An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

Food Institutional Research Measure

Final Report

'Improving the Eating Quality of Irish Pork'
(PORKQUAL)

DAFM Project Reference No: 11/F/057

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Collaborating Research Institutions and Researchers:
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Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental →			Applied →			Pre Commercial
1	2	3	4 X	5	6	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	**I: Sustainable Food Production and Processing**

Key words: *(max 4): Pork, Quality, Packaging, Enhancement.*

1. Rationale for Undertaking the Research

Pork quality and yield is greatly influenced by pre-slaughter handling, method of slaughter and chilling practices. Under EC regulation (No 853/2004: specific hygiene rules for food of animal origin), it is specified that meat must be chilled to 7°C along a chilling curve that ensures a continuous decrease of the temperature. Chilling slows the onset of rigor and the rate of evaporative weight loss, thereby affecting both meat quality and yield. Issues related to chilling regimes such as conventional batch chilling (24-hour cycle) include the requirement for large chill rooms, the heat peak and high weight losses. Blast or ultra-rapid chilling systems aim to remove heat from pork carcasses in 3-4 hours and is commonly used in the pork industry. While chilling pork carcasses quickly helps to minimize the occurrence of PSE meat, cold shortening can occur resulting in tougher pork meat. This phenomenon occurs when meat, in a pre-rigor condition, is rapidly chilled below 10°C when the adenosine triphosphate (ATP) level is still high (pH above 6.0). Ageing could partially reverse this, but pork is generally not aged before distribution to retailers.

The negative effects of cold shortening on tenderness are minimized by pre-rigor processing techniques such as electrical stimulation and the method of carcass suspension. Electrical stimulation involves the application of an electrical current through a carcass or a muscle which hastens the process of rigor mortis by accelerating post-mortem glycolysis, thereby lowering the early pH and increasing the rate of pH decline. This technology is a valuable tool for avoiding conditions such as cold shortening which would result in less tender meat even after ageing. Electrical stimulation should be considered as part of a total process as it has particular advantages for ultra-fast cooling and hot boning applications. The principle of suspending carcasses from the aitch bone (pelvic bone), rather than the achilles tendon, for improving tenderness in beef and lamb has been known for many years. Suspending carcasses from the aitch-bone results in stretching of some of the commercially more important muscles thereby preventing shortening when *rigor mortis* sets in. Aitch bone suspension has also been suggested as a method for improving pork tenderness.

Hot boning involves the removal of muscles or cuts up to 90 minutes post-mortem. The advantages of hot boning are reductions in weight loss during chilling and reduced drip loss during storage, due to the increased water holding capacity of the muscle proteins at the higher pH. Hot boning also reduces chilling costs when compared to conventional boning practices. The PiVac electro-pack system is a wrapping technique that is applied to pre-rigor hot boned muscles using an elastic wrapping material to prevent shortening and toughening of the meat during rigor. It operates by stretching tubes of highly elastic films to the inside walls of a packing chamber using a vacuum. The longitudinal forces exerted by the elastic film hinder muscle contraction during rigor.

Intensive pig production and husbandry practices has resulted in a highly efficient pork production system where pigs are bred to achieve a lean growth rate. However, there are concerns that the eating quality of pork meat has been compromised i.e., the succulence of pork has been reduced due to lower intramuscular fat (IMF) content. Increasing IMF in pork can be achieved though using breeds and genetic lines with a higher IMF content, for example the duroc pig breed.

As a result of the negative effects of rapid chilling, lack of aging and lower IMF on pork quality, research into novel processing systems is required by the Irish pork industry to

produce pork of consistently good eating quality. Post-mortem interventions and processes (alone or in combination) such as electrical stimulation, hot boning, PiVac restraint, hanging methods, ageing and enhancement may increase pork quality and tenderness and merit investigation. In addition, optimised packaging and storage conditions are of critical importance with respect to pork quality and shelf-life. Optimum conditions (gas mixtures and headspace to meat ratio) for effective modified atmosphere packaging (MAP) of pork meat were also investigated.

2. Research Approach

The overall aim of this multidisciplinary project was to enhance the eating quality of pork meat and a multi-faceted research approach was employed at various points along the pork processing chain.

