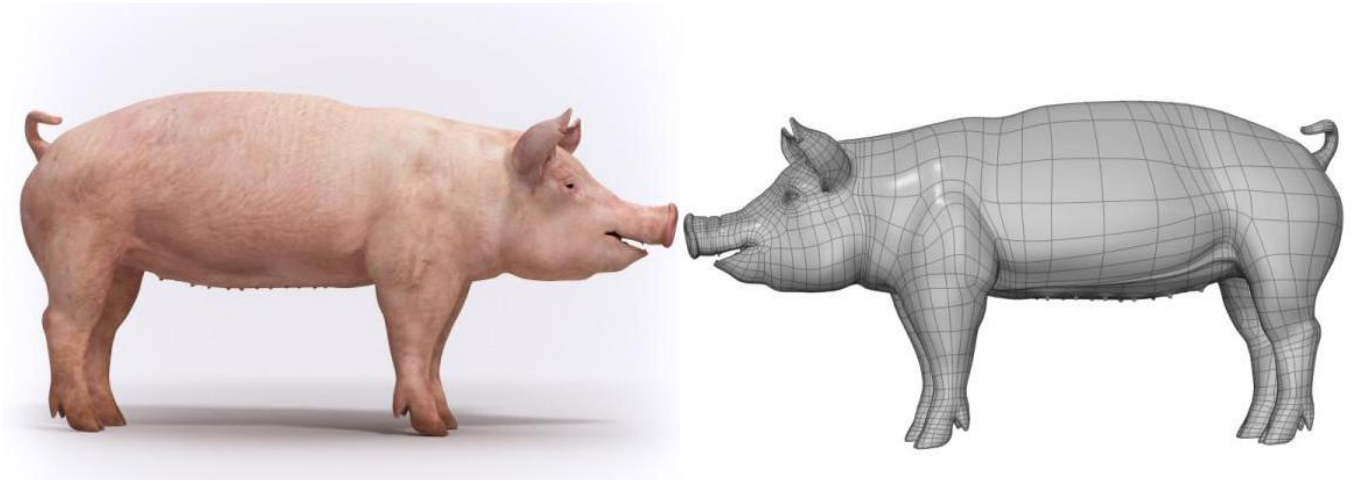


USE OF NOVEL TECHNOLOGIES TO OPTIMIZE PIG PERFORMANCE, WELFARE AND CARCASS VALUE



Swine Cluster 2 Project #1237

Canadian Centre for Swine Improvement



ACKNOWLEDGMENTS

This project was carried out by research teams from various organizations across Canada. The following people were particularly involved in the project:

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- Alberta Agriculture: Nigel Cook
- Centre de développement du porc du Québec: Frédéric Fortin, Patrick Gagnon, Philippe McSween, Jean-Gabriel Turgeon, Violette Caron-Simard, Léonie Morin-Doré, Sébastien Turcotte, Marie-Pierre Fortier, Hélène Fecteau
- Ontario Swine Improvement : Dan Cohoe
- Western Swine Testing Association : Wim VanBerkel
- Université Laval: Jean-Paul Laforest, Jean-Michel Beaudoin
- McGill University: Michael Ngadi, Laura Liu
- Prairie Swine Centre: Lee Whittington, Bernardo Predicala, Alvin Alvarado
- University of Guelph: Renée Bergeron
- Canadian Centre for Swine Improvement: Brian Sullivan, Brianna Sullivan, Jim Groves, Li Li, Mohsen Jafarikia, Laurence Maignel

This project was funded by Swine Innovation Porc within the Swine Cluster 2: Driving Results Through Innovation research program. Funding was provided by Agriculture and Agri-Food Canada through the AgriInnovation Program, provincial producer organizations and industry partners. Funding was also provided by Alliance Genetics Canada, AlphaGene, Centre de développement du porc du Québec, Fast Genetics, Porc Notre Dame, Sand Ridge Farm and Western Swine Testing Association.



EXECUTIVE SUMMARY

The size of livestock farms has increased dramatically in recent times, resulting in larger numbers of animals cared for by a decreasing number of livestock producers. Use of new and novel technologies is becoming increasingly important to ensure and to satisfactory care of animals and adequate technical and economic performance of the farm. There is also an opportunity to measure new traits in pig populations with novel technologies becoming available and more affordable over time. Precision Livestock Farming (PLF) could assist livestock producers through automated, continuous monitoring of the animals. The observation data can be translated into key indicators on animal welfare and health, productivity and environmental impact. A number of PLF tools have been developed at laboratory levels and as prototypes. The overall objective of the project was to bring some of those tools from the lab to the farm. Technologies such as automatic water intake recording, monitoring of body temperature through infrared thermography, activity monitoring using accelerometers, vision systems and Bluetooth technologies and weight prediction devices were developed and/or tested in research facilities across Canada. Some of the PLF tools developed in pilot studies (smart drinkers and infrared cameras) were transferred into a more commercial environment to carry out a few trials in a grow-finish barn.

The number and size of slaughter plants has followed the same trend as pig farms in recent years, resulting in fewer and larger facilities with higher line speed. The need for quick, objective, automated approaches to monitor carcass composition and quality is increasing, as well as new approaches to replace subjective visual scoring systems and time-consuming, expensive reference methods for carcass and meat quality assessment such as full cut-outs and chemical analyses. Adopting new tools for carcass composition and meat quality evaluation will also be an asset in developing uniform and objective carcass grading systems. The project looked at novel technologies including 3D vision for carcass classification, near infrared spectroscopy, nuclear magnetic resonance and hyperspectral imaging for meat quality evaluation, as well as new approaches to sort bellies based on their firmness and physical properties.

Highly experienced Canadian teams from different disciplines have joined forces to deliver a useful PLF Blueprint. This project confirmed the potential of several emerging technologies for the Canadian swine industry. It also provided insight into what problems must be overcome when installing the modern technology. More research and automation is required in several cases, while some tools are already available for innovative breeders and producers. For all technologies tested in this project, keys to success include training, standards and good data management systems. In addition, applications of novel technologies will require basic user interfaces such as smartphone applications. This already exists for infrared thermography and could be extended to other technologies such as weight prediction tools, 3D

scanning and animal tracking systems. A key aspect identified in all pilot studies relates to data management and processing. The most important thing is not what information is collected, but how it is used and combined with other farm data. Effective data management, including combining data collected from various devices, requires standards in data format and transfer, which are still to be developed, and systems that combine data from multiple sources and promptly provide useful information for timely decisions of end-users.

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1. Introduction

Advances in precision livestock farming have been impressive over the last few years around the world. Canadian pig breeders and producers have always been receptive to new technologies and processes that allow them to monitor their pigs and help to produce better breeding pigs and hogs. These have allowed Canada to reach and maintain a status of a highly efficient and high quality pork producing country worldwide.

A number of new tools become available on the market every year, but little information is generally available to have a good idea of their reliability, accuracy and cost-efficiency. Current issues for the Canadian swine industry generate new needs in terms of data recording. For instance, feed costs currently represent about 60% of production costs, but breeders and producers don't have ways to accurately monitor feed efficiency, except by installing expensive feed intake recording stations. Animal behaviour, conformation and leg soundness are evaluated mostly using subjective assessment, and are not recorded routinely in all breeding farms. Carcass composition and meat quality can be accurately measured through a standard carcass cut-out and detailed meat quality evaluation, which require traceability and are time-consuming and expensive to carry out. Recent developments, especially in computer vision and tracking technologies, provide new opportunities to collect information on live pigs (behaviour, conformation, feed and water intake, etc.) and on carcasses (carcass and cut composition, lean and fat composition, etc.). As these technologies are further developed, the costs associated with their use decrease over time, making them potentially more affordable for research barns, breeding farms, commercial farms and packing plants. This project gave the opportunity to explore several new technologies that could potentially be applied in breeding and commercial farms as well as packing plants if they prove to be accurate, convenient and affordable. They could provide better ways to collect data on traditional traits and approaches to collect data on new traits of interest. Some very promising technologies were selected, some of which were recently developed in Canada, to be used on live pigs and carcasses.

In the swine breeding context, new phenotypes are necessary for earning the maximum benefit from investment in genomic evaluation and selection in Canadian pig populations. New traits in areas such as behaviour, conformation, feed efficiency, meat quality and meat nutritional value could be improved through genomic selection if objective and accurate phenotypes were collected in reference populations. This project looked at validating some of the new technologies available to provide objective indicators of performance, welfare and carcass value, and then using these technologies in commercial trials. The pilot studies, carried out in various universities and laboratories across Canada, each focused on a different technology, but all aimed at a common objective: test and validate new approaches to measure traits of interest for pig breeders, producers and packers.

2. Pilot Studies

2.1. Live animals

2.1.1. Automated recording of individual water usage

Automatic feed dispensers have been used in pig farms and research stations for many years to collect individual feed intake data. These are sometimes coupled with relatively sophisticated weighing systems that provide a predicted weight each time a pig enters the feeder. Collection of individual water intake data is of interest as well. Firstly, automatically monitoring feed and water intake as well as behaviour can help in detecting potential health or welfare issues in growing pigs in addition to providing behaviour measurements. Secondly, daily water intake could be a phenotype of high value to approach sustainable pig production and resistance to heat or drought. Measuring individual water intake also provides a way to know the exact dose a specific pig has received when medication is provided in drinking water at a known concentration.



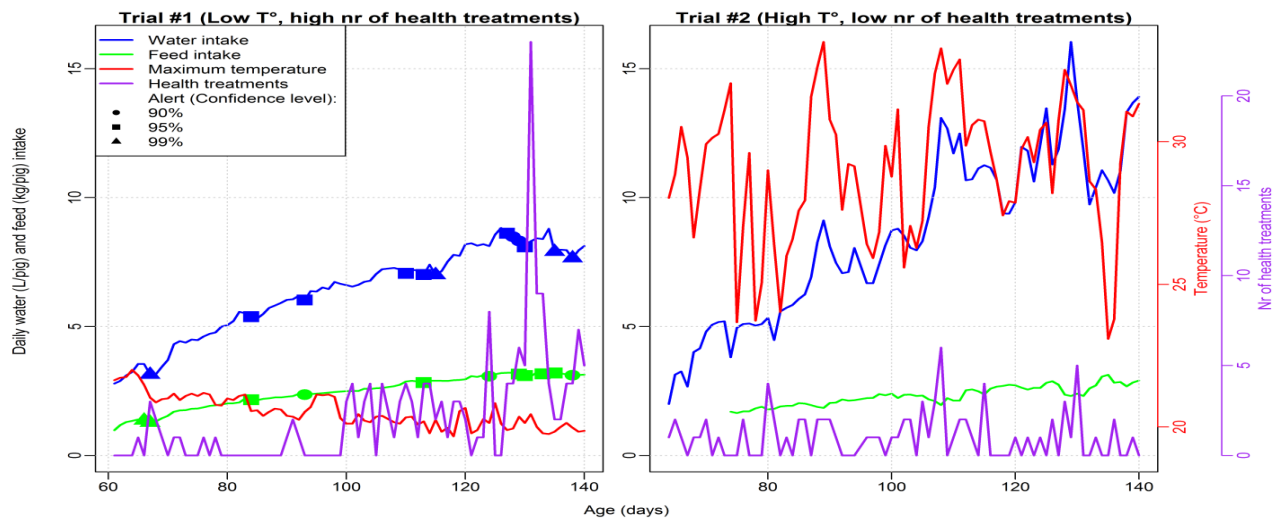
This project took place at the Deschambault Swine Research Station in Quebec, Canada. The station is a 360 pig nursery-finisher facility. It is owned by the Centre de développement du porc du Québec (CDPQ) and is equipped with sophisticated equipment used to answer research questions from the pig sector. A system for measuring individual water intake was designed and developed by CDPQ and tested in 2014 in three pens. These ‘smart drinkers’ include an RFID antenna for individual identification and a system to measure the precise volume of water consumed at the drinker, both from the nipple and in the bowl. The Deschambault Swine Research Station is now equipped in the finishing area with smart drinkers in all (28) pens in the grow-finish room. Data recorded on about 700 pigs in two trials carried out in 2015 and 2016 were analyzed to study daily water intake patterns on both a pen basis and an individual basis and explore links with other traits such as feed intake, growth performance and carcass quality.

