1. PROJECT TITLE AND APPLICANT

1.1 Benchmarking Carcase Quality In Scottish Pigs

1.2 Operational Group Members

- Quality Pork Ltd [the Applicant]
- Scottish Pig Producers Ltd
- Scotlean Ltd
- Tulip UK Ltd (*now known as Pilgrim's Pride Ltd*)
- Innovent Ltd (*replaced by Hellenic Ltd*)
- Quality Meat Scotland

2. EXECUTIVE SUMMARY

The project ran from April 2018 to April 2020, was led by Quality Pork Ltd, the company that operates the largest pig abattoir in Scotland at Brechin. Other participants were drawn from through the supply chain: two farmers marketing cooperatives (Scottish Pig Producers & Scotlean); the pork processor Tulip UK; information technology company Innovent; and the levy body Quality Meat Scotland.

The aim of the project was to develop a benchmarking scheme for meat quality via carcass or eating quality to give added value to the Scottish supply chain through differentiation. Also, by creating tools for benchmarking data will be collected to stablish the Scottish herd range of values for different meat and carcass traits. By establishing which factors are potentially detrimental to meat quality, the effects of different management systems (in farm, at arrival to the abattoir, or post-mortem) could be researched. Finally, the outputs of the project were to share across the industry from farmers to further along the supply chain, with retail, customers and consumers.

At the start of the project, a newly recruited professional joined Quality Pork Processors (QPP) abattoir in Scotland and after few group and industry discussions a monitoring plan to collect carcass data from the abattoir was put in place after protocols approval. The start of the data collection was delayed due to the shortage of CO2 for which the abattoir stopped killing pigs for a month.

When killing was resumed, data collection started first with pH and temperature of incoming carcasses at several time points, later on drip loss and colour analysis were incorporated. With improvements in sample collection and tools, the number of samples collected per week increased. Later, new analysis was implemented such a colour analysis, marbling, cooking loss and tenderness.

Trials were carried out with different lengths of lairage time, carcass/ meat samples time in the chiller and genetic lines. Also, industry collaborations made possible to incorporate welfare assessments such as stomach ulceration scoring and tail biting scoring to some trials. Despite several challenges encountered during the project (for example, CO2 shortage) most of the objectives were achieved. A vast amount of data was collected from nearly 65,000 carcases across 50 farms and conclusions were reached and shared across, which leaded to

further changes in the company, such as the implementation of pH testing as a monitoring tool, being QPP the first abattoir in the group to do so.

The results show that the vast majority of the carcase from Scottish pigs meet the category of Good or better defined in the scientific literature. Finally, the outputs of the study are constantly being shared with customers which shows the commitment of the company and the Scottish farmers to work in differentiating the Scottish supply chain with added value, and further work is planned to continue that legacy.

3. PROJECT DESCRIPTION

The pork industry has selected genetics that target maximal efficiency of animal growth and performance. The Scottish industry in collaboration with genetics companies, feed manufacturers and health surveillance institutions developed over the years better understanding of the needs of these genetically superior animals, allowing them to approach their genetic potential.

Meat palatability describes overall eating experience achieved when consuming a meat product, this is affected by factors such as tenderness, juiciness and flavour; ultimately it is the individual consumer that determines the palatability of the meat.

Consumers base their purchasing on visual elements of the product such as colour or marbling, for which exploring and accounting for these factors became relevant for a project to benchmark Scottish meat.

Pre slaughter factors that affect meat quality include genetic background, feeding, environmental conditions, handling, transportation, lairage, etc.

The pork industry has selected for leaner, heavier muscled boars due to an increased emphasis on production efficiency and greater appreciation for lean vs fat. Unfortunately, selection of lean has been associated with not so favourable effects, such as paler meat, less tenderness and smaller loin muscle area.

Post-mortem factors in the abattoir also play a role in palatability, including stunning procedure, bleeding process, length of time between slaughter and chilling, rate of chilling, ageing postmortem, fabrication and further processing. Most of these steps are regulated by law and policies but some of them are intrinsic from each retailer/manufacturer.

Most of the quality focused research performed in this work included extensive measurements of pH and temperature due to their influence in other traits, but also colour, water holding capacity/drip loss, marbling and lastly tenderness and cooking loss.

Ideally, this data could have been paired with supplementary studies such as chemical determination of IMF (intramuscular fat), but due to the cost and the aim to develop an industry-friendly benchmarking system these methods were not used.

3.1. Project outline

The project was led by Quality Pork Ltd, from April 2018 to February 2021 and coordinated by Andy McGowan from SPP.

The operational group was established to merge relevant actors from the industry and the Scottish supply chain. It consisted of the core project partners, supplemented occasionally by others participants who took part in the debate and expressed their needs and concerns towards the project and current situation of the Scottish supply chain.

The group held discussions quarterly for which a quarterly report was drafted with a summary. Other participants were briefed about findings when relevant, physical meetings

from the operational group were hard to coordinate as the company representatives are based in England, and towards the end of the project the worldwide COVID19 19 pandemic restricted all sorts of travels and most of the meetings were held via Microsoft teams.

The project aimed to discuss the benchmarking data and which factors can affect and up to which extent the carcass and meat quality.
This was expected to achieve through:

- Elaborating protocols for data collection that are applicable to an industrial abattoir setting.
- Implementing methods widely described by literature and compare results to scientific data.
- Plan and perform trials with different production scenarios which are realistic and relevant to the Scottish supply chain.
- Construct an extensive data base with historical data from the incoming farms to QPP abattoir to be available in the future for further work.

3.2. Material and methods

a. Data sources

- **Scottish farms and Scottish supply chain**

There are approximately 1m piglets born in Scotland annually but only a minority go through abattoirs in Scotland just now. The following diagram shows where they go:

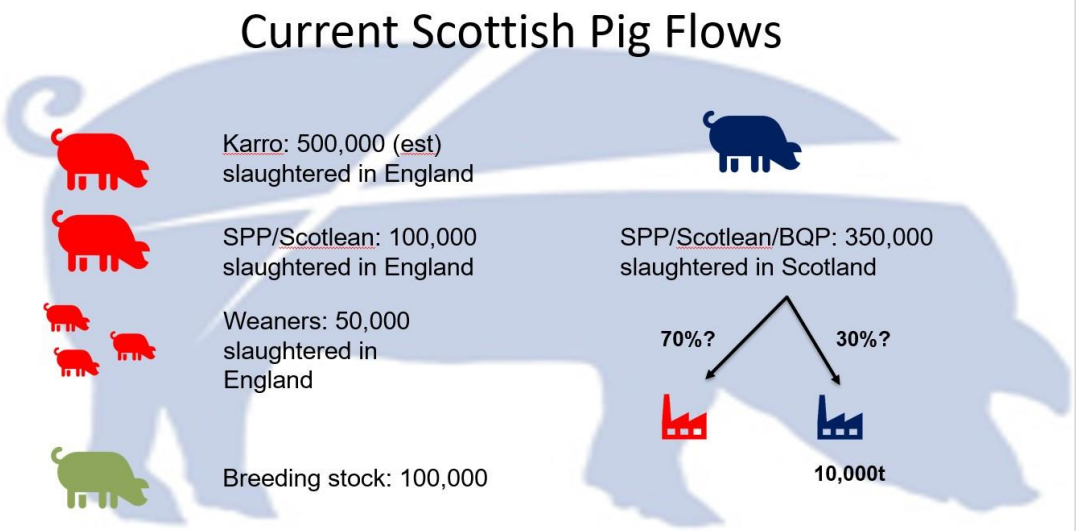

Figure 1. Scottish supply chain overview.

The farms sampled corresponded to great area of Scotland, varying in herd size, production system, genetics, management, nutrition, etc. in figure 2 a map with the location of the sampled units can be seen:

Figure 2. Sampled farms.

- **QPP abattoir**

Site background

Quality Pork Processors is a private limited company that contract kills on behalf of Tulip Ltd. (Pilgrims UK) for the Scottish supply chain. Before an arrangement was agreed with QPP, all Scottish pigs had to either travel long distances for slaughter to the closest abattoir in England or a smaller abattoir with lower kill capacity.

QPP is owned by the Scottish farmers, with a board drawn from representatives from the two bigger pig producer groups in Scotland, SPP and Scotlean, along with the Agriculture Director from Tulip.

On August of 2017 the abattoir had a fire incident where no livestock or staff were damaged but involved important fire and smoke damage to the infrastructure. After the initial damage assessment were carried out and clean-up operation began but the site remained closed.

The site reopened on November of 2017 with reduced throughput but aims to increase the levels from before the incident. Recently in 2019 the site earned accreditation to export directly to China and its looking to increase its quota in the following months.

Site operations

QPP is the smallest site of the Pilgrims group. Runs operations 5 days in the week with livestock staying overnight under strict control 24 hours.

QPP is also the only site in the group enabled to slaughter sows and finishing pigs. The site slaughters weekly around 6000 pigs and up to 450 sows.

The reasons for smaller numbers compared with other group sites are: the speed of the line enables a kill of roughly 100 pigs/hour, and this speed decreases when sows are being slaughter which is normally 2 to 3 days a week. The speed of the line is highly dependent on the killing capacity as well. All pigs and sows are slaughtered using a CO2 chamber, under the lead Official Vet (OV) supervision and animal welfare officers.

Pigs are put though the CO2 chamber, stick and pass through a scald tank, singer and dehairer. Pigs go through the gambrel table and pass through a flamer and they enter the clean part of the abattoir.

Once in the clean part of the abattoir pigs go through several points were operators performed activities in each station, white and red offal is removed and transported through a conveyor belt to the gut room. Hearts and lungs are inspected by a Food Standard Scotland (FSS) officer before moving to another room to be separated and packed.

Gastrointestinal track, including stomachs and guts are moved to the gut room, where the stomachs are emptied and cleaned from undigested feedstuff, this was a crucial point in the project where the status of stomach ulceration was assessed. The rest of the guts are cleaned and placed in salt an ice for conservation for casings.

Once the carcasses move along the slaughter line, they pass by the contamination assessment and carcasses that need further inspection are moved to the detailed line. Carcases then reach the grading point were an MLC (Meat Livestock Commission) officer probes the carcass for back fat value and the next MLC officer records the hot weight (HW) and a grading number is issued for the carcass and stamped in both sides. Right after this the tenderloins are removed from both sides of the carcass and they enter the blast chill.

The blast chill process takes the carcass approximately an hour and half across temperatures of -15 to -20 degrees C, after leaving the blast chiller carcasses are directed to the commercial chiller to different rails according to its grade number. Carcasses will remain in the commercial chiller where they are expected to be kept under 5º C until they make their way to the cutting room, approximately for 20 to 22 hours.

Once the carcass enters the cutting room, the heads are removed, then the hindfeet. The carcass is completely separated in half and each side gets cut in legs, shoulder and middles. Trotters are separated and all primals (order dependant) are hang into “xmas trees” or dolavs, labelled and carried into a lorry controlled by an operator of dispatch.

The operations from the site only allow to obtain meat samples if they are taken from tenderloins or if they are taken directly by the cutting room staff in one of the primals as no further butchery is performed in the site.

b. Operational Group meetings

An operational group was defined after the recruitment of the individual in charge of data collection. The operational group included members of SPP and Pilgrims Supply chain (Agriculture Department). Occasionally members of QMS, Academia, Vets, different industry segments were invited for discussion.

c. Collaboration with the industry

During the length of the project, different industry segments showed interest to collect data from QPP and this task was coordinated by the QPP based staff from this project.
The industry collaboration included feeding companies which aimed to look at the relation/influence of stomach ulceration in meat quality, Innovent Tech. Ltd., which as part of a larger project included meat quality assessment as extra data to pair with animal welfare scorings on farm.

d. Analysis

- **Data collection progression.**

For the second half of year 1 data was collected and recorded manually with a pH meter in spread sheets, this limited the ability of collect larger sets of data. pH and temperature were recorded from an increasing number of farms weekly in two time points, also: the kill number (pig ID at the abattoir), hot and cold weight (HW, CW), probe value and lean meat% (LM%) were paired to the ID and also the pig got assigned a sample number. Meat samples from fillet trim were used to record drip loss with drip loss pads.

Progressing to year 2 a new pH meter was purchased which allowed storage to up to 100 samples each time. After recording the data, the pH meter was connected to the laptop, emptied from data and data collection could resume. This upgrade allowed data collection from multiple carcasses when the carcasses leave the blast chiller creating an extra time point.

A colorimeter Koica Minolta was borrowed from the Scottish Rural University College (SRUC) and allowed to carry colour readings with an objective method.

As mentioned before, drip loss% was initially measured with the drip loss pads technique (filter paper absorption method (D' Souza, et al. 1998) but the method wasn't as accurate and representative as expected. A drip loss rack was manufactured by the engineering team, made of stainless steel and suitable for cleaning and disinfection by the hygiene team on daily basis. Due to this the rack could remain the commercial chiller with other product as long as the meat samples were segregated and the killing date and identity of the samples were displayed in a sign.

By this point the meat samples collected for analysis were taken from the middles (primal) by an operator in the cutting room moving from the getting the samples from fillet trim. The collection of meat samples was a concern due to the site operations. The samples collected from the middles had larger size and were more representative from the carcass and comparable to samples used in literature.

Due to the size sample, marbling and subjective colour of the meat chop was possible to score. For the purpose marbling and colour cards were purchased from Pork checkoff (National Pork Board, 2011). That allowed extra data.

A portable vacuum pack unit was purchased and with that meat samples (chops and tenderloins) were vacuum packed for cooking loss analysis with the suos vide method.

Finally, a Tenderometer (Tenderscot, Pentland Material Supply, Midlothian, Scotland) was purchased with its correspondent kit, which allowed tenderness data to be recorded, this was the last analysis incorporated to the project.

Weekly, depending on planning up to 30 meat samples could be collected from the cutting room and analysed through all the available tests and, with traceability kept, single samples could be traced back to farm and with carcass information.

To run all the meat quality analysis 3 days on the week were necessary from slaughter to tenderness. All the analysis performed are explained in detail in the following section.

- **Carcass sampling**

pH

In an industrial setting, such as an abattoir, pH testing is not a periodic practice. The pH and temperature of carcases is considered the most basic parameter than can directly or indirectly affect other quality traits.

Considering the lack of background information on pH range of values from Scottish carcasses, pH and temperature sampling was the first protocol to be implemented.

After successive discussion with the production manager, and little to no input from the technical department (as at the start of the project there was no Technical manager on site) a preliminary protocol was drafted and tested after the purchase of a pH meter.

pH and temperature in carcasses was recorded in 2 time points (minimum), which are: pH 45 minutes after slaughter (pH0, Figure 3a from data collection point), just before the carcass enters the blast chiller, and pH before entering the cutting room, while still in the chiller (pH24, figure 3b from the collection point), which is equivalent to 20 to 22 hours post mortem.

It was possible to add an extra time point which will be the equivalent of pH after leaving the blast

Figure 3. a) Position for pH0 sampling, after grading, before the blast chill. b) pH24 testing in the commercial chiller.

chiller (pH2), but this was not routinely performed as it interfered with other data collection times.

pH was collected from the loin area in the above mentioned timepoints as a modification (less time points) from Sterten et. al. (2010).

Due to the characteristics of the pH meter available on site initially 20% of the batch was recorded manually in a random count and all the kill numbers were noted as well as the farm.

When the new pH meter (HI 98163, Hanna Instruments Inc., UK, figure 3a) was purchased, which could automatically record up to 100 samples and then download data in the computer, this leaded to record nearly 80% of the carcasses in a batch. The size of a batch of incoming pigs can be from 20 to 200 pigs, being the most common 180 pigs/batch.

For general monitoring data recording up to 100 pH/temperature readings were recorded per batch in both time points. Just sampling for pH/temperature is a 2-day job as the carcass needs to be held in the commercial chiller for approximately 20 hours before leaving to the cutting room.

To perform meat quality analysis for a batch corresponding to a farm, up to 3 farms were selected in a day and up to 30 carcasses were tagged at the time point of pH0. These carcasses were paired with a kill number and their correspondent hot and cold weight, probe values and LM%.

Figure 4. a) pH meter HI98163 b) Carcass tagged for meat quality sampling in differentiated rail in the commercial chiller.

Tagged carcasses are placed in a differentiated rail in the commercial chiller to be sent to the cutting room together (Figure 4b).

On the following day after slaughter tagged carcasses are sent to the cutting room together and pH24 is recorded separately.

The same procedure applies for temperature as both pH and temperature are recorded at the same time with the same probe.

Carcass weights, probe and LM%

Carcass information is obtained directly from the company's digital platform recorded by the MLC. One operator is in charge of measuring and noting the backfat number and kill number (ID number), also if it is boar or gilt. Slightly further in front in the line, the second MLC operator enters the carcass HW. Based on both values LM% (lean meat %) is calculated with its correspondent formula.

All this information is available within few hours after kill on the digital interface from the company.

Condemnation data

Through the company digital platform (Hellenic) is possible to obtain quality performance reports from each farm coming to the abattoir. This includes ante and post-mortem casualties and summary, condemnation reports, offal reports daily and historically.

Also is possible to pair this information with time spent in lairage. Condemnation data can be paired to the kill number which provides more detailed information on the health status of an individual.

- **Meat quality sampling**

Drip loss (DL%)

In the early stages of the project drip loss was recorded with the modified wet paper method, which consisted in weighting a meat sample, placing it in a absorbent piece of paper, cover it with film paper and place it on the chiller for 24 hours, then weighting the sample again and the difference in weight was considered as drip loss% (modification of Almeida Torres et. al., 2017).

Samples were collected from the same location where pH0 was recorded, from tenderloin trim. Later samples were further "cleaned" from fat or connective tissue until reaching a homogenized value of 100gr/sample for each sample collected. In Figure 5 can be seen how a tender loin trim looks like after "cleaned" from fat and connective tissue.

Lastly, the samples were placed in a tray with sample ID number and covered with film paper (Figure 6 a and b).

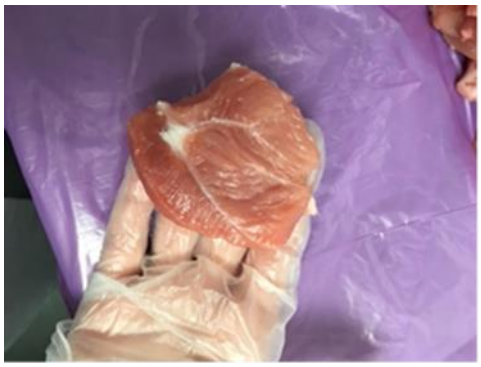

Figure 5. Meat sample from fillet trim after cleaning.

The method had plenty of weaknesses, considering that the trim was sampled from the carcass's tenderloin which is removed from the carcass on the kill day rather than 24 hours after, like most literature suggest. The appropriate moment to take meat samples so the sample goes through a 24 hours maturation process as part of the carcass.

Also, the sample size was not ideal to carry out all the analysis expected. Operations wise, this method was an efficient, as it didn't involve waiting in the cutting room for the final pigs of the day to collect the samples or staff availability to help.

Figure 6. Samples labelled and placed in trades in commercial chiller for drip loss analysis.

Later in the project the method was replaced for a gravitational method with "hanging drip loss", which dues its name to the use of gravity force as the only force acting to conduct the liquid off the meat, through hanging the meat in a vertical position in a plastic bag to collect the liquid (Almeida Torres, et. al. 2017).

The principle is the same as drip loss% was calculated as % of the initial weight (after the sample has been cleaned from excess of fat, weighted and identified with a sample ID number in a bag) minus the weight after 24 hours in the chiller divided by initial weight (Figure 7).

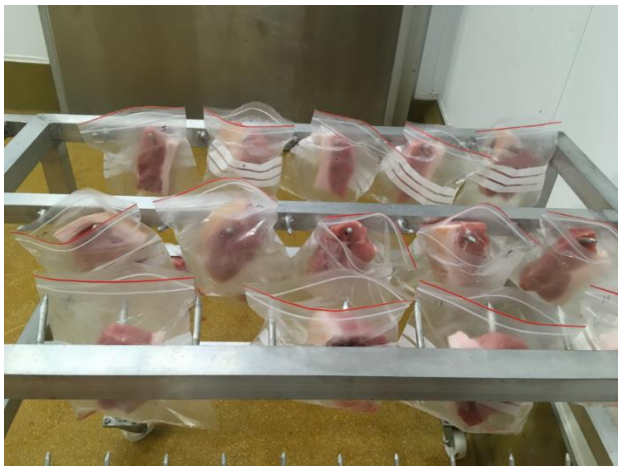

Figure 7. Drip loss rack with samples in commercial chiller.

The material used to hang the meat samples in the chiller was a rack manufactured for the project. The drip loss rack had a capacity to hang up to 30 meat samples and meant a better representation of drip loss mimicking the system used to transport primals in "xmas trees" rather than in doulavs.

Samples started to be collected directly from the cutting room, from the middles. In the Figure 9 can be seen the representation of primal splitting of a half pig carcass in shoulder, middles and legs.

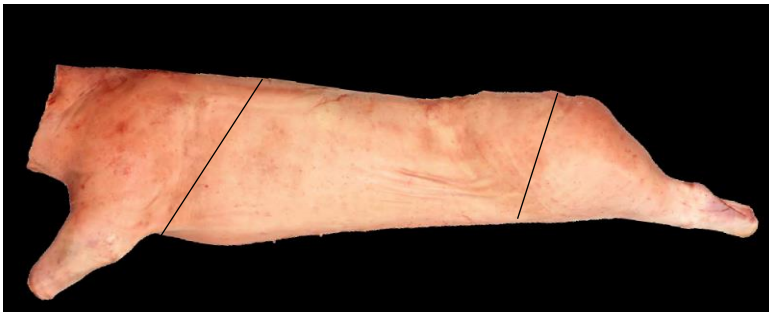

Figure 9. Representation of pig carcass division in primals.

In the cutting room, all carcasses are split in two after head and forefeet removal, followed by the leg primal separated and last the middle and shoulder. An operator was assigned to cut a chop from the front of the middle (approx. 300 gr), which was collected in a plastic bag with ID (sample number and slapmark).

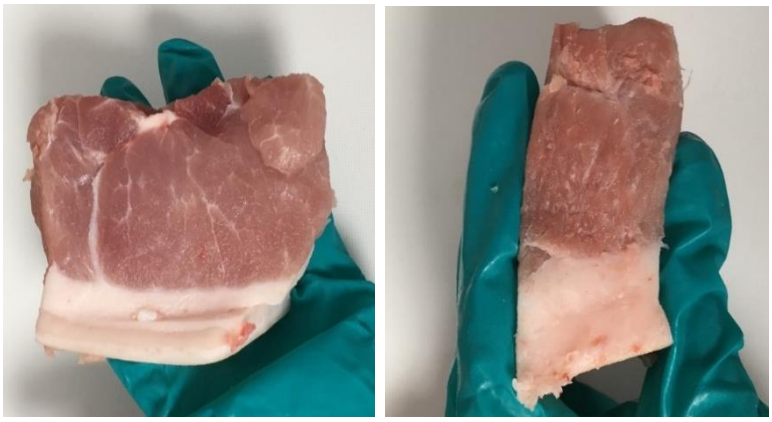

Figure 8. Samples collected from the cutting room after preparation for drip loss%.

After samples have been collected in the cutting room, the samples were cleaned and homogenized in weights (100 uo to 250 gr)(Figure 8) an placed in plastic bags with sample ID and take to the chillers hanging rack.

Samples bags were closed and only opened on the following day for 30 minutes before weighting.

Colour

The first 30 minutes after muscle tissue is exposed to air are critical for its “blooming”, which is the reduction of myoglobin “purple” to oxymyoglobin “red” which gives the meat an attractive appearance (Summan et al. 2013)

Instrumental (objective) colour measurement was recorded with a Koica Minolta CR-450 (Figure 10 a), Illuminant D65, calibrated using the calibration function against a white tile. After 24 hours in the chiller, bags were opened and left to bloom(still in the chiller) for 30 minutes. After, samples were

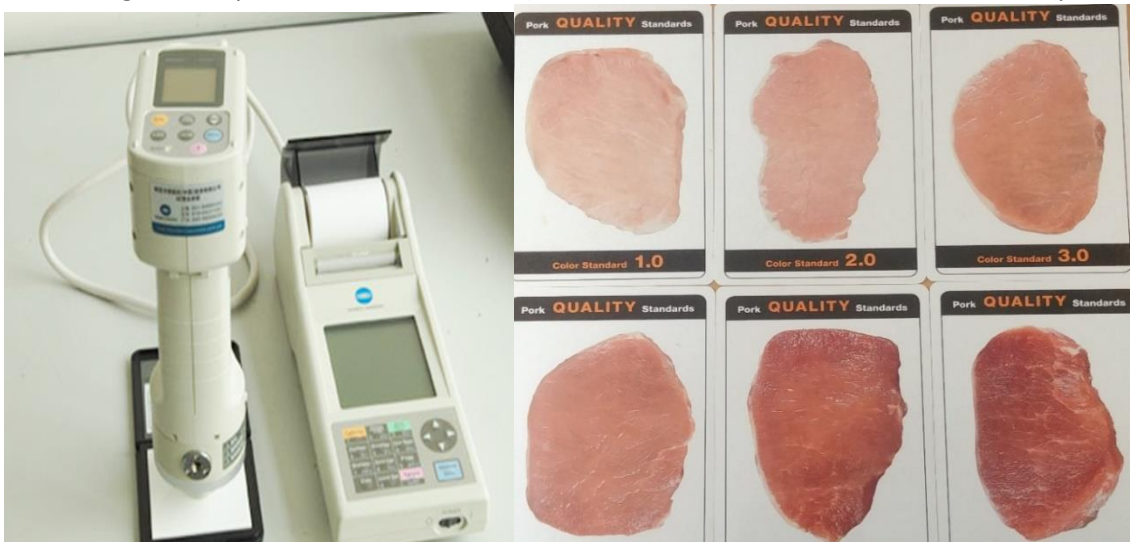

Figure 10. a) Koica Minolta CR-450. b) Colour standard cards from Pork Check off

removed from the plastic bag and patted dried with paper towels, weighted for drip loss calculations and colour analysis was performed with the Minolta colorimeter in 2 areas of the sample. Results were noted down as L* (paleness), a* (redness) and b* (yellowness) of the meat (Dai et al. 2014).

Immediately after, colour was subjectively scored with the colour standard cards from the Pork Checkoff. The scale of colour goes from 1 to 6 being the palest value 1 and the darkest 6. Colour was recorded, in loin samples as suggested by the Pork check off user guide.

Marbling

Marbling was recorded with a subjective method using the Pork Checkoff cards, the scale goes from 1 to 6 and then 10 which is the ultimate marbling value (Figure 11).

Marbling was recorded on the 3rd day after killing at the same time as drip loss and colour.

Figure 11. Marbling standards cards from Pork Check off.

Cooking loss

The cooking loss method used was the *sous vide*, or heating raw meat packed inside a vacuum pouch in a water bath at specific temperature (Pathare, PB et al. 2016).

On the 3rd day after killing, after drip loss, colour and marbling was determined each sample was vacuum packed in polyethylene bags and gave an ID.

A water bath was set up in the morning to 90º C and samples were introduced one by one until the temperature of the water stabilized again.

The samples were cooked in the polythene bags in a thermostatically controlled water bath at 90 degrees C for 90 minutes (Figure 12).

After cooking, samples were cooled under tap water for 30 minutes (Figure 13) (Adam, Y.S.I, et al. 2015)

Figure 12. Thermostatically controlled water bath with meat samples.

Figure 13. Samples cooling in tap water after cooking.

After cooling down samples were taken off the bags and exudate fluid was dried with paper towels and weight was recorded.

Cooking loss was determined as a percentage of initial weight.

Tenderness (Slice Shear force and Warner-Bratzler)

Tenderness is measured either subjectively through a consumer or trained panel on sensory methodology or objectively using mechanical methods. Like for all previous analysis, *longissimus dorsi* muscle (loins) were used, which might not be the greatest indicator of overall tenderness for the whole carcass, but this portion is of great economic importance.

There are several methods to assess tenderness, going from sensory trained panels (expensive) to objective tenderness assessments. In an attempt to find mechanical methods for assessing tenderness the Warner-Bratzler shear force method (WBSF) was developed. Unfortunately, there is high degree of variation in the protocols used to obtain data. Furthermore, the fibre orientation in the core sample is crucial, the method is also laborious and repetitive.

The other method used is the Slice Shear Force method (SSF).

Figure 14. Tenderscot

Tenderness analysis was performed with the Tenderscot (Pentland Precision Engineering Limited, Midlothian, UK)(Figure 13), after each test, the instrument displays the maximum force obtained in Newtons (N).

The operating speed for each test has been pre-programmed into the Tenderscot, where the blades for each test need to be installed to the machine and switch the key to get to the right speed test.

- Warner-Bratzler (WBSF)

This test is conducted with sub samples obtained preferably from the core of the meat sample. From the samples obtained from the cutting room was possible to obtain two cores with the desired dimensions, the width of the sample is 12.7 mm with fibre orientation longitudinal through the core (Figure 15,a).

The test is set up with the “V” blade (Figure 15,b), attached to the parallel rods, the anvil needs to be attached to the circular base under the parallel rods to ensure the v-slot lines line up with the centre of the sample. The test speed setting for this test is position 2 (250 mm/min blade speed)

Figure 15. a) Core sample for WB analysis b) V blade used for WB analysis.

After sampling preparation, the sample is placed with the correct fibre orientation into the holder/anvil, the lid is closed, and the green button is pressed. Once the test is completed the pull frame returns to the start position with the highest force value on display.