Hot boning, electrical stimulation and PiVac wrapping studies

Initial research examined the effects of pre-rigor processing techniques (combinations of hot boning (HB), electrical stimulation (ES) and PiVac wrapping (PI)) on the quality and tenderness of selected pork muscles from standard commercial pigs with low (pietrain breed) and higher (duroc) levels of intramuscular fat (IMF). Cold boned (CB – control) and hot boned muscle treatments were vacuum packed and stored for 7 days post-mortem. Physico-chemical characteristics of pH, sarcomere length, texture (WBSF), sensory eating quality, protein degradation (SDS-PAGE), instrumental surface colour (CIE L*, a* and b*), drip loss (%) and water holding capacity (WHC) by NMR relaxometry (T22 population %) were subsequently measured.

Carcass hanging and ageing studies

Additional pre-rigor intervention techniques such as carcass hanging methods (achilles tendon (AT) and pelvic bone suspension (PB)) and ageing time and their influence on the quality and tenderness of low and high IMF pork muscles, sliced into steaks, vacuum packed and aged for 7 and 14 days, were examined. Carcass temperature and pH decline profiles, proximate compositional analysis (protein, moisture, fat, ash), surface colour, texture (WBSF), sensory analysis (hedonic and intensity descriptors), cook loss (%) and WHC (%) measurements were recorded. Experimental design and workplan modifications (from the original proposal) included a reduction in the number of trial animals, no vertebral cutting (not permitted on the slaughter day), sarcomere length and protein degradation by SDS PAGE measurements were carried out.

In order to further enhance eating quality, pork meat (low and high IMF) from the most promising primary processing systems (hot boning, electrical stimulation, PiVac wrapping) and carcass intervention techniques (hanging methods and ageing time) was to be further examined in combination with optimised modified atmosphere packaging (MAP) (gas composition, gas headspace to meat ratio) and value-adding brine injection techniques (enhancement). A lack of promise demonstrated by the primary processing/intervention techniques resulted in the use of pork striploins (commercial supplier) for all MAP and value-added pork trials.

Modified atmosphere packaging, enhancement and marination studies

The effect of six modified atmosphere packaging (MAP) gas mixture combinations (oxygen (20, 30, 40 & 70%), carbon dioxide (30 & 60%), nitrogen (20, 40 & 70%)) on the quality and shelf-life of packaged pork slices was investigated. An optimum gas mixture of 70% O_2 : 30% CO_2 was identified and used to investigate the effect of varying the gas headspace to meat ratio (2 :1 – 0.5 : 1) in MAP on pork quality and shelf-life.

Aquamin (mineral source from marine algae) and solubilised pork protein (SPP) were selected for evaluation as potential phosphate replacers in enhancement brine solutions (injection enhancement and marination trials) for pork meat. Additional ingredients added into brine formulations included phosphate (positive control), salt and rosemary (nanoparticle solubilisate). Injected pork loins were cut into steaks and stored in MAP (70% O_2 : 30% CO_2). Marination of pork slices was carried out in vacuum pouches which were subsequently vacuum packed and stored for up to 8 days at 4°C.

Quality and shelf-life measurements carried out for the MAP, enhancement on marination trials included MAP gas headspace analysis, proximate compositional analysis, pH, colour, lipid oxidation (TBARS), microbial growth, texture, drip loss, WHC, cook loss and sensory analysis (hedonic/intensity) at selected time intervals. In addition, the effect of health-related labelling on consumer or assessor preference (halo effect) was assessed using marinated pork.

3. Research Achievements/Results

Hot boning, electrical stimulation and PiVac wrapping

Individual (hot boning (HB), electrical stimulation (ES) and PiVac (PI)) and combinations (HBES, HBPI, HBESPI) of pre-rigor processing techniques were applied to pork muscles (M. *longissimus thoracis et lumborum* (LTL), M. *semimembranosus* (SM), and M. *biceps femoris* (BF) muscles) from Pietrain pigs and to LTL muscles from pigs with low (Pietrain) and high (Duroc) levels of intramuscular fat (IMF). All cold (CB) and hot-boned muscle treatments were vacuum packed and stored at 2-4°C for 7 days post-mortem. In all muscles the rate of pH decline was greatest in the HBESPI treatment. Muscle sarcomere length was not significantly influenced by