The main factors affecting water intake were temperature, sex, number of drinkers per pen and whether the drinker has a cover. Castrates drink significantly more than the other sexes, with Improvest-treated boars tending to catch up at the end of the growing phase. Water intake and feed intake were highly correlated, however, there was a large seasonal effect, with pigs eating less and drinking more in summer months. Water intake can be used to predict growth and feed conversion at the pen level, provided temperature and sex are used in the prediction. Individual pig predictions are less accurate, mainly because of large variation in wastage. When the barn temperature is stable and comfortable, water intake can be used at the pen or barn level as an indicator of health issues. Warning levels can be set-up and were shown to predict health issues up to 3 days prior to clinical symptoms.



There were large temperature differences between trials. Recording days were separated in two categories, one for comfortable temperature (below 22°C) and one for uncomfortable temperature (over 22°C). It was found that temperature had a large impact on the pig’s water consumption. Indeed, temperature was directly

related to water consumption. Another goal was to see if water consumption can be a good predictor of factors such as feed intake, average daily gain, feed conversion, meat quality and health problems. Water consumption had a correlation with feed intake and feed conversion, but there was no correlation with average daily gain or meat quality. To study health problems, statistics were calculated only for comfortable temperature days, because on hot days the pig's water consumption increased drastically. The hypothesis was that a sick pen's water consumption would decrease before the appearance of physical symptoms. It was found that with an alert threshold of 10%, it was possible to detect a drop in water consumption 3 days before health treatment. In comparison, for the same pigs, feed intake could help detect a health problem only one day before appearance of clinical signs. For the summer trial, where all the days were at uncomfortable temperatures, another statistical approach was used. The solution was to define an alert which takes into account both water and feed intake. Five reductions in consumption were detected by the combined feed/water system. Only two of these points showed an early decline in the onset of physical symptoms that resulted in individual treatments.



Daily water and feed intakes at the barn for trials #1 and #2 along with daily maximum temperature inside the barn and the number of individual treatments (used as a proxy of health status). Three different alert levels, based on daily variations of water and feed intakes, were used to predict health treatments for trial #1. For trial #2, high temperatures prevented the prediction of health issues.

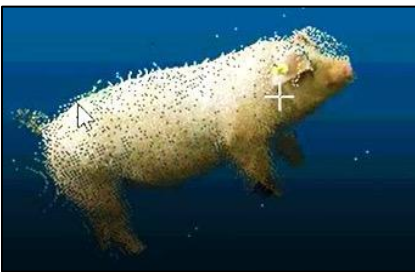
For research purposes, smart drinkers are still in operation at CDPQ's Deschambault Swine Research Station and are now part of the standard performance recording protocol. Since November 2015, more than 2,000 pigs have been raised in a disease-challenged environment and water intake data has been collected. The smart drinkers have been constantly maintained and optimized in order to improve their accuracy for group and individual recording. Group and individual water intake data were analyzed jointly with live and carcass data collected on pigs tested at the Deschambault Swine Research Station. Water intake data (individual or on a pen-basis) was analyzed jointly with many other traits collected on station-tested pigs including individual feed intake, growth and feed efficiency, carcass composition, meat quality, health and behaviour. Water intake recording systems provide a lot of useful information. For short-term applications, recording systems by pen would be a good option as they don't require electronic identification of individual pigs and

can be done with a simpler version of smart drinkers. A simplified version of the CDPQ smart drinker was tested at the end of the project at the Prairie Swine Centre research barn (see section 3.1 for more information).

For more information about this project, a detailed report is provided in Appendix 1.

2.1.2. Vision systems to predict live performance and carcass data

Weighing animals is one of the most important and frequent tasks for the producer during the finishing period for pigs because an animal's weight is a good indicator for its growth and health. It is also the main parameter in determining the date of shipping to the slaughterhouse. There has been a lot of work over the past decades to develop automated, contactless systems to predict weights in several species. In pigs, predicted live weight, carcass weight and cut weights are of interest to assess the value of a hog. Computer vision tools also offer opportunities to collect predicted live weight, linear body measures and conformation traits on each pig, several times a day, without any animal handling. Several fixed and mobile devices are already commercially available such as the OptiSort hog sorter (Hoelschter+Leuschner, Germany), the OptiScan hand-held device (Hoelschter+Leuschner, Germany), the ClicRweight system, the Wuggl device, the PiggyCheck tablet application or the eYeScan system from Fancom. The objective of this project was to test and evaluate different animal weighing systems in order to determine their ease of use and functionality on commercial farms as well as their reliability. In the first years of the project, CDPQ worked on testing the OptiSort hog sorter based on a 2D image analysis. The predicted weights provided by the OptiSort system were quite good within a range of +/- 3 kg compared to scale weights, but only for live weights up to about 105 kg. The system was developed in Germany and is thus adapted to the average slaughter weights in Europe. CDPQ also designed a fixed setup using Kinect 2 cameras to collect images and create 3D models of live pigs. In 2017, a portable device called PigWei was also tested in collaboration with the Ymaging company (Spain).

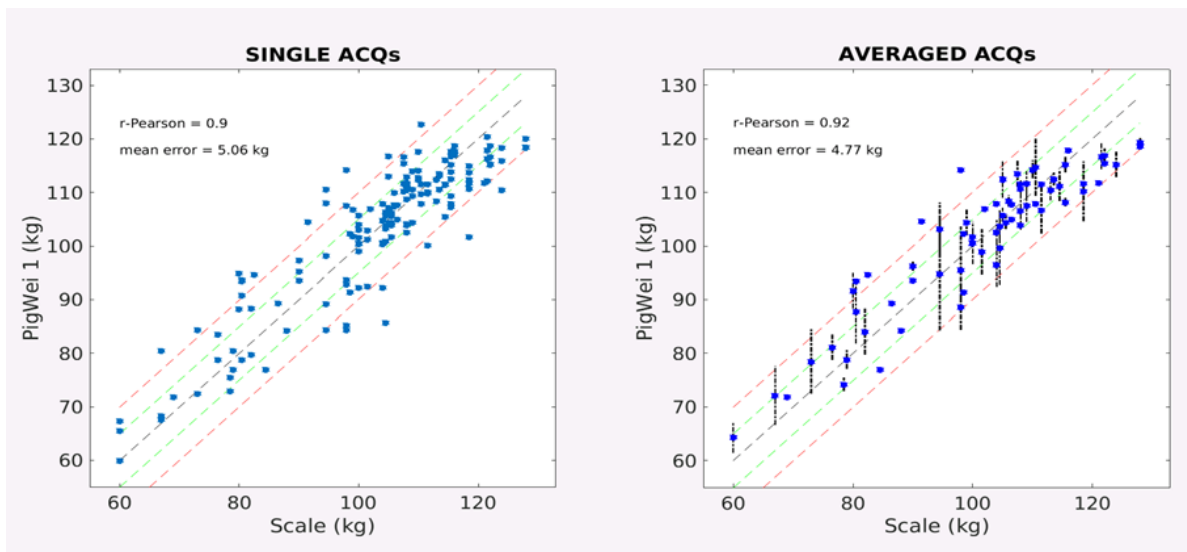


For the Kinect system developed by CDPQ, a specific design was created to capture images using three 2nd generation Kinect cameras positioned around a 3 by 3 foot pen. One camera was fixed on the ceiling to capture the top of the pig, while the other two were inserted in holes on each side of the pen. For each pig three pictures were collected by each camera every five seconds for one minute. Images were collected on a total of 295 pigs. A sample of 43 pigs was retained for the analyses. As a first indication of the prediction capability of the vision system, correlation

coefficients between observed and estimated primary cut weights were calculated. Correlations were moderate (between 0.2 and 0.4) for live and carcass weight, half carcass, ham and middle weights. Correlations were low and not significant for shoulder weight and for all individual primary cuts expressed as the percentage of the half carcass. For half carcass, ham and middle (side + loin), there was a relationship between observed weight and the predicted value provided by the vision system. However, the confidence intervals are very wide and show that the vision system, in its current form, cannot provide accurate predictions.



For the PigWei device, the technology was initially developed for Iberian pigs in Spain and needed some development to work with Canadian pig breeds. To do so, all captured images were sent to the Ymaging company to update and test their weight prediction equations. The PigWei instrument was found to be easy to use and practical. The display is user friendly and the size of the device makes it easy to transport and to manipulate. The battery also has a long life, which allowed for the completion of entire video capture sessions without interruption. A total of 370 pigs were scanned in June and July 2017 in order to calibrate the prototype, and in August 2017 a blind test was carried out on 115 pigs in order to assess the accuracy of live weight predictions. In the calibration phase, the Pearson's correlation obtained between scale weights and the PigWei predictions was 0.9 with a mean error of 5.06kg, which indicates some promising results for further use. In the validation test, the correlation was 0.48 for those same parameters. The average absolute difference between predicted and scale weights was 2.39 kg, with a standard deviation of 11.8 kg. It shows that the algorithm still needs improvements to be usable in the commercial farm environment but has good potential.



Main results from the PigWei calibration phase, using single image acquisitions (ACQ) as observations (Single ACQs) or the average of all image captures for each animal (Averaged ACQs)

There is room for improvement for both technologies tested. With the Kinect system, the design for image capture should be improved, and image processing and analysis should be automated. For the PigWei system, the algorithm can be better adapted to Canadian pigs, and the device will be modified to maximize the quality of captured images. Both technologies show promise for implementation in a commercial setting.

For more information, a detailed report is provided in Appendix 2.

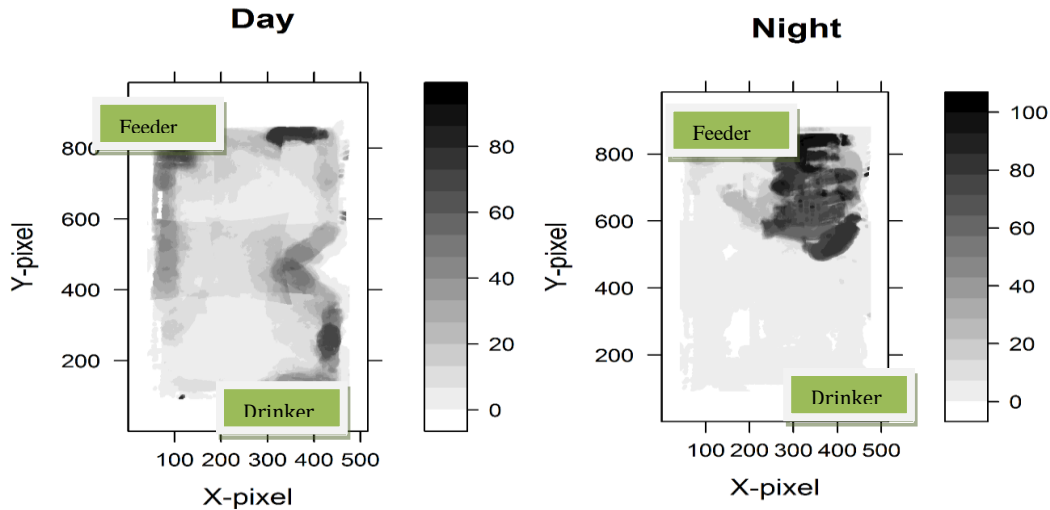
2.1.3. Automated recording of pig's movements and behaviour using tracking technology

Many different methods can be used to obtain data on the location and movements of pigs, such as visual observations, video recording, accelerometry, tracking algorithms, etc. The information can be used to evaluate activity levels, behaviour and welfare. Some video tracking software allows the study of a lot of

parameters such as active and inactive time, velocity, acceleration, movements direction, distance travelled, time spent and number of visits in a specific area. This type of program is commonly referred to as an 'Animal Tracking System' (ATS). This type of software uses video recordings which allow the observation of animals without the effect of human interaction, which comprises a large part of their lives.

The project took place in the Deschambault Swine Research Station, in Quebec. This is a nursery-finisher facility which can hold up to 360 pigs. The station is equipped with sophisticated amenities to cater to the research needs of the pig sector. The objective of this project was to accurately track the position and movements of pigs in their environment using camera and Bluetooth technologies. All the tracking devices were installed in the same pen to compare the results obtained by each device with the fewest indirect effects. For the Bluetooth device, a complete basic system was bought from the Quuppa company (Espoo, Finland) including five Quuppa locators, each containing seven RFID antennas. For the camera system, four TRENDnet TV-IP310PI cameras (TRENDnet Inc., California, USA) were installed in the pen. Two near infrared devices were also installed in the middle of the ceiling to allow the TRENDnet cameras to see the pigs when the lights turn off in the station.