- Slice Shear Force (SSF)

The rapid SSF is conducted on a sample of 50 mm X 10 mm with the fibre axis longitudinal through the sample, the sample needs to be 25mm thick with a fibre orientation of approx. 45 degrees.

The SSF test blade is flat (Figure 16) and needs to be attached by the two screws on the top of the parallel rods, the anvil is attached same as the previous test.

The speed set for this test is position 3 (500 mm/min blade speed).

After sampling preparation, the sample is placed with the correct fibre orientation into the holder/anvil, the lid is closed, and the green button is pressed. Once the test is completed the pull frame returns to the start position with the highest force value on display.

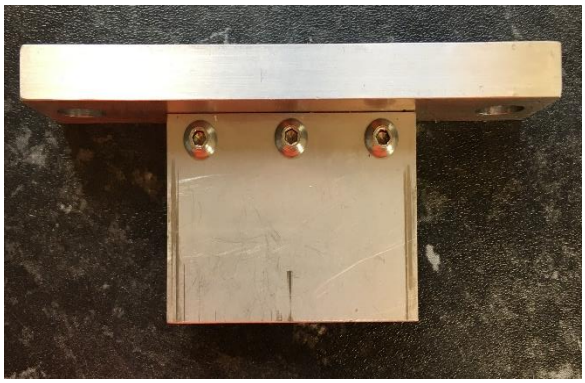

Figure 16. Blade used for SSF test.

Statistical analysis

Statistical analysis was performed using Genstat (18th edition).

Summary statistics were calculated for mean, minimum and maximum value recorded, total values, upper and lower quartile, standard deviation, coefficient of variance.

Correlation coefficient were calculated, correlations were tested two sided against 0.

General analysis of variance was performed when there were more than 2 variables to compare, treatment structure was considered as each factor to test, such as lairage treatment, month, etc. Multiple comparisons option was enabled, Fishers unprotected LSD means with means with different letters used with a significance level of 0.05.

When only two variables were compared student two sample t-tests were used, with one variate with group factor, two sided.

Frequency tables were presented after variables were calculated in the desired range and converted to factors.

Linear regressions were plotted, Multiple R (correlation coefficient), R square (coefficient of determination), adjected R square and Standard error were calculated for each plot and described when relevant.

- **Reporting**

Project update reports were performed quarterly, elaborated between the project manager and project working group. Reports revolved around the number of samples taken, any trends and figures present, problems in data collection and consequent alterations to the plan schedule, collaborations (external, with industry), diffusion or the work, any presentations and meetings that took place in which data was presented.

One Friday a month a summary presentation was sent to the direct line managers and supervisors with relevant findings, further work and conclusions.

Weekly catch ups were arranged between the working group.

Individual reports were shared with the producers. The reports consisted of a summary of results from sampling over the past years, for carcass and meat quality results. The reports also included comments on extra variables such as lairage, cut or drip loss treatment, and condemnation data and additional results if the farm took place in additional trials (ulceration scoring, blast chiller curve, etc.)

4. FINDINGS

4.1. pH and temperature

During the conversion of muscle to meat, gradual depletion of energy stores (glycogen) transform to lactic acid builds up in the tissue leading to a reduction of pH (Huff-Lonergan, et al. 2005).

pH is highly related to temperature. Like all metabolic processes', glycolysis in the muscle suffers direct effect from temperature (Rosenvold et al. 2003). Higher temperatures speed up processes, but this is not a linear relation, this idea is supported by the study of Dokmanovic et al. (2015). Short term stress before slaughter is known to accelerate metabolism and result in higher muscle temperature and lower pH (England et al. 2013).

Carcasses maintain body temperature for some time after slaughter as the metabolic process don't stop immediately. The temperature that carcasses have before slaughter will affect the decline post-mortem, therefore delaying the complete stop of the muscle metabolic processes.

a) Site values

Values collected since 2018 to 2020 (approx. 62.000 time points), Table 1 shows average values for the site without any grouping as following:

Parameter	Mean	Median	SD	Variance
pH0	6.49	6.47	0.2	0.06
Temp0	28.6	27.7	4.2	8.3
pH24	6.10	6.15	1.38	1.9
Temp24	5.9	5.5	2.8	7.9

Table 1. Summary pH and temperature values from the site (2018-2020)

Overall values from the site showed than 7% of the total pH0 values were above 6.99 and 1% was below 6.0. From the remaining 92% (if considered as 100%), 56% of values were between 6.5 and 6.8 and 43% between 6.1 and 6.4 (Figure 17).

Threshold values for pH have been defined in literature: PSE for pH0 ≤6 at 45 minutes after slaughter and/or pH24 ≤5.5, Normal for pH0 being 6.4 and pH24 of above 5.5, and DFD for pH0 above 6.4 and pH24 above 6.0 (Adzitey, et al. 2011) . For this project some of those values were considered as reference.

The average high pH24 value can be partly attributed to the use of blast chilling, according to Hambretch et al. (2004) with blast chiller commonly associated with higher ultimate pH compared to conventional chilling.

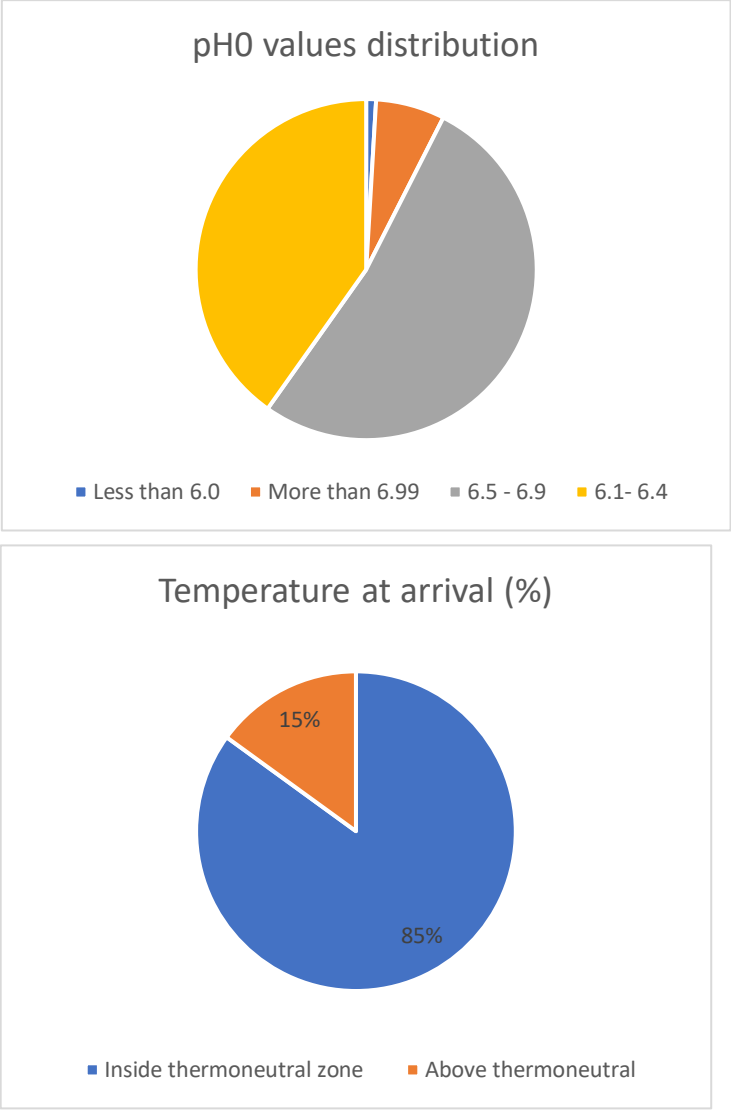

Figure 18. Temp0 distribution when values were either outside or inside the thermoneutral zone.

Regarding temperature at arrival, lairage meetings from the group defined that the thermoneutral zone for bacon pigs (from 60 to 90 kg) was a wide range from 18 to 32 degrees C, only 15% of the total samples were not in this range, all of them above the thermoneutral zone, none below (Figure 18).

Looking at overall pH24 values, 73% of all recordings were in a range between more than 5.5 and less than 6.2, which is considered acceptable pH after 24 hours. Only 2% of the values recorded were below 5.5.

Seasonal data

Monthly average values for across a year of sampling for pH and temperature are displayed in the table below and plotted. There is statistical difference between the values, warmer months of the year, from May to September showed higher carcass temperature at arrival, significantly different (up to 3ºC) higher than the coldest months November, December, January.

Temperature started to rise from February again at least 2ºC until May, where the highest value was recorded (Table 2, Figure 19).

Month	pH0	temp0	pH24	Temp24
JAN	6.53^{e}	26.78^{a}	6.181^{c}	5.99^{cde}
FEB	6.511^{c}	28.08^{c}	6.129^{bc}	6.564^{h}
MARCH	6.421^{a}	28.85^{e}	6.15^{c}	6.19^{dfg}
APRIL	6.52^{de}	28.91^{e}	6.09^{ab}	6.33^{g}
MAY	6.46^{b}	30.7^{h}	6.12^{abc}	5.513^{b}
JUN	6.51^{cd}	29.63^{f}	6.14^{bc}	5.96^{cd}
JUL	6.42^{a}	29.57^{f}	6.046^{a}	5.35^{ab}
AUG	6.462^{b}	29.73^{f}	6.12^{abc}	5.33^{ab}
SEPT	6.41^{a}	30.0^{g}	6.15^{c}	5.22^{a}
OCT	6.58^{g}	28.36^{d}	6.169^{c}	5.88^{c}
NOV	6.46^{b}	27.95^{c}	6.12^{abc}	5.11^{a}
DEC	6.55^{f}	27.62^{b}	6.13^{bc}	6.04^{cdef}

Table 2. Monthly average values for pH and temperature.

**Values in the same column with the same letter are not significantly different at a 5% level.*

A similar pattern was followed by pH0, which recorded lower values for the warm months and slightly higher values around winter. pH variation through the year was not as great as the temperature variation, probably because temperature is a driver of pH but is not the only element that influences it.

The study by Guardia et al. (2005) supports the increase in up to 3.4% of DFD pork in winter compared to summer (higher overall pH values), this could be due to glycogen storage being depleted in the pigs as they tend to group together in order to create a microclimate to increase the surrounding temperature at the expense of energetics reserves in the muscle, leading to less lactic acid production and higher pH values.

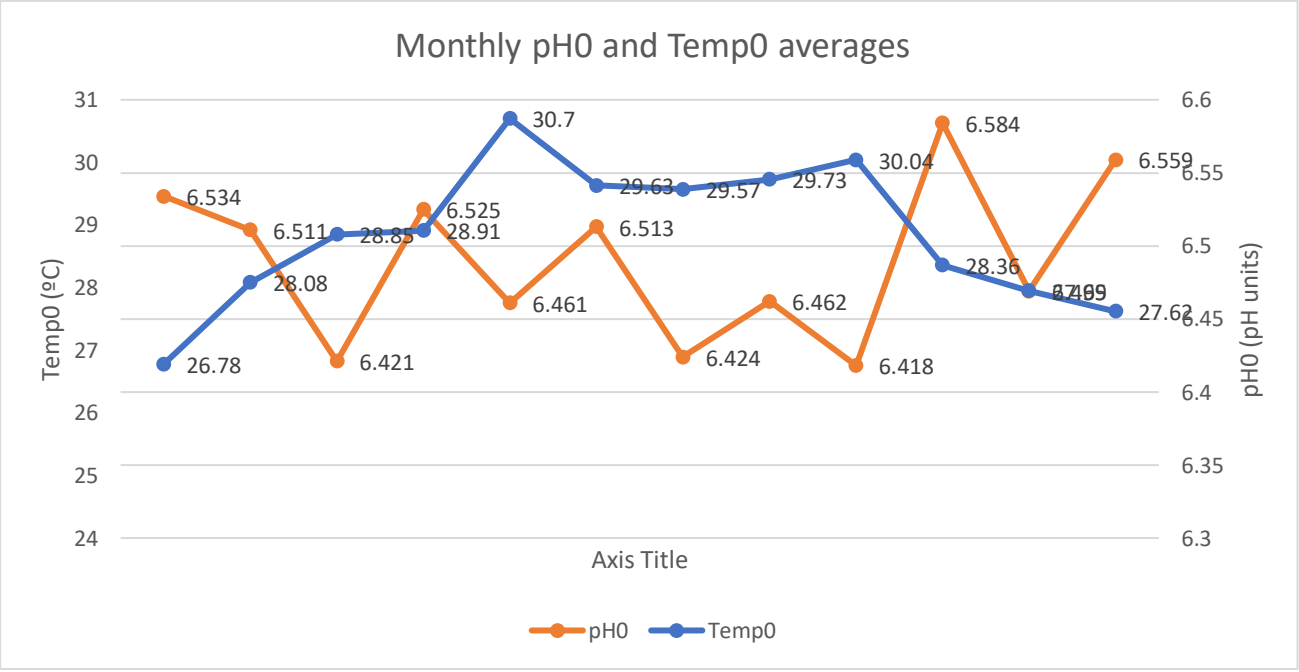

Figure 19. Monthly variation of pH0 and Temp0.

Interestingly, an opposite behaviour was seen for data taken in the chiller. pH24 values were statistically different but not to a big extent between months with no apparent pattern. This could be due to the fact that carcases are expected to be coming from an equalized environment at the

time of probing, having been held in the chiller around 22 hours already, so whatever pH or temperature difference between carcasses caused by environmental factors at slaughter was not noticeable at this point.

For reference, Brechin cold weather, January, November and December are around 6 º C during the day and could go below zero at night-time. Summers are warm, with daily temperatures in July reaching 18.6º C and nights of 10.7º C. (Source: Gazeteer for Scotland, supported by the School of Geosciences, University of Edinburgh and the Royal Scottish Geographical Society).

Scotland has been experiencing hotter and longer summers, therefore ambient temperature was affected. While conditions in the lairage are monitored constantly and comply with all animal welfare regulations from customers, regulating bodies and the Group, in terms of space allowance and waiting time before loading the pigs off the lorry, is inevitable to have higher ambient temperatures in the summer. Pigs are provided with fresh water and there are water sprinklers in the lairage, also vet and animal welfare assistants oversee the pig's status over day and night.

b) Correlations

Overall and seasonal data

According to data recorded over the project, the correlations were not as strong as expected (more like, moderate), but also the data set is larger than any other paper consulted, as it was collected over a period of two years (Table 3).

pH0	--			
Temp0	-0.3	--		
pH24	-0.04	-0.08	--	
Temp24	-0.02	-0.06	-0.3	--
	pH0	***Temp0***	***pH24***	***Temp24***

Table 3. Overall correlations.

The relation between initial and ultimate pH was not strong nor very significant, probably because these two parameters are under the influence of different factors. pH decline and ultimate pH are affected by the amount of glycogen at slaughter while pH0 depends on post mortem glycolysis which is influenced by genetics, pre- slaughter factors, and combination of all (Dokmanovic, et al. 2015)

It has been seen that during the summer the correlation between temperature at slaughter and pH0 became stronger suggesting the influence of the temperature increases once a threshold is reached, this is not a linear relationship, as other factors are expected to also influence pH values.

Table 4 shows correlations for temperatures and pH values in the warmest months (June, July, August and September). Both pH and temperatures are negatively correlated, which was expected, but the values at the first time points show a stronger correlation (-0.12).

	pH0	***Temp0***	***pH24***	***Temp24***
pH0	--			
Temp0	-0.12076	--		
pH24	0.003506	-0.05564	--	
Temp24	0.043534	-0.07036	-0.03092	--

Table 4. Correlation between pH and temperature during warm months.

The correlations are weaker in the winter months (November, December and January), going to -0.04, also the correlations after 24 hours became lower (Table 5).

	pH0	***Temp0***	***pH24***	***Temp24***
pH0	--			
Temp0	-0.043766	--		
pH24	0.063445	-0.04074	--	
Temp24	0.100282	-0.08708	-0.012491	--

Table 5. Correlation between pH and temperature during cold months.

Suitable pH/temperature decline models have been of interest for research for many years, but much remains to be undertaken on estimate the compliance rate for pH decline. It's now assumed that pH decline as a function of temperature is a fixed effect exponential decay rather than a linear one due to the low correlation and R values seen.

Is also important to consider there are alternative variation to exponential decay models as this last ones impose the idea that pH monotonically decreases with increasing temperature, and this is not the case all of the time, as exponential decay modelling from data in other papers failed to produce an appropriate fit as well (Van de Ven et al. 2013).

c) pH curves (blast chiller)

In recent years, research on pork carcass chilling has been focused on accelerated cooling to minimize evaporation-induced loss in carcass weight and the incidence of microbiological contamination, also is expected that blast chilling may improve meat properties due to decreasing rate of post-mortem metabolism (Rybarczyk et al, 2015).

The SOP is to have carcasses not surpassing the blast chiller to go to the commercial chiller, only under exceptional circumstances (severe partial condemnation or breakdown of some sort). Not many samples of chilling without passing through the blast chiller were recorded over the months for that reason. Also, recording data from a severely partly condemned carcasses would not have been suitable for comparison with a normal carcass, as there could be an underlying condition on the pig which caused the condemnation (pleurisy, abscesses, etc.) which could impact on the body temperature of the pig making it unsuitable for comparison.

Due to the abattoir operations and chiller settings is not possible to take random samples of temperature and pH of carcasses once they left the blast chiller and are assigned to their correspondent rails. The feasible alternative is to obtain an extra time point for measurement when the carcasses leave the blast chiller and are on their way to be assigned to a rail by the chiller operator, this time point was assigned as pH2 (pH2 hours).

Commercial chillers operate at a strict temperature control and is expected carcasses will comply with regulation and be 5º C (or under) at the moment they enter the cutting room.

The rapid reduction in muscle temperature before it reaches the appropriate level of acidification may result in carcass shrinkage (loss of weight). Shrinkage during blast chilling may especially affect high yielding carcasses, due to their lower external fat content and faster heat release (Rybarczyk et al, 2015).

Blast chilling also pre-disposes to crust freezing of the skin and muscles located directly beneath the skin, but temperature in the deep muscle seems to be unaffected by the effects of the blast chiller.

Table 6 shows pH/temperature curves from 11 farms (100 samples/farms) in three time points, 45 minutes after kill (pH0), 2 hours (pH2) and 24 hours (pH24).

	pH0	Rate of decline of pH (0 to 2 hours)	Temp0	pH2	Temp2	pH24	Rate of decline of pH (2 to 24 hours)	Temp24
Farm1	6.599^{ef}	0.0368^{ab}	28.8^{ab}	6.535^{d}	7.14^{e}	6.058^{bcd}	0.020^{cd}	7.012^{f}
Farm2	6.555^{d}	$- 0.04^{a}$	29.3^{ab}	6.635^{de}	2.41^{a}	5.932^{ab}	0.035^{de}	5.25^{e}
Farm3	6.629^{f}	0.0201^{ab}	28.27^{ab}	6.589^{d}	6.4^{e}	6.121^{cde}	0.023^{d}	3.802^{bc}
Farm4	6.566^{de}	-0.0167^{ab}	28.24^{ab}	6.599^{de}	7.08^{e}	6.194^{def}	0.020^{cd}	4.238^{cd}
Farm5	6.618^{f}	0.7157^{d}	25.9^{a}	6.638^{de}	4.90^{c}	6.257^{f}	0.019^{cd}	2.063^{a}
Farm6	6.428^{b}	0.035^{ab}	25.40^{a}	6.356^{c}	5.44^{cd}	6.24^{ef}	-0.005^{a}	3.944^{bcd}
Farm7	6.601^{ef}	-0.0694^{a}	29.18^{ab}	6.827^{g}	4.63^{bc}	6.166^{cdef}	0.020^{bcd}	3.979^{bcd}
Farm8	6.629f	0.35^{c}	26.23^{a}	5.851^{a}	3.90^{b}	5.875^{a}	-0.001^{ab}	3.376^{b}
Farm9	6.568^{de}	-0.0446^{a}	29.89^{ab}	6.691^{ef}	2.62^{a}	6.169^{def}	0.090^{f}	2.252^{a}
Farm10	6.479^{c}	0.1307^{b}	31.78^{b}	6.179^{b}	4.89^{c}	6.127^{cdef}	0.002^{abc}	4.2^{cd}
Farm11	6.731^{g}	-0.0217^{ab}	27.21^{ab}	6.77^{fg}	4.96^{c}	6.034^{bc}	0.043^{e}	4.573^{de}
Farm12	6.238^{a}	-0.013^{ab}	27.69^{ab}	6.26^{bc}	6.43^{de}	5.854^{a}	0.020^{bcd}	4.81^{de}

Table 6. pH, temperature and rate of decline of 12 farms on three time points.

**Values in the same column with the same letter are not significantly different at a 5% level.*

According to Figure 20 the pH decline is not pronounced over the 2 hours the carcasses are in the blast chiller, which is expected considering the aim if the blast chiller is decrease or stop the decline, not encourage it, the largest pH decline is seen on the following hours when the carcasses rest in the commercial chiller.

But looking at the rate of decline per hour in 5 out of 12 farms, the decline was faster in the 2 hours in the blast chiller compared to the (approx.) 20 hours in the commercial chiller. This was unexpected and no concrete explanation for this.

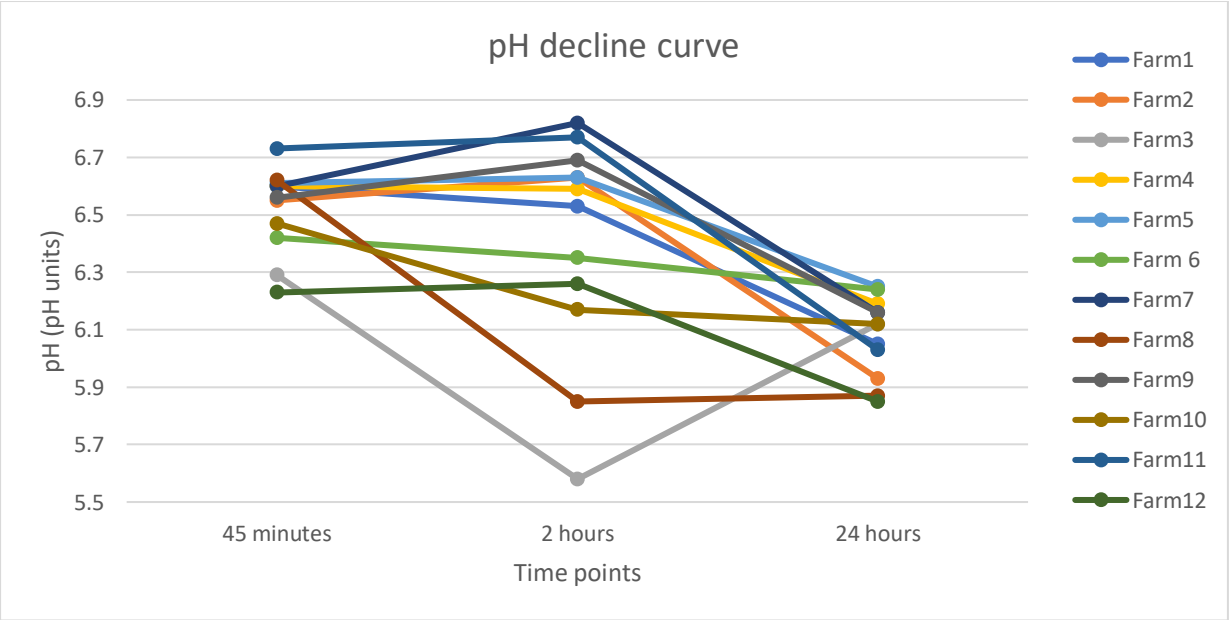

Figure 20. pH decline curve from 12 farms over three time points

The lower rate of pH decline in the first hours in the blast chiller match the findings from Rybarczyk et al, (2015), where one of its "rapid chilling" systems was comparable to the one used in QPP.

There was no statistical difference between temperature at arrival from all the farms, but this changed after the pass through the blast chiller. Numerically, the temperature does suffer a sharp decline in the blast chiller and none or few changes after, which is expected (Figure 21).

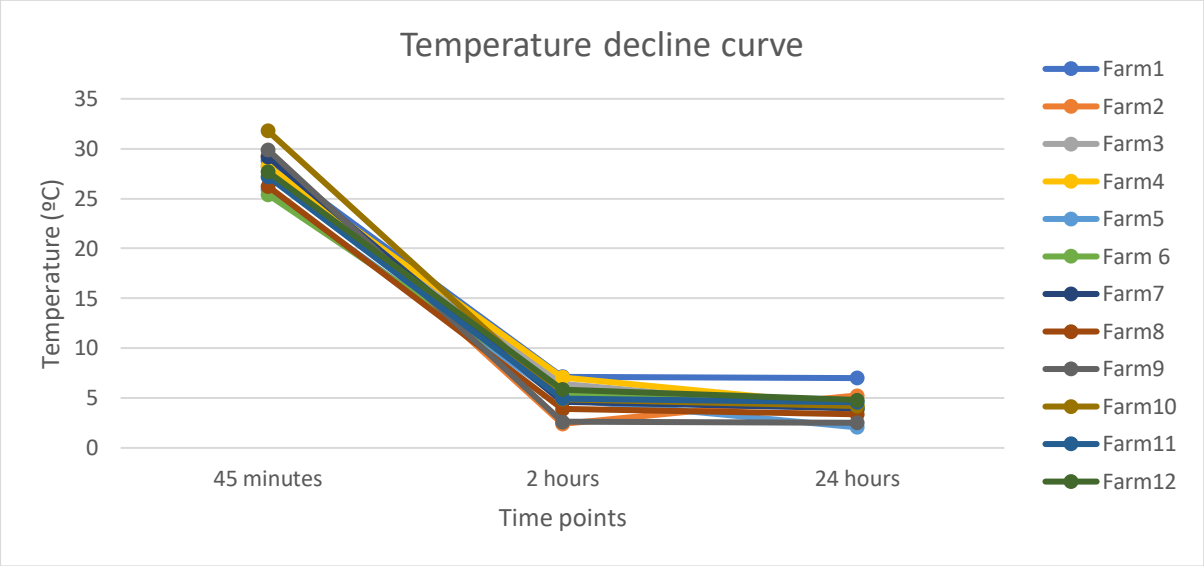

Figure 21. Temperature decline curve from 12 farms over three farms.

Pre slaughter stress has been shown to increase carcass temperature and pH decline. Rapid chilling is not able to compensate for the detrimental effects that pre slaughter stress can have on meat quality indirectly (Hambretch, et al. 2004), therefore more trials from this type could be needed to understand deeply the extent of impact of abrupt temperature changes and pre slaughter conditions in the pH decline.

4.2 pH, temperature and carcass traits

a) Temperature curves by weight

There is an increasing interest from the industry to increase slaughter weight. In a review of heavy-weight pigs, some issues such as additional rail support, shackle and cooler space are reviewed to facilitate coping with this changes, chilling capacity is also addressed, as it might be compromised by heavier carcasses. Slower chilling has the potential to compromise pH decline, affecting other quality traits (Harsh, et. al, 2017).

Higher slaughter weighs also mean in most cases higher temperature in the deep muscle and higher heat release from the carcass. Temperature control is extremely important to ensure carcasses are being cooled fast enough to comply with food safety and quality standards.

Carcasses sections chills at different rates, Arkfeld et al. (2016) stated that equilibrium temperature of a loin muscle occurred at 14 hours post mortem, yet the deep leg muscles had still not equilibrated with ambient temperature at 22 hours in the chiller, at 14 hours it was still 1º C above chill temperature.

Temperature curves were recorded from pigs from several weights which are representative to the bacon pig and extreme weights. Data was recorded using a temperature logger, which was placed on the carcass right ham immediately after it left the blast chiller and entered the commercial chiller, the logger was removed once the carcass entered cutting room. Temperature at slaughter was recorded on the line 45 minutes after kill.

As in commercial settings heavier and lighter pigs are killed at any time of day regardless of weight, therefore was not possible to equalise all the slaughter times for sampling, same situation occurs in the cutting room, when rails of pigs from the same grade are sent for cutting in batches, relying on the chiller mapping of the day making sure one chiller is empty before the other one so incoming pigs of the day can be placed in. That is the reason why some curves are shorter than others.

In order to be able to make comparisons of the temperature curves as all carcasses entered the blast chiller in different times of the day, the following time points were considered and calculated: initial temperature (slaughter time, Temp0), Temp2 (at the time of leaving the blast chiller), time required to decrease 10ºfrom initial temperature (Temp10), time when carcass reached equilibrium temperature with the chiller (5.9º C) TempEq were used as comparative points, the last time point is the temperature at the moment the carcasses entered cutting room (Temp24).

Table 7 shows the values used to draft a curve. Slight difference can be seen in temperature at arrival, becoming higher with heavier weights. The blast chiller decreased the carcass temperature approximately 8 to 10º C, for all weights. It took an extra 5 to 7 hours besides the 2 hours on the blast chiller to decrease temperature 10º from the initial temperature, longest times recorded were for 85 and 75 kg, interestingly.