The results from the Quuppa device showed that the pigs walked approximately 2 km daily, in a pen measuring 16 by 10 feet. Some correlations are high as expected, for example there was a positive correlation between the distance travelled by the pig and its time in movement (0.54) as well as a negative correlation between resting time and the distance travelled (-0.54). The distance travelled is positively correlated with feed intake (0.28) and surprisingly negatively correlated with water intake (-0.38). Feed intake is also positively correlated with the time spent at the feeder estimated by the Bluetooth system (0.27), despite some difficulties to detect the signal close to the feeder as explained below. Water intake is positively correlated with the time spent at the bowl (0.46). The time spent at the water bowl was positively correlated with time in movement (0.23) and negatively with resting time (-0.23). In this project, some problems were encountered with the Bluetooth device. It is interesting to mention that this device had never been used in an environment as difficult as a pig finishing pen. The pigs moved a lot, and they tend to chew everything, including the tags fixed at each other's ears. Another problem encountered in the analyzed data with the Bluetooth system was the interference between the Insentec feeding system and the ear tags. The Insentec system is made completely with metal and prevents the Bluetooth system from detecting the tags. When the data was analyzed, it was impossible to determine the exact feed area because of this interference. It would also cause the same problem in another situation where a metal object in the pen would block the radio waves and alter the results.



Occupation (%) for each pixel in the pen spanning two hours during the day (left panel) and at night (right panel)

Some improvements were needed for both technologies tested. The Quuppa system had tags that were not custom made for pigs, and these tags had a battery life that was too short (maximum 2 weeks) for application on farm. The TrendNet cameras required a specific software package to automatically review the videos and observe the pig’s movements. Further research and development of this technology specifically for animal production and movement could allow for implementation of these promising tracking devices to track pig’s movements, behaviour and aid in early detection of problems.

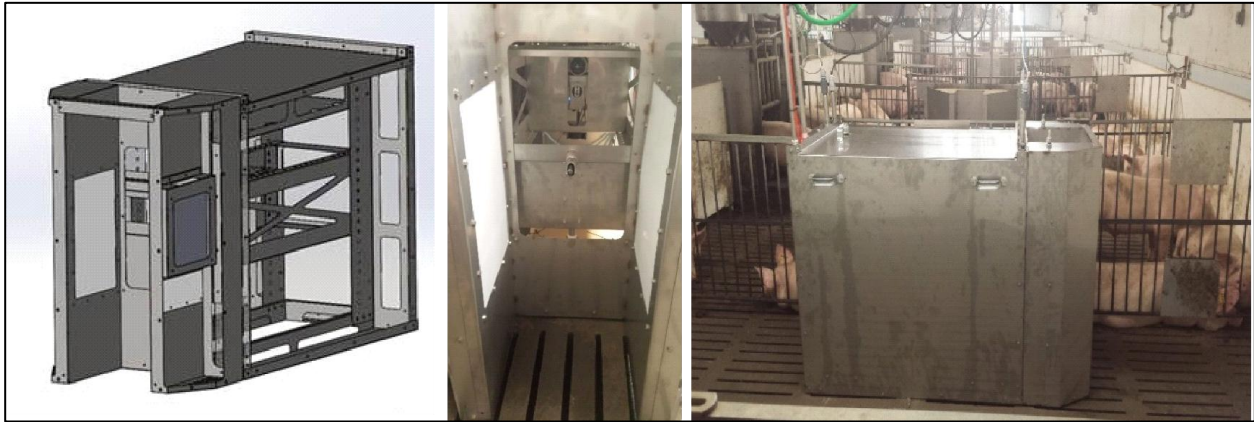
For more information, a detailed report is provided in Appendix 3.

2.1.4. Automated recording of pig body temperature using infrared technology in the eye area

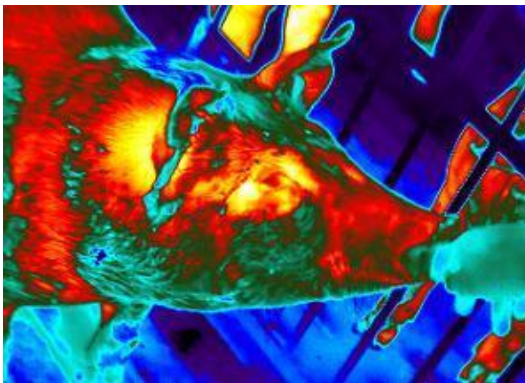
Infrared thermography (IRT) for medical applications was developed in the 1950s and has been adapted to many different areas since then. The value of the technology in pig production and research resides in its ability to provide temperature information on animals with a non-invasive method. There is, however, a need to define standard measurement sites in order to optimize the use of the IRT data as a predictor of health, stress and performance. The principal objective of this study was to apply infrared thermography on a commercial farm in order to estimate pig’s temperatures by using a spot near the eye. Some additional objectives were to evaluate good conditions of application, develop a method to automatically detect the pig’s eye and evaluate if data can be used when eyes are not visible on the image.

This project took place at the Deschambault Swine Research Station located in Quebec, Canada. The research station is a 360 pig nursery-finisher facility. It is owned by the Centre de développement du porc du Québec (CDPQ) and is equipped with sophisticated equipment to answer research questions from the pig sector. The project had two different phases, the first phase took place in summer 2015 and the second phase in autumn 2017. In 2015, the project consisted of taking manual and individual pictures of 50 different pigs to measure the temperature of their eye and ear. The camera was then placed in a pen for one week with 12 females to take pictures of them from above the water bowl. The second phase involved installation of two different infrared cameras in a pen with 8 castrated pigs for one day to take pictures of the pigs in order to

measure the temperature of their eyes. The use of two types of infrared cameras, Flir A325sc (\$11,000) and Flir AX8 (\$1,300) allowed for comparison to see which one would be better to use on commercial farms, and to evaluate if a difference in price and quality has a big impact on collected temperature.



In phase 1, the goal was to evaluate if the eye temperature is better and easier to measure than ear temperature. For the 50 pigs measured, the maximum temperature from the eye was 38.1°C and from the ear was 37.9°C. The mean temperatures were 36.1°C and 36.8°C for eyes and ears, respectively. Based on those results, it was possible to determine that maximum temperature is the data that works better. There was some variability (a standard deviation of 0.71°C), which shows that measurements from eyes and ears are both usable, even if eye temperatures are generally higher and closer to the body temperature. The A325sc camera was installed for one week during which 6000 images were captured. Of these, only 6.7% were selected based on the criteria that the ear temperature was seen. The ear temperature was used because the installation made it impossible to see the eye's temperature. The temperatures obtained were between 35.8 and 36.8°C.



In phase two, both FLIR cameras were installed with a new water bowl custom made for this project. The FLIR AX8 was programmed to take a picture every time a pig presented itself in front of the camera. Of the 600 photos taken on the single day, 46% were useable. The pictures were clear, and it was possible to see the eyes in the majority of them. The A325sc took clearer pictures, but it was not possible to program the camera with the same parameters as the AX8, so the A325sc took a picture every 5 seconds, whether there was a pig in the frame or not. With this set up, the camera took 18,000 pictures. The pictures were selected based on times where it was known that a pig was drinking. There was a mean difference of 0.8°C between the AX8 camera and the A325sc camera, with the A325sc having the highest temperature. The temperature difference between the two cameras was low, but constant. Displayed temperatures could probably be adjusted with a mathematical formula.

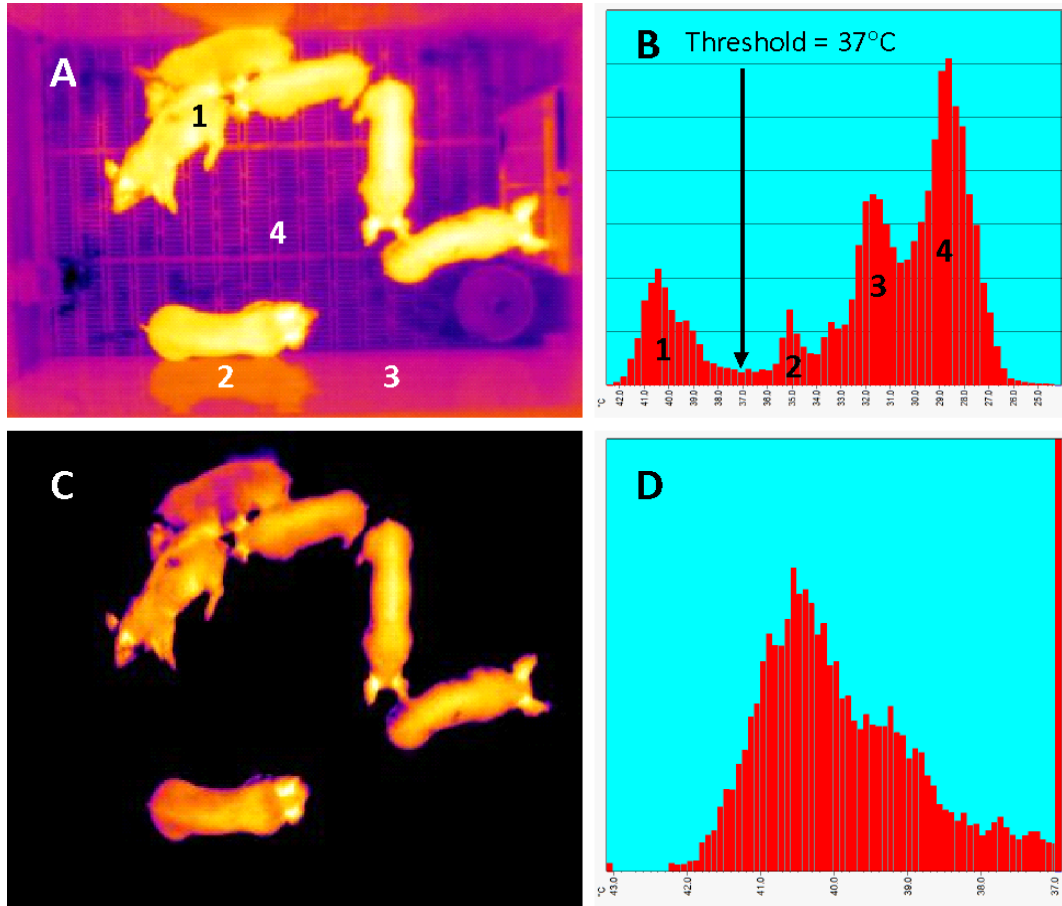
Promising results were obtained with this new water bowl designed specifically to hold the cameras securely and make it possible to adjust the height of the cameras. There are however some practical issues that need to

be addressed before implementation in commercial barns. For example, software should be enhanced so that it can compare images and temperature automatically as the process is time consuming when done by a person. The next step would be the use of the water bowl with infrared camera system over a longer period of time to monitor individual changes in body temperature, and to test and improve the reliability of the system.

For more information, a detailed report is provided in Appendix 4.

2.1.5. Application of infrared thermography

Infrared thermography (IRT) can be used for a variety of applications in the pork industry, such as the assessment of stress effects in live animals on subsequent pork quality, early diagnosis of disease, bio-surveillance of animal populations, ranking of animals for metabolic efficiency or assessment of acute pain. Research at Lacombe Research and Development Centre (LRDC) has focused on the development of a prototype, automated IRT technology platform, utilizing broad-spectrum infrared cameras linked to a computerized diagnostic program. The system can be used to remotely and non-invasively study thermal biometrics in cattle and swine. The automated, thermal scanning system at the LRDC can be used for projects involving detection of diseases, determination of feed-efficient animals, and for the assessment of metabolic reactions to stress and pain models in swine. Assuming that the aforementioned applications are scientifically established, the system could be further developed and expanded for use in commercial swine barns. Costs for this system are estimated to be approximately \$1/pig with a returned value of approximately \$20/pig (both health diagnostics and metabolic efficiency). The aim of this project was to develop approaches for using IRT to monitor pig performance, welfare, and carcass value. In order to develop these systems, the relationship between the radiated temperatures measured by the IRT and metabolic efficiency in normal and stressed conditions needs to be established. Additionally, IRT data are being used to assess whether metabolically efficient animals are more stress and disease resistant, whether growth performance and stress reactivity translate into significant carcass quality attributes and if IRT can be used to detect disease. For this project an IRT system has been installed at the LRDC pig barn to collect infrared thermography images and analyses are currently being conducted to evaluate these relationships.