Weight (kg)	**Hours after slaughter**	**Temperature (ºC)**
68	Temp0	26.7
	Temp2	17.1
	5- Temp10	7.9
	6-TempEq	5.9
	11- Temp24	2.9
75	Temp0	27.2
	Temp2	17
	5- Temp10	7
	8-TempEq	5.9
	20- Temp24	3.5
78	Temp0	28.6
	Temp2	18.8
	4.5- Temp10	8.8
	8- TempEq	5.9
	22 – Temp24	2.7
83	Temp0	27.7
	Temp2	19
	4.5-Temp10	9
	10.5- TempEq	5.9
	19- Temp24	2.8
85	Temp0	28.3
	Temp2	17.5
	7.5- Temp10	7
	10.5- TempEq	5.9
	17.6- Temp24	4.1
88	Temp0	28.2
	Temp2	19
	5-Temp10	9
	9.5- TempEq	5.9
	19- Temp24	2.8

96.6	Temp0	31.2
	Temp2	20.5
	3.5-Temp10	10.9
	9.5-TemEq	5.9
	16.5- Temp24	3.8
100	Temp0	28.6
	Temp2	20.9
	4-Temp10	10.9
	10- TempEq	5.9
	21-Temp24	3.1
105	Temp0	28.6
	Temp2	20.9
	4-Temp10	10.9
	10- TempEq	5.9
	21-Temp24	3.1

Table 7. Temperature data on different time points.

Reach equilibrium temperature with the chiller is important from a compliance point of view, as if carcasses were to be checked they would not be allowed to leave the chiller nor product be dispatched if it was above this temperature.

In some cases, carcasses kept lowering temperature after reaching equilibrium with the chiller up to 3º less, but in other cases carcasses were cut not long after reaching this temperature

In Figure 22 the number of hours that it takes to reach equilibrium temperature with the chiller increases as the weight increases, from 6 hours from the lightest carcasses to 10 hours for carcasses above 100 kg.

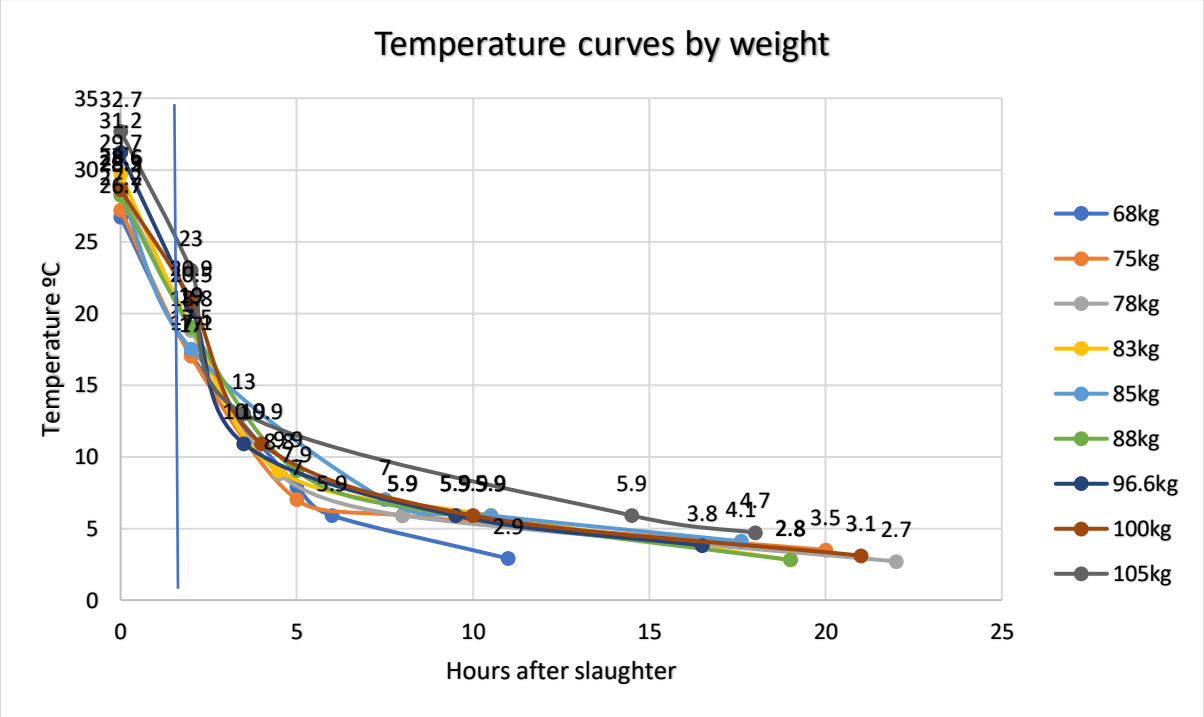

Figure 22. Temperature curves from bacon pigs of different weights.

The importance of this type of study is understanding the dynamic of temperature with different weights, as carcasses that weight dcerease temperature slower, therefore they should be kept in the chiller longer to guarantee they reach equilibrium temperature and stay in the chill longer, giving them the chance to keep decreasing and stabilize.

Interestingly, and consistent with data displayed before, weights and initial temperatures were positively correlated (0.91). There is also a negative correlation on initial temperature and the number of hours required to decrease 10 degrees C (-0.45) (data not shown).

b) Weights, probe, LM% related to meat quality

Carcass and meat quality data was merged from all the meat quality sampling. Was possible to keep traceability and retrieve all the carcass information from each pig, such as Hot weight (HW), Cold weight (CW), probe (p2), Lean meat % (LM%), if boar or gilt.

An overall correlation table for carcass and meat quality traits with HW and CW, probe and LM% without any grouping shows the following relevant relations:

HW	-0.3241	0.2286	0.1576	0.0698	0.1813	0.2419	0.1027	-0.0153
CW	-0.3229	0.2268	0.1554	0.0712	0.1819	0.243	0.1034	-0.0157
Probe	0.0478	-0.0452	-0.0947	0.1639	-0.0322	0.1909	0.1405	-0.1424
LM%	-0.1601	0.1232	0.1571	-0.1497	0.0899	-0.1255	-0.1183	0.1456
	pH0	**Temp0**	**DL%**	**L***	**a***	**b***	**Marbling**	**Colour**

Table 8. Correlations between Carcass traits and meat quality traits without grouping.

**all correlations had a P≤0.001*

There is a negative correlation between pH0 and carcass weights (Table 8), suggesting higher weights related to lower pH at slaughter, also, a positive relation can be seen between carcass weights and temperature 45 mins post-slaughter (Figure 23). Cooling temperatures related to weights have been discussed before, also has been stated that the rate of pH decline and temperature are highly dependent, but seems that the pH fall could have a threshold value (37 ºC) from which above there is little to no influence on the muscle glycolysis (Maribo, et al. 1998), that could explain the low correlation value.

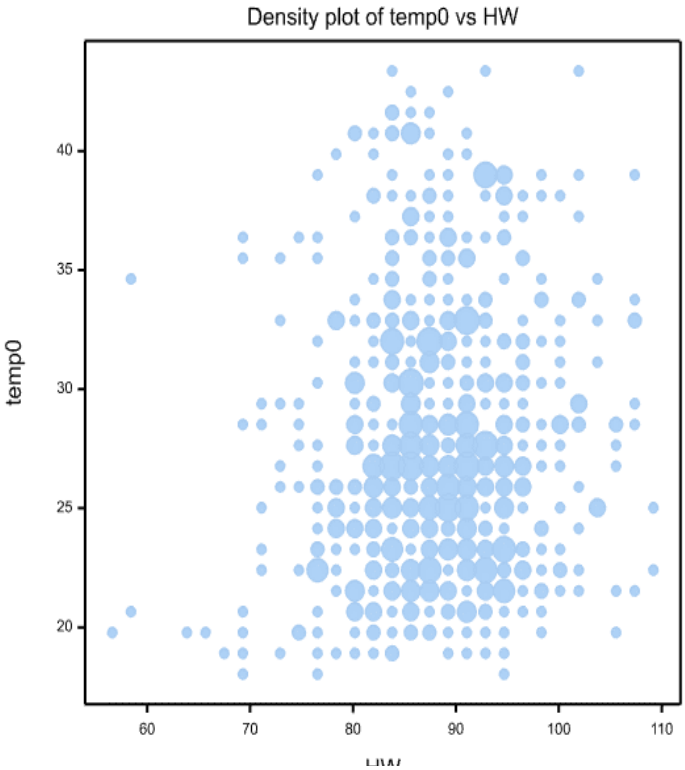

Figure 23. Density plot Temperature at slaughter (Temp0) as a relation of Hot Weight (HW).

Interestingly there was no remarkable correlation between pH and temp after 24 hours and weights nor probe (data not shown).

Drip loss was positively correlated to weights, this is in line with findings from Rybarczyk et al. (2015), who sustained that increase in carcass weights resulted in increased drip loss, but also related this finding to an increase in probe values, which was not seen in the data.

L* correlated positively with probe values and negatively with LM% (lower lean, more pale), while a* had a positive correlation with weights, this last matches the findings of Harsh et al. (2017), where he reported heavier carcasses were redder.

b*, or yellowness of the meat was positively correlated to weights and probe, and negative with LM%, and shares the same kind of relation as marbling scoring with all the carcass traits. The relation between b* and marbling scoring is explained in the Intramuscular fat section.

Marbling scoring and probe values correlated positively, which is a good indicator of the subjective method to asses IMF content.

Finally, card colour scoring correlated negatively with probe values and positively with LM%.

When all samples were separated into HW categories, ANOVA was calculated to see differences between meat quality traits, results can be seen in the following table, traits not included had no statistical difference between groups:

HW (kg)	Probe	pH0	Temp0	pH24	Temp24	Marbling	Colour
50 to 70	8.92^{a}	6.614^{ab}	21.61^{a}	6.039^{ab}	6.709^{c}	1.615^{ab}	3.538^{c}
70 to 80	10.13^{a}	6.54^{b}	26.76^{b}	5.984^{a}	6.348^{b}	1.457^{a}	2.685^{ab}
80 to 90	10.99^{b}	6.51^{ab}	27.77^{bc}	6.059^{b}	5.775^{b}	1.602^{a}	2.767^{ab}
90 to 100	11.57^{c}	6.54^{ab}	28.44^{c}	6.077^{b}	5.378^{a}	1.754^{b}	2.944^{a}
100 +	12.65^{d}	6.466^{a}	28.66^{c}	6.053^{ab}	5.079^{a}	1.635^{ab}	2.673^{a}

Table 9. Analysis of variance of Carcass and meat quality traits from carcasses grouped by weight.

**Values in the same column with the same letter are not significantly different at a 5% level.*

There was a significant difference between probe values for increasing weights, with lower probe for lighter pigs (Table 9). There is an increasing temperature at slaughter with increasing kg, with 7 degrees of difference between the lightest and heaviest pigs, the only statistically significant difference was between the lightest pigs with all other weight groups and the 70 to 80 kg pigs to the 90 to 100 and 100 and above kg. There was no significant difference between pH range of values between all the weight groups.

For pH24, the lowest value recorded was for pigs from 70 to 80 kg, which was statistically lower than all the heavier pig's group. Temperature after 24 hours does not follow the same pattern as temperature at slaughter, heavier carcasses (90 kg and above) had the lowest recorded temperatures, followed by 80 to 90 kg and 70 to 80 kg, and lastly, the highest temperature recorded was for the lightest group.

For marbling, increasing HW seems to increase marbling, which goes in hand with the relation of probe and increasing slaughter weight, but the scoring remained in 1, which is the leanest score possible. With subjective colour, there was significant difference in scoring only between the lightest group and all the other groups.

Colour scoring showed statistically higher (darker) scoring for lighter carcasses compared to all the other weight groups.

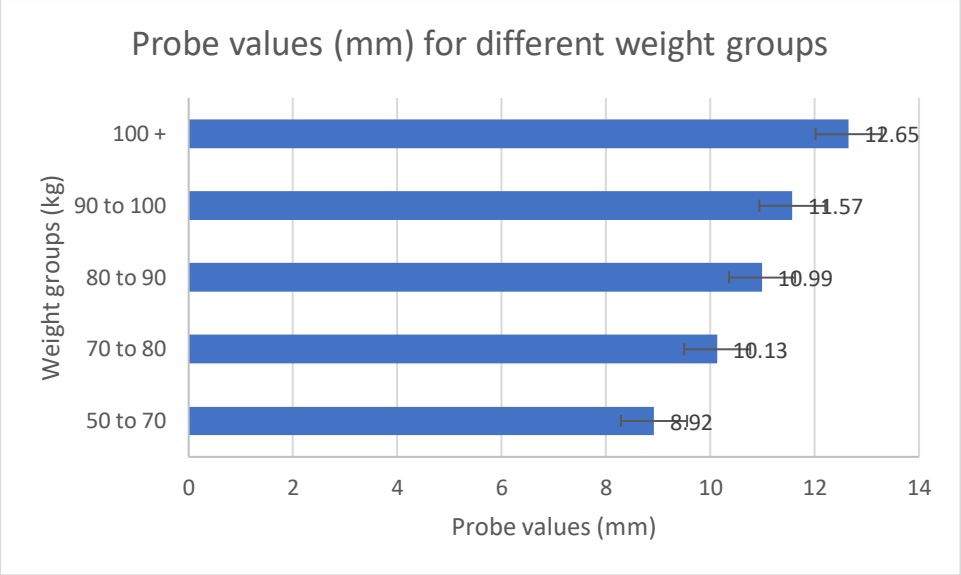

Figure 24. Increasing probe values with increasing HW for different weight groups.

Carcasses in groups were analysed for correlations:

50 to 69 kg:

HW	-0.5108	0.4535	-0.3427	-0.4493	0.0768	-0.0585	-0.5135	-0.2611	-0.0987	-0.5263
CW	-0.5249	0.432	-0.3521	-0.4746	0.0773	-0.0346	-0.5343	-0.2641	-0.1244	-0.5617
probe	0.5458	0.0458	0.6615	-0.1513	0.512	-0.2162	-0.7168	-0.5541	-0.1295	-0.2685
LM%	-0.0517	0.4869	-0.0928	-0.1141	-0.0622	0.3619	0.0772	0.1783	-0.29	-0.2534
	pH0	**Temp0**	**pH24**	**Temp24**	**Drip loss%**	**L***	**a***	**b***	**Marbling**	**Colour**

70 to 80 kg:

HW	**-0.2235**	**0.2286**	0.1959	0.1016	0.304	0.043	**0.225**	**0.3365**	-0.1874	-0.2102
CW	**-0.2417**	**0.1832**	0.2363	0.0791	0.2987	0.0385	**0.2536**	**0.349**	-0.1765	-0.1878
probe	0.0569	0.0405	0.1047	-0.0988	-0.2503	0.1559	-0.0141	**0.1018**	**0.1621**	-0.0234
LM%	-0.0789	-0.0192	-0.0866	0.102	0.2779	-0.1516	0.033	-0.0734	-0.177	0.0106
	pH0	**Temp0**	**pH24**	**Temp24**	**Drip loss%**	**L***	**a***	**b***	**Marbling**	**Colour**

80 to 90 kg:

HW	**-0.185**	0.0568	**-0.1679**	**-0.1292**	-0.047	0.022	-0.1328	-0.0507	-0.1066	0.0492
CW	**-0.185**	0.0531	**-0.17**	**-0.1278**	-0.0514	0.024	-0.1324	-0.0482	-0.1055	0.0493
probe	0.0718	-0.1198	0.0072	**-0.1546**	-0.1231	-0.0196	-0.0767	0.0803	-0.0353	-0.0016
LM%	-0.0896	0.1224	-0.0246	0.1409	0.1155	0.0231	0.0633	-0.0818	0.0232	0.0061
	pH0	**Temp0**	**pH24**	**Temp24**	**Drip loss%**	**L***	**a***	**b***	**Marbling**	**Colour**

90 to 100 kg:

HW	**-0.117**	**0.1637**	0.0932	**-0.2175**	0.0653	0.0295	0.1053	0.0862	-0.017	0.0765
CW	**-0.1174**	**0.1626**	0.0909	**-0.2194**	0.0666	0.0269	0.106	0.0837	-0.0164	0.0779
probe	0.0394	-0.0356	0.1427	0.047	**-0.2843**	0.0538	0.0782	0.0382	**0.155**	**-0.2242**
LM%	-0.0525	0.0492	-0.137	-0.0667	**0.2942**	-0.051	-0.0712	-0.0304	**-0.1599**	**0.2296**
	pH0	**Temp0**	**pH24**	**Temp24**	**Drip loss%**	**L***	**a***	**b***	**Marbling**	**Colour**

100 kg and more:

HW	**-0.2179**	0.0635	**-0.1275**	**-0.1722**	0.0668	-0.192	**0.6373**	**0.331**	**0.3237**	**0.3383**
CW	**-0.2175**	0.0673	**-0.1275**	**-0.1697**	0.064	-0.1954	**0.6357**	**0.329**	**0.3228**	**0.3397**
probe	**0.2828**	**0.2619**	0.2295	**-0.5167**	**-0.2801**	0.3556	0.2015	0.6217	0.1633	-0.094
LM%	**-0.3067**	-0.2725	-0.2448	0.5148	**0.2932**	-0.3817	-0.1494	-0.6049	-0.1396	0.1262
	pH0	**Temp0**	**pH24**	**Temp24**	**Drip loss%**	**L***	**a***	**b***	**Marbling**	**Colour**

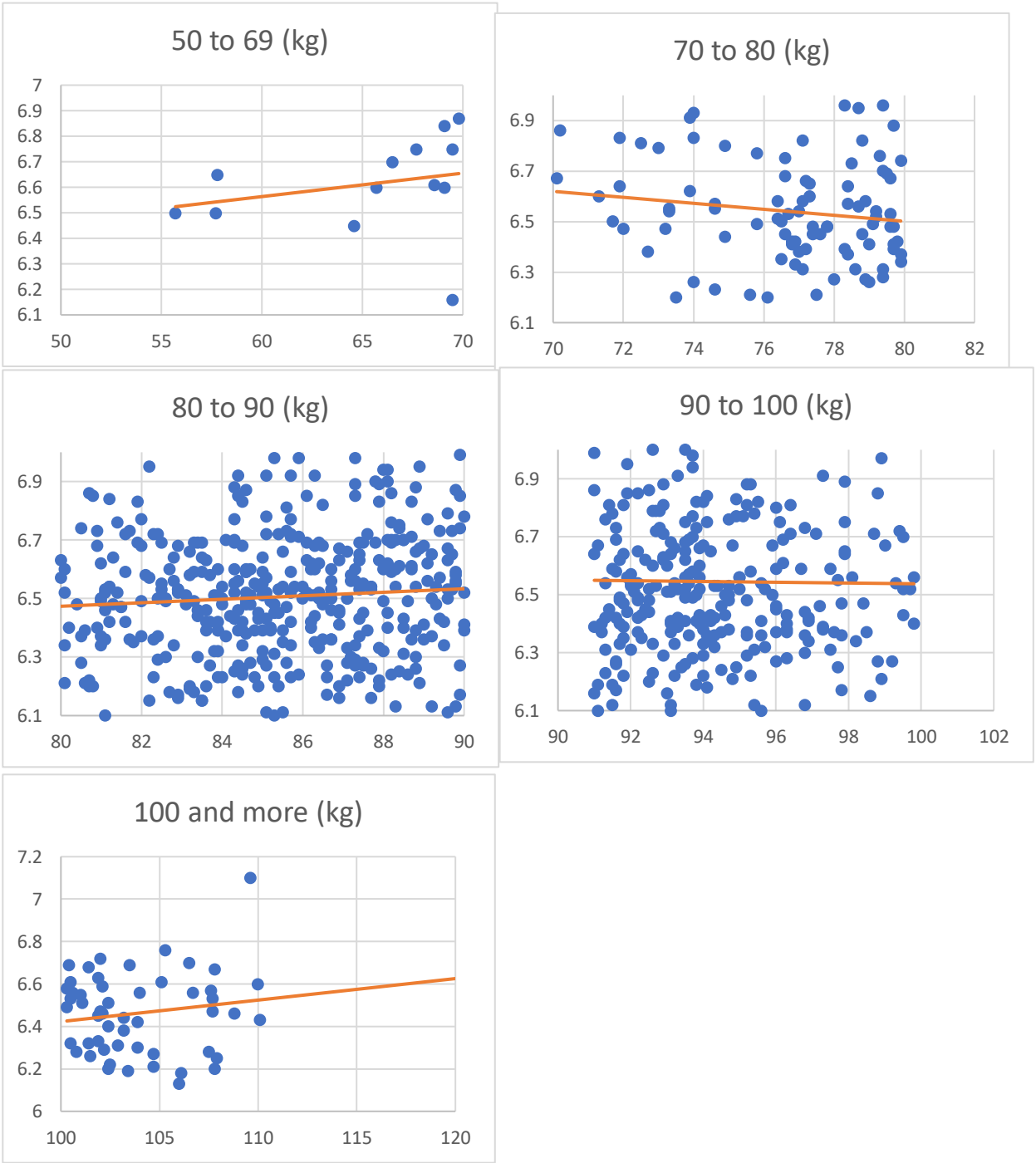

Figure 25. pH0 as a relation of Hot Weight (HW) for different group weights.

The correlation values for pH and weights and probes were the strongest at the lightest and heaviest weights. While temperature was strongly correlated with weights in lightest pig groups (up to 80 kg).

The relation between weight and temperature is not linear, neither the relation between pH and other quality traits. Chilling affects pH mainly in the period between 3 and 4 hours post mortem (Hambretch et al, 2004), chilling heavier carcasses is a slower process, which seem to match the results of the above correlation for all weight groups, but unfortunately the relation wasn't as strong as expected in the heaviest group.

Regarding drip loss, in all weight groups it was negatively related to the probe value, while for the 70 to 80 kg group was strongly correlated to weights.

L* only had a moderate to strong relation with the heaviest groups and with probe values, where for lighter pigs, higher probes gave darker meat whereas for heavier pigs' higher probes gave lighter meat.

Heavier carcasses gave redder meat and lighter carcasses gave less red meat, another example of opposite relation of weight variation to quality traits.

b* had a negative relation with weights.

Marbling had a negative correlation with weights for the lightest pigs and for the 80 to 90kg group; the correlation became positive (for both traits) in the heavier group. The effect of marbling scoring in the heaviest group was quite noticeable and it agrees with findings about increasing probe values with increasing weights.

Colour scoring was negative correlated with probe for all the weight group.

c) Gender and carcass and meat quality traits

From the meat quality data collected over the two years, a gender comparison between Boars and gilts was made, results are displayed in the following table:

Parameter	Boars	Gilts	p value
pH0	6.52[a]	6.51[a]	0.64
Temp0	28.29[a]	27.62[a]	0.13
pH24	6.05[a]	6.06[a]	0.64
Temp24	5.69[a]	5.89[a]	0.99
Drip loss%	1.58[a]	1.48[a]	0.08
L*	48.33[a]	48.58[a]	0.18
a*	14.94[a]	15.07[a]	0.16
b*	7.03[a]	7.13[a]	0.064
Marbling	1.62[a]	1.64[a]	0.76
Colour	2.82[a]	2.8[a]	0.79
Cooking loss%	30.63[a]	29.48[a]	0.10
HW	87.8[a]	88.8[a]	0.064
CW	86.1[a]	87.05[a]	0.052
Probe	10.77[a]	11.53[b]	≤0.001
LM%	62.31[a]	61.49[b]	≤0.001

Table 10. Analysis of variance of carcass and meat quality traits by gender.

**Values in the same column with the same letter are not significantly different at a 5% level.*

There was no significant difference between none of the meat quality traits.

Gender did not influence pH values in neither timepoint enough to be statistically significant, which is according to what's seen on literature (Channon, et al 2016) (Maiorano, et al. 2011). Whereas the opposite was seen for temperatures at slaughter in this study compared to Channon data.

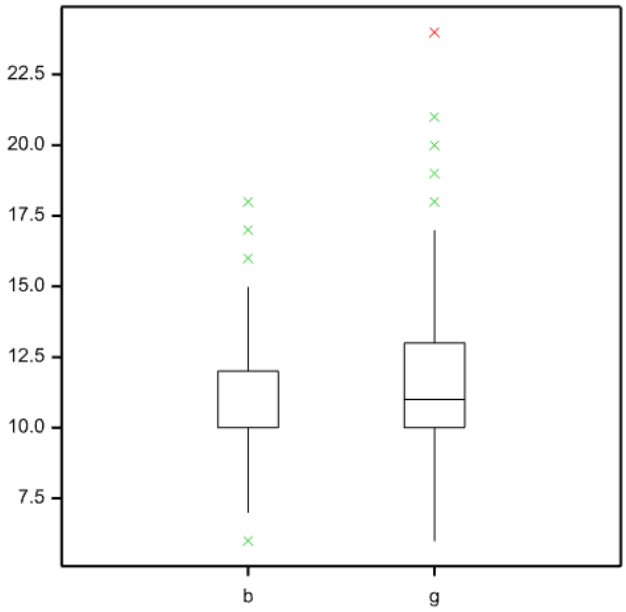

Figure 26. Boxplot of probe (mm) value distribution by gender, boars (b) vs gilts (g)

Only numerical difference showed slightly higher temperature at slaughter for male carcasses, also higher drip loss% (Maiorano et. al. 2011) and cooking loss%. Similar trends for higher cooking loss and drip loss are expected considering most of the loss during both processes involve water being expelled due to protein denaturation, which has been extensively mentioned as dependent on temperature (Aaslyng et al. 2015). Higher drip loss was recorded for entire males in Channon et al. (2016) compared to females but not strong enough to be significant.

There was some significant difference in probe (Figure 26) and lean meat% values, suggesting higher values for gilts compared to boars, which is the opposite of what was seen in the above-mentioned study by Maiorano. Most of the available literature on carcass and meat quality traits is available between females and castrates.

4.3. Drip loss

Drip loss originates from shrinkage of muscle cells after slaughter, causing the water to be expelled outside the cells, this is partly encouraged by pH decrease after death (Den Hertog-Meishke, M. et al. 1997). Pork with ultimate pH below 5.5 will typically have higher drip due to a reduction in the capacity of binding water when compared to "normal" quality pork.

Retention of water is relevant for further processing, as it prevents excessive purge loss and helps retaining water while cooking. A pork product with low water holding capacity will tend to have an excessive amount of purge in the packaging (and in the bottom of the transport).

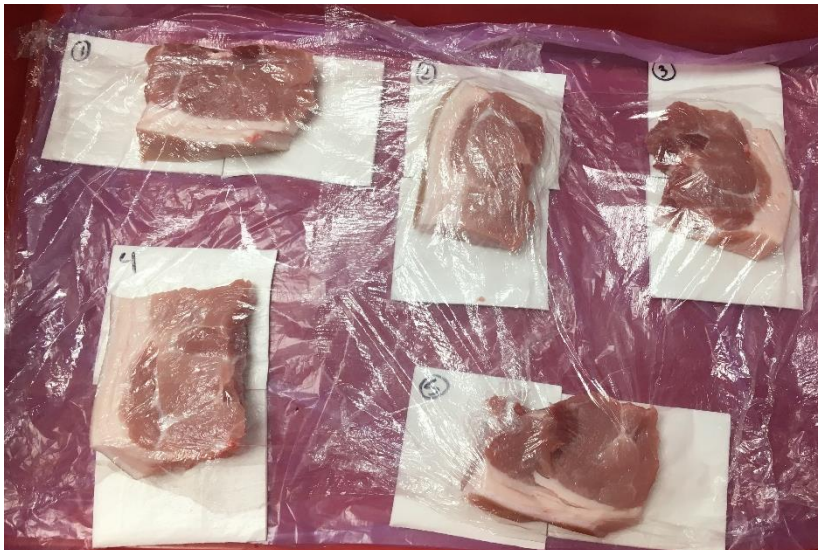

Figure 27. Drip loss samples with drip loss pads method, used until the end of 2018.

Purge is often perceived by the consumer as "blood", regardless the misconception its presence in excess is not desirable as the customer tends to avoid it. Weight loss due to "purge" or drip loss ranges from 2 to 10% when meat is cut into chops (Watanabe et al. 2018).

The biochemistry behind drip loss is complex, but can be summarize: the lower the ultimate pH, the closer the muscle cell protein will be to lose its isoelectric point (balance between negative and positive ions) , leading to poor space left in the cell for water to be bound. With not existing space available inside the muscle cells the water will tend to scape to the space between the cells and be loss in the form of exudatives (Den Hertog-Meishke, M. et al. 1997, Huff-Lonergan et al. 2005). The result of all this is higher liquid loss when products are being cooked and a final product being dry and less appealing.

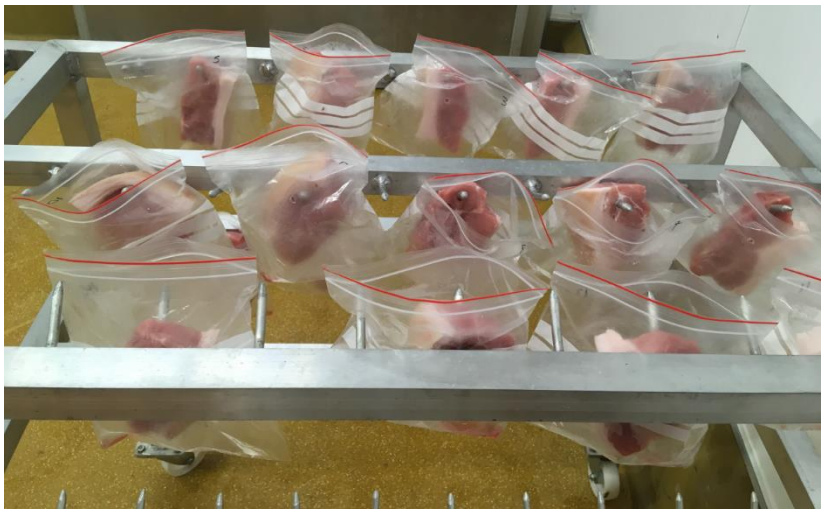

Figure 28. Drip loss samples with hanging method, used from 2019 onwards.