Infrared image of a group of pigs and the temperature distributions before and after the application of a threshold temperature of 37°C: A) infrared image of pigs in pen, B) temperature distribution of pigs and pen, C) infrared image above threshold of 37°C, D) temperature distribution greater than threshold. In Fig 1.A and 1.B 1 = pigs, 2 = reflected radiated temperature, 3 = pen wall, 4 = floor.

Nursery pigs were monitored with the IRT system between the weights of 9 kg to 30 kg and split into two groups: medicated and non-medicated. Medicated pigs received additives in their feed for maintaining weight gain, stimulating appetite and preventing dysentery. The IRT data were collected in each pen for measuring the average temperature of the pigs, the maximum temperature of the pigs and quantifying clustering behaviour. In order to isolate the pigs in the IRT images, a threshold was applied so that only temperature data corresponding to the animals were isolated. Among the nursery pigs, medicated piglets consistently had a higher average and maximum temperature than the non-medicated pigs. Both groups of pigs also had clear temperature change patterns throughout the day, where there was a notable temperature decline between 5 and 9 am, with temperatures recovering by 1pm. Clustering behaviour was similar between both the medicated and non-medicated pigs and was associated with changes in the radiated temperature throughout the day. From the preliminary analysis of these data it was apparent that the different cameras used for data collection and the experimental replicates had an effect on the analysis. This would be

an important consideration in the application of an IRT system as data are not directly comparable without adjustment.

In a separate trial, grower pigs were monitored using the IRT system from approximately 30 kg to 110 kg. In this trial, feed intake was monitored using a recording system that identifies individual pigs with radio frequency identification tags. The grower pigs were subjected to a one day feed withdrawal at 35, 65 and 105 kg. Saliva samples were collected and analyzed for cortisol content prior to and during feed withdrawal and again one day after feeding resumed to monitor the stress response. The stress response data are being used to analyze the relationship between the radiated temperature and stress.

In the grower pig trials, several young pigs were able to fit into the feeders at once making it difficult to analyze the IRT images for individual animals. However, it was observed that examining the total amount of pixels above the threshold temperature for a pen may give an indication of growth performance. These data corresponded well with a typical growth curve of pigs. The stress data and the carcass data analyses are underway. However, the preliminary results reveal several practical considerations for IRT monitoring systems and demonstrate interesting alternative applications for pig monitoring.

For more information, a detailed report is provided in Appendix 5.

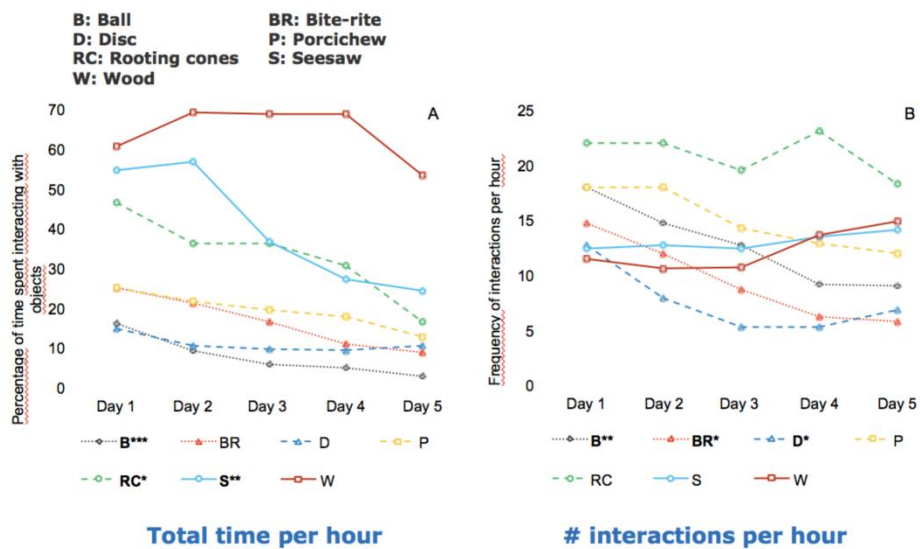
2.1.6. Use of accelerometers to assess pig activity levels



Behavioural studies of pigs toward objects often rely on real-time analysis or on video analysis. These two methods are associated with a risk of human subjectivity and variations of results between observers. They are also time-consuming, which can lead to high labour costs and limit the number of observations that can be analyzed. Some automated recording techniques have been tested in the past, but they are only reliable for some specific objects. A more versatile technique of automation could rely on accelerometers, as they have been used for many years for multiple applications. The negative impacts of barren pens on the welfare of pigs can be reduced by providing enrichment objects, on which pigs can express some species-specific behaviours. Enrichment objects are practical and can be implemented where particulate enrichments, such as straw, can't be supported by the slurry system. Many studies have compared different objects, focusing notably on their characteristics and dispositions, but many

questions remain. In this regard, more research is needed to identify some key indicators of effective and low-cost enrichment objects. Accelerometers could be used to facilitate these types of studies as an alternative to video recording. The overall objective of the project was to validate the use of accelerometers as tools to investigate pig behaviour as they interact with enrichment objects. Evaluating the quantity and quality of these interactions can give us insight into the level of welfare they experience. For instance, the provision of environmental enrichment has been shown to affect various indicators of welfare, such as improved health and performance, increased play and exploration, as well as reduced aggression, tail biting and fear of humans.

In a first trial, seven different objects (boomer ball, plastic ring with wood, bite rite, see saw, rooting cones, porcichew, disc with chains) were individually put in barren pens for five day periods. The experiment was conducted at the Deschambault Swine Research Station in Quebec, Canada. The station is a 360 pig nursery-finisher facility owned by the Centre de développement du porc du Québec (CDPQ) and is equipped with sophisticated equipment used to answer research questions from the pig sector. A fully randomized experimental design was used, repeating four times for every treatment. Pigs were castrated crossbred males, housed in groups in fully slatted pens measuring 2.6 m x 4.9 m. There was an average (\pm SD) of 12 ± 3 pigs per pen, weighing 61 ± 9.2 kg on average during the recording periods. Every object was coupled with an accelerometer provided by Quattrium Inc. (WIDL1000 - Wireless Inertial Sensor/Data Logger, QC, Canada). They recorded at a frequency of 4 Hz and had a wake-up threshold of $1.25 \times g$ to start the recording. Simultaneously, each pen was video-recorded with a camera (TRENDnet: model TV-IP310PI, Torrance, CA, United States) fixed on the ceiling. After five days of recording, both sets of data were retrieved for each object before the beginning of the next recording session. Behavioural analyses were based on time spent interacting with the object (calculated in terms of duration, rounded to the nearest second) and frequency from day 1 to 5, as seen on the video recordings. An interaction was defined as any intentional object-directed behaviour performed with the snout, head or legs (pushing, hitting) and with the mouth (chew, bite, pull, shake). Four timeframes of one hour each were analyzed every day from video recordings.



The accelerometry analysis was performed on Scilab 5.5.2 (Scilab Enterprises S.A.S, Orsay, France). An algorithm was developed to first synchronize data with the video recordings. Then, the algorithm filtrated and classified data, based on predetermined metrics related to the amplitudes and patterns of accelerations. Results from this process were compiled in the same way as the video analysis and then compared. The degree of agreement between both analyses was evaluated with a concordance correlation coefficient (CCC). Only five objects were kept to evaluate the performance of the algorithm due to numerous problems with the accelerometers. The CCC between video analysis and accelerometry analysis varied from one object to another, ranging between -0.02 and 0.05 for interaction frequency and between -0.01 and 0.27 for interaction time. Those results were inconsistent between objects but also between different days for the same recording period for an object.

In a second trial, three objects from trial one were used to evaluate the effect of cleanliness (objects that were more prone to get soiled and easy to clean) and a new object was used to evaluate the effect of renewability (a piece of rope). Two of the same objects were presented at the same time for five consecutive days in the same barren pen, following a randomized complete block design and repeating four times for each of the four treatments. One object was not cleaned or replaced for five days (control object) whereas its duplicate was cleaned or replaced daily (treatment object). As in the first trial, pigs were castrated crossbred males and were housed in groups in fully slatted pens measuring 2.6 m x 4.9 m. The average number (\pm SD) of pigs per pen was 13.5 ± 1 , weighing 47 ± 7 kg on average during the recording periods. Each pen was video-recorded with a camera (TRENDnet: model TV-IP310PI, Torrance, CA, United States) fixed on the ceiling. Behavioural analysis based on video recordings was the same as in the first trial and was done for both objects in the same pen. Data from each object were compared to its duplicate every day, looking for a preference between control and treatment object at any given time.

To be acceptable, the CCC should have been 0.75 or higher (a subjective value determined from previous applications seen in the literature). The low CCCs obtained in this study can be attributable to some key factors. Among them, the accelerometers failed to record numerous interactions due to the wake-up threshold. This threshold has shown to be successful to extend the battery life for five days and to limit the quantity of recorded data filling up the memory. However, since an acceleration higher than $1.25 \times g$ had to be recognized to wake an accelerometer up and start the recording, many soft manipulations of the objects have been left undetected. Also, the recording frequency had to be set at 4 Hz in this experiment because any higher settings would have filled the memory capacity too quickly. However, this has proved to negatively affect the efficiency of the algorithm since quick movements could often not be recorded at their peak g values, weakening the classification performances of the algorithm. Altogether, the methodology developed in this study was unsuccessful to create a reliable behavioural analysis based solely on accelerometry data.

On the other hand, a complete behavioural analysis based on video recordings has been done for the first trial. Time spent on objects was affected by object \times day ($P < 0.05$) and the frequency was affected by objects ($P < 0.0001$) and days ($P < 0.001$). The object that had the greatest overall interaction time was a piece of wood ($P < 0.05$) but that preference was not seen in terms of interaction frequency. All objects have been manipulated to different levels, showing the importance of some characteristics (e.g. rootable and chewable) and dispositions (e.g. fixed on the floor) to raise the level of attractiveness. Interaction time declined significantly throughout the five days for some objects, but the piece of wood was the least affected by time. In this research, analysis based on manipulation time seemed to be more representative of the interest toward the enrichment objects than when it was based on the frequency of manipulation. For instance, a ball and the piece of wood showed similar mean frequencies of interactions (12.7 for the ball and 12.1 for the wood) but on average, pigs spent over eight times as many seconds interacting with the wood (22 seconds for the ball vs 189 seconds for the wood). In addition, mean duration of interaction changed differently over time between objects, the interest for the ball declining a lot more rapidly than for the piece of wood.

Pigs seemed to like the piece of wood because of its destructible nature, which can also sustain the interest in time. Objects presented on the floor were more manipulated if they were fixed than mobile. When fixed, pigs could manipulate them in a more vigorous way. In addition, pigs could use the area where the fixed object was as a resting area, increasing the manipulation time and the cleanliness of the area and the object.

Suspended objects were more manipulated if they were made from a more flexible and chewable material (e.g. a rope or rubber sticks versus hard plastic and chains).

No clear preference has been noted from cleaning or replacing for any object for neither the interaction time nor the interaction frequency. Control and treatment objects have been manipulated to similar extents and those manipulations declined comparably in time for both objects. Only the replaced rope seemed to show no reduction of manipulations from day 2 to day 4 but this effect was not statistically significant. With the aim of providing a choice of practical enrichment objects to farmers, this study shows that a daily wash of soiled objects or a daily replacement of destructible objects is unnecessary.

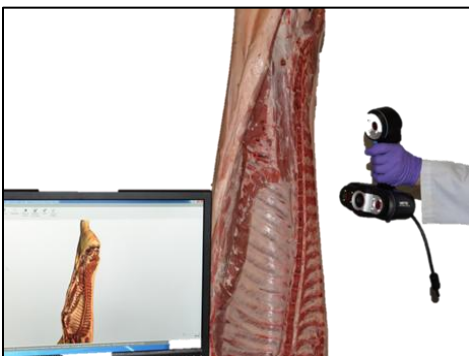
Behavioural analysis based on accelerometer data was inconclusive. Some key problems have been pointed out to improve the results if any similar application is studied in the future. Behavioural analysis based on video recordings showed different levels of interest toward enrichment objects and showed that cleaning or replacing an object daily does not change the interest of the pig for that object. The automation of behavioural analysis using accelerometer in enrichment objects has some potential but much more must be done to improve the results compared to a video analysis.

For more information, a detailed report is provided in Appendix 6.

2.2. Carcasses

2.2.1. Use of 3D vision systems for rapid and objective hog carcass quality assessment

In packing plants, the value of hog carcasses is currently predicted using simple measurements, at a standard site, which were developed many years ago and are also used in the payment system. There are currently huge opportunities to use computer vision systems to assess more accurately not only carcass weight and leanness, but also the weight and lean yield of each carcass cut, allowing for efficient carcass sorting and valorization. There is a need for tools that could be used in commercial conditions in order to evaluate carcasses in a very objective way. New approaches using 3D vision for carcass evaluation have been developed at AAFC-Sherbrooke in recent years, and proved to be very accurate. The objective of this study was to test and validate a 3D scanner as a tool to assess carcass/cuts weight and leanness, and to calibrate the algorithms used to predict carcass quality.

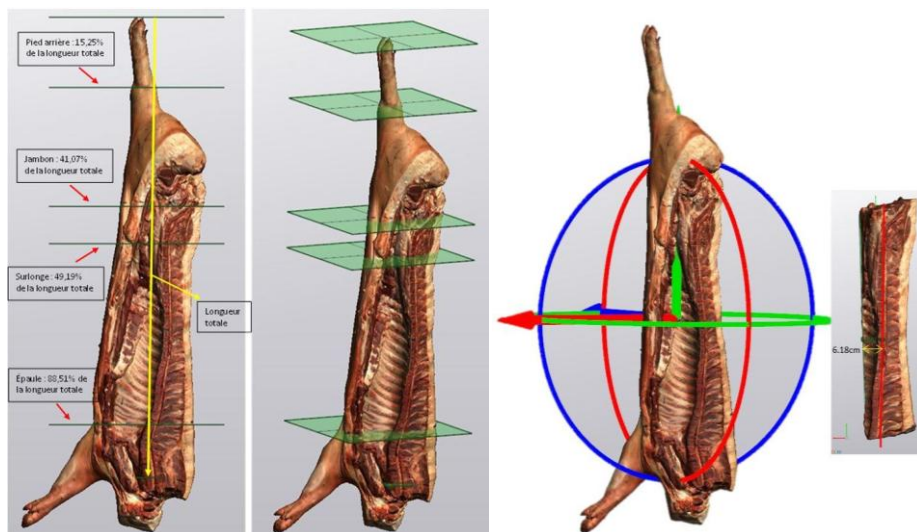


A portable 3D scanner (GoScan50 by CreaForm) was tested on 10 half-carcasses and gave very good results in terms of 3D scanning quality, repeatability, colour reproduction and speed. The software package provided with the scanner allows some basic measurements and 3D model management. In 2017, 200 half-carcasses were sampled in Quebec packing plants in order to provide a variable data set representative of carcass conformation and composition found in commercial plants. Each half-carcass was scanned with the GoScan50 and the Vxelement software package from CreaForm.

Various measures were also collected including temperature, carcass length, sex, number of ribs, conformation, backfat thickness and bio-impedance. The carcass was split into primal cuts (loin, ham, shoulder, belly) and each cut was then scanned independently with the GoScan50

scanner. The carcass was then fully cut into commercial cuts according to the Canadian Pork Buyer's Guide (2011) and each cut weight was recorded. A chop was collected at the 4th last rib and digitized using a 2D scanner. Most commercial cuts were ground and their composition was analyzed using the FOSS FoodScan. All 3D models of half-carcasses and primal cuts were stored and are being analyzed using various linear and volume measurements. Virtual cuttings are developed on 3D models. The study provided very detailed data on 200 half-carcasses for carcass characteristics, primal and commercial cuts characteristics, which are very valuable considering the sampling was done to provide good variability and also commercial representativity. Data analysis of 3D models is underway and algorithms are developed and automated to provide prediction models using 3D scanning. This will allow the predicting of weights for primal and commercial cuts as well as detailed cuts, meat weight (fat and lean) and lean content.

The 195 carcasses kept for the analysis (95 females and 100 castrates) weighed between 83.8 and 117 kg, with backfat thickness ranging from 7.6 to 30.6 mm. The number of thoracic vertebrae ranged from 14 to 16 and the number of ribs from 14 to 17, while all hogs had 7 cervical vertebrae and 6 lumbar vertebrae. Loin eye area ranged from 39.6 to 78.6 cm². Regarding primal cuts, the average weight was 12.5 kg (10.0-14.8) for the shoulder, 12.0 kg (9.4-14.0) for the ham, 12.3 kg (9.5-15.0) for the loin and 8.7 kg (6.3-11.0) for the belly. The fine composition of each half-carcass was determined, showing an average carcass lean proportion of 51.7 % (43.4-60.0), fat proportion of 23.2 % (13.4-33.2), bone proportion of 6.5 % (5.2-8.2) and skin proportion of 3.4 % (2.4-4.5). Many other traits were collected on each half-carcass, showing that the carcass sample available for the study was very variable in terms of size and composition, which is necessary for this area of research.



Standard positioning of cutting planes in virtual carcass cutting. Carcass rotation and standard cutting procedure to split loin and belly.

Using this data set, 3D models were processed with the objective of developing algorithms to predict weight and composition of the carcass and each primal and commercial cut. Two main approaches were used: simple regression and 3D model shape recognition analyses using specific statistical analyses. In both cases, 3D models of carcasses were first processed to perform virtual cutting. This step was performed using the VXmodel software provided with the GoScan50 device. The first step consisted of aligning 3D models of carcasses so that they are all presented in the same position in the XYZ space. Secondly, a 3D model

cleaning was necessary, using automatic and manual processes, in order to remove small defects and missing areas on 3D models. Finally, a standard virtual cutting process was applied to each carcass, using specific landmarks on the carcass and applying straight cutting lines to split the foot, ham, sirloin, shoulder, loin and belly. Additional virtual cutting was applied to the shoulder to define the five further cuts (picnic, hock, butt, front foot and jowl).

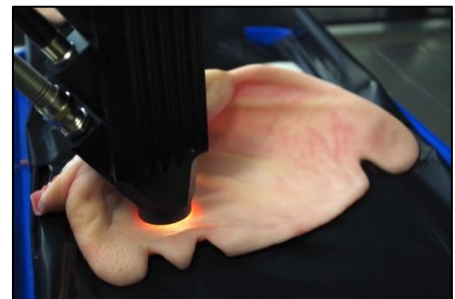
An innovative prediction method based on 3D shape recognition and deep learning approaches (RM3D) was developed. With the RM3D method, preliminary results showed mean prediction errors of 0.38kg and 0.51 kg for ham and loin weight prediction, respectively. For the eleven commercial cuts studied, using RM3D leads to lower prediction errors compared to a prediction simply based on the half-carcass weight. The standard prediction error ranged from 3.2% to 9% of the actual cut weight. For the prediction of overall carcass composition, the best prediction accuracy was found for lean content, with a mean standard error of 0.968 kg (4.1%).

Additional work is underway to compare RM3D predictions with predictions based on linear measurements on virtual 3D models of half-carcasses. More validation and automation are still required to reach a fully automated 3D vision system to assess carcass quality. For commercial application, a compromise must be found between image quality and scanning speed.

For more information, a detailed report is provided in Appendix 7.

2.2.2. Using near infra-red spectroscopy to predict carcass traits from pig ears

Hog carcasses can be classified into lean yield index categories based on warm weight, backfat and loin depth measurements used to assign payments to producers. In addition to lean yield assessment, adipose tissue content and fatty acid (FA) composition could improve evaluation of carcass merit and allow further sorting. FA composition contributes to the nutritional value and processing ease of pork. Measuring fat content and FA composition is time consuming and costly, requiring fine carcass cutouts and solvent extraction of lipids and gas chromatographic analysis. Measuring the iodine value (IV) of pork fat is a more rapid way to determine the degree of FA unsaturation. Near infrared reflectance spectroscopy (NIRS) is a sensitive, fast, and non-destructive technology that has shown great potential for predicting the FA profile of pig subcutaneous fat and for classification of pigs according to breed and feeding regime. After proper calibration using a representative set of samples, NIRS technology enables minimally trained personnel to routinely collect data and simultaneously analyze samples. The aim of this project was to determine if NIRS data collected from pig ears could be used for classification of carcasses according to various carcass traits. This approach was tested in ears removed from pig carcasses and with measurements taken from the ears of live pigs four days prior to slaughter.



Using NIRS data collected from the ear has been shown to be effective for predicting total fat in humans. The ear was selected for predicting total fat in humans as this region gave the clearest NIRS data. Applying this approach in live pigs would allow inexpensive and rapid phenotypic prediction. Classification of phenotypes related to carcass merit could be very useful for the purposes of customizing diets in pigs which

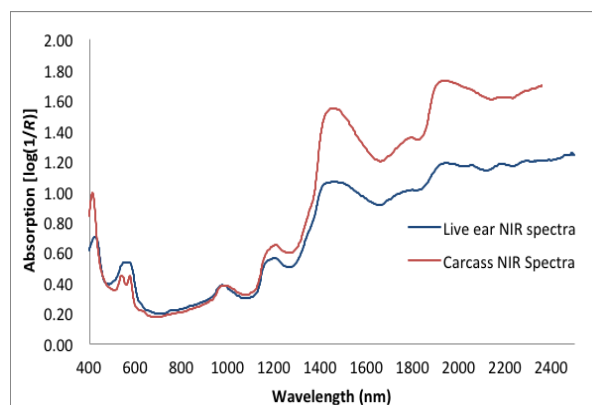
are under or over finished and potentially for genetic selection. Pigs (n=195) from several genetic backgrounds, genders, diets and slaughter weights were raised at the Lacombe Research and Development Centre (LRDC) in Lacombe, Alberta. Pigs were sired by Duroc, Lacombe and Iberian boars and were fed a typical Western Canadian commercial diet (control) or a high-oleic or high linolenic diet for the last three weeks prior to slaughter, in order to create variability in carcass and fat composition for the trial.

Carcass traits were measured on pigs and then each carcass was assigned a classification based on the value of these traits. The thresholds for the classifications were assigned with two approaches: the first approach was based on the median value of the carcass traits, and the second on classifying only more extreme carcasses. For example, with the first approach all carcasses were classified as having high or low total fat, in the second approach, only the carcasses with extremely high or low fat would be classified.

With the reference classifications defined, a statistical model was developed using the NIRS data from the carcass ears and the classifications were estimated. From the carcass ears, most of the carcass traits except Omega-3 and iodine value were correctly classified for both thresholds (>80% correct classifications). The accuracy of classification was higher for most carcass traits with the classification based on extreme values. As such, obtaining NIRS from the ears of pig carcasses could potentially be used for sorting carcasses prior to fabrication. However, when these models were then applied to the NIRS data collected from the live pig ears, the accuracies were substantially lower (<50% correct classification for most traits).

Therefore, this approach was successful for classifying total carcass fat, total subcutaneous fat, loin subcutaneous fat, fat depth, lean depth, lean meat yield, mono-unsaturated fatty acids, poly-unsaturated fatty acid and omega-6 fatty acids using data collected on the carcass ears. However, these models were not successful for classifying any of the measured traits in live animal ears.

In the initial phase of this study, where NIRS data was collected on pig ears removed from carcasses, the laboratory setting allowed strict control of parameters related to the NIRS data collection. For example, the ears were clean, hairless and held against a flat surface which allowed high quality data collection. In the live pigs, despite being sedated, it was noted that the ears moved due to breathing and twitching of the pigs. As well, the live pigs had hair on the ears and residual dirt which was not easily removed. These factors likely introduced noise in the NIRS data and therefore reduced the accuracy for classification.



Sample NIR spectra collected from the ear of the same pig 4 days prior to slaughter and after slaughter



The population where the live ear data was collected were pigs with representative commercial genetics (Yorkshire × Landrace × Duroc) and had a low range in carcass traits relative to the calibration population, which had more diverse genetics. As such, many classifications using the thresholds established with the calibration population were not well represented. In order to continue assessing classification using live animal NIRS data, further analysis and improvements to the NIRS data collection are required. Alternative approaches to the analysis of NIRS data

could include filtering NIRS data to only include wavelengths that explained the most variability in carcass traits and different statistical transformations of the NIRS data. Additionally, continuing to collect NIRS data on live animals will create a larger dataset to evaluate classification models. In terms of improving the quality of the NIRS data collection, different locations on the ear should be evaluated, along with shaving the ear prior to data collection and placing a clamp on the ear to define a consistent location. While NIRS may not be capable of sorting live animals from ear scans using the approaches evaluated in the present study, it could be applied for carcass classification purposes by meat packers collecting NIRS data from carcass ears.