The methods used for drip loss% in the project have been explained in the Material and methods section. A modification of the method leaded to consider the data from the beginning of 2019 and 2020 for stats as this was the chosen method which mimics drip loss on meat in more realistic way, because of both methods differ both sets of data could not be combined.

a) Drip loss% data

From the total number of meat samples evaluated with the drip loss gravitational method, the average for the site from all meat samples was 1.6% (SD. 1.2 and Variance of 1.48).
When looking at summary statistics, 24% of all drip loss samples represented more than 2% drip loss but when increasing the value to a 3% drip the value drops to 8% of the total meat samples.

Month	Drip loss%
January	2.07^{bd}
February	2.05^{bcd}
March	1.904^{bcd}
April	1.245^{a}
May	1.159^{a}
June	1.088^{a}
July	1.315^{a}
August	1.444^{ab}
September	1.480^{abc}
October	1.477^{ab}
November	1.722^{abcd}
December	2.023^{bcd}

Table 11. Drip loss% average from meat samples over the years per month.

**Values in the same column with the same letter are not significantly different at a 5% level.*

Drip loss over the months (Table 11) is showed in Table 11. Interestingly drip loss did not followed the same pattern of increase as colour, which tended to become higher (higher L*, paler) in the summer months, whereas drip loss behaviour showed increment in the colder months.

Drip loss% was compared with the calculated drip loss from the carcasses hang in the chiller from which the samples were extracted. In this last case, drip loss% in carcasses was calculated as the difference between HW and CW, when full traceability was possible (meat sample and carcass) the correlation between results was too weak to be significant.

The additional drip loss calculation made for this project with loin samples tries to mimic the extra drip loss the primals will lose during its transportation to the sites in England for further processing, as there is no further operations in the site after cutting into primals (shoulder, middle and leg).

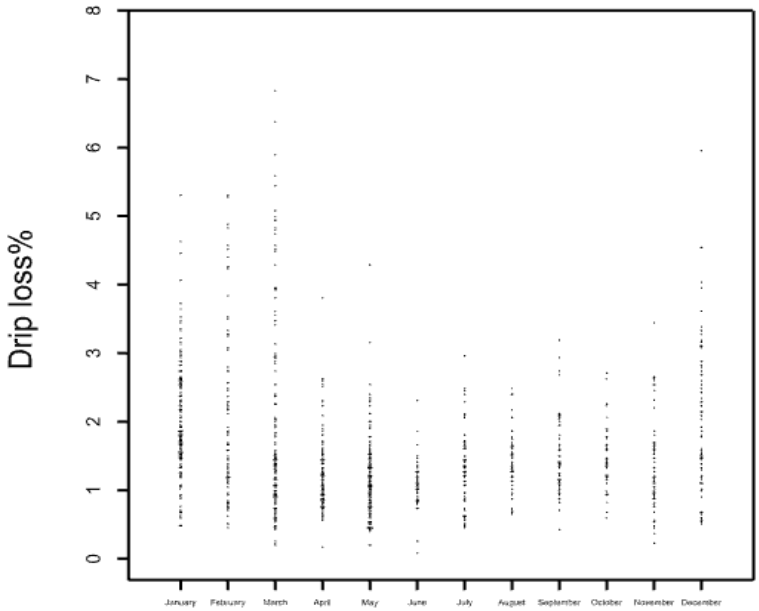

Figure 29. Drip loss% average from meat samples per month over the years.

b) Drip loss% and other quality traits

When analysing Drip loss% with other quality traits, its relation to temperature and pH is considered first.

Weak correlation was seen between pH0, temp0 and drip loss% (Table 12) , suggesting this is not a linear relation.

Figure 30. Drip loss samples at commercial chiller hanging from drip loss rack.

In addition to this, other influencing factors are suggested by den Hertoj-Meischke et al. (1997), starting by rate of pH decline rather than absolute values, muscle type, composition and location of the muscle in the carcass (factors inherent from the carcass), chilling rate, hot boning (factors regarding slaughter and further processing).

On the other hand, pH24 and temp24 were moderately correlated to drip loss%, lower pH values at 24 hours correlated with higher drip loss, and higher carcass temperatures in the chiller (after 24 hours) correlated to higher drip loss from the meat samples, this corresponds with the relations found in

Juncher et al (2001), suggesting that lower pH24 results in higher levels of lactate, which cause of drip loss%.

As most of the moisture is held within the structure of the muscle fibres and muscle cells, water holding capacity is affected as well by physical factors as well as chemical. pH fall post mortem induces protein denaturation and an increase in space between muscular cells (besides the biochemical events already explained), which increase drip loss.

Parameter	Drip loss%	P value
pH0	-0.04	1.94
pH24	-0.22	≤0.001
Temp0	0.06	0.14
Temp24	0.12	≤0.001

Table 12. Correlation between Drip loss% and pH and temperature.

Considering the meat samples were taken from the carcasses after 24 hours (after pH24 and temp24 has been recorded) can be speculated that changes in the muscle biochemistry suffered in the first hours after slaughter have consequences in meat quality even after hours in the chiller. In Ryu et al. (2005) a (also negative) stronger correlation between drip loss% and pH24 was seen, confirming that the lower pH24 gives more exudative meat.

On the previous point Hambretch et al. (2004) sustained that most of the protein denaturation occurs in the first hour post-mortem, when carcasses are above 30º C, therefore the importance of adequate temperature management considering that, if the chilling starts too late or is not efficient enough will be too late to repair the damage that has been caused on an earlier stage, this is particularly relevant for rapid pH declining carcasses, which might even have completed great extent of its glycolysis before entering the chiller.

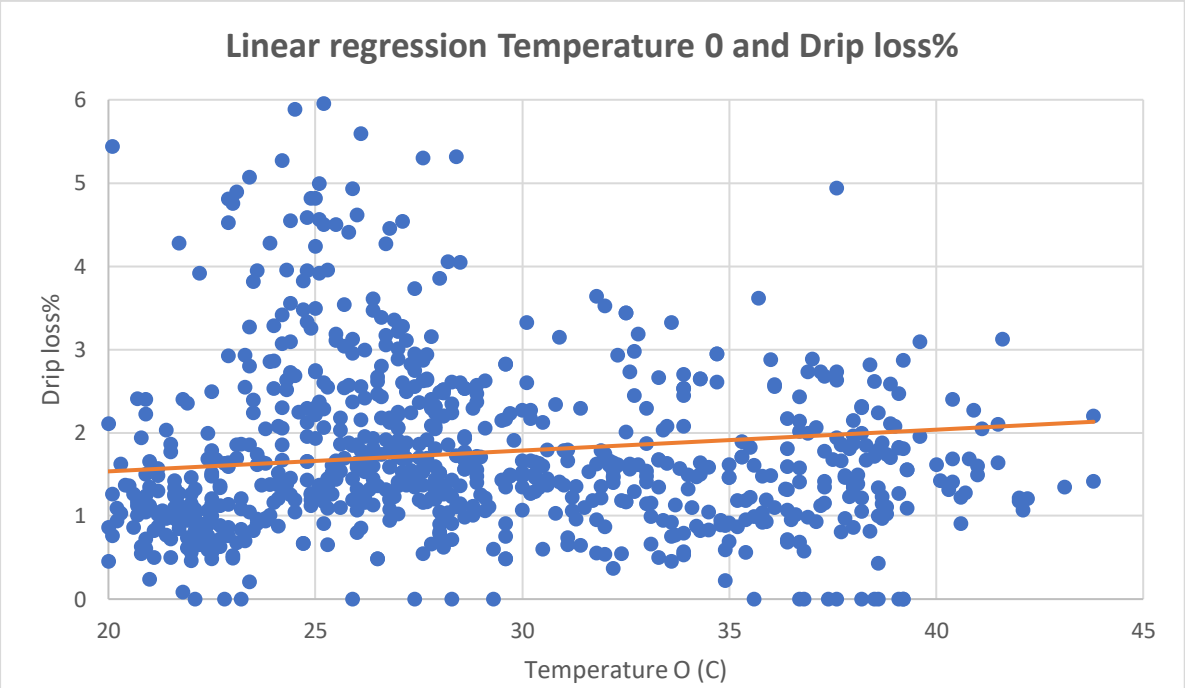

Figure 31. Linear regression temp0 and drip loss%

On the moderate relation between pH24 and drip loss%, Fischer, et al. (2007) stated that this relation is also not linear, pH24 makes little influence above 6.0 due to greater distance of the pH to

the isoelectrical point of proteins resulting in less attraction between proteins and more space for water.

Unfortunately, linear regression (Figure 31) analysis did not show strong dependencies between the variables. For Temperature 0 (independent variable) and drip loss (dependent variable) the correlation coefficient was 0.27 and the R square value 0.07, indicating a poor fit to a linear model.

For temperature at 24 hours the correlation coefficient was 0.28 and R square 0.07, in both cases the SD was 1.1 (Figure 32). The linear regression became slightly stronger if only considering the coldest months (December, January, February, March) but not enough to be relevant.

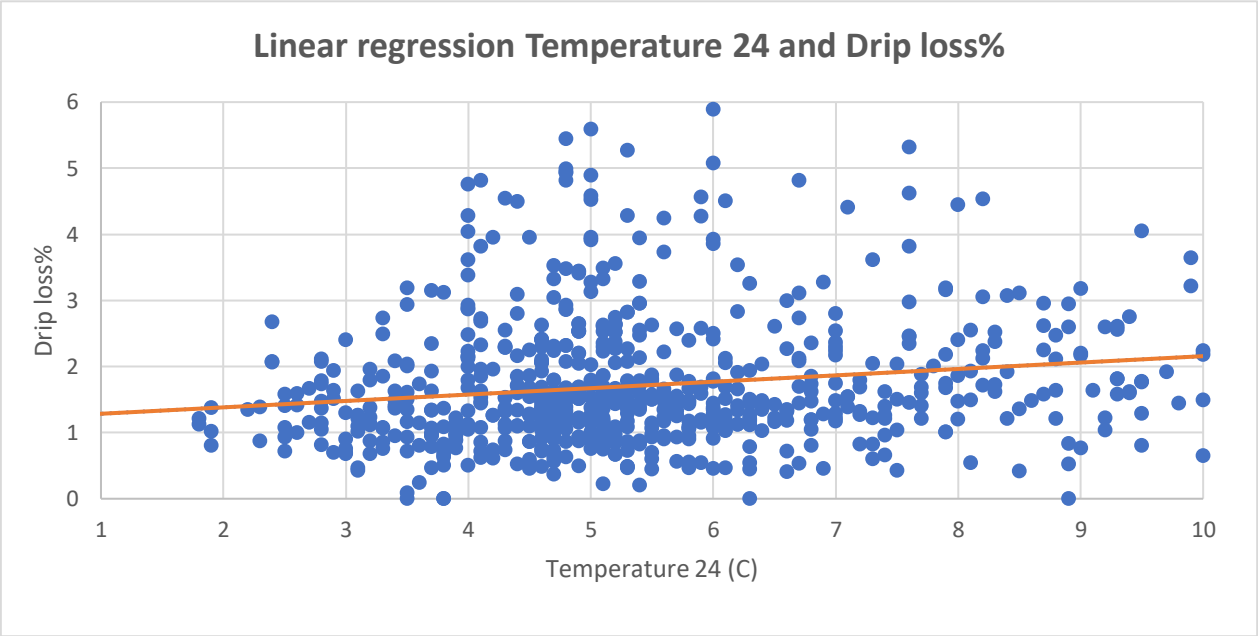

Figure 32. Linear regression Temp24 and drip loss%.

Drip loss% was correlated to other quality traits (Table 13).

L* correlated weakly but positively with higher drip loss, which is expected considering both factors are affected by the same processes in muscle biochemistry (protein denaturation).

Marbling correlated negatively with drip loss% which is referred in literature as the effect of fat occupying space that can be potentially be used for water, which will later scape to the extracellular space, similar findings have been suggested by Rybarczyk et al. (2015).

Parameter	**Drip loss%**	**P value**
L*	0.14	0.15
Marbling	-0.21	0.02
Cooking loss%	0.36	≤0.001

Table 13. Correlation between Drip loss% and other quality traits.

Cooking loss% was unsurprisingly correlated with drip loss (Figure 33), considering both events follow similar paths for releasing water from the muscle cells. According to (Pearse, et al. 2011), the explanation for this is that cooking processes denature proteins, which directly influences the structural characteristics of the meat and its water distribution, the temperature threshold for this is

not completely agreed, but ranges from 40 to 50 ºC which is below our cooking temperatures for analysis.

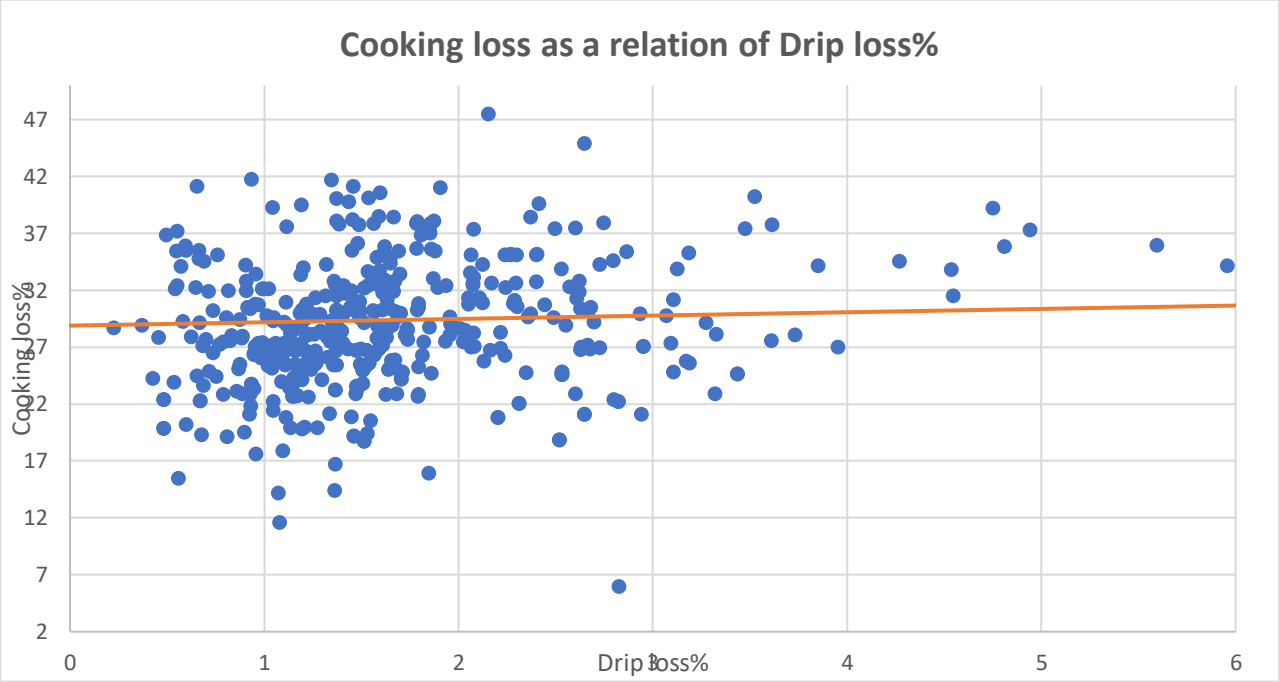

Figure 33. Cooking loss as a relation of Drip loss

The relation between tenderness tests and drip loss% will be developed in another section.

4.4. Meat colour

Colour is one of the first attributes that consumers evaluate when buying meat. The industry has an important duty on educate consumers regarding how colour influences palatability, and the industry must work to produce pork in an acceptable and consistent colour standard (Holmgaard et al. 2012)

For methods used to asses meat colour refer to the Materials and methods section.

a) Colour data

The L*indicates paleness/darkness of a product and has been referenced by Mancini et al. (2005) as the best indicator of PSE and DFD, being values above 51 considered “pale”, this last based on Rocha et al (2006). The L* illuminant threshold value for PSE are ≥50 and for DFD ≤42.

The summary values for all colour measurements taken on the site can be found in the following table:

Parameter	Mean	SD	Variance
L*	48.08	2.6	7.0
a*	15.18	1.3	1.9
b*	7.1	0.66	0.44
Colour subjective	2.7	1.0	1.0

Table 14.Summary values for colour traits.

Summary statistics from the site showed that from over 1000 samples analysed with the Koica Minolta colorimeter, 22.1% were above 50 (categorized as Pale), whereas the remaining 67.4% were

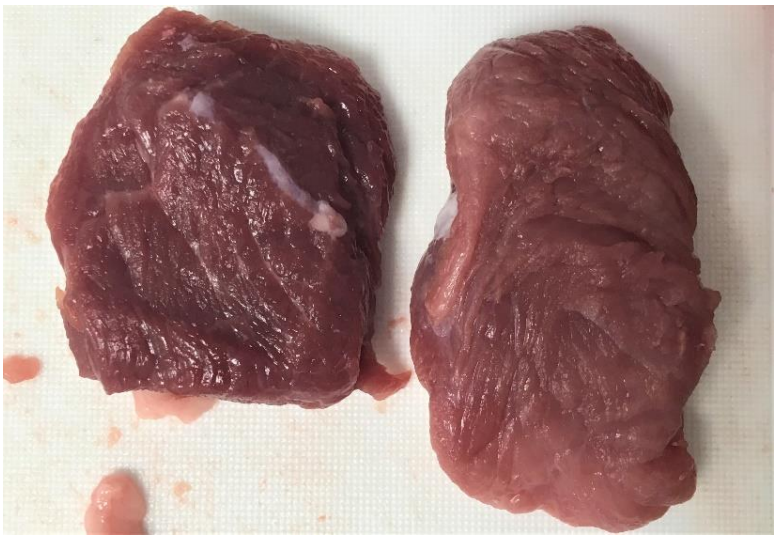

Figure 34. Difference in colour from two meat samples.

in acceptable parameters and 10.5% of meat samples with L*values below 45, which can be potentially categorized as “dark” meat.

When looking at the summary numbers of the subjective colour measurement (Pork Checkoff cards) an 11.5% of the samples scored 1 (lowest colour scores possible or Pale meat), which is half of the % recorded for pale meat using the Koica Minolta (objective method). This last shows the potential of the Pork checkoff cards to be a quick reliable method to asses meat colour in an abattoir if variables such as training and human factor are taken into consideration.

The following table shows the correlation between L*, a*, b* and the Pork checkoff colour cards:

Parameter	L*	a*	b*	Colour cards (Pork checkoff)
L*	--			
a*	-0.1974	--		
b*	0.3504	0.5053	--	
Colour cards (Pork checkoff)	-0.4699	0.2030	-0.1510	--

Table 15. Correlation between colour parameters and Pork checkoff cards

**all correlations had a P≤0.001*

Correlations between the other colour parameters showed inverse relation between paleness and redness of the meat in the samples.

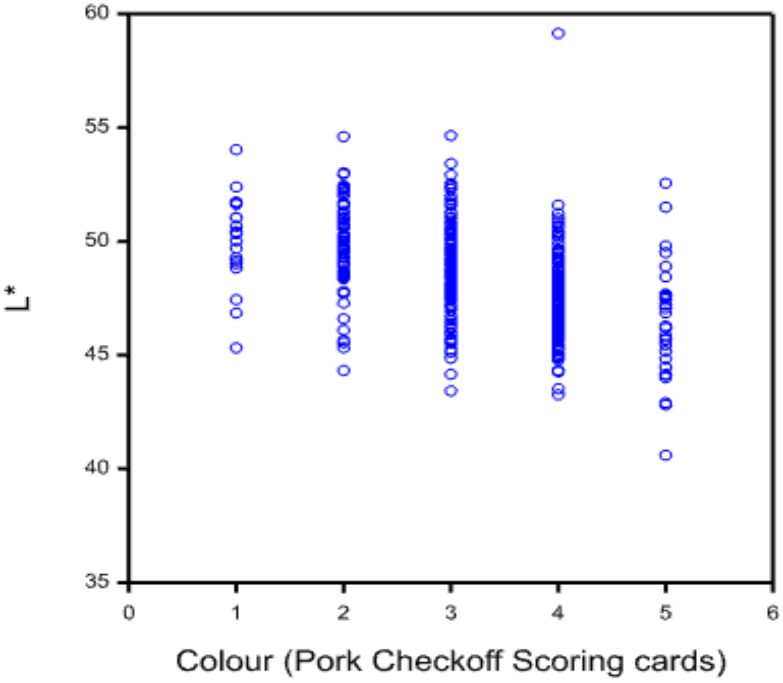

Figure 35. Correlation L and Pork Checkoff cards.*

L* and a* correlated negatively, and it is consistent with other publications such as Gajana et al. (2013) and Ryu et al. (2005), stating that increase in lightness translates in decrease in redness in muscle. This last paper also sustained the same positive correlation between b* and L*.

The Colour cards correlated negatively with L* in a moderate to high level, meaning that the highest L* (closest to 50 or above) the lower scoring card number (closer to 1, palest scoring), which proved to be quite useful for a commercial colour assessment (Figure 35).

The relation between L* and both pH time points was negative but too weak to be plotted. A stronger correlation was expected considering the relation between L* (light scattering) and protein denaturation (Brewer et al, 2001). On the other hand, denaturation is accelerated by higher temperatures, and both timepoints of temperatures and L* there had moderate correlations.

Figure 36. Meat sample and pork checkoff card for analysis.

When performing linear regression analysis, Temp0, the result was a correlation coefficient of 0.33 value and an R square of 0.11, which is fairy poor to explain the dependency of the variables L* and initial carcass temperature, the same applies for the SE (22.72), which seems to indicate that the average temperature and L* fall not close to the regression line. Dokmanovic, et al. (2015) also found a negative correlation between L*and Temp0.

The relationship became stronger when looking at temperature after 24 hours (Temp24), with a correlation coefficient of 0.37, R square of 0.14 and SE of 3.03 (Figure 37). Still too weak to attribute changes in paleness of the meat entirely to carcass temperature, which leads to hypothesize that up to certain value the temperature in both timepoints (separately or individually) are drivers for meat paleness but after certain threshold the dependence becomes weak, not fitting a linear regression model.

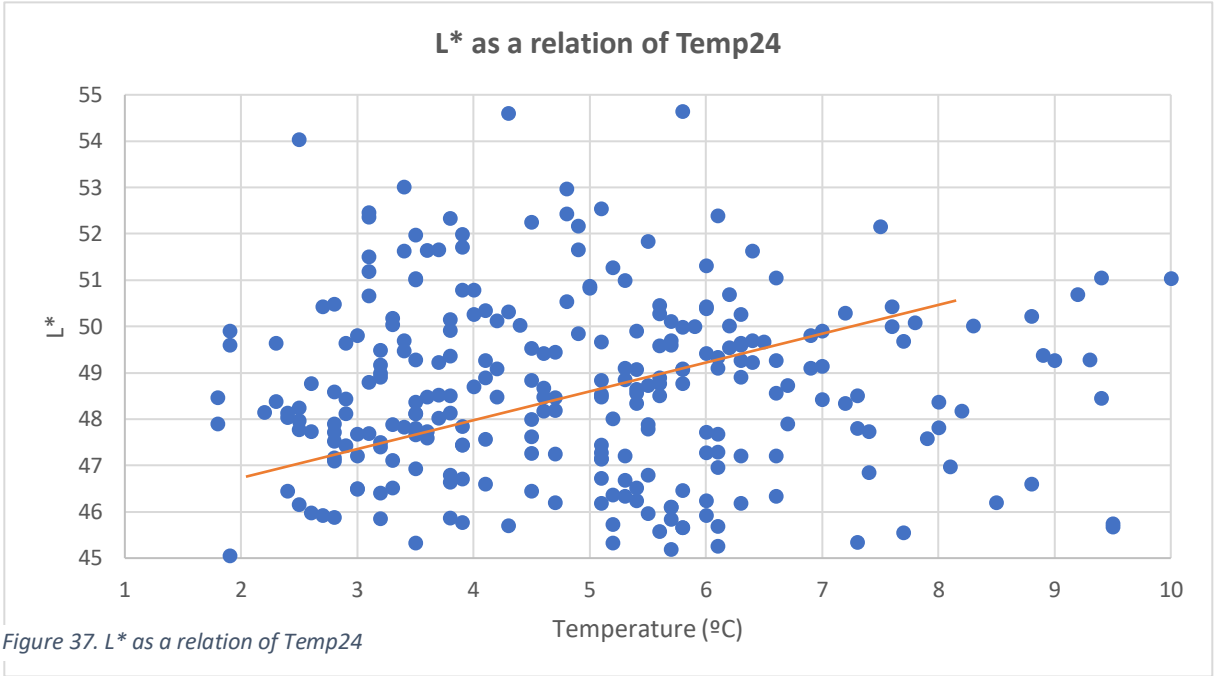

Figure 37. L as a relation of Temp24*

The only linear regression model found to explain L* was its dependency to a* or redness of the meat, which didn't come as a surprise to be highly dependent (0.93, R square of 0.96) (Figure 38).

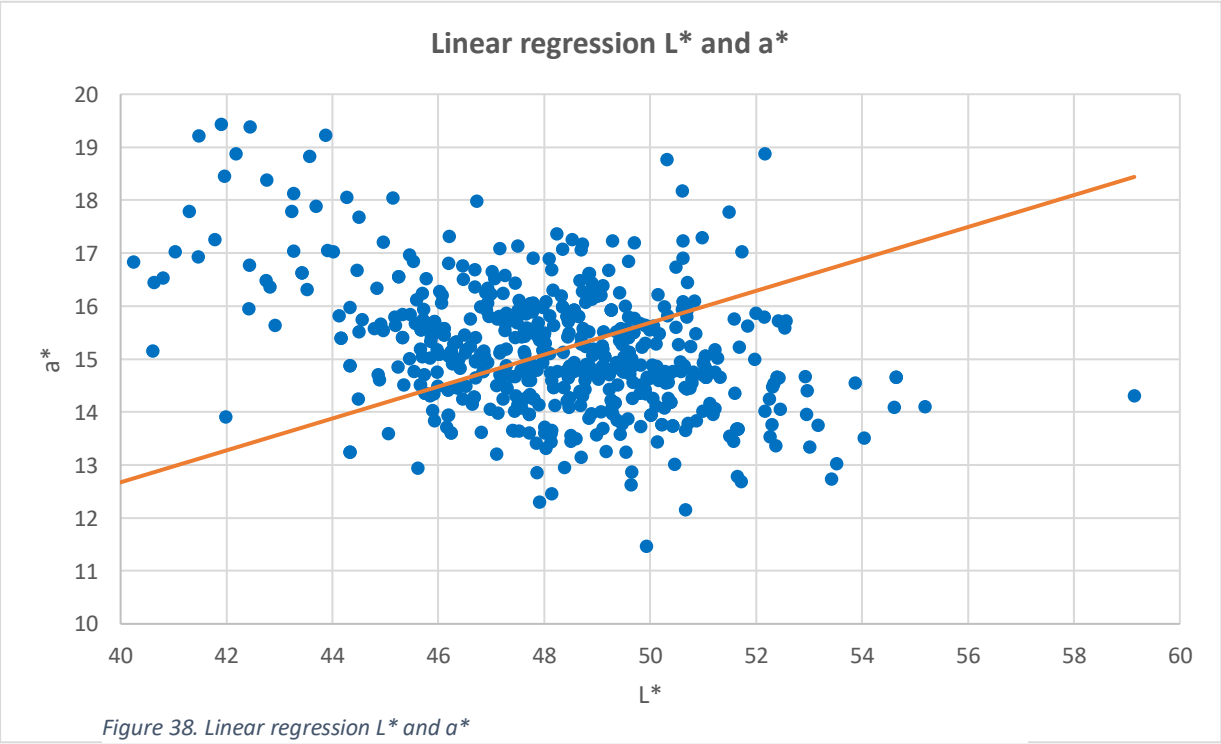

Figure 38. Linear regression L and a**

When grouping the L* factor over months can be seen significant differences between January and the rest of the months. January had the darkest meat value recorded. February and March had some of the palest values, no feasible explanation can be found for this but attribution to the farm itself.

There was a consistent higher value through the summer months which could be attributed to the higher environmental temperatures impacting directly into carcass chilling and indirectly in the pH.

Is important to note that through the year the L* values were always under 50 which is the undesired value for pale meat.

Month	L*
January	43.40[a]
February	48.85[ef]
March	49.16[f]
April	47.99[bcd]
May	48.0 [bcd]
June	48.39[bde]
July	48.76 [ef]
August	48.63 [def]
September	48.49 [def]
October	47.78 [bcd]
November	47.53[b]
December	47.53[bc]

Table 16. L average values of meat samples per month over the years. *Letters differ when P value is ≤.001.*

b) Meat colour related to other meat quality traits

L* of the meat showed a weak positive correlation with drip loss% (0.14, P≤0.15), similarly and in a lower value, the correlation with cooking loss% was also weak (0.07, P≤0.09). The relation between drip loss% and L* is briefly mentioned in Brewer et al. (2001) when describing the increase of free water that follows protein damage caused by denaturation, which cases higher light scattering and tissue appearing "lighter", the same relation is also seen in Ryu et al. (2005).