For more information, a detailed report is provided in Appendix 8.

2.2.3. Determination of age of bruises on pig carcasses

The presence of skin lesions is an animal-based criterion in the animal welfare assessment and an economical issue resulting in economic loss due to carcass downgrading and additional handling for carcass inspection. Lesions are commonly assessed on the carcass using pictorial standards or by giving a score based on their number and type. However, no reliable technique exists for the determination of the age of skin lesions in pigs. As injuries can occur at any moment during the marketing process, knowing the time of infliction may be very helpful to reduce or prevent their occurrence. The objective was to develop objective methods to count, categorize and determine the age of bruises on pork carcasses on the slaughter line.



This objective was achieved through the study of the lesion healing process *via* histological and histochemical analyses of lesions at different stages of the healing process. The most common method to determine the age of bruises is through visual evaluation of colour, which presents some degree of subjectivity. This study involves the identification of the cytokines involved in wound healing, the testing of tools to mimic a bite- or claw-type lesion on the pig skin and bioptic techniques for skin sampling, and the validation of analytical kits for cytokine analysis in tissues. A total of 100 barrows were delivered to the AAFC experimental finishing unit in Sherbrooke, Quebec. Pigs were allotted to 8 pens of 12 pigs each. Groups of 2 different pens were mixed 4 times (at the farm 1 and 2 days before slaughter, in the truck and in

lairage at the plant). Lesions were noted on each live animal before and after each mixing and followed through the study by counting and identifying them. Pictures of skin lesions were also taken in the cooler and assessed by objective (Minolta colourimeter) and subjective colour methods, number and severity (scores).

The spectrophotometer colour measurements allowed identifying <7h or >25h old lesions. These results were validated by the variation in the expression of 6 genes involved in the lesion healing process over time. The analysis of skin inflammation was also able to detect a difference between <7h and >25h old lesions. In addition to this ongoing experimental work, some follow-up is underway with Candido Pomar's team in relation to the 3D carcass evaluator, which also includes a camera able to collect high definition colour pictures that will be used to detect, count and classify bruises automatically using image analysis. Results indicated that visual colour observation was not sufficiently accurate to discriminate lesions by time of infliction ($P > 0.10$), while the spectrophotometer variation in ΔL^* and Δa^* values allowed the identification of < 7 h or > 25 h old lesions ($P < 0.05$). Similarly, the expression of CCL2, IL6, ITGA3, MMP1, and SERPINE1 genes was higher ($P < 0.05$) in < 7 h old lesions, while TIMP1 gene expression was higher ($P < 0.05$) in > 25 h old lesions. As for the histological analysis, the severity of inflammation was correlated with the age of the lesion (lower score in <7 h old lesions and higher score in > 25 h old lesions; $P < 0.05$). The spectrophotometric colour assessment of the carcass lesions at slaughter appears to be a reliable method to discriminate between fresh and older lesions on the carcass at the abattoir.

Based on the assessment of pre-slaughter carcass lesions in this study, the spectrophotometric colour assessment of the lesion on the carcass appears to be a suitable and rapid technique for discriminating between fresh lesions (< 7 h) occurring between loading and slaughter and old lesions (> 25 h old) originating from the farm. As for the histological analysis, the severity of inflammation was correlated with the age of the lesion. The analysis of gene expression and the inflammation response in the skin lesion at slaughter supported the spectrophotometric colour results in this study. This relationship shows the potential of these techniques for the validation of on-line objective determination of the lesion age. There may also be some usefulness of this type of assessment using the pig as a model for scientific purposes in human studies and for forensic investigation.

For more information, a scientific paper is provided in Appendix 9.

2.2.4. Application of rapid methods for non-invasive assessment of pork quality - Nuclear Magnetic Resonance (NMR)

Conventional methods for the determination of fat consistency such as fat hardness, fatty acid composition, and iodine value are generally laborious, time-consuming, and destructive to the samples, and therefore not suited for on-line applications. This work investigated the possibility of determining these parameters from pork back fat using time-domain nuclear magnetic resonance (TD-NMR).



Solid fat content (SFC), which is an indicator of fat consistency, was measured by TD-NMR at temperatures between 0 and 45°C. The SFC measurements were then correlated to fat hardness, fatty acid composition, and iodine value. A total of 230 samples from pigs were analyzed in three experimental series. Using simple linear regression (SLR) with parameters extracted from melting curves as well as SFC measurements at ~0°C, the best correlations ($|R| > 0.7$) in all series were obtained for linoleic acid and iodine value. By performing leave-one-out cross-validation and partial least squares regression (PLSR),

calibration models were established using SFC measurements at all temperatures. The modeling results were in general better than with SLR, and the best calibration results were achieved in series 2 for iodine value with calibration correlation coefficient R_C and root-mean-squared error of calibration (RMSEC) of 0.92 and 2.37%, respectively, and 0.87 and 1.31% for linoleic acid.

NMR signals combining free-induction decay and Carr–Purcell–Meiboom–Gill echoes were also acquired at 0°C on raw fat (series 3). Again, calibration models were established by PLSR, first with previously determined solid fat at ~0°C as well as raw fat composition determined by traditional methods and also with traditional parameters such as fatty acid composition and iodine value. In the first case, the best calibration results were achieved for total lipid content with R_C and RMSEC of 0.77 and 0.0263 g, respectively, and 0.76 and 0.0374 g for solid fat at ~0°C. In the second case, the best calibration results were achieved for stearic acid with R_C and RMSEC of 0.99 and 0.16%, respectively, and 0.77 and 1.43% for linoleic acid.

This work investigated the possibility of determining meat composition in fresh, thawed, and thawed–ground pork loins by using time-domain nuclear magnetic resonance (TD-NMR). By performing leave-one-out cross-validation and partial least squares regression, calibration models were established using NMR signals from 100 samples in two series. These signals yielded superior predictive performance for quantifying water and protein content than lipid content. For thawed samples, reducing the sample size impaired the lipid content determination. The modeling results were better for thawed–ground samples than for fresh samples. The best calibration result for thawed–ground samples was achieved with calibration correlation coefficient R_C of 0.9992, 0.9500, and 0.9781 and root-mean-squared error of calibration (RMSEC) of 1.68, 1.77, and 2.77 g for water, lipid, and protein content, respectively.

Another calibration was performed on a smaller scale (30 samples) using weighed amounts of chicken breast and pork back fat as lean and fat components, respectively. R_C of 0.9995 and 0.9966 and RMSEC of 1.29 and 0.80 g were obtained at 4°C for the lean and fat components, respectively, and comparable numbers were obtained for analyzed water, lipid, and protein content. Better calibration results were obtained with a shorter time between sample preparation and NMR analysis. New samples (8) were analyzed to validate the performance of the calibration. The explained variance of prediction R_P^2 was slightly reduced for the lean component compared to the explained variance of cross-validation R_{CV}^2 ($R_P^2 = 0.9790$ vs. $R_{CV}^2 = 0.9978$), but was lower for the fat component ($R_P^2 = 0.6751$ vs. $R_{CV}^2 = 0.9677$), likely due to the different composition of the fat used for sample preparation of the calibration and validation batches. The use of lard is recommended as the fat component for further calibration using this phantom sample method.



For meat composition, either as lean and fat components or as water, lipid, and protein content, the actual method was validated with test samples for the calibration done using the 6-cm probe (samples between 60 and 230 g). The whole process, calibration and validation, could also be repeated on the large 11-cm probe, for which samples up to 900 g could be analyzed. The use of lard is recommended as the fat component for subsequent calibration using weighed samples, in order to eliminate the variability due to pork back fat composition. Temperature stabilization was more important than time between sample preparation and NMR measurement. The long-term objective is to be able to objectively, rapidly, and non-invasively orient meat products, either fresh or processed, toward their respective markets based on on-line estimates of their composition in real time.

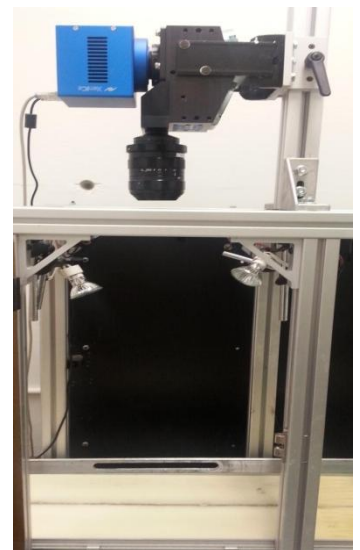
TD-NMR SFC measurements could statistically be used to predict fat hardness measured with a durometer, proportion of some major fatty acids, and iodine value. When using SLR, it was shown that building the whole melting curve is not necessary, since a single SFC measurement at $\sim 0^{\circ}\text{C}$ gave equivalent or better correlations. As expected, PLSR performed better in general than SLR, indicating that there is useful information in SFC measurements at higher temperatures, although at the expense of longer analysis time. Even though the SFC measurement itself is rapid (6 s per sample per temperature), pure fat is required for the AOCS method [2], and an alternate NMR approach bypassing the lengthy purification procedure gave encouraging results in order to obtain a usable method for soft fat assessment. The new procedure tested involved measuring the NMR signal based on T_2 relaxation on raw fat at 0°C . From the results obtained, it is suggested for future work to monitor a combination of T_1 and T_2 relaxation instead which appears necessary to better discriminate between liquid fat and water protons.

For more information, a detailed report is provided in Appendix 10.

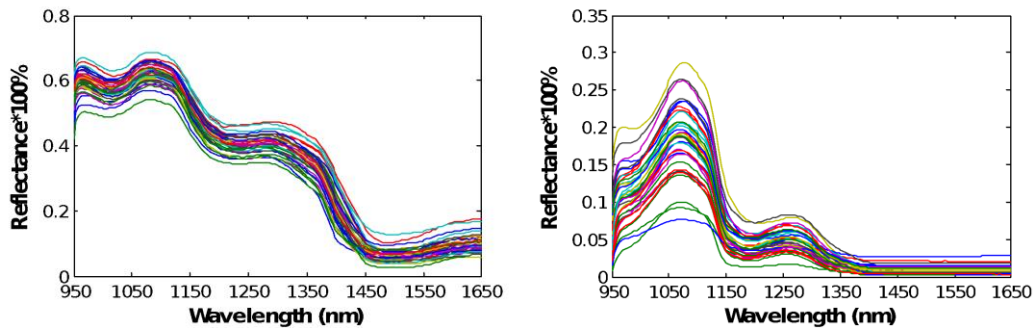
2.2.5. Application of rapid methods for non-invasive assessment of pork quality - Hyperspectral Imaging for marbling assessment

Conventional methods for determination of intramuscular fat (IMF) content in meat are generally laborious, time-consuming and destructive to the samples, which therefore are not suited for on-line applications. This work investigated the possibility of determining the IMF content in both frozen and thawed pork loins from the longitudinal (naked or internal) section by using near-infrared hyperspectral imaging (HSI). In this work, both the spectral information and image texture information were extracted by mean spectra and gray-level co-occurrence matrix (GLCM) algorithms, respectively.

The mean spectra extracted from both frozen and thawed pork samples were pre-processed using different methods. By performing leave-one-out cross validation and partial least squares regression (PLSR) modeling methods, the calibration models were established using original mean spectra, pre-processed mean spectra and GLCM parameters. The obtained results showed that for both frozen and



thawed pork samples, the models established using mean spectra gave more accurate calibration results than those obtained using GLCM parameters. Thus the extracted GLCM parameters yielded inferior predictive performance for quantifying IMF content of both frozen and thawed pork samples. Using both the original mean spectra extracted and the pre-processed mean spectra, the modeling results were better for frozen samples than for thawed samples. The derivative transformations outperformed multiple scattering correction (MSC) method in improving the modeling performance, and the best calibration result for frozen samples was achieved with RC and RMSEC of 0.94 and 0.35%, respectively, by the pre-processed mean spectra of MSC + 2nd derivative + SG smoothing, and 0.80 and 0.62% for thawed samples by the pre-processed mean spectra of MSC+1st derivative.



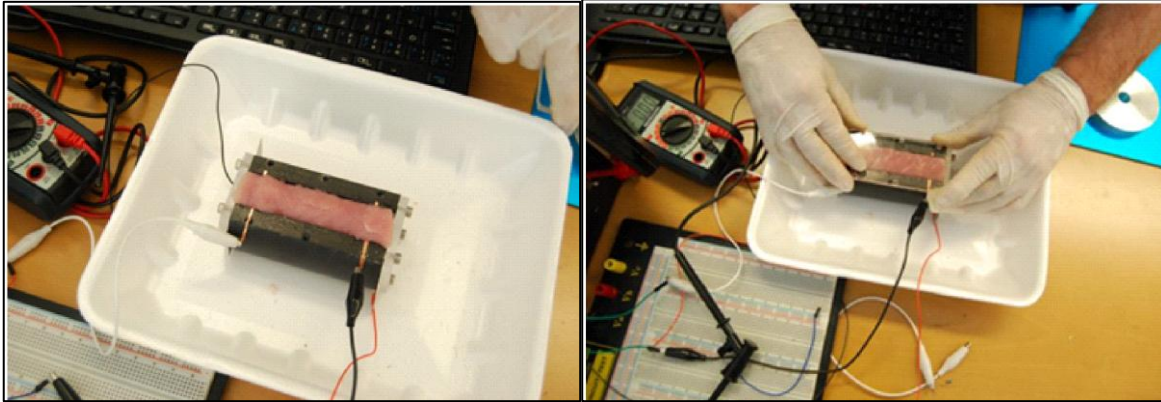
For more information, a detailed report is provided in Appendix 11.

2.2.6. Use of quick, non invasive technology to predict marbling in fresh pork loins

Intramuscular fat (IMF) is a key meat quality trait for most export and domestic markets. In recent years, there has been a lot of research done on opportunities to control IMF (decrease or increase) in pork meat using genetics and feeding strategies. One of the current challenges is that loin marbling is not easy to assess without actually cutting the loin to score it (visually or using computer vision). There is a need for technologies in commercial conditions that allow for the prediction of loin marbling without cutting the loin. Many trials have been carried out to predict loin marbling by visually scoring the outside surface of the deboned loin, or by scoring the loin on one of its end cut sections, but the accuracy is very low. There are ways to actually access internal compositional information by using meat and fat electrical properties such as inductance. Recent results suggest that induced current and resistance measurement could provide good predictions for loin marbling or intramuscular fat. This is used in several areas and can be included in a device for quick, non-invasive, non-contact measurements.

The objective of this study was to test a technology to predict marbling levels in uncut loins. The project was led by the Centre de développement du porc du Québec (CDPQ). For testing, a small-scale lab prototype device was designed by an engineering company (Nyx Dimensions) to collect measurements based on the induced current approach and was tested using materials of various natures and compositions. Results were encouraging and lead to a measurement cell designed specifically for soft tissues such as meat samples. Unfortunately, this device couldn't be contactless due to technical limitations. A measurement cell was designed to measure meat samples of about 100 grams. It was composed of a plastic frame, two stainless steel plates and two copper strips positioned at 1 cm on each side of the cell. The inside volume of the cell was 10*2.5*2.5 cm. Loins were sampled in a Quebec packing plant to provide samples with a large

variation of marbling levels. In each loin, three meat samples were collected using a custom knife at the front, middle and rear of the *longissimus dorsi* muscle. A total of 65 meat samples were used in the analysis, with an average weight of 92 g (68 to 136), average intramuscular fat content of 3.04 % (0.74 to 7.14) and 2.57 points average marbling score (1.0 to 4.25). Drip loss, which was assumed to affect electrical properties of the meat, ranged from 0.74 to 13.19 with an average of 4.65%.



Resistivity measures were carried out on each sample, after current induction, every 100 milliseconds for an average of 21 readings per sample. The average resistivity was 384.85 ohms (205.86 to 976.56) on average for the 65 samples available. Simple statistics were computed on the data set and showed a good correlation between IMF and marbling score (+0.82), confirming the wide range of marbling in meat samples. Resistivity results were found to be negatively correlated with drip loss (-0.41) but not significantly correlated with marbling or IMF.

More research is required in this area and some technical/equipment issues have to be solved before reaching a safe, contactless prototype.

For more information, a detailed report is provided in Appendix 12.

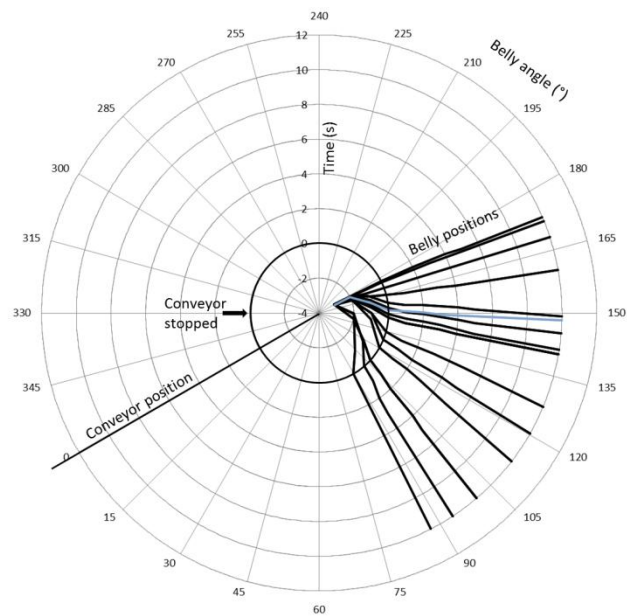
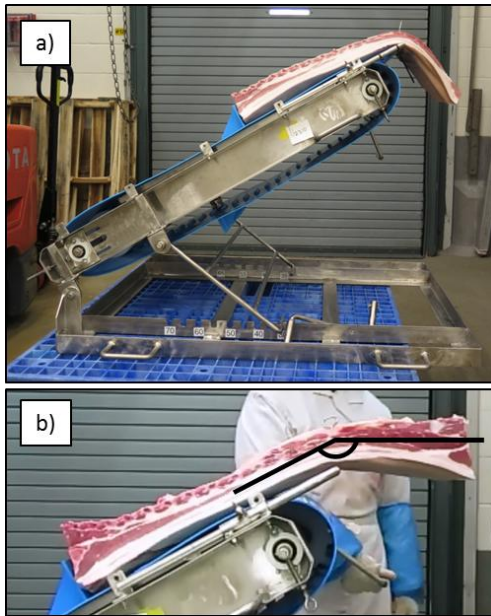
2.2.7. The Belly Sorter – Sorting bellies on degree of firmness

In Canada, since approximately 2010 the value of the pork belly has been increasing. The pork belly primal has exceeded the value of the next most valuable cuts, usually the butt or the loin, by 1.25 to almost 2.5 times, and in 2017 its value frequently exceeded the value of the ribs, which have long been the most valuable cut. There has been a concurrent increase in bacon purchase by consumers, and for distiller grain inclusion in hog diets by producers. Such diets are low cost for high energy, but tend to produce hogs with soft fat. Soft fat poses a problem for bacon processing because the bellies are difficult to handle and do not slice well, leading to increased product loss. Thus, processors have begun to manually assess bellies to winnow out those which are unsuitable for bacon production. Currently these assessments occur following ribbing, and are fully subjective. Objective and automated assessment of pork belly firmness could improve the accuracy of sorting and speed at which bellies can be assessed. The aim of this study was to evaluate the use of belly drop angle as a means of assessing firmness from pork belly primals. Pork bellies which are too soft are not suitable for bacon production. An ideal sorting procedure would remove the softest bellies early in the fabrication process to maximize the opportunity for differential handling. The caudal end of pork belly

primals, containing ribs, were suspended over a nosebar positioned beyond the fore edge of a conveyor. The drop angle that formed was measured over time to determine how the belly angle changed following a stop in the conveyor.

Categorization was explored using the bending properties of the pork belly primal as a measure of firmness. In this project, categorizations were conducted using pork bellies obtained early in the fabrication process to allow maximization of the alternate potential of bellies rejected from bacon production. Belly angle was measured by placing bellies on a short, custom-constructed, manually-controlled conveyor. The conveyor was adjustable from 30° to 70°, with a movable nosebar (diameter = 14 mm) positioned beyond the fore edge of the conveyor belt to provide a firm bending edge for the belly and to keep the caudal edge of very flexible bellies from re-encountering the conveyor belt when bending. A camera on a tripod was placed directly in-line with the bar to ensure that drop angle measurements from movie clips would be free of parallax distortion. Various objective and subjective measurements were collected on each belly and used in an overall statistical analysis. A total of 356 bellies were processed in 2017.

In the preliminary evaluation, different conveyor inclines from 30° to 60° were assessed to determine which angle was best to differentiate belly firmness. A conveyor incline of 60° was too high as some handling problems were noted, while an incline of 30° avoided these issues. Firmness from drop angles could be differentiated soon after the release of the belly, despite bellies continuing to bend for up to 120 seconds. This preliminary study also established a bend site of 24 cm from the caudal end of the belly which would be suitable as a bend site for nearly all bellies.



a) Custom manually-advanced, conveyor with adjustable nosebar to provide a firm, small diameter bending point for the belly. b) Measurement of the drop angle.

Polar plot illustrating the manner in which bending occurs over time, using a selection of bellies moving at approximately 8 cm/s up to the bar. The pale line shows a firm belly in which there was a relatively large change in bending just prior to stopping.

In the subsequent study on a 30° incline, bellies travelled along the conveyor at a low speed until the bend site was reached. The conveyor was then stopped and the drop angles were measured at several time points. A moderately strong correlation between bend angle and the subjective floppiness assessment was observed at the moment the conveyor stopped, with no additional waiting time required. This indicated that, potentially, a stop in the conveyor would not be required to sort bellies according to drop angle.

At a 30° incline, which permitted a drop of up to 120°, most of the measured bend angles were within a range of 0-90° below parallel to the conveyor, suggesting a horizontal conveyor may be suitable for bend angle assessments. Several bellies had bend angles which did not correspond well with the subjective measurements of firmness. This could be a result of a fold in the flank conferring rigidity in the belly and could be addressed by flattening bellies before placing them on the conveyor. The accuracy of a horizontal conveyor and the effectiveness in flank fold flattening procedures will need to be assessed in future studies.

The results of this project suggest the drop angle of pork belly primals could be feasibly utilized as a method for sorting bellies based on firmness. A set of five subjective scales was developed for evaluating belly fat, lean and overall firmness. Of these, it may not be necessary to collect the finger depression scale for fat as this measure was highly correlated with the subjective fat firmness scale. The results of this project also highlighted several practical considerations for sorting pork bellies according to bend angle. High conveyor incline angles resulted in handling problems and did not reflect the contribution of lean to overall firmness of the belly. A bend site 24 cm from the caudal end of the primal belly appears to be appropriate for almost all bellies. Belly angle was moderately related to subjective floppiness assessments performed at the middle of the ribbed belly, and would make it possible to sort bellies for firmness very early on the production line.

While technologies such as machine vision or even just electronic eyes to aid in categorization based on the drop angle could be employed for sorting bellies, there could be a much simpler solution for automated sorting: using the normal behaviour of the bellies in response to gravity as they leave the conveyor. The space filler between the end of the conveyor and the nosebar could be removed and the bar could be used for sorting. Firm bellies would move off above the bar to be received by another conveyor, while very soft ones would bend with the conveyor belt and pass behind the bar to a conveyor or bin below. Three simple automated systems for sorting bellies based on firmness were proposed, where each would employ the effect of gravity on the unsupported caudal end of the belly.

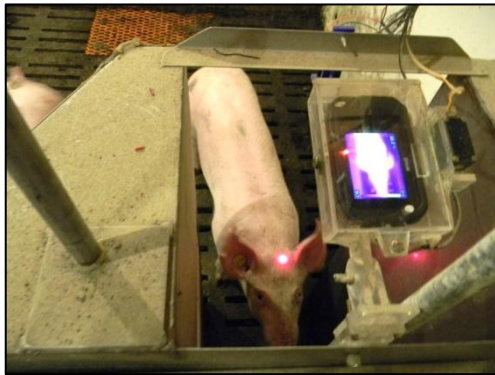
For more information, a detailed report is provided in Appendix 13.