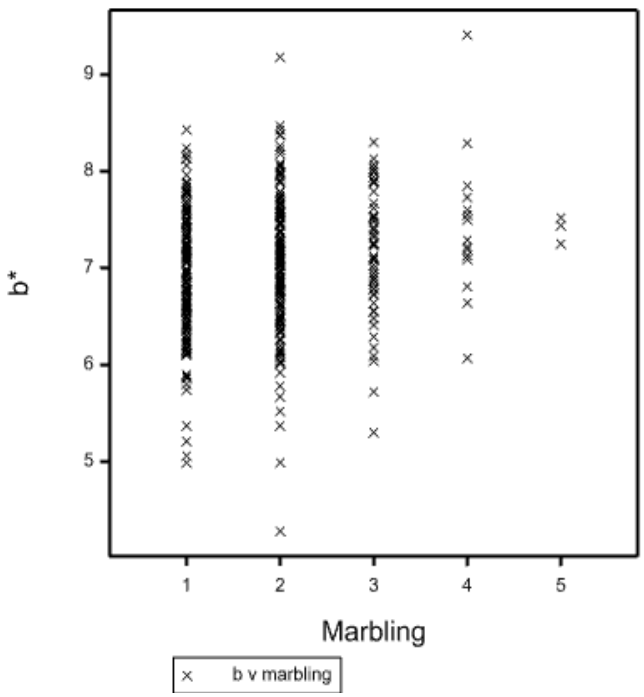

Figure 39. Meat b and marbling scoring.*

Interestingly, b* correlated positively in a moderate to high value with marbling scored by Pork Checkoff (Figure 38).

The Pork checkoff cards scoring correlated weakly (and negatively) as well with Drip loss% (-0.04, P≤0.5).

Cooking loss% correlated negatively and moderately with the card scoring (-0.31, P≤0.01).

Correlation coefficients from a* and b* with temperature and pH are the following:

	a*	b*	pH0	pH24	Temp0	Temp24
a*	-					
b*	0.43	-				
pH0	-0.02	0.04	-			
pH24	0.10	-0.009	0.04	-		
Temp0	-0.25	-0.28	-0.01	0.17	-	
Temp24	0.18	0.11	0.13	0.24	0.07	-

Table 17. a and b* related to pH and temperature values. *all correlations had a P≤0.001*

a* and b seems to be moderately and negatively correlated with Temperature at arrival (-0.25, -0.28 ,P≤0.001), which can help to not out rule completely the influence of temperature in meat colour.

The relation between b* and pH24 matches Juncher et al. (2001) and Ryu et al. (2005) suggesting that low pH24 results in higher b values, especially in the first days of meat storage, but the findings here did not correspond to the data from that paper in terms of a* and pH24.

The relation of colour and tenderness is developed in the tenderness section.

4.5. Intramuscular fat / marbling

a) Overview and site values

The role of intramuscular fat or marbling on eating quality of pork has been a focus in a lot of research. Lower levels of intramuscular fat are desired in pork which is derived from continuous work in the pig genetics industry to decrease fat levels. Unfortunately, the current perception of pork by costumers has been affected by this, the product being perceived as dry and with little flavour.

The pork industry focus on carcass lean resulted in correlated reduction of IMF within the loin and ham which might contribute to reduction of eating quality, therefore the understanding of the role of IMF on eating quality is relevant. To this day the methods of estimating IMF are chemical and costly and can't be performed at industrial levels. The current approach is based on calculating LM% in each carcass based on modelling and with this develop a grading system.

Farmers are payed and penalised based on grading, which is performed by methods approved by the EU with tools that can estimate LM%. Carcass grading in abattoirs have been historically performed by MLC (Meat & Livestock Commission).

LM% in most abattoirs is predicted based on the fat depth at the P2 (last rib of the carcass and 6 cm the middle line) position and cold carcass weight, with the Intrascope, other registered tools are MKII Ulster probe, Henessy probe, Ultra Meat'er, Fat-O-Meter and Autofom v 1.0.

The current method deployed at QPP, and through the tulip group is the Intrascope, the method has weaknesses in the human error, considering several points:

- Reference point from the middle of the carcass relays on the ability of operator to split the carcass in half properly (where this is performed manually).
- The P2 position only accounts for one point of the carcass, and with the current improvements in nutrition and genetics fat distribution in carcasses differs.
- The human element of change from operator to operator.

On the current benchmarking project, meat samples were assessed for marbling in a subjective method using cards from the Pork Check off (National Pork Board, 2011). The possible scorings are in the Material and Methods section.

Observations from the samples processed showed that the average recorded for the site is 1.6 (SD 0.7) from a scale of 1 to 5 as no 6 nor above was ever recorded, leading to conclude most of the pork chops evaluated are poorly marbled.

The % of each scoring through the whole sampling period are summarized in the table below:

Marbling Scoring	% of the total over sampling period
1	49
2	39.2
3	9.5
4	2
5	0.3

Table 18. Distribution of Marbling scoring from samples over the years.

Marbling based on the Pork Checkoff cards have been recorded from a representative number of samples from each farm tested for meat quality along with other traits.

Below, images from pork samples from QPP with its correspondent marbling card score are shown:

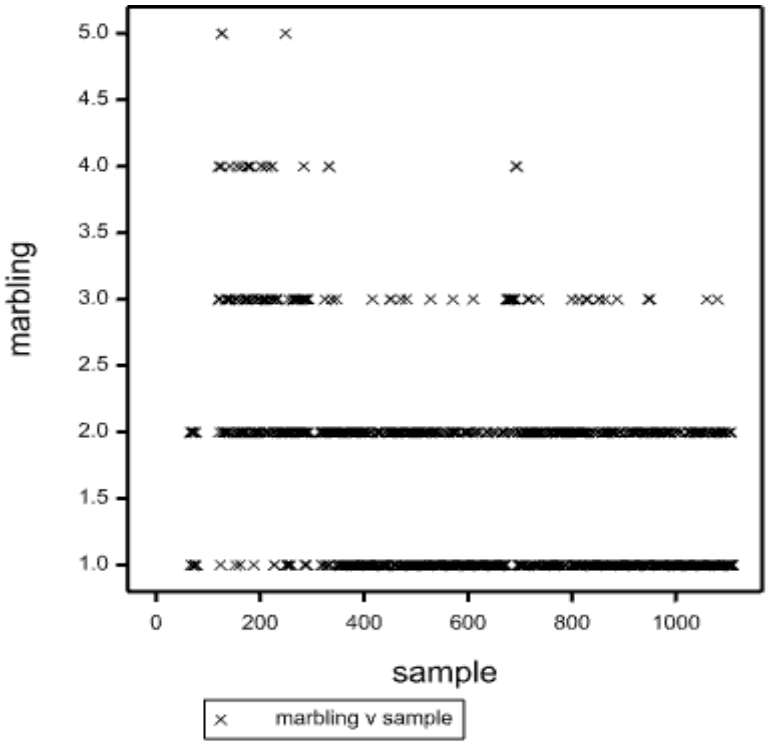

Figure 33. Marbling samples distribution by score.

Figure 34. Meat samples next to scoring card.

b)Intramuscular fat/ Marbling related to other meat quality traits

The correlations between marbling and pH and temperature were not significant, whereas with this study, marbling was shown to be correlated b* and a* and to a lower degree with L*, this last relation was also supported in Juarez et al. (2005).

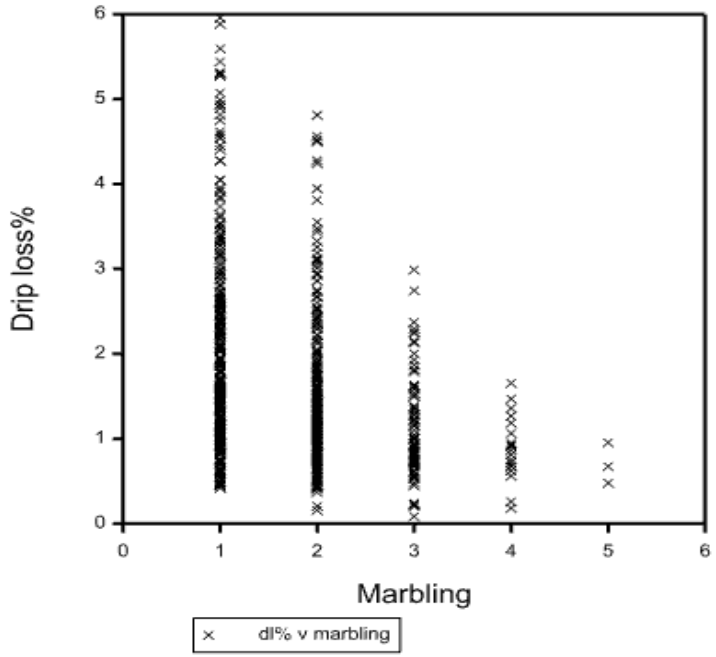

Figure 35. Drip loss as a relation of marbling samples.

Also, as marbling increases, drip loss decreases (-0.21, P≤0.001) (Figure 35).

Correlations between marbling and pH24 show a possible relation between both traits, Dokmanovic, et al. (2015) suggested that, because energy reserves (glycogen) in the muscle are distributed among intramuscular fat, muscles with higher intramuscular fat content will have less space for glycogen deposits, which leads to less glycolytic potential, higher ultimate pH and to an extent less drip loss.

On the relation of marbling and drip loss% as well, Juarez et al. (2009) sustains in his study on enhancing pork quality through genotypes and chilling that leaner pork are more likely to lose moisture over chilling than pigs with higher fat content.

Also, Watanabe et al. (2018), states that similar as in beef, moisture content correlates negatively with pork.

When looking at linear regression equations, marbling showed a Correlation coefficient of 0.36 with pH24 and R square of 0.13, the SE was 1.39. It is still a week fit to the model which indicates that ideally the relation of marbling and pH24 might be linear up to certain extent.

The influence of marbling on tenderness is developed in the following chapter.

When meat samples were grouped based on their marbling scoring the following results were seen:

Marbling scoring	temp24	Drip loss%	a*	b*	Colour	Cooking loss%	HW
1	5.662^{b}	1.8^{c}	14.8a	6.95^{a}	2.536^{a}	30.95^{b}	87.7^{a}
2	5.455^{ab}	1.426^{a}	15.11^{b}	7.06^{b}	2.96^{b}	29.31^{a}	88.64^{ab}
3	4.914^{a}	1.162^{ab}	15.17^{b}	7.16^{b}	3.342^{c}	31.66^{b}	89.68^{b}
4	5.518^{ab}	0.844^{ab}	15.81^{c}	7.37^{b}	3.5^{c}	30.35^{ab}	89.76^{ab}
5	5.518^{ab}	0.702^{a}	15.38^{abc}	7.40^{ab}	4bc	30.35^{ab}	93.43^{ab}

*Table 19 Samples grouped by marbling scoring. *Letters differ when P value is ≤.001.*

There was no statistical difference between values for pH, temperature at slaughter, probe or LM% between marbling scoring groups.

Temp24 hours was lower and statistically different for scoring 3 and 1, this corresponds with the higher drip loss value recorded also for scoring 1, drip loss decreased as the scoring increased.

Lower scoring seems to indicate less “red” and “yellow” meat. Also, colour scoring increased when marbling scoring increased, this was significant for scoring 1 and 2 compared to higher scoring.

Cooking loss was only statistically different for scoring 2 (highest cooking loss recorded) and 1 and 3.

As HW and CW increased, marbling score increased as well, there was not statistical difference between weights.

4.6. Cooking loss

Physical properties and eating quality of meat are affected by cooking temperature and time. During cooking meat proteins are denaturated and this causes structural changes in meats textural profile (Pathare et al. 2016).

Cooking loss depends on raw meat quality, centre temperature and cooking procedure (Aslyng, et al. 2003). Cooking loss is of interest because it is expected to explain the variation in juiciness but also because it influences the appearance of the meat. A high cooking loss gives an expectation of a less optimal eating quality, besides being of great importance to the further processing.

Figure 36. a) Vacuum packed meat samples ready for water bath b) Meat samples after sous vide cooking.

The cooking procedure is explained in Material and Methods section. Samples were cooked fresh unless they were kept frozen for tenderness analysis in which case, they remained frozen in the bags until thawed for analysis.

The average cooking loss% from the site with this method was 29.40% (SD 6.77 and variance 45.83), which is consistent with Pathare et al (2016). Only 1.6% of the total samples recorded values or more than 50% cooking loss.

Like all cooking methods, cooking instigates water loss in the food, expanding liquid content while some fat is lost, cooking causes structural changes that decrease the water holding capacity of the meat. Water binding and migration during cooking are caused by denaturation and contraction of proteins (Pathare et al. 2016)

When looking at monthly data from cooking loss there is small but statistically significant difference along the year. Data shows the higher cooking loss was achieved in the colder months (except April), this follows a similar path as drip loss%.

Month	Cooking loss%
January	30.4 ^{cd}
February	30.83^{cd}
March	27.77^{ab}
April	31.91^{d}
May	29.67^{c}
June	29.^{67bc}
July	29.67 ^{bc}
August	28.46^{abc}
September	29.30^{bc}
October	30.18 ^{cd}
November	26.73^{a}
December	30.44 ^{cd}

Table 20. Monthly variation of cooking loss from meat samples over the years.

When looking at correlation data, the only significant correlation (P≤0.001) from cooking loss was with temp24 (0.13), which follows the same pattern drip loss% had with temperature at 24 hours.

Parameter	Cooking loss%	P value
L*	0.007	0.94
Marbling	-0.31	0.001
Drip loss%	0.36	≤0.001

Table 21. Correlation of cooking loss% and other quality traits.

Correlation with other meat quality traits showed that L* was poorly correlated with cooking loss, whereas Drip loss% was moderate to highly correlated to cooking loss, while marbling was the same, but in a negative correlation.

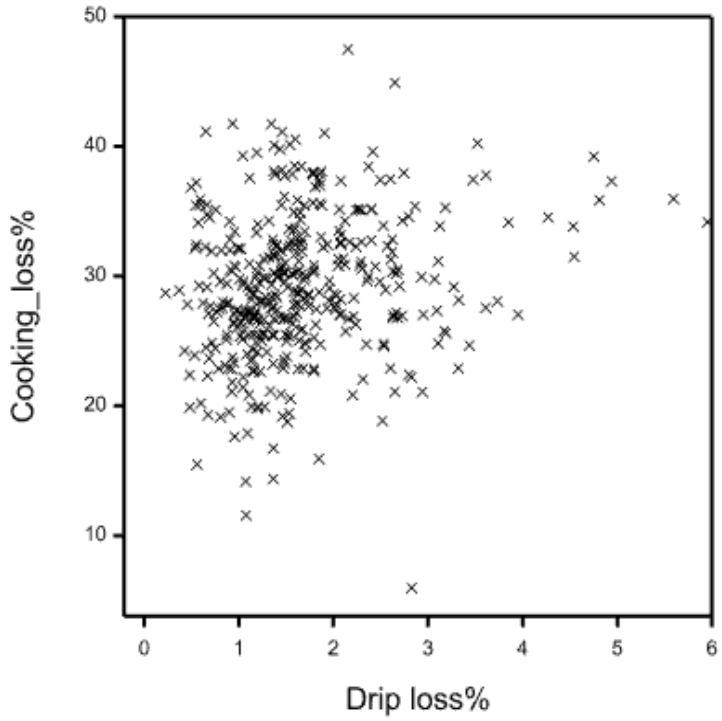

Figure 37. Cooking loss as a relation of Drip loss%.

Linear regression analysis between drip loss% and cooking loss% showed a correlation coefficient of 0.25 and a R square of 0.06, standard variation of 13.45. Linear regression coefficients with all other parameters were not significant.

This indicates that the question is not whether the pH or drip loss directly affected cooking loss but what is the area or threshold of influence rather than the linear relationship.

Also, considering the water escapes from the meat as consequence of protein denaturation the key points to look for this trait could be: previous denaturation (after

slaughter, during chilling) and cooking end point, as higher cooking temperatures denaturate more proteins, therefore release more liquid, this last is especially relevant for fresh pork.

Results from the cooking loss analysis are not as conclusive as expected, most of the reference literature uses oven cooking, stir fry or grilling as cooking loss methods and results are not easily comparable to cooking loss with sous vide.

Further discussion of cooking loss and tenderness are developed in the tenderness section.

Further discussion on the effects of cooking loss on further processing are discussed in the supply chain exercise section.

4.7. Tenderness

One of the most important attributes for a consumer is tenderness, in response to this the industry has made conscious effort to improve upon the tenderness levels of all meat products in order to increase demand.

To quantify factors that influence tenderness, historically the Warner-Bratzler shear force method have been used (W-B), but such method has plenty of weaknesses, including extensive labour, variation in quality and consistency of muscle core used, inconsistent protocols, etc. In response to that the Shear Force method was also developed (SSF), this last method has shown closer correlation with sensory panel assessments. For the current project both methods were used to evaluate meat tenderness in Scottish pigs.

Stablishing a tenderness benchmark level for the Scottish industry could lead to new valued added marketing schemes.

The methods and two tests used to measure tenderness have been explained in the Materials and Method section.

Average values in N for the site for both tests are presented in the following table:

Parameter	Mean	Median	SD	Variance
Warner-Bratzler	54.04	53.06	13.25	175.5
Slice Shear Force	58.2	55.67	17.91	320.7

Table 22. Tenderness site values

WB= 5.50kgf and SSF=5.93kgf.

Values obtained are nearly double of what was obtained by Ngapo et al. (2012)

Correlation of both tenderness tests with other quality traits are shown in the next table:

pH0	-									
Temp0	-0.01	-								
pH24	0.02	0.12	-							
Temp24	0.44	-0.09	-0.04	-						
Drip loss%	*-0.05*	*0.13*	*-0.03*	*0.01*	-					
Marbling	0.00	0.25	-0.23	-0.05	-0.09	-				

Colour	0.04	-0.07	0.16	0.01	-0.00	-0.11	-			
Cooking_loss	-0.04	-0.10	0.06	-0.19	0.005	0.04	0.10	-		
W-B	0.30	0.02	-0.11	-0.029	-0.09	0.01	-0.03	-0.00	-	
SFF	0.02	0.06	-0.14	-0.11	0.00	-0.13	-0.13	0.09	0.17	-
	pH0	***Temp0***	***pH24***	***Temp24***	***Drip loss%***	**Marbling**	**Colour**	**Cooking_loss**	**W-B**	**SFF**

Table 23. Correlation table for tenderness tests and meat quality traits.

The study by Lonergan et al. (2007) sustains that higher pH is associated with lower WB (negative correlation) which was seen in these results. pH seemed to have a lot of influence in certain quality traits and receive influence from fat content at a certain threshold.

There was a mild relation between temp24 and both tenderness tests. This can be attributed to cold shortening, which is encouraged by lower temperatures (White et al. 2006), Rybarczyk et al (2015) also sustained the risk of carcasses falling into cold shortening if temperature falls below 10 and the pH is above 6. The cold shortening dynamics are quite complex, according to Reese, et al. (2002) not only the ultimate pH value is relevant to see this phenomenon, but also the rate of decline (slow) with a fast decrease in temperature could lead to this.

Ngapo et al (2012) showed a positive correlation between tenderness and cooking loss, which was only relevant for SSF in this data set, and in a smaller number.

The same study showed a negative correlation between tenderness and L*, in the last stage of the data collection, the only colour scoring method was the Pork checkoff cards, for which the lower scoring values represented paler meat (higher*). The relation that was found was as well negative between both tenderness tests and colour (lower colour scoring or “paler” meat with higher N recorded, less tender meat).

Tenderness correlated negatively with colour in Huff-Lonergan et al. (2002) using the Star Probe which is a method comparable to W-B, this match the findings for the results seeing in the data collected as paler colour tended to be less tender.

Results obtained by Ryu et al (2005) show similar W-B values than the ones obtained in the site. Also, its positive correlation with pH0 and negative with pH24 are in line with these findings.

Finally, SSF and marbling correlated negatively in Blanchard et. al. (2000), the poor relations between fatness measurements and eating quality (specially tenderness) as demonstrated in the correlations can be explained with the presence of a threshold value, especially for intramuscular fat, rather a simple linear relationship.

4.8. Supply chain exercise

a) Overview

Muscle abnormalities represented a problem for the meat industry for over two decades. PSE (Pale, Soft, Exudative) hams lost substantially more weight during transit and processing than Normal or DFD (Dark, Firm, Dry) hams and suffer from higher shrinkage losses, also PSE hams are responsible for higher cooking loss and production of exudate (Jeremiah, et.al. 1987).

PSE meat per-se does not represent a current issue in the industry due to improvements in genetics, slaughter methods, etc, but losses along the supply chain are consistent, part of it can be traced back to raw material. The presence of meat defects called “destructured” or “structureless zones” have

been reported frequently, consisting in PSE-like areas in the deep muscle, which can be exudative, pale and lead to loses along manufacturing. This problem was noted while impacted initially the slicing, and slicing yield is highly related to meat structure quality (Vautier et. al. 2008).

Structureless zones have variable chemical composition and can be visually absent in raw material (fresh meat) but appear after the cooking process (Hugenschmidt et al, 2010).

b) Materials and Methods

Primal data (QPP Brechin)

Farms with similar history of weight consistency across batches were sampled in 2 separate days, in 2 separate weeks to complete a number of 500 legs (per week) for ham manufacturing. Groups involved in the trial were named Group 1 (G1) and Group 2 (G2).

Meat quality data (QPP Brechin)

pH and temperature from 40% of the animals of each farm involved in the trial was taken in two time points, at arrival (40 minutes after kill) and before leaving to the cutting room (roughly 22 hs after slaughter).

After kill, the carcasses were arranged in the chillers to be kept in a group in 7 rails, cut and dispatched together, on both weeks of trial. Pigs from the 2 slapmarks were loaded in 32 xmas trees with 16 legs each and labelled with a special label corresponding to the trial to be identified for intake in Tipton. Primals of interest (legs) were weighted in the cutting room before dispatch.

Butchery

Legs from both trial days were identified and taken in together, butchered in the same line and butchery yields were obtained. Costings based on yields were calculated by the operations team from both groups of farms.

Ham manufacturing

Data obtained from G1 and G2 from ham manufacturing: fresh weight, injected weight, weight into tumbler, brine intake %, weight before stripping, striped weight, roast weight, roast loss%, cooking loss% and total yield%. Finally, pH and chemical analysis from raw material and finished product from both batches.

c) Results and Discussion

Carcasses

Overview of weights and probe values can be seen in table 24.

Group	Farm	HW kg (SD)	Probe mm (SD)
G1	Farm1	87.03 (5.44)	10.71 (1.47)
	Farm2	93.52 (5.19)	11.17 (1.7)
G2	Farm3	89.90(5.51)	10.84(1.57)
	Farm4	87.39 (6.44)	10.53(1.41)

Table 24. Carcass weight by farm.

G1: For this farm, 83.47% of the carcass were between 80 to 95kg. F2 had only 61.6% of its carcasses between 80-95 kg.

Ideally, F1 and F2 should have had similar weights to be called “homogeneous group”. A third farm scheduled for the trial was killed first, but due to the arrangement of the chiller, the operator choose to send the rails correspondent from the 2nd and 3rd farms.

G2: F3 76.92% of the weights fell into 80 to 95 kg, F4 78.89% of the weights fell between 80 to 95 kg.

Summary of the group’s results can be seen in the following table 25, there was statistical difference only between weights, not in probe or lean meat%.

Group	HW	CW	Probe	LM%
G1	90.26[a]	88.46[a]	10.94[a]	62.12[a]
G2	88.57[b]	86.8[b]	10.69[a]	62.24[a]

Table 25. Carcass weights, probe and LM% by group.

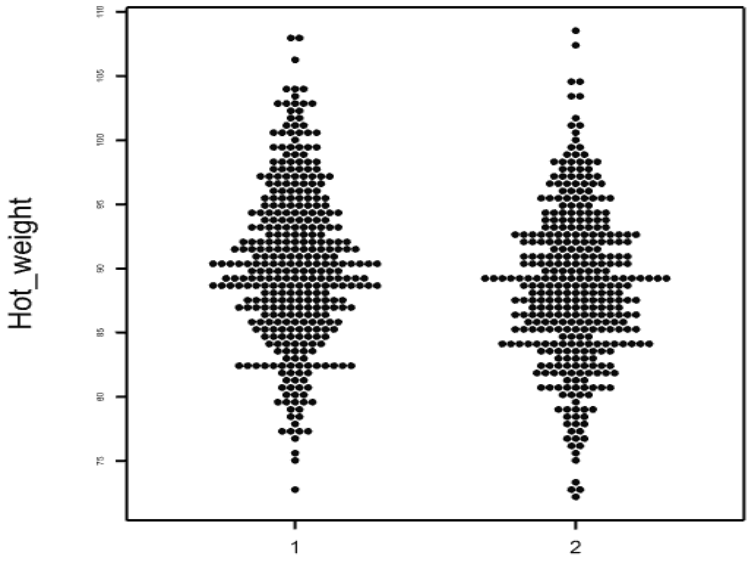

Figure 38. Hot Weight distribution from G1 and G2.

Figure 38 shows the HW distribution, G1 had a smaller spread (SD) and most of its carcasses are above 90 kg, while G2 had a large spread of variation from the lightest to the heaviest.

Legs

All the legs were weighted in the cutting room before dispatch, figure 35 shows the weight distribution of all legs that took part in the trial. At first sight is noticeable the number of outliners, when most of the weights were between 10.5 and 13.5 kg.

The legs were weighted with tail bones, but a correction was made based on average tail bone weights and the leg weights without tailbones calculated based on that, for both groups.

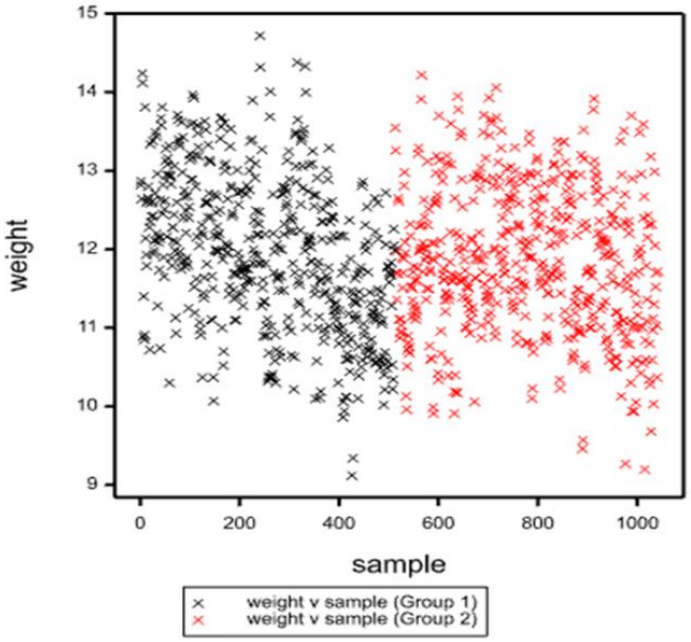

Figure 39. Leg weight distribution per group.

If the legs are grouped in that rage of weights, G1 had 12% of its legs as outliners, while G2 had 10%, most of them below the expected weight (Table 27).

Group	Weight	%
G1	Above 13.5 kg	6%
	Below 10.5 kg	6.8%
G2	Above 13.5 kg	6.2%
	Below 10.5 kg	3.8%

Table 26. Weight distribution of legs from both groups.

Looking at summary values from leg weights (table 28) , G1 was heavier, with more extreme values (maximum and minimum) and higher SD. Even considering the median (which is not influenced by outliner values) legs from this group were heavier, but there was no statistical difference between leg weights.

The boxplot (Figure 40) shows the weight distribution between both groups. The median value (line dividing the box in 2 sections, shows higher weight for G1 (as expected) and a broader distribution of weights.

	G1	G2
Mean =	11.96	11.85
Median =	11.95	11.79
Minimum =	9.12	9.2
Maximum =	14.72	14.22
Standard deviation =	0.979	0.924
Variance =	0.959	0.853

Table 27. Summary statistics from leg weights from both groups.

Heavier legs are preferred when discussing yields, as it takes time to butcher a leg regardless its size, but when discussing quality is important to notice that weight of the primal is supposed to be more muscle than fat.

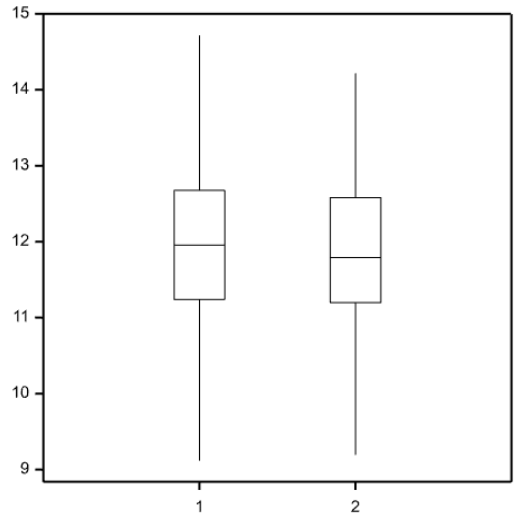

Figure 40. Box plot with leg weight distribution.

Meat quality data

pH and temperature were recorded from a % of the farms involved in the trial on the kill day and cutting day (Table 29).

G1 had consistently higher temperatures in both time periods, which corresponded with lower pH values. The pH values are not in the PSE level. Temperature and pH are closely correlated, for both time points, higher temperatures were negatively correlated with lower pH values, (-0.46 and -0.37 for day 1 and day 2).

Parameter	G1	G2	P value
pH0	6.44a	6.57b	≤0.001
Temp0	32.84a	31.45b	≤0.001
pH24	6.01a	6.19b	≤0.001
Temp24	7.20a	5.75b	≤0.001

Table 28. pH and temperature data from carcasses from both groups.

Regardless groups, heavier pigs correlated positively with higher temperatures both at arrival and after 24 hours (0.4 and 0.19 respectively) (Data not shown).