3. Commercial trials and field applications

3.1. Application of novel technologies in commercial trials

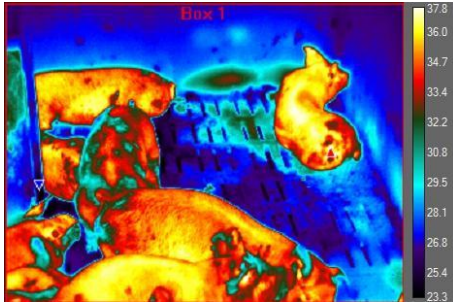
Technologies developed or tested in pilot studies were used in experimental/research conditions. There remains a need to apply these new tools in environments closer to commercial conditions, in order to determine whether or not they can be transferred to commercial operations. In this context, Prairie Swine Centre (PSC) conducted preliminary commercial trials on two selected technologies deemed close to commercial application. Two novel technologies, the individual water consumption system and the infrared thermography system, were installed in a grow-finish room with a total of 84 pigs in 6 pens. The individual water consumption system installed in each pen was composed of a nipple drinker attached to a water flow

meter with an RFID reader and antenna to capture the electronic ear tag number of individual pigs. Low-resolution infrared cameras (model C3 from FLIR) were installed on top of drinkers in order to collect images of an individual pig while drinking. In addition, two high-resolution cameras (model A325 from FLIR) were installed to provide group pictures. Group images were collected several days pre and post pen mixing and/or exercise, in order to detect temperature patterns and clustering behaviour. To assess whether the two novel technologies were capable of detecting pigs that may be stressed due to routine husbandry practices during the rearing period, two types of stressors were introduced to selected pigs during the trial: (1) moving of pigs to the barn hallway and herding them through a pre-defined route for 10 minutes, and (2) mixing of unfamiliar group of pigs to each pen. Two trials were completed: Trial 1 was conducted from July to September 2017 while Trial 2 was from October to December 2017.



Water intake - At the start and middle of the trial, pigs tended to consume more water after the moving activity (exercise). On average, pigs consumed about 3889.6 mL of water in the 24 hours before stress was induced at the start of the trial and increased to about 4138.1 mL in the 24 hours after the moving activity. A similar trend was observed in the middle of the trial when water consumption increased from about 5225.9 mL/day to 5787.0 mL/day after stress was induced. These results may imply that grower pigs consumed more water when stressed. No apparent trend was observed on the water consumption towards the end of the trial. Pigs may have high tolerance at this stage of production. A more stressful condition might be needed in order to see any apparent trend in water consumption when pigs are close to market size. In contrast to the moving activity, water consumption generally decreased 24 hours after mixing of unfamiliar pigs into the pen. Throughout the trial, pigs consumed an average of about 5387.2 mL/day of water prior to the mixing activity; this decreased to about 4738.2 mL/day 24 hours after stress was introduced. The decrease in water consumption might be due to aggression that occurred between some of the focal pigs and introduced pigs after mixing, which subsequently prevented some of the focal pigs from drinking. The increase seen at the beginning and middle of each trial combined with the decrease caused by mixing at the end of the trials could explain the overall lack of increase in water consumption from the beginning to end of each trial.

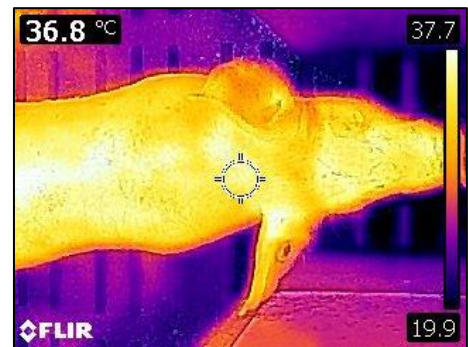
Body temperature - During the start and middle of the trial, no considerable change in body temperatures was observed. Towards the end of the trial, when pigs were close to market weights, a slight increase in body temperature was observed after the moving activity. Pigs had an average body temperature of about 36.5°C



before the moving exercise; this increased slightly to about 36.8°C after they were moved out to the hallway and brought back to the pen. The minimal change in body temperature could mean that the moving activity was not strenuous enough to cause a marked change in body temperature of pigs. In addition, regardless of stress induction, the average body temperature of pigs during each trial seemed to be influenced by the room temperature. In trial 1, there was no considerable change in body temperature throughout the

trial (from start to end); a similar trend was observed in the average room temperature. However, in trial 2, a considerable decrease in body temperature was observed as the trial progressed. On average, the recorded temperature of the pigs, captured by the C3 camera, at the start of the trial was about 37.5°C and decreased to 35.7°C at the end of the trial. Similarly, the average room temperature at the start of the trial was about 20.3°C and dropped to 16.5°C at the end of the trial. The change in room temperature was due to changing outdoor conditions as trial 2 was conducted in early October to late December.

Data from the individual water consumption system showed that grower pigs tend to consume more water when stressed, and water consumption increased as the pig grew regardless of stress induction. As captured by the infrared thermography system, aggression as a result of mixing unfamiliar pigs to the pen caused an increase in the recorded body temperature of pigs. The system also showed that the pigs' body temperature was affected by changes in room temperatures. Additionally, installing the two novel technologies and inducing stress due to moving and mixing had no considerable negative impact on the pigs' production performance. Further work on



implementing these two novel technologies in other parts of the barn such as breeding, gestation and nursery is recommended to assess their performance with regard to optimizing sows/gilts/piglets' performance and welfare and to conduct an economic analysis for the entire barn. Technologies can be modified by replacing C3 IR cameras (small, low cost, and low resolution) with other IR technologies (such as IR board cameras) for ease in synchronizing with drinking activity data, continuous data collection, cost savings and robustness.

For more information, a detailed report is provided in Appendix 14.

3.2. Demonstration of use of genomics to predict and enhance pig performance and carcass value

Recent research on genomics has clearly shown great potential to increase the rate of genetic improvement for traits that are already evaluated with traditional genetic evaluation methods (BLUP). However, the potential is even greater for traits that are difficult or expensive to measure and improve using BLUP methods alone. This project focused on the use of novel technologies to make it practical, affordable and accurate to measure many traits that fall into both of these categories. It will generate large amounts of data from commercial trials that can contribute to the application of genomics, especially for traits that are difficult or expensive to measure. The goal of this project was to compute genomic evaluations on the breeding population as well as young boars and demonstrate the potential for predicting and enhancing traits related to pig performance and carcass value.

This new study started at the end of 2016 with the genotyping of breeding animals by several users of the CCSI program. Genotyping results were centralized in the CCSI database and used in genomic evaluations for several key traits. Participating farms and AI centres from Quebec (4), Ontario (9), Saskatchewan (2) and Alberta (1) submitted tissue samples for genotyping with a 50K (Eurofins) or 70K (Neogen) SNP panel. Genotyping for this project was carried out at the Eurofins BioDiagnostics Laboratory in River Falls, Wisconsin, USA and at Neogen/GeneSeek Laboratory in Lincoln, Nebraska, USA. Tissue samples collected on farm were shipped to the laboratories between April and December 2017. DNA was then extracted from the ear tissue or semen samples and run using the 50K or 70K SNP chip panel. Results were prepared by the labs and shared with CCSI where the genomic evaluations were completed. Approximately 22,000 animals were genotyped for the project. There were two sets of animals that were used in this project. The first was the current population of breeding sows and boars, including Durocs, Yorkshire and Landrace. The second was a sampling of young boars sampled for the purpose of demonstrating the usefulness of genomics for early selection. All sampled animals are in the Canadian Swine Improvement Program (CSIP) database. Genomic evaluations were run on 19 traits, and various groups were used to validate the predictive value of progeny GEBVs. The GEBVs were calculated before performance testing to validate the prediction accuracy of GEBV for future performance of pigs and compare it with traditional BLUP evaluation. The gebv software (Sargolzaei et al., 2009) was used to compute the GEBVs following the equivalent model of VanRaden (2008). The traits studied were total number of piglets born (TPB), backfat thickness (BFT), growth rate (age to 100 kg live weight, AGE) and loin depth (adjusted to 100 kg live weight, LDP). The de-regressed EBV (dEBV) of studied traits were calculated following the method proposed by Garrick et al. (2009). The dEBV is effectively an adjusted phenotype which as the contribution of parent EBVs removed and adjusts records for differences in non-genetic effects such as the contemporary group environment.

Pigs born after July 1, 2017 were used to validate genomic selection on various traits. Given that not all genotyped animals have dEBV information for all traits, the number of animals in the training and validation populations for each trait was different. The average size of training (validation) populations across studied traits was 8,022 (1,223), 7,979 (1,168) and 10,609 (1,317) animals for Duroc, Landrace and Yorkshire breeds, respectively. The accuracies of genomic predictions were estimated as the Pearson correlation between GEBVs of September 2017 and dEBVs of March 2018 for the animals in the validation population for each breed. Except AGE in Landrace and Yorkshire breeds, the GEBV of September 2017 showed 12-63% higher correlation with adjusted phenotypes of March 2018 than September 2017 EBVs.

A large reference population was established over the course of the project. This population continues to grow as many genetic suppliers continue to genotype their animals. Of these animals, many also have phenotypic measurements. GEBVs for all animals are available for extraction, by the users with access to those animals, on the CCSI website. CCSI is now working with users on routine use of genomic evaluations within the Canadian Swine Improvement Program. The GEBVs will replace traditional EBVs in genetic decision-making processes.

For more information, a detailed report is provided in Appendix 15.

4. General Discussion

The technologies studied in this large project are at various stages of development and in several cases, require more testing and automation. However, some of them were transferred in commercial trials and provided valuable information and interesting lessons. In most cases, automation will be critical, as well as data management. Most new technologies tested generate large amounts of data that need to be stored, processed and interpreted in an optimal way. Real-time decision making tools and monitoring applications should be a priority. In addition, being able to combine information from various technologies would be essential. In most cases, new technologies are developed separately, but in reality there is a need for a global approach to combine data from various sensors and programs, which requires standards for data storage and exchange.

Most technologies tested as part of this project allowed collecting objective and accurate data on traditional and new traits of interest.

- On live animals, new approaches to predict live weight and carcass value using vision systems are very promising as they will allow multiple recordings per day with minimal animal handling. New traits such as water intake, body temperature and behaviour through activity levels provide new avenues for monitoring pigs during grow-finish phases and could also be developed to be used in farrowing crates and nurseries.
- On carcasses, quick, non-invasive and accurate methods to predict carcass and meat quality such as 3D vision, near-infrared spectroscopy, spectrophotometry, nuclear magnetic resonance and hyperspectral imaging all have a tremendous potential to replace, in the near future, traditional methods that are either visual/subjective or tedious, expensive and destructive such as carcass cutout and laborious chemical analyses. They could be applied to the whole carcass or specific cuts and help in designing accurate and objective carcass grading and sorting systems in Canadian packing plants. This project also included innovative work on pork bellies, which haven't been studied much in the past, as the primal loin is often considered as the reference cut.

Some of the technologies nearest to application for live pigs (smart drinkers and infrared cameras) could be combined and used in commercial trials at the end of the project. It was clear that transferring these technologies from research facilities to more commercial conditions could be a challenge initially in terms of installation, adaptation of the various components, maintenance of sensors and data storage. However, the amount of valuable, objective and accurate data automatically collected on a daily basis offers tremendous opportunity for use on farm and at the packing plant.

5. Conclusions and Perspectives

This project confirmed the potential of several emerging technologies for the Canadian swine industry. More research and automation is required in several cases, while some tools are already available for innovative breeders, producers and packers to try. For all technologies tested in this project and others that weren't, keys to success include training, standards and good data management systems. In addition, applications of novel technologies will require basic user interfaces such as smart phone applications. This already exists for infrared thermography and could be extended to other animal production tools such as weight prediction tools, 3D scanning and animal tracking systems.

A key aspect identified in all pilot studies relates to data management and processing. Even for technologies already available on the market, very little training and support is provided on these aspects. More important than what data is collected, is how the data is used and combined with other farm data. Effective data management, including combining data collected from various devices, requires standards in data format and transfer, which are still to be developed.

This broad-spectrum project hopefully helped with demystifying some of the novel technologies currently developing in the pig production world. The amount of data and novel results generated as part of the project is impressive, and will translate into communications, publications and further research beyond the project. All activities relied on the expertise and dedication of experts in various research areas across Canada, demonstrating the strength of Canadian swine research and innovation. Working on precision farming and novel technologies requires constant efforts to stay current on advances in other countries and other industries that could be used in the Canadian swine industry. A careful, continuous watch is necessary through national and international networking to be able to keep informed and remain a leader in proposing and testing new approaches.