Butchery

Both farm groups were sent to butchery with one-week difference. Traceability was kept and yields and costing from both groups were calculated, in addition to a comparison to the standard.

As expected, there was a higher intake from G1 (in kg) considering the legs were heavier. G1 was heavier by 18.9 kg.

The product of interest for this exercise was the defatted gammon, for which G1 yielded 60 kg more than G2. The expected standard yield for this product is 50.6%, for which G1 had 0.73% less than the standard and G2 had 1.53% less. In figure 41 for each group the yields of deffated gammon compared to the standard are presented.

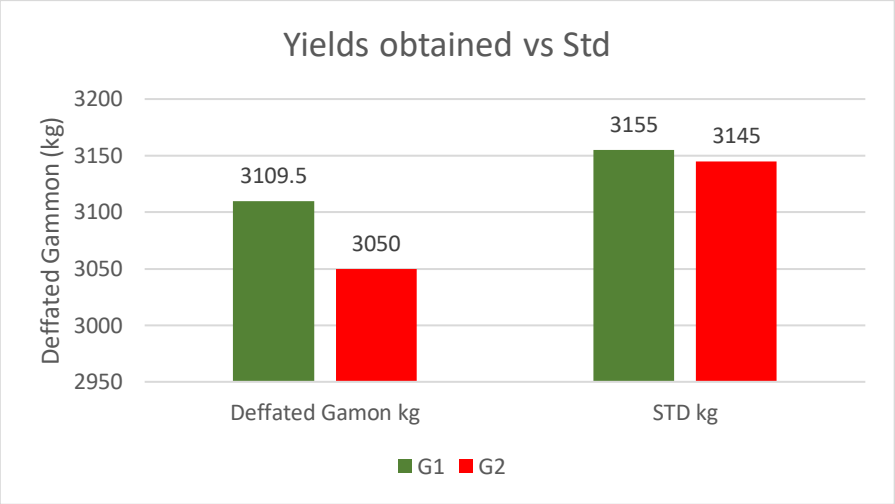

Figure 41. Butchery yield obtained by group compared to the standard.

There was almost not significant difference between innershank and leg hock meat from both groups (Figure 42).

Also, between groups was yield of dark meat, which G1 had 13kg more compared to G2.

There was more trimming done in G2, which represented 10.68% of the total intake from the legs compared to the 9.41% from G1.

In terms of fat, there was difference between batches, being fat 5.77% of G1 intake and 4.95% of G2. Considering the low price of this product, is not ideal to have to trim much fat.

The difference between bones in both groups was small (3kg), suggesting that the main difference between heavier legs was due to mostly fat and muscle.

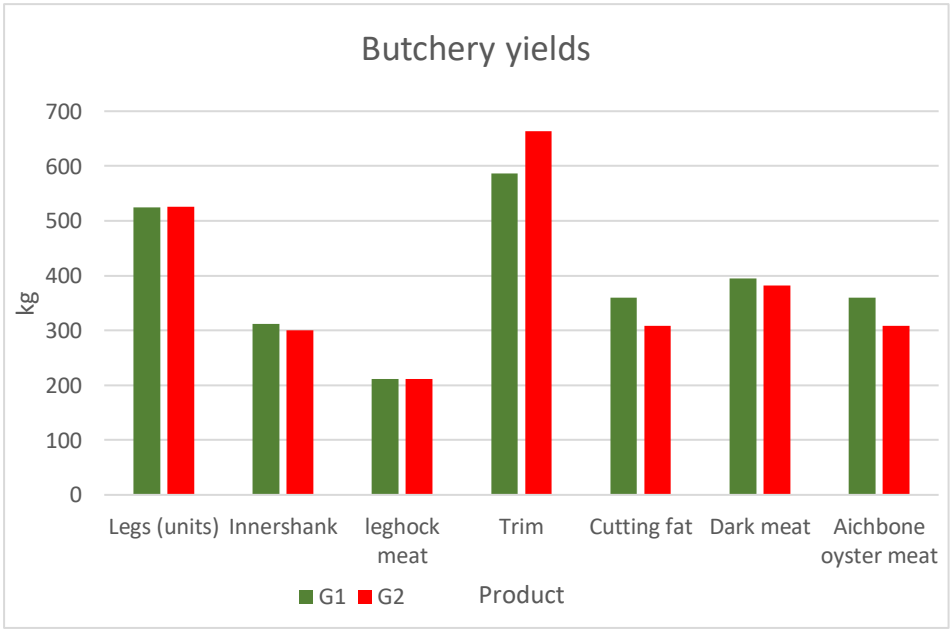

Figure 42. Butchery yields from both groups.

Considering the final output, there was a difference of 58.6 kg between groups, (which started in 18.9 kg in the intake).

Cost analysis was performed for butchery yields as well (data not shown).

Ham manufacturing

In practice, increasing slaughter weight and age of pigs means increasing both the ham weight and the ham adipose tissue thickness. In the present exercise, the pigs were of similar age, therefore, higher ham weight can be related to higher weight, better ham conformation or muscularity or fattiness.

Regarding the fat thickness, higher trimming losses were observed for hams of the thickest fat class, while boning losses were unaffected by weight or fat thickness. However, lower dehydration losses (in the form of dripping or evaporation) in hams with thicker fat could compensate for higher trimming losses giving lower overall losses, and indicating a benefit of using fatter hams, but it wasn't really the case in this exercise.

The study by Candek, et al.(2009) states on this points, that the heavier ham weight was important in determining the ham dehydration losses (although this study was on dry hams), with heavier hams exhibiting higher daily moisture losses due to larger contact area for exchange. The fact that heavier/bigger hams have larger contact area for heat exchange could explain higher absolute daily weight losses in heavier hams during butchering, cooking, roasting, especially if these areas have been left uncovered after fat trimming.

Even in the range of pH values considered as normal (in the case of the present exercise), was expected that there could been an effect of pH value on the injecting phase, even though both G1 and G2 had 0.1% difference in injection %, which is not significant (Table 30).

Group	Fresh (kg)	Injected (kg)	Injected %	Onto cook (kg)	Stripped kg	Cook loss %	Roast loss %	Total yield %
G1	3105	3636	17.1	3651	2794	23.5	4.8	85.7
G2	3047	3565	17	3568	2897	18.8	4.7	90.6

Table 29. Ham manufacturing yields per group.

When looking at injected kg, there was a 43 kg difference between groups in gained weight (which corresponds to the difference of 0.1% in injected %). When the product got cased to cook, after tumbling, G1 had 15 kg more while G2 had 3 kg more, which is not clear. After striping the product, there was a 23.5% cooking loss for G1 and a 18.8% for G2 (Figure 43).

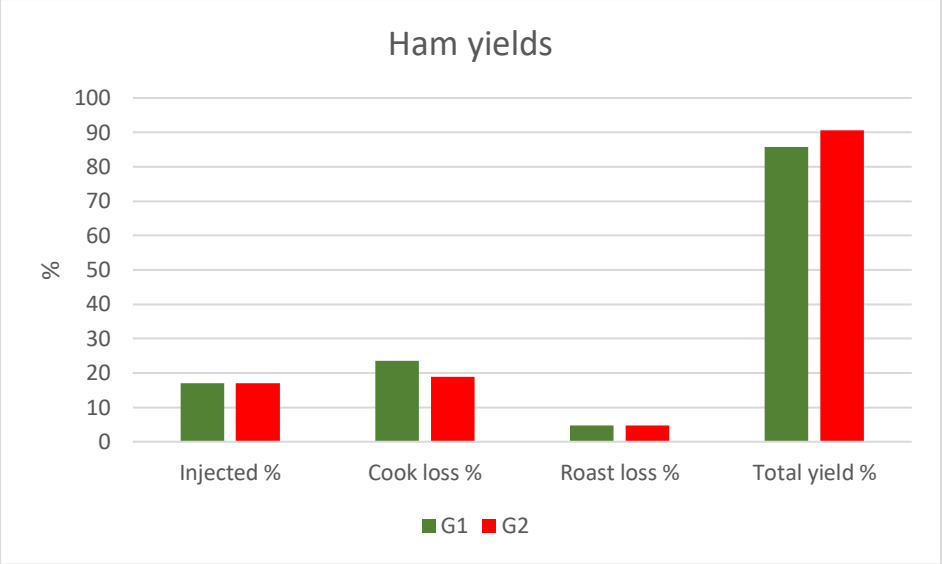

Figure 43. Ham yield comparison (in %) between groups.

The standard cooking loss achieved as usual is 18% but even up to a 22% is possible. Reasons for a higher cooking loss could relate to dripping loss. This is important considering that there is precook chilled storage period where dripping can occur, dripping loss is different from evaporative loss, normally seeing at roasting.

Finally, both batches went onto roasting, yielded values according to the standard (5%), having G1 4.8% and G2 4.7%. According to Jeremiah et al. (1987) DFD normally produces lower curing and smoking loses (evaporative loses), the meat from both groups in this exercise (in terms of pH24) were closer to be DFD than PSE, therefore we can speculate that due to the higher pH values overall roasting loses were kept on the standards.

When looking at total yields, G1 yielded 87.7% and G2 90.6%. The standard contemplates an 85.8 but achieved as normal is 90%. Poor values from G1 are not surprising considering that total yield uses fresh weight and roasted weight, which was already affected by the cook weight.

For G1 performing 87.7% meant 165 kg less than the actual achieved standard, while for G2 there was no loss compared to the standard.

Chemical analysis

Fresh meat and finished product were sent for biochemical analysis, meat from G1 showed slightly more moisture content and subsequent les dry matter than G2. Protein content was lower, and fat and ash were higher, pH in this group was significantly lower compared to G2.

Chemistry	**G1**	**G2**	**p-value**
Moisture (g/100 g fresh)	73.8	73.5	NS
DM	26.24	26.5	NS
Protein (%of DM)	83.43	85.2	NS
Fat (%DM)	10.32	10	NS
Ash (%DM)	4.26	4.15	NS

Total carbohydrate (g/100g fresh)	0.7	0.4	NS
pH	5.43	5.67	≤0.05

Table 30. Chemical composition of fresh meat.

Considering the chemical analysis results, larger differences between the raw material and finished products were expected. Is possible that the leg muscles suffer from "structureless/destructured zones", which resemble PSE meat in some characteristics. This is a common phenomenon in cooked hams which carries on influence from the raw material and is exacerbated during processing.

Meat from G1 presented slightly less DM and protein than G2 (Table 31), this relates to higher fat content which leads to less lean meat. G1 had overall higher weights, higher cutting fat but no difference to G2 in probe or LM% values.

The higher total carbohydrate content of G1 could be an indicative of higher glycolytic potential, which means the muscle had more glycogen reserves that after being metabolized produce lactic acid and drop the pH of the muscle, which relates to the lower pH value of this group.

A lower pH value causes the protein to denaturalize, but as this analysis does not show the type of protein is hard to make conclusions on this point, this protein denaturation could be the reason for the lower protein count in G1. Lower protein count on PSE-like zones in meat due to lower protein solubility (consequence of protein denaturation) and is mentioned in Laville et al.(2005) but the study does not show overall protein count in the samples to compare to this exercise. Lower pH value also causes lower water holding capacity, leading the water to scape from within the muscle fibres, especially during cooking, which might explain the higher cooking loss while manufacturing.

The main cause of low pH values is high temperature previous and during slaughter, which accelerates muscle metabolism and lactic acid production. Several factors can cause higher temperatures in a carcass, and a statistical difference between both groups temperatures was seen.

Vouitla et al. (2008) refers to the influence of heavier carcass weights and low pH on the presence of this defects in deep muscle, specifically refers to ≤35º C in the deep muscle and a pH below 6.2. Is important to point out that both carcass pH and temperature were recorded from the middles (due to access of the carcass in the line and in the chillers) so deep ham temperatures were probably higher than the value recorded. The difference in temperature declines between carcass portions has been observed before, Arkfeld et al. (2016) sustains that middles (loin muscles) reach equilibrium temperature with the environment 14 hours after chilling, while for deep legs muscles this can take up to 22 hours.

The slightly higher temperature from G1 compared to G2 was sustained even after 24 hours in the chiller, (also the pH24 from G1 was lower than G2 at this stage), and this lower pH value remained until the fresh meat reached Coalville (Figure 44).

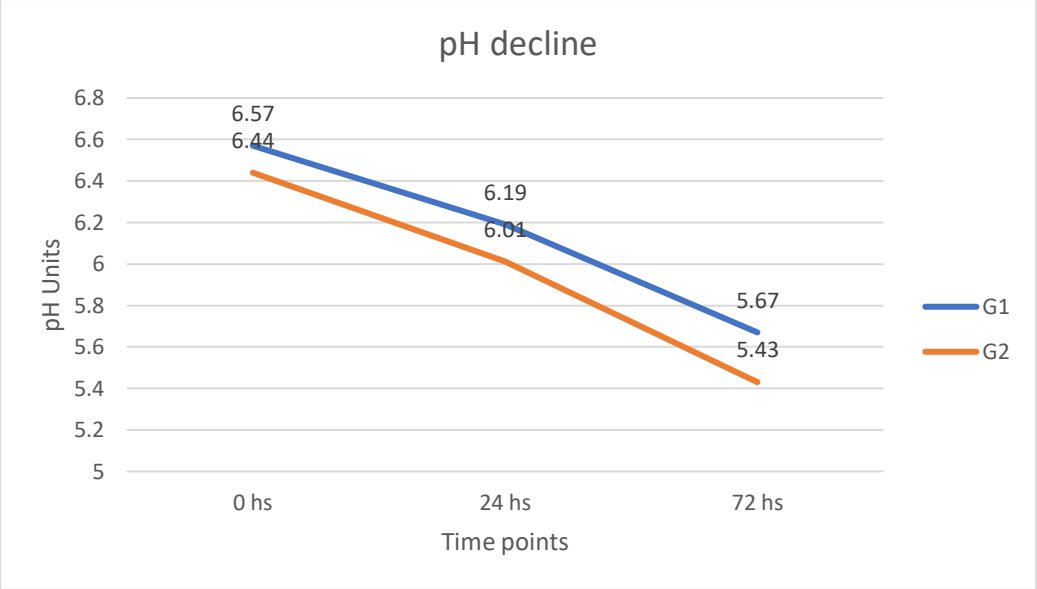

Figure 44. pH decline over three timepoints from both groups.

Regarding the finished product analysis, was not possible to get results from cooked product from G2. Available results from G1 are presented in the table below.

Product	**Moisture (g/100g fresh)**	**DM**	**Protein (%DM)**	**Fat (%DM)**	**Ash (%DM)**	**pH**
Mid tier ham G1	**69.8**	**30.18**	**78.26**	**8.7**	**2.58**	**5.92**
Destructured ham (Hugenscgmidt et a. 2010)	69.4	30.6	85.56	2.9	11.8	N/A
Normal ham (Hugenscgmidt et a. 2010)	71.9	28.1	81.17	5.5	13.8	N/A

Table 31. Chemical composition of cooked ham.

When hams were categorized based on their ultimate pH value, in the study of Hugenschmidt et al. (2010), some parameters of its destructured and "normal" hams are comparable to the results from G1. Briefly, the study cited above mentions 3 groups of hams were based on their ultimate pH (pH24), in low, middle and high pH24 hams, considering this, G1 falls onto the high pH group (with a ph24 ≥6 and ph72 ≥5.89).

In this group of the study, both "normal" and destructured hams were analysed and its chemical values compared. Destructured hams have higher DM and protein content, less fat and ash compared to normal hams. The amount of protein from G1 hams and DM is comparable to this group, but the amount of fat is much larger but the ash is much lower.

In the mentioned study, when quantifying the high-pH group for raw material, there were no apparent destructured zones, but defects were present in cooked hams, therefore the low levels of apparent defects in raw material cant out rule the presence of destructured zones later on, considering this can

develop as a reaction of the meat towards insufficient cooking, excessive mechanical treatment or loss of intramuscular cohesiveness.

The pHu or the final pH can't be considered as a reliable indicator of defects in cooked ham, the course of pH and temperature decline of early postmortem are also important. In early postmortem partial denaturation of meat protein occurs, helping to develop destructured zones.

An increased thickness of the muscle layer around the centre of the leg, due to larger carcass and heavy weights delays chilling by reducing the heat influx, the same effect has been seen from thicker subcutaneous fat layers on the centre of the raw hams.

Unfortunately, for this exercise the influence of leanness in the appearance of destructured zones wasn't remarkable. Also, due to the missing results the amount of DM, ashes and crude protein from both batches of hams can't be compared but would be interesting to add a colour analysis as well to finished products, as destructured hams are expected to have brighter colour.

d) Conclusions

The exercise was useful to identify one potential problem on the supply chain from Scottish pig carcasses. Destructured zones in hams are a common quality problem which can develop from early stages such as slaughter.

Temperature decline from early post mortem must be monitored carefully, especially in the core of the legs, considering the trend of getting higher weights and heavier muscling. Higher weights for carcasses in Scotland are accompanied with thicker fat layers and this can affect heat circulation and lead to lower pH values, which can be sustained all along the processing, causing detriment on the final product.

Influencing factors of post mortem pH and temperature such as nutrition, days in farm, fasting, health status, cooling, storage, processing can contribute to the development of destructured zones in ham. This defect can lead to poor brine binding (not seen in this exercise) but also to high cooking loses due to poor water holding capacity of the meat.

Chemical analysis did not reflect differences from fresh meat of both groups clearly but was possible to speculate over the effect of high carbohydrate content on pH and glycolytic potential.

Literature recommends the use of slightly DFD meat for cooked products (pHu from 5.6 to 6.3), which represents a compromise between water binding (yield, cohesion of slices, consistency), ability to take brine (salt absorption, colour development), eating quality and shelf life.

An addition to further analysis could be finished product colour analysis, to relate the protein content of the cooked hams to their objective colour, as higher protein content should be negatively correlated with paleness of the ham (Tomovic et al., 2013), fresh meat colour analysis could also help categorizing meat at this stage.

As this study was made on the basis of using fresh product with ideal flow, which means, raw material was not stored in any of the sites, but sent away straight after butchery and cooked with no delay, this can potentially not reflect loses in yield due to storage, as the use of frozen/thawed pork can have severe impact in the yields depending upon inherent muscle quality, for this, will be interesting to perform this same exercise with that scenario and account for the impact.

4.9. Factors influencing meat quality in the abattoir- Lairage time and chiller time

Over several months a planned trial was set up to include 8 similar farms (with similar size, provenance, regularity in coming to the abattoir, distance to the abattoir, feeding method, etc.) to different scenarios that are representative to the industrial setting, in the table below the possible scenarios are explained:

Arrival to site	Carcass cut (and sampled)	Drip loss
Kill in the day (day lairage)	Day after	Day after
		Over weekend
	After weekend	Day after
Kill the day after (overnight lairage)	Day after	Day after
		Over weekend
	After weekend	Day after

Table 32. Trial diagram of possible scenarios in the study.

a) Kill on the day, Cut the day after (sampled) and drip vs Overnight treatment

This was the most linear treatment, being "ideal", where neither carcasses or raw material are kept on the chillers 2 days before being cut, transported and processed.

When looking at the two separate scenarios, overnight stay for the pigs have a slight negative effect, especially in pH and temperature at slaughter time.

Parameter	Kill cut Drip	Overnight Kill cut drip	p value
pH0	6.6[a]	6.43[b]	≤0.001
Temp0	26.66[a]	28.66[a]	0.029
pH24	5.77[a]	6.04[b]	≤0.001
Temp24	5.03[a]	6.43[a]	0.022
Drip loss%	2a	2.26a	0.69
Colour	2.12a	1.92a	0.273
Marbling	1.97a	1.4a	0.001
Cooking loss%	31.29a	34.57a	0.055
Warner-Bratzler	52.40a	51.41a	0.059
Slice Shear Force	49.51a	68.57b	≤0.001

Table 33. ANOVA for Kill on the day vs overnight pigs, cut and drip on the following days.

The pH0 recorded was lower for pigs kept overnight, temperature of this group was also higher compared to pigs that arrived and were killed on the same day. This could be due to the lairage time factor as no other difference was recorded in terms of farm health reports nor weather.

The effect of lairage in pigs is contradictory in a lot of literature, some research suggest only benefits in letting pigs rest after arrival but some research suggest the unfamiliarity to new environment, mix with new pigs (especially if farms were sex split before) and the fight to stablish new hierarchy can have detrimental effects. In this case the pH0 and Temp0 were slightly affected by overnight stay of pigs, none of the values are in the risk to be PSE, but there was an apparent effect on keeping pigs overnight.

pH24 hours was higher for overnight pigs compared to pigs kill on the arrival day. Both values were in the desired range (neither PSE or DFD). The possible explanation for higher pH values after 24 hours after lower values at slaughter time could be the depletion of energy storage in the muscle (in the form of glycogen) after the overnight stay in the lairage, this could potentially explain the

temperature but higher pH values. Rocha et al. (2005) in his study on DFD incidence in pork explains the appearance of higher pH24 as possible chronic stress and use up of energy reserves, this prevented lactic acid from forming up to an extent to lower the muscle pH. Several authors have proposed the increase of DFD risk with extended lairage times, but the above-mentioned study proposed a lairage time of 1 to 3 hours for animals to recover from the journey and unloading.

Drip loss% was slightly higher for pigs kept overnight (not statistically significant), this could potentially be due to influence from pH0 and temp0 rather than values after 24 hours (both correlations for after slaughter times and drip loss% suggested this).

Colour had slightly paler value for pigs kept overnight as well and cooking loss, was higher for pigs kept overnight.

Tenderness was evaluated with two test, SSF and W-B. W-B had higher values (less tender meat) for pigs killed on the day compered to overnight pigs (not significant), SSF recorded higher values for pigs kept overnight (statistically significant) compared to pigs killed on the day.

Correlation data from all the parameters for the Kill-Cut-Drip treatments can be seen in the following table:

pH0	**1**	-									
Temp0	**2**	-0.08	-			**Kill on the day**					
pH24	**3**	0.14	0.29	-							
Temp24	**4**	0.73	-0.11	-0.40	-						
Drip loss%	**5**	-0.03	0.23	0.07	0.12	-					
Marbling	**6**	-0.38	0.68	-0.04	-0.38	0.10	-				
Colour	**7**	0.03	-0.27	0.29	-0.17	0.00	-0.17				
Cooking loss	**8**	-0.18	-0.01	-0.10	-0.18	0.00	-0.25	-0.03	-		
W-B	**9**	0.10	0.01	-0.29	-0.11	-0.10	-0.01	-0.27	0.10	-	
SSF	**10**	0.16	0.08	-0.36	-0.06	0.02	-0.16	-0.35	0.18	0.07	-
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Table 34. Correlation table kill on the day treatment.

The most remarkable correlations were both tenderness measurements with pH24 (Figure 40), there was a strong negative correlation between values, suggesting the lowest the pH24 the less tender meat (more N recorded), this was unexpected considering findings in literature suggest the opposite relation, this corresponds with results from Ngapo et al. (2012).

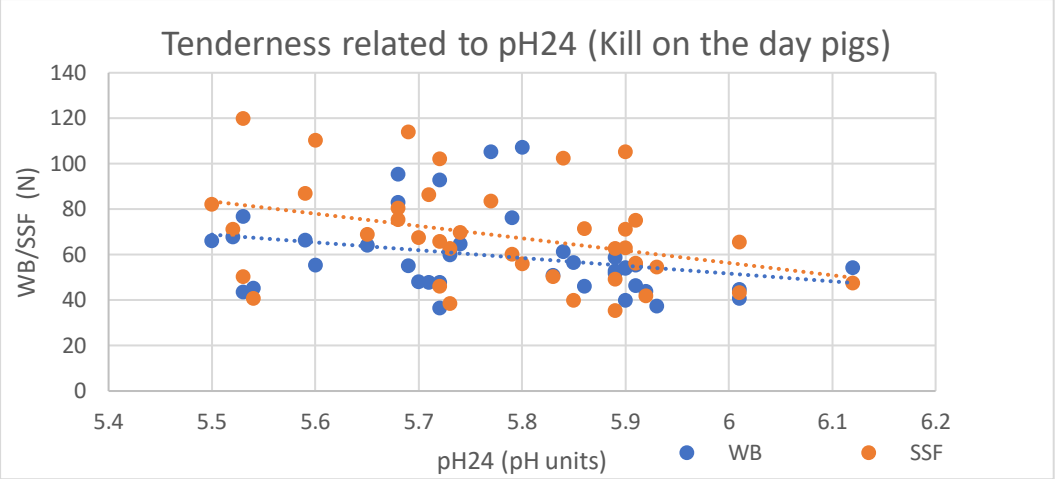

Figure 40. Tenderness as a relation of pH24, Kill on the day treatment.

The other interesting correlation found was meat colour with tenderness (Figure 41), a strong negative correlation showed that paler meat (colour score 1) tend to have lower tenderness values (higher resistance, more N), which also corresponds with findings from Ngapo et al.(2012) interestingly, colour and pH24 had a high positive correlation, higher pH24 lead to darker meat (high colour scoring).

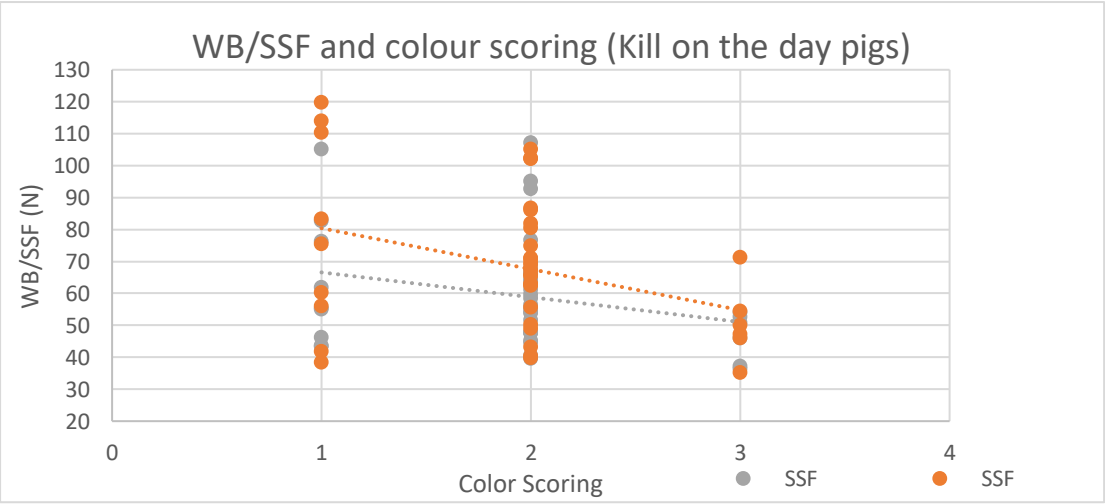

Figure 41. Tenderness related to colour scoring, Kill on the day treatment.

For the overnight treatment, where pigs were killed the day after arrival, cut (and sampled) and analysed the day after the correlation table is the following:

pH0	**1**	-									
Temp0	**2**	-0.13	-			**Overnight**					
pH24	**3**	-0.12	0.50	-							
Temp24	**4**	0.20	0.12	-0.34	-						
Drip loss%	**5**	-0.02	0.25	0.04	0.41	-					
Marbling	**6**	0.10	-0.09	-0.12	-0.15	-0.35	-				
Colour	**7**	-0.29	-0.30	0.43	-0.05	0.17	-0.04	-			
Cooking loss	**8**	-0.02	-0.21	0.12	0.20	0.03	0.02	-0.26	-		
W-B	**9**	0.05	-0.24	0.01	-0.61	-0.13	0.03	-0.29	0.03	-	
SSF	**10**	-0.17	0.05	0.51	-0.66	-0.04	-0.07	-0.06	0.28	0.63	-
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Table 35. Correlation table for Overnight treatment.

Values for correlation when pigs were kept overnight differed from pigs killed on the day. While pH24 kept having an influence on the tenderness values, the higher the values the less tender the meat will be, but this was only relevant for the SSF test, while for temperature the same trend remained, the lower the temp24 the less tender the meat was, this was a high negative correlation (compared to pigs killed on the day).

Linear regression for tenderness and temp24 was found for overnight kept pigs, in this case, temp24 and WB had a multiple R coefficient of 0.61 and an R square value of 0.36, for SSF the multiple R was 0.65 and the R square was 0.42, temperature after 24 hours was statistically higher for overnight pigs, an also for SSF.

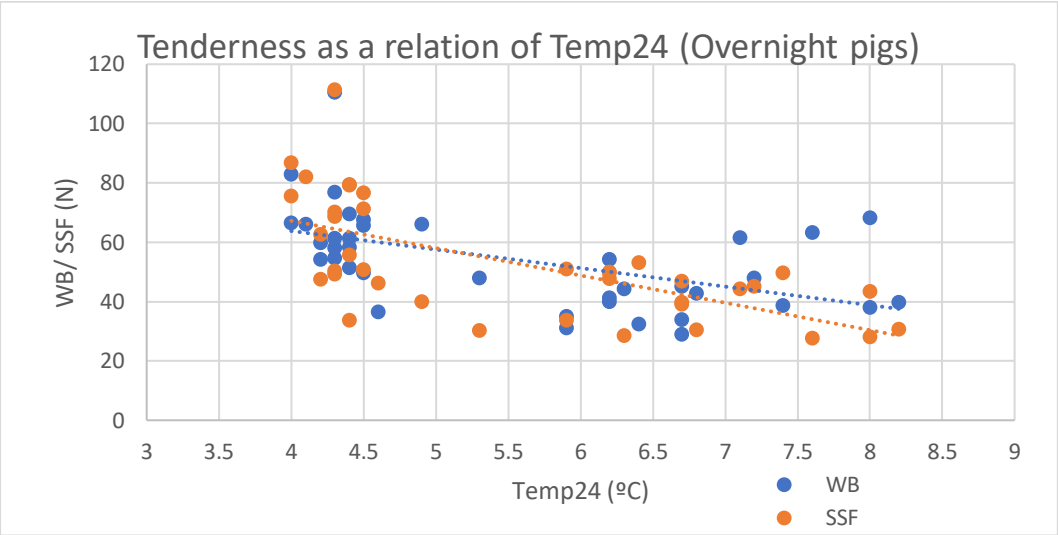

Figure 42. Tenderness as a relation of Temp24, Overnight treatment.

In between other correlations, marbling had a weaker relation with temperature at slaughter for overnight pigs (-0.09) compared to kill on the day pigs (0.68), this trend after 24 hours was negative for both treatments (-0.38 and -0.15), where higher marbled pigs had lower temperatures.

Drip loss% correlated with temp24 as well, having higher drip at higher temperatures, in both treatments.

The same relation was maintained for colour, the paler meat the less tender.

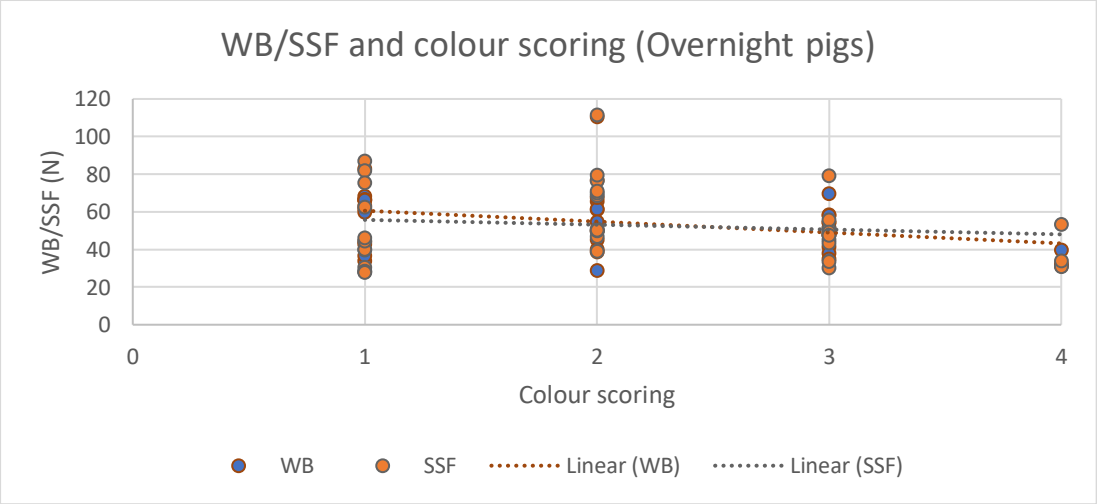

Figure 43. Tenderness test in relation to colour scoring, Overnight pigs.

In overnight pigs, marbling seems to have a positive effect on drip loss%, higher marbled samples dripped less. Unfortunately, marbling didn't correlate with any of the tenderness measurements on this treatment.

In summary, both treatments showed similarities, when the temp0 was higher, the pH0 was lower, and this was stronger for the pigs kept overnight, which displayed both the higher temperatures and lower pH0. Also, temp24 influenced pH24 in both treatments, higher temperatures after 24 hours related to lower pH24 values.

Both temperature time points were positively correlated to drip loss%, higher temperatures caused higher drip loss%.

The same applied to colour scoring, when the temperature was higher (in both time points), the colour scoring was lower (paler).

For both treatments, the lower the temp24, the tougher the meat, which is expected according to literature.

It seems like for when pigs are killed, cut and left to drip as meat samples (regardless lairage treatment), the main driver for tenderness will be temperature (and pH) in the chiller, and this seems to be related to meat colour, the paler, the tougher.

Marbling had an unexpected absence of relation with tenderness, the correlations were not strong enough to mention, but this result can be slightly conflicting considering this is a visual marbling scoring, not a chemical one.

b) Kill on the day, cut (and sampled) after weekend and drip vs Overnight treatment

Pigs were sampled after being either killed on the day or after an overnight stay, on a Friday, and cut on a Monday, same day there were sampled and drip and analysed the day after.

Statistical comparison between treatments can be found in the following table:

Parameter	Kill on the day, cut after weekend, drip	Overnight stay-kill, cut after weekend, drip	p-value
pH0	6.45[a]	6.26[a]	0.006
Temp0	26.94[a]	29.09[b]	≤0.001
pH24	6.15[a]	6.08[a]	0.413
Temp24	6.516[a]	6.07[a]	0.094
Drip loss%	2.95[a]	2.31[a]	0.561
Marbling	1.26[a]	1.37[a]	0.31
Colour	2.07[a]	2.34[a]	0.07
Cooking loss%	35.66[a]	37.6[a]	0.32
Warner-Bratzler	53[a]	53.56[a]	0.77
Slice shear force	52.83[a]	56.51[a]	0.18

Table 36. ANOVA for kill on the day vs overnight treatment for pigs cut after the weekend.

There was only statistical difference between treatments for temperature recorded at slaughter time, being higher for pigs kept overnight, in relation to this, pH0 was numerically lower for this treatment. This is similar to what was seen in the previous trial.

For the treatment Kill on the day, the correlation table can be seen:

pH0	1	-									

Temp0	2	-0.41	-				**Kill on the day**				
pH24	3	0.12	0.17	-							
Temp24	4	0.37	-0.51	-0.15	-						
Drip loss%	5	-0.20	0.06	0.08	0.44	-					
Marbling	6	0.23	-0.09	-0.05	-0.00	-0.00	-				
Colour	7	0.04	-0.21	0.09	-0.14	0.22	0.24	-			
Cooking loss%	8	0.01	-0.11	0.16	0.50	-0.03	-0.09	0.37	-		
Warner-Bratzler	9	0.04	0.11	0.14	0.0	-0.40	-0.31	-0.06	-0.08	-	
Slice shear force	10	0.21	-0.03	0.02	-0.08	-0.19	-0.05	-0.43	-0.39	0.0	-
		1	2	3	4	5	6	7	8	9	10

Table 37. Correlation table for kill on the day treatment, for pigs cut after the weekend.

pH0 was negatively correlated to Temp0, Drip loss% and positively correlated to marbling. Temp0 was correlated with paler colour scoring. A line regression was calculated for pH0 as a function of temperature at arrival, Multiple R (correlation coefficient) was 0.41 and R square (coefficient of determination) was 0.17.

pH24 was negatively correlated to Temp24.

Drip loss correlated negatively with tenderness, lower drip loss% related to higher N recorded or "tougher" meat. A linear regression for these two parameters was calculated, the results for correlation coefficient were 0.19 for WB and 0.35 for SSF, and the R square (coefficient of determination) was 0.03 for WB and 0.12 for SSF.

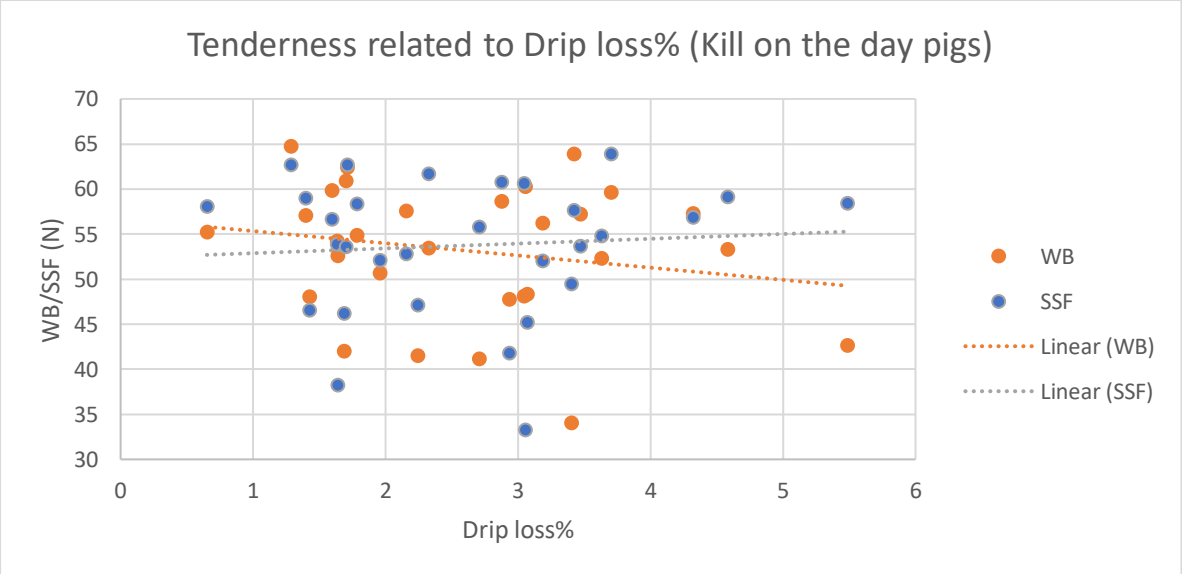

Figure 44. Tenderness related to drip loss for Kill on the day cut after the weekend treatment.

Marbling had a negative correlation with tenderness, indicating that higher marbling resulted in less N recorded, less SSF and WB or "tender" meat, this value was particularly stronger for WB.

For the overnight staying pigs, this is the correlation table:

pH0	1	-									
Temp0	2	-0.40	-				**Overnight**				
pH24	3	-0.16	0.30	-							
Temp24	4	0.71	-0.28	-0.03	-						
Drip loss%	5	0.22	0.26	0.18	0.68	-					
Marbling	6	0.09	0.07	-0.32	-0.24	-0.21	-				

Colour	7	0.32	0.28	-0.10	-0.37	-0.50	0.13	-			
Cooking loss%	8	-0.58	0.42	0.26	-0.22	-0.33	-0.00	0.36	-		
Warner-Bratzler	9	0.06	-0.20	-0.16	-0.22	-0.29	-0.24	-0.07	-0.15	-	
Slice shear force	10	0.16	0.049	-0.13	0.02	-0.16	-0.16	-0.15	0.06	0.26	-
		1	2	3	4	5	6	7	8	9	10

Table 36. Correlation table for Overnight stay pigs, cut after the weekend treatment.

Similarly, to what is seen in the kill on the day treatment, pigs kept overnight which had lower pH0 had higher temperatures at slaughter. A linear regression was calculated for pH0 as a function of temp0 (Figure 45), the multiple R (correlation coefficient) was 0.38 while the R square (coefficient of determination) was 0.15.

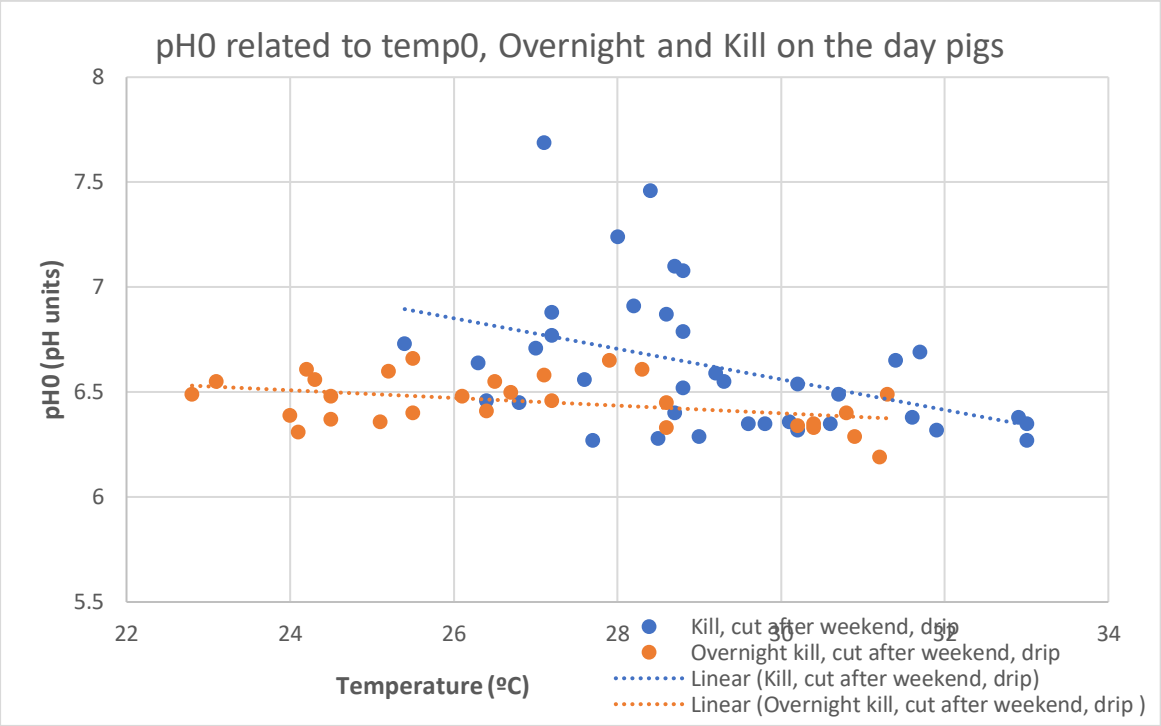

Figure 45. Linear regression of pH0 as a function of Temp0 for Overnight treatment, cut after weekend pigs.

Unlike the kill on the day pigs drip loss% was not negatively correlated to pH at slaughter.

Temp0 and temp24 were positively correlated with drip loss%, values were higher in the overnight treatment. This is similar to the previous scenario of kill-cut-drip, and correlations are stronger, could be due to the influence of the time spent in the chiller being longer.

Colour had a different relation to temp0 compared to the kill on the day pigs, when for overnight pigs' higher temperatures at slaughter related to darker meat, there was no explanation for this.

pH24 and temp24 in both treatments was negatively correlated.

The relation of pH24 and tenderness data was negative for this treatment but positive for pigs kill on the day.

The linear regression calculated for drip loss% and temp24 showed a multiple R (correlation coefficient) of 0.59 and a R square (coefficient of determination) of 0.35, this was much weaker for

the kill on the day treatment (Figure 45). Is worth to mention that for the overnight pigs the temp24 value was not statistically different than pigs killed on the day.

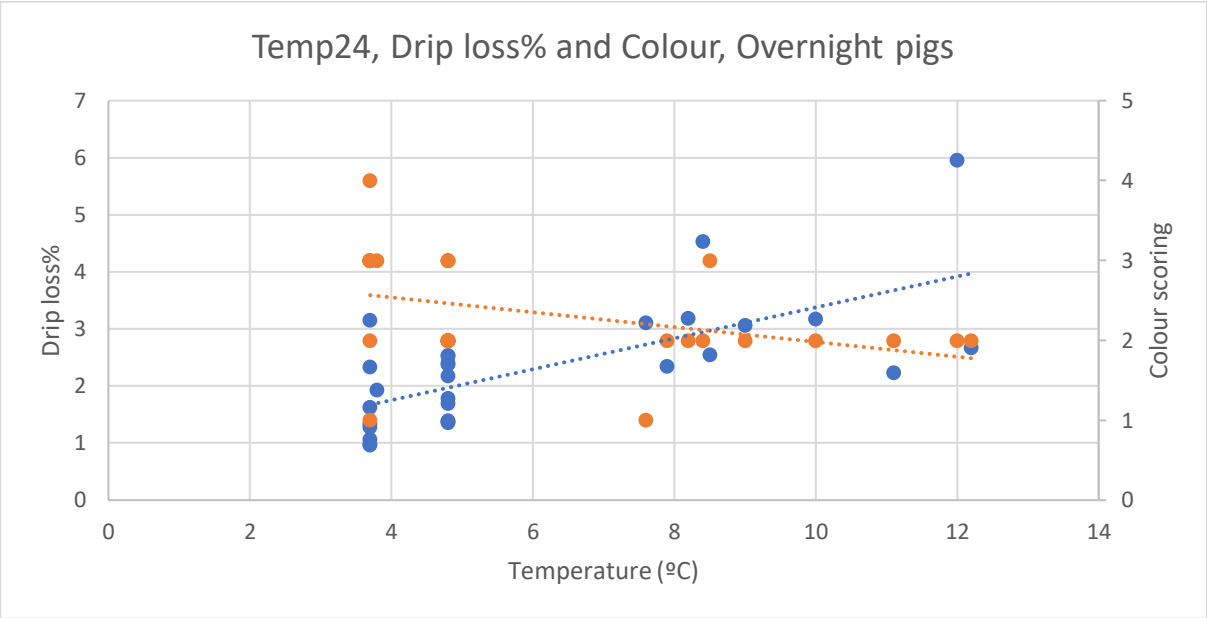

Figure 46. Drip loss% and Colour as a relation of Temp24.

Temp24 correlated negatively with colour for both treatments, suggesting the higher the temperature after 24 hours, the paler the meat, but there was not statistically difference between these results.

Drip loss% and colour were negatively correlated in overnight pigs but not on kill of the day pigs.

WB is negatively correlated to pH24 and temp24 in this treatment, unlike in the kill on the day pigs.

In both treatments lower drip loss% related to higher WB, also to SSF, this was seen as well in the trial for pigs not cut after weekend, for both treatments for WB.

Marbling was negatively correlated for both treatments to tenderness analysis, meaning higher marbling related to lower WB/SSF (more tender meat). The linear regressions for both treatments were calculated but neither the multiple R or R square gave significant values.

c) Kill on the day, cut (and sampled) the day after, drip over weekend vs Overnight treatment

This scenario is representative of carcasses that are cut on a Friday and the primals transferred to the other plants for further processing on the same day and left for further processing over the weekend. A higher drip loss% is expected as the product is left on the chiller for longer than in normal days operations. The aim of comparing these two scenarios (overnight and kill on the day) was to see if there was any evidence of influence of pH/temperature values caused by the variation in meat quality analysis.

Differences between both lairage times can be seen in the following table:

Parameter	Kill on the day, cut, drip over weekend	Overnight stay-kill, cut, drip over weekend	p-value
pH0	6.63[a]	6.34[b]	≤0.001

Temp0	27.89[a]	27.46[a]	0.52
pH24	5.8[a]	5.91[a]	0.08
Temp24	5.75[a]	4.64[b]	≤0.001
Drip loss%	3.91[a]	3.3[a]	0.52
Marbling	1.34[a]	1.45[a]	0.45
Colour	2.27[a]	1.8[a]	0.047
Cooking loss%	35.54[a]	33.77[a]	0.32
Warner-Bratzler	47.33[a]	60.27[b]	≤0.001
Slice shear force	53.5[a]	64.07[a]	0.006

Table 37. ANOVA for kill on the day vs Overnight treatment for pigs killed, cut and left to drip over weekend.

There was significant difference between pigs kill on the day and pigs which stayed overnight for pH0, pigs which stayed overnight had lower values at slaughter time but there was no difference in temperature. There was no difference for ph24 but yes for temperature after 24 hours.

There was no difference between drip loss%, colour, marbling nor cooking loss between treatments.

Tenderness recorded with both tests showed higher WB and SSF for pigs that were kept overnight but was only statistically significant for WB.

A correlation table for kill-cut (and sampled) and left to drip over the weekend can be seen below:

pH0	1	-									
Temp0	2	-0.21	-				**Kill on the day**				
pH24	3	0.47	0.46	-							
Temp24	4	0.47	0.57	-0.39	-						
Drip loss%	5	-0.10	-0.05	-0.36	0.11	-					
Marbling	6	-0.32	-0.02	-0.30	-0.15	0.00	-				
Colour	7	0.37	0.26	0.53	0.14	0.04	-0.22				
Cooking loss %	8	-0.03	-0.10	0.08	-0.37	-0.19	-0.15	-0.02	-		
WB	9	0.85	0.17	-0.47	-0.43	-0.16	-0.13	0.36	0.08	-	
SSF	10	-0.30	-0.14	-0.21	-0.58	-0.00	0.14	-0.01	0.26	-0.29	-
		1	2	3	4	5	6	7	8	9	10

Table 38. Correlation table for Kill on the day treatment, cut and drip over the weekend.

Like in previous trials, pH0 showed a negative correlation with Temp0. pH0 was also correlated negatively to higher drip loss% and marbling.

Temp0 was correlated to positively to colour, which was not expected.

pH24 correlated negatively with temp24, drip loss% and marbling, but positively with colour, which is what is expected according to literature.

Temp24 correlated negatively with marbling and cooking loss%.

Tenderness measurements correlated negatively with pH24, leading to lower pH24 values, higher WB and SSF (less tender meat), the same was seen for temp24, with lower temperatures higher values for SSF.

Marbling had a mixed relation with tenderness tests, higher marbling had a negative correlation with WB (higher marbling, less WB value, more tender), but the opposite was seen for SSF (positive correlation).

Interestingly, there was a strong correlation between darker meat colour and higher WB values, less tender meat, this was the opposite of what was seen in the other scenarios, but more according to what's seen on literature. This relation could have become stronger due to the time the meat had to "mature" over the weekend.

Linear regression for pH24 and WB had a multiple R value of 0.47 and R square 0.22, for SSF the linear regression coefficients were lower, with a multiple R of 0.21 and R square of only 0.045.

The linear regression for WB and temp24 showed multiple R 0.43 and R square of 0.19, and for SSF Multiple R is 0.58 and R is 0.34. This leads to speculate that the meat tenderness can be moderately explained by the pH24 and temp24, thus, the relation between tenderness and pH and temperature after 24 hours can be more linear in this case than in any other scenario.

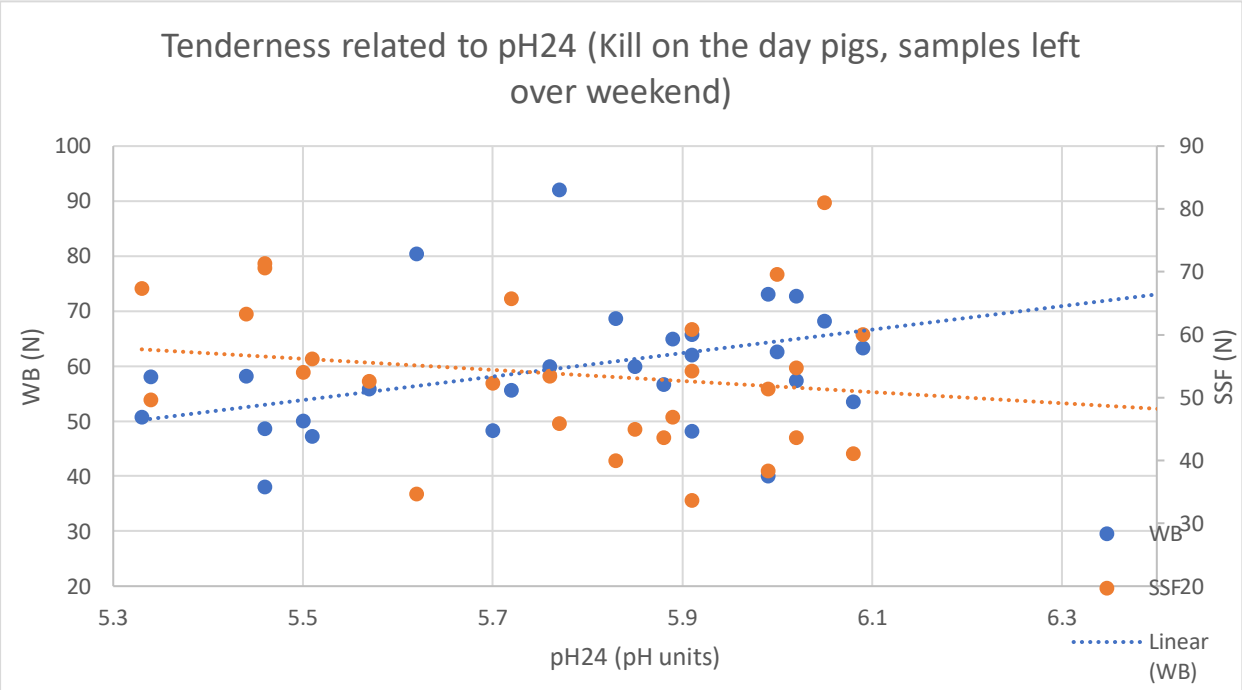

Figure 47. Tenderness as a relation of pH24.

A correlation table for the overnight treatment can be seen below:

pH0	1	-									
Temp0	2	-0.12	-				**Overnight**				
pH24	3	-0.06	0.03	-							
Temp24	4	0.04	0.01	-0.23	-						
Drip loss%	5	-0.00	-0.06	-0.26	0.00	-					
Marbling	6	-0.04	-0.01	-0.34	-0.11	-0.27	-				
Colour	7	0.08	-0.13	-0.19	0.02	0.15	-0.03	-			
Cooking loss %	8	0.15	-0.14	-0.30	-0.47	0.07	0.09	0.01	-		
WB	9	0.05	-0.00	-0.25	0.21	0.02	-0.10	0.29	0.04	-	
SSF	10	0.12	-0.02	-0.11	-0.35	-0.01	-0.04	0.14	0.24	0.08	-
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Table 39. Correlation table for Overnight treatment, cut and drip over weekend.

There is a negative correlation between temperature at slaughter time and pH0, also there was a negative correlation between pH0 and drip loss%. pH24 and temp24 were negatively correlated as well, same with drip loss% and both tenderness tests. Same as for the kill on the day treatment the temp24 was negatively correlated with the tenderness tests.

Marbling was negatively correlated with both tenderness tests. Colour was positively correlated with tenderness tests.

For this scenario both pH and temp24 seem to have a direct effect on tenderness, besides this, all the relations between pH and temp are similar to the previous results.

d) <u>All treatments</u>

Little can be deducted from an overall correlation table, therefore a separate table with the correlation results from the 6 different scenarios is presented below, only the relevant correlations (above 0.1) are noted, and the reference number for each trial is displayed in the reference box:

	pH0	Temp0	pH24	Temp24	Drip loss%	Marbling	Colour	Cooking loss	W-B	SSF
pH0										
Temp0	1,2,3,4,5,6(-)									
pH24										
Temp24			1,2,3,5,6(-)							
Drip loss%	3,5(-)	1,2,4(+) 5(-)	5,6(-)	2,3,4,5(+)						
Marbling	1,3,5(-)	1(+)	2,3,4,5,6(-)	1,2,4,5(-)	2,5(-)					
Colour	2(-) 3,5(+)	1,2,3,6(-) 4,5(+)	1,2,5(+) 4,6(-)	3,4(-)	3,5,6(+) 4(-)	1,5(-) 3,4(+)				
Cooking loss		3,5,6(-)		2,3(+)						
W-B										
SSF		3,5(-)	1,3,5,6(-) 2(+)	1,2,5,6(-)	2,3,4,5(-)	1,3,4(-) 5(+)	1,2,3,4(-)	3(-) 5(+)		

REFERENCE: Kill-cut-drip (1), Overnight kill-cut-drip(2), Kill- cut after weekend-drip(3), Overnight kill-cut after weekend-drip(4), Kill-cut-drip over weekend(5), Overnight kill-cut-drip over weekend(6)

Table 40. Correlations response from each lairage/chiller treatment.

For all treatments, a clear relation was seen between higher temperature of the carcass at slaughter time and lower pH0, this is widely explained in literature, the relation became stronger when pigs were kept overnight.

For the treatments overnight kill-cut-drip and kill-cut after weekend-drip a low pH at slaughter time correlated with lower colour scoring (paler meat), in (2) treatment colour scoring was paler and pH0 was lower than pigs killed on the day, and for treatment (3) pH0 was lower but colour scoring was darker for overnight pigs, in the trial (3) partly darker colour can be attributed to longer maturation time in the chiller, but it was still interesting to see it relating to pH0.

Temperature at slaughter time had a lot of relation with other quality traits. For two overnight treatments higher temperatures at slaughter related to higher drip loss%, and for (1) treatment, but the opposite was seen for (6). When looking at results from drip loss when samples were left to drip

over the weekend there was no statistical difference between lairage treatments, therefore this last relation is questionable.

For pigs from (1) higher marbling seemed to have a relation with lower temperatures at slaughter.

The lack of effect in overnight vs kill on the day results can be attributed to many factors, being genetics one of them. The pigs are fed overnight in the abattoir and more likely share the same pattern of feed withdrawal, so the actual effect of lairage mixing could be the mild cause of some differences. Fasting reduces glycogen content in muscle by as much as 20% in the pigs loins for over a 24 hour period, yet this reduction is not enough to reduce the total glycogen below a threshold value to affect the phU (England et. al 2013).

Colour had relation with temperature at slaughter as well, for three treatments higher temperatures at slaughter related to paler colour, whereas for an overnight treatment and a kill on the day treatment the relation was opposite.

For nearly all treatments, lower pH24 related to high temperatures after 24 hours, which matches what's widely described in literature.

For pigs on (5) treatment, lower pH24 related to higher drip loss%, this finding was relevant as this treatment has the higher drip loss% considering it remains in the chiller extra two days before being further processed.

Marbling seem to have a negative relation with pH24, with lower values achieved from higher marbled scored samples.

pH24 was negatively correlated with colour (lower pH24, higher colour scoring) for two overnight treatments were either carcass or meat sampled was left over the weekend. This overthrown slightly the common assumption that low pH24 leads to paler meat, leading to speculate this potential paleness can be reversed if meat is left to mature slightly longer.

For some treatments, both overnight and kill on the day, higher temperatures in the chiller related to higher drip loss%. On the other hand, higher drip loss% correlated negatively with marbling, higher marbled samples had lower temperatures in the chiller.

Regarding tenderness, for nearly all treatments, lower carcass temperatures in the chiller related to less tender meat, which is much due to the relation of muscle contraction and cold temperatures.

Drip loss% correlated negatively with the tenderness tests, samples that dripped more were less tender, this relation was seen regardless lairage treatment.

Unfortunately, marbling had mixed relations with tenderness tests, especially SSF. It seems that for W-B, higher marbling had a positive effect on tenderness in all kill on the day treatments, and when samples were left to drip over the weekend. The effect was not relevant for the overnight pigs.

Finally, paler colour of samples related to less tender meat, except when the meat was samples were left to drip over the weekend, in this case, darker meat related with less tenderness.

4.10. Gut health in relation with pH values (Gut health project)

a) Overview

The aim this tris trial was work in collaboration with the feed industry, to measure and record the incidence and severity of gastric ulcerations and general gut health in pigs in Scotland and linking

this to risk factors on farm and historical pH data from the abattoir. The *pars oesophogea* (upper portion of the stomach, in connection to the oesophagus) was scored both in terms of keratinisation and ulceration using a well-known 0-10 scoring scale by an external partner from the feed industry and pH was evaluated from the same farms over the course of two years.

Gastric ulceration is thought to be a common problem, however the prevalence in the UK is not properly known due to lack of monitoring. It is a welfare concern as severe ulceration can lead to mortality from bleeding, but it is not currently known how gastric mild-medium ulceration affects the growth, efficiency and welfare of pigs and therefore what the economic impact to the producer is.

The intention of this trial was to establish the level of incidence and severity of gastric ulceration in Scotland and link scoring results to the risk factors on farm (feed type) and abattoir (lairage) and relate this information to historical pH and temperature value of pigs (from those farms).

A limitation to monitoring ulceration in the abattoir is that ulceration can occur within 12 hours and can heal relatively quickly (Friendship et al. 2004). Severely affected pigs may have died suddenly on farm, and therefore would not have been captured in the data.

b) Method

Scoring system training and validation was carried out by Professor Jill Thomson, Veterinary Centre Manager Edinburgh, SRUC Veterinary Services and a third partner from the feed Industry.

Scoring was carried out following the 0-10 scoring scale developed from Jensen et al., 2017 (Table 42).

Gastric score	Evaluation of the white part of the stomach (keratinisation, ulcer and scarring)	Description
0	No visible keratinisation. No erosion or ulcers. No scar formation.	The white part of the stomach by the mouth of the oesophagus is white, shiny, smooth and elastic.
1	Keratinisation below 1mm.	Keratinisation: mucosa around the mouth of the oesophagus gradually changes structure (keratinises) into cusp regeneration.
2	Keratinisation over 1mm.	
3	Keratinisation is papillomatous.	
4	Erosion in <10% of the white part.	Erosion: the protective layer of mucosa has disappeared resulting in direct access to the underlying sensitive tissue.
5	Erosion in >10% of the white part.	
6	Ulcer in <10% of the white part or slight scar formation.	Ulcer: deep changes in the mucosa, possibly bleeding. Scar: old injuries partially healed during scar formation. During scar formation, fibrous tissue (fibrosis) forms and the tissue turns inelastic and contracts.
7	Ulcer in 10-50% of the white part or scar formation with slight fibrosis.	
8	Ulcer in >50% of the white part or scar formation with clear fibrosis.	

9	Contracted oesophagus, where diameter of oesophagus is approx. 10mm	Scar: old injuries partially healed during scar formation. During scar formation, fibrous tissue (fibrosis) forms and the tissue turns inelastic and contracts. In the most severe degrees, the mouth of the oesophagus contracts to a narrow, inelastic aperture.
10	Contracted oesophagus, where diameter of oesophagus is below 6mm.	

Table 41. Stomach ulceration scoring system (Jensen et al. 2017).

Excluding the training, scoring in the abattoir took place over 6 different days between 7th December 2018 and 15th March 2019.

The scoring staff were stationed permanently in the gut room, one handling the stomachs and scoring while the other was helping with scoring and recording the scores on the scoring sheet. It was regularly watched for a change in batch of the pigs and placed a coloured piece of plastic in the gut tray to mark a change in batch of pigs. This would come through to the gut room and it would be marked on the scoring sheet that there was a change in batch.

A gut room operator would cut the stomach from the rest of the digestive tract, it would then be cut from the middle down the length of the stomach and turned inside-out. Here it would be given to the team to wash off and study the *pars oesophagea* for scoring.

Data from the gut room scoring was paired with historical data available from the farm from pH and condemnation data from that date.

Results

A total of 2,865 stomachs were scored from 36 batches of pigs.

Figure 48. Gastric ulceration results from all batches scored.

The full range of gastric ulceration scores were given throughout the project from score 0 to score 10. Figure 47 shows the variation in scores within and between batches.

From all farms recorded, 75% were between scores 1 and 3, which is only keratinization, no erosion, 10% presented scores 4 to 5 (erosion) and 15% scores from 6 to 8 which is ulceration, no overall healthy scoring farm (score 0) was obtained by any farm and no contracted oesophagus (score 9 to 10) was recorded.

When the farms were grouped in Dry or Wet feeding there was no statistically significant difference between methods, but Wet feeding had numerically higher score (4) compared to dry feed (3).

c) Scoring related to historical pH and temperature data

It was not possible to stablish direct relation between historical farm values and the ulceration scoring. For acute ulceration, in theory, an effect on carcass traits (pH and temperature at slaughter) could have been detected, for this, the threshold considered was if 20% of samples over two years recorded pH0 in the PSE levels and/or temp0 was outside comfort temperature.

Four of the sampled farms had nearly or more than 20% of its total temperature at slaughter above comfort and scored in the keratinization range. One of the farms with temperature at slaughter above comfort scored in the erosion range. No farm which scored in the ulceration range had temperature at slaughter above 20% of comfort temperature.

This leads to suggest there might be a slight influence in the general wellbeing of pigs (which could be affected by different degrees of ulceration), immediately before slaughter in carcass measurements, but the relation was too weak to reach further conclusions.

Chronic ulceration, which leaded to higher scoring (score 8 and above) was not registered greatly, this could potentially have matched with values of DFD meat, indicator of exposure of long term stress, but so many other factors (and combination of factors) can cause this condition that would not have been acceptable to attribute DFD values directly to chronic ulceration.

Acute and chronic ulceration seem to have a higher effect in farm parameters, such as growth rate, FCR and feed intake rather than a direct effect on meat quality.

Type of feeding (wet vs dry) did not lead to any statistical difference, neither did flooring type (slats vs straw).

There is a large variance in degrees of ulceration within and between herds in Scotland. Recommendations for a further study include non-anonymity and a more precise batch separation method, for the scoring team to enable to investigate the potential causal factors of the gastric ulceration (including feed formulation).

Also, repetitive scoring for farms will be useful to stablish a single average scoring for a farm, rather than basing its scoring in only one sampling.

4.11. Animal welfare indicators (tail biting) in relation with carcass and meat quality – Tail tech project

Some of the project partners were also involved in an Innovate UK funded-project call Tailtech: Developing an Early Warning System for Pig Tail Biting. It was identified that there was an opportunity to enhance the Tailtech project by linking their trial pigs into the work of this project and in return, give the opportunity to investigate the impact of on-farm health problems on eating quality. It also provided funding for additional equipment and consumables. *[Note: no payment was received from the Tailtech project for time input from either the Project Manager or Technical Experts].*

The project consisted in different pen treatments at an experimental farm which used technology to detect indicators of tail biting between pigs. Regular farm scorings for tail biting, flank biting, ear biting, lameness, nasal and ocular secretions and other lesions were performed. From the farm data, the last scoring before slaughter was considered, also, the health reports obtained from the ante mortem inspection on site.

Once pigs were slaughtered in separated batches, a stomach scoring was performed and carcass and meat quality data collected, this included: HW, CW, probe, LM%, pH and temperature at arrival and before cutting, drip loss%, colour, marbling, cooking loss and tenderness.

When full traceability was possible, data was paired down to individuals, which is the case for all carcass and meat quality data and health reports. For farm and stomach scoring the average of the treatment group was considered to make conclusions.

Finally, 2 experimental batches were put analysed, in November of 2019 (batch 1) and January 2020 (batch 2). There were three experimental groups: BWWW, BZZZ and BXXX.

Batch 1

a) Health Scoring**:** BWWW more severe cases of tail biting, while BXXX more new fresh wounds with high score. BZZZ had more cases of severe ear biting, with more severe score and fresh biting for the left side, for the right side was BXXX. BWWW had more ocular lesion observations and both BWWW and BXXX had the same amount of lame pigs, more than BZZZ.

b) Stomach scoring:

Slapmark	**Score (average)**	**SD**	**Variance**
BWWW	2.25	2.6	6.9
BZZZ	2.7	1.94	3.7
BXXX	1.57	1.01	1.03

c) Health reports

BWWW: 1 case of abscess, 2 trims due to contamination, 4 contamination condemnations.
BZZZ: 1 case of pleura, 2 trims due to contamination.
BXXX: 1 case of pleura, 1 case of pericarditis, 1 case of trotter contamination.

d) Carcass and meat quality data

Parameter	**BXXX**	**BWWW**	**BZZZ**
pH0	6.45^{a}	6.45^{a}	6.41^{a}
Temp0	34.56^{a}	35.08^{a}	34.16a
pH24	6.16^{a}	6.062^{a}	6.163^{a}
Temp24	3.58^{a}	5.42^{c}	4.5^{b}
Drip loss%	1.412^{a}	1.52^{a}	1.42^{a}
Colour	2.6^{a}	3^{a}	2.4^{a}
Cooking loss	24.5^{a}	23.98^{a}	23.73^{a}
Tenderness (WB)	35.84^{a}	24.63^{a}	27.84^{a}
Marbling	1.4^{a}	1.6^{a}	2^{a}
HW	88.78^{a}	94.58^{a}	86.98^{a}

CW	86.98[a]	92.68[a]	85.22[a]
P2	17.6[a]	15.6[a]	17[a]
LM%	56.16[a]	57.96[a]	56.16[a]

There was no statistical difference between treatment groups for pH in none of the time points and temperature at arrival.
Temp24 was different from all slaps, being the highest for BWWW, this could relate to the higher drip loss obtained from this slap but there was no statistical difference.
No statistical difference for either colour, marbling or cooking loss.
Tenderness showed a significant difference with tougher meat for BXXX slap, this last corresponds to the lowest temperature in the chiller as well.
The only significant difference for carcass traits was on p2 (backfat scoring) which was significantly higher for BXXX as well, and the less LM% was for BWWW.

e) Conclusion

Farm results are mixed, BXXX has the higher score of fresh wounds and ear biting for the right side, also the higher number of lame observations (with BWWW), non of this was noticeable for carcass or meat quality values at slaughter but there was a significant difference with the other pen groups on tenderness values.
BWWW was the heaviest farm, with more cases of tail biting and ocular lesions, also more lame pigs then BZZZ. This farm had the highest temperature after 24 hours in the chiller and numerically higher drip loss values.

Batch 2

a) Health scoring: BWWW had more severe cases, followed by BZZZ also in fresh wounds. BWWW was the only slap with flank biting cases. BWWW had more cases in general and more severe of ear biting. BXXX had more observations of ocular discharge and lesions.

b) Stomach scoring

Slapmark	Score (average)	SD	Variance
BWWW	6.4	1.8	3.5
BZZZ	4.8	2.1	4.8
BXXX	5.55	1.98	3.94

c) Health reports

BWWW: 2 cases of pleurisy, 1 trim due to bruising, 1 case of pericarditis, 1 case of pneumonia.
BZZZ: 2 case of pleurisy, one of pericarditis.
BXXX: 1 case of pleurisy, 1 case of pneumonia.

d) Carcass and meat quality traits

Parameter	BXXX	BWWW	BZZZ
pH0	6.69[a]	6.88[a]	6.8[a]
Temp0	27.32[a]	27.94[a]	27.82[a]

pH24	6.162[ab]	6.298[b]	6.18[b]
Temp24	6.2[b]	4.92[a]	5.62[ab]
Drip loss%	1.991[a]	2.32[a]	2.154[a]
Colour	1.2[ab]	1.4[ab]	1[a]
Marbling	2.2[a]	2.4[a]	2.4[a]
Cooking loss	27.32[a]	26.59[a]	30.67[a]
Tenderness (WB)	35.75[a]	41.94[a]	35.86[a]
HW	85.32[a]	81.72[a]	86.6[a]
CW	83.6[a]	80.08[a]	84.86[a]
P2	10.6[a]	10.8[a]	10[a]
LM%	62.12[a]	61.7[a]	62.76[a]

There was no significant difference between parameters at slaughter nor pH24. For Temp24, there was a significant difference between BWWW (lowest temperature) and BXXX (highest temperature). BWWW had the highest drip loss recorded. BZZZ had the higher cooking loss.

The higher N recorded (lower tenderness) was recorded for the BWWW group.

There were no significant differences between carcass traits.

e) Conclusion
Regarding farm scoring, the worst treatment group was BWWW, which also presented the worst stomach scoring and slightly more cases of condemnation for the health reports. Regarding meat quality, this group presented the less tender meat, which can be partially attributed to low temperatures after 24 hours. BZZZ had the second highest stomach scoring and followed BWWW in farm observations, but there were not visible effects of that on meat quality.

<u>Overall conclusion</u>

Data from farm, stomach scoring, health reports and meat quality provided variable results from which it was difficult to identify clear conclusions.

Some treatment groups which scored poorly on farm and with the stomach scoring could possibly reflected in meat tenderness, but no other meat quality trait showed differences between treatment groups. Lack of effect in other quality traits could be due to sampling.

Limited inherences can be made from meat quality and animal welfare scoring on farm, a more extensive data set with less complex farm scoring over a longer period of time would be more useful to be able to conclusively identify effects on meat quality.

5. FINANCE

5.1. Sum Awarded

£114,920 awarded; subsequently revised down to £94,930.

5.2. Details of expenditure

COSTS	Total Budget	Total Claimed	Total Remaining
Direct Project Costs			
QPL Project Manager	£60,000	£60,000	£0
Technology Specialists	£24,440	£23,480	£960
Running Costs			
SPP Management, reporting & administration	£10,140	£10,140	£0
Op Gp meeting catering	£350	£0	£350
Total	**£94,930**	**£93,620**	**£1,310**

The technology specialists from Hellenic did not need their whole allocation to complete the work so there is an underspend of £960. The Operational Group catering costs have not been claimed since they were frequently taking place as part of other meetings so this is underspent by £350.

6. PROJECT AIMS/OBJECTIVES

a) AIM
Generate data to be able to benchmark Scottish pig carcasses, through data collection in the abattoir, and identify which factors from farm, lairage and post slaughter can affect carcase and eating quality

b) OBJECTIVES
- Benchmarking Scottish pig carcasses based on eating quality
- Elaborating protocols for data collection that are applicable to an industrial abattoir setting.
- Implementing data collection methods widely described by literature and compare results to scientific data.
- Plan and perform trials with different production scenarios which are realistic and relevant to the Scottish supply chain.
- Construct an extensive data base with historical data from the incoming farms to QPP abattoir to be available in the future for further work.

c) MILESTONES
M1: Operational group identified with all the relevant actors for the project (June 18)
M2: Review of Scottish supply chain within the industry, strengths and weaknesses and draft protocols for relevant data collection from the abattoir (AUG 18)

M3: Beginning of data collection (JUN 18)
M4: incorporation of new analysis (OCT 18)
M5: Weekly reports started (JUL 18)
M6: First quarterly report and presentation (DEC 18)
M7: Collaborations with industry (JAN 19)
M8: Incorporation of meat quality data to Hellenic system (APR 19)
M9: Individual farmers reports (APR 19)
M10: Benchmarking results reporting (APR 20)

d) TARGETS

PHASE 1

- Recruit individual in charge of data collection. (JAN 18)
- Familiarization with abattoir operations and conformation of operational group (JUN 18)
- Finalization and approval of data collection protocols for the abattoir (JUL 18)

PHASE 2

- Start data collection (AUG 18)
- Collaborations with industry (JAN 19)
- First findings and reports (DEC 18)

PHASE 3

- Continuous data collection (APR 19)
- Findings and preliminary results presentation (NOV 19)
- Plan for follow up projects based on industry interest (JAN 20)

7. PROJECT OUTCOMES

a) Project progress against objectives

- Benchmarking Scottish pig carcasses based on eating quality.

This was not achieved as such because the market and the industry are still not ready to benchmark on the basis of eating quality. Values for benchmarking were achieved for all the meat quality traits but no valid comparison could be made with herds in England as there is no similar set of data ever collected in another abattoir from the group.

- Elaborating protocols for data collection that are applicable to an industrial abattoir setting.

This was achieved towards the beginning of the project but just after the first 6 months a definitive protocol for sample collection was stablished which kept improving while getting more used to the abattoir operations, newer protocols were added as new meat quality analysis were incorporated. Early definition of pH and temperature protocol allowed plenty of data collection from the beginning. The protocols were used for the site to stablish their own SOPs to perform these measurements.

- Implementing data collection methods widely described by literature and compare results to scientific data.

This was achieved after a thorough literature review and “trial and mistake” runs in the abattoir to see what is suitable to perform in an industrial setting without disturbing operations but still representative of commercial scenarios. Methods used to determine all the quality traits were

adapted from literature and scientific papers to be comparable to such. Extensive referencing was made through the report.

- Plan and perform trials with different production scenarios which are realistic and relevant to the Scottish supply chain.

This was achieved through planning and collecting data over months, but in order for data to be significant a number of variables had to be considered, therefore the trials were not as numerous but enough to give a preliminar view.

- Construct an extensive data base with historical data from the incoming farms to QPP abattoir to be available in the future for further work.

An extensive data base of approximately 60.000 time points for pH and temperature was built for more than 60 producers with more than 3000 meat samples.

b) Date milestones were achieved (Original target vs actual)

- M1: Operational group identified with all the relevant actors for the project (JUN 18/JUN 18)
- M2: Review of Scottish supply chain within the industry, strengths and weaknesses and draft protocols for relevant data collection from the abattoir (AUG 18/JUL 18)
- M3: Beginning of data collection (JUN 18/JUL 18)
- M4: Incorporation of new analysis (OCT 18/NOV 18 and ongoing)
- M5: Weekly reports started (JUL 18/ JUL 18 and got replaced by quarterly reports)
- M6: First quarterly report and presentation (DEC 18/ DEC 18)
- M7: Collaborations with industry (JAN 19/ NOV 18)
- M8: Incorporation of meat quality data to Hellenic system (APR 19/ Non achieved)
- M9: Individual farmers reports (APR 19/ APR 19 and ongoing)
- M10: Benchmarking results reporting (APR 20/ APR 20 and ongoing)

8. LESSONS LEARNED

8.1. Issues and challenges

The project suffered unplanned issues such as the CO2 shortage that stopped operations in the site for a month. Sampling was set to start when that happened which delayed the start of data collection the first year.

The second challenge was the lack of resources in the site to start working. An individual was recruited for carrying out and manage the project on site, but equipment and tools were needed to do so, such as pH meter, colorimeter, colour cards and tenderometer. Some piece of equipment was very costly and were able to be incorporated with external funding from collaborations with the industry, this caused the incorporation of new analysis to be done across the two years the project lasted.

An issue the project presented was the fact there was only one person responsible for all the sampling, analysis, data arrangement, stats, writing and other accessory tasks for the project. Overseeing all the tasks that limited the number of samples that can be taken.

Another issue was the regularity to hold big operational group meetings. Two of the main components of the operational group were based in England and physical meeting were held only when one of the members went down to other plants or when someone was able to come up to Scotland, and to coordinate that with further participants availability was very complicated. The last

months of the project the COVID 19 pandemic made all the communications through Microsoft Teams. Communication through the whole project was good regardless.

The lack of a previous database from carcass/ meat quality from any other site in England made the project results for Scotland unable to be compared fairly with any other dataset. Also, lack of previous experience inside the company in developing functional protocols for an industrial setting was challenging.

The two-year duration of the project was good enough to collect data and fix the site values for several meat quality parameters but not enough to brand the Scottish pigs based on eating quality, as further work needs to perform for that.

Finally, another important lesson learned was the sampling size, the size stablished since the beginning of the project suffered variations while the protocol was updated, the selected size was enough to carry on all the meat quality analysis but wasn't enough to carry many repetitions for tenderness analysis; to amend this will be required to sample more carcasses or sample the same carcass twice but this last puts a high risk for the cutting room operator as he needs to sample two middles following each other's which can be a HSE hazard due to the conveyor belt speed.

9. COMMUNICATION & ENGAGEMENT

9.1. Details through the project lifetime

Introductory meetings were held within the first quarter of the project, and quarterly reports were elaborated to show the report progress. In the first quarter of the project weekly short summaries were sent to the core operational group to show findings of the week, this was later replaced to more spaced summaries in the form of a presentation. One of the members of the operational group was in charge of cascade the preliminary findings/ project status to the farmers.

Presentations of the projects scope and preliminary results were performed for several groups, including farmers, QMS and other industry partners. Within the company, the project was presented in meetings for the Agriculture department, Supply chain, Technical and for customers coming to site which have products from the retailer labelled as "Scottish".

Detailed reports from all the information correspondent to each farm/unit and multiple batches were sent out at the end of the project to the farmers. This consisted on the results recorded from the assessment of its batch which could range from just pH and temperature to more, including analysis of meat quality, blast chiller curves or if it participated in any other welfare assessment.

9.2. Impact

The company, QPP and customers showed positive response to the work done over the two years. This was manifested through all the presentation and update meetings.

The retail customers which encourage the development of differentiated supply chains considered that quality "needs to be a focus point, same as animal welfare", and praised the initiative taken to develop this project.

The discussion on the final consumers shift on what they look for at the time to purchase meat products showed that this kind of studies contribute to show that the continuous animal welfare standards achieved are reflected in the product quality, and now that is possible to account, with numbers, to build a brand.

Tulip, through its technical group was pleased with having a person on site from the company to support operations, made communications slightly easier and helped to clear out issues from complains from further down the supply chain with incoming product from QPP.

Benchmarking based on eating quality has study cases such as the Wagyu meat in Japan or the MSS system in Australia, which consolidated a brand and a price due to a standard of eating quality expected. Unfortunately, the company nor the UK market of pork meat are yet ready to operate based on eating quality, deeper and extensive research is needed for that, from all components of the pig industry to be able to benchmark their products as well. A necessary step for that to happen is the improvement in carcass grading, which at the moment is quite rudimentary.

Grading systems need improvement as they will be a key tool to estimate lean meat%, which will give additional information to eating quality without having to rely entirely in chemical analysis for fat content, especially if LM% can be calculated for each primal. Improving grading systems has been in the industry agenda for some time, but when this project came across it became more evident than ever that this is the direction to move for the Scottish industry.

10. KEY FINDINGS AND RECOMMENDATIONS

The data generated was able to profile the range of pH/temperature values from the site, these leaded to implement pH recording as a regular SOP after the project, in line with the project recommendations. Also, has been suggested by the group that pH recording can be implemented as a monitoring tool in case there is a breakdown in the line or a change in the SOPs, when changes or delays in the line needed validation, pH and temperature range of values could be used as reference points, values from QPP were categorized according literature.

Findings on pH and temperature: there is monthly (seasonal) variation in carcass temperature, at arrival being higher in warmer months, possibly attributed to environmental temperature, variations for pH are not that remarkable seasonally.

At the moment there was no SOP on when to switch the sprinklers on to refresh the pigs, as this was left to the criteria of the operators, now is been discussed to install a precision thermometer and stablish a critical point in which they will go on automatically.

The relation between pH and temperature is not linear, at no time after slaughter. Both pH values (pH0 and pH24) are influenced by different factors. pH0 depends on genetics, pre-slaughter factors and combination of both, while pH decline and pH24 are affected by the glycogen present at slaughter and carcass chilling.

On pH dynamics, pH decline is minimum during the blast chiller contrary to carcass temperature. Rapid chilling can't compensate for pre slaughter stress impact on pH, this will only achieve rapidly decrease of temperature in a warm carcass with an already accelerated pH decline, risking other quality problems to develop. Ideally, pre slaughter stress should be kept at minimum, for which plenty of recommendations are available, from improving lairage conditions and time, transport, pen mixing and genetic traits, each herd should spend resources on identifying their inherent potential stressors.

The relation of weight and temperature decline was clear, higher weights means delayed chilling in the deep muscle which could compromise pH decline, while a portion of the carcass already reached chiller temperature, other parts can take up to a couple of hours more to do so.

This data can help in the nearby future to manage killing of heavier pigs earlier in the day and get cut last in the day to ensure heavier carcasses have enough time to chill deeply before getting cut, this can be done through planning and farm communication.

Regarding drip loss%, changes in the muscle biochemistry suffered in the first hours after slaughter have consequences in meat quality even after hours in the chiller, this could help explaining the strong correlation between drip loss% and pH24. Drip loss relation to pH24 is not linear neither, and potentially holds a threshold of 6.0.

Drip loss was positively related to marbling and IMF, the benefits of reintroducing marbling to pork are complicated, as pork is perceived as a "fat" meat. Also, there is evidence suggesting a positive influence of marbling on tenderness, up to certain extent.

Meat colour had a strong relation with carcass temperature, which also suggest a threshold value after which warmer carcasses lead to paler meat, all product to the biochemical changes post-mortem. Meat paleness was synonym of "less red" meat.

During the supply chain exercise, the relation with weight and muscle depth was evident as well as issues with ham yields after cooking. Results were not conclusive, when looking at chemical composition of raw material and data collected but was speculated that the hams could be suffering from "pse-like" sections (denaturated zones) which can potentially decrease the final product quality from different points. Extensive supply chain studies like this could be mimic when customer complains concerning quality are raised, as part of the root-cause analysis.

Regarding lairage treatments, overnight lairage pigs had higher temperature after slaughter and lower pH0, also temperature influenced pH24. Finally, lairage treatment had mixed effects for tenderness, with overnight pigs giving tougher meat overnight but only in W-B test. Marbling also had mixed effects.

Lack of more effects from overnight lairage can be due to factors such as genetics, mixing with unfamiliar pigs rather than feed withdrawal. Lairage times in QPP when not overnight is normally too short to make an impact on meat quality, also, the lairage capacity is much lower than in other commercial abattoirs.

With different carcass/meat samples treatments for days in the chiller, lower tenderness related to lower carcass temperature in the chiller and higher drip and paler samples, except for colour when samples were left to drip over the weekend, which suggest a "maturation" effect of the meat. Also, pH24 had mixed relations with colour, normally lower ph24 will lead to pale meat, which was reversed in some treatments by longer time in the chiller.

11. CONCLUSION

The project aimed to benchmark Scottish pig carcasses in order differentiate the Scottish supply chain based on eating quality. This was slightly ambitious and lacked some knowledge when initially proposed. However, the project did prove that the vast majority of pig carcases at QPL Brechin meet the standards that scientific literature suggests should be classified as good or better.

Comprehensive benchmarking based on these characteristics was not possible, considering there is no equivalent values from similar supply chains (England) to draw comparisons, also, currently the pork industry is not looking to benchmark on eating quality but is moving towards that.

In order to develop a new benchmarking system, an extensive data collection from the actual state of the carcasses had to be performed and this was successfully achieved over the course of two years, a robust amount of data was generated from many parameters of carcass and meat quality, the data helped understanding the relation between traits and the factors that directly or indirectly influences them. Also, it helped to create a range of values that are particular to this site, and therefore the Scottish supply chain, that is the first step of the benchmarking process.

The project faced numerous challenges such as money constraints to get equipment, limitations from the site and CO2 shortage that delayed the data collection and then in the last months the COVID19 pandemic restricted all the travel and all interactions between the operative group had to be carried out remotely.

Some SOPs and practices will be adopted in the site as a follow up of the project, and further work to differentiate the Scottish supply chain will carry on, starting with smaller groups of producers. Also, in terms of benchmarking through eating quality the UK is moving slowly but steady in that direction, preparing trials to improve carcass grading systems based on automated tools, which can help predict LM% more accurately, with plans that these techniques will be implemented in QPP soon. The project has made much progress towards benchmarking Scottish pig carcases through eating carcass and to supply chain differentiation.

APPENDICES

1. ABREVIATIONS

SPP: Scottish Pig Producers

QPP: Quality Pork Processors

Co2: Carbon dioxide

IMF: Intramuscular fat

OV: Official Vet

FSS: Food Standards Scotland

MLC: Meat Livestock Commission

HW: Hot weight

QMS: Quality Meat Scotland

CW: Cold weight

LM%: Lean meat %

SRUC: Scottish Rural University College

pH0: pH 45 minutes after slaughter

Temp0: temperature 45 minutes after slaughter

pH24: pH in the chiller (approx. 18-22 hs)

Temp24: temperature in the chiller (approx. 18-22 hs)

pH2: pH after leaving the blast chiller (approx... 2 hours)

Temp2: temperature after leaving the blast chiller (approx. 2 hours)

DL%: Drip loss%

L*: Lightness of the meat

A*: redness of the meat

B*: yellowness of the meat

SOP: Standard operations procedure

PSE: Pale Soft Exudative

DFD: Dry Firm Dry

CCP: Critical control point

Temp10: time required to decrease 10 degrees from initial temperature

TempEq: time when carcass reached equilibrium temperature with the chiller (5.9 C)

P2: backfat probe values

W-B: Warner-Bratzler Shear Force

SSF: Slice Shear Force

N: Newtons

G1: group 1

G2: Group 2

pHu: ultimate Ph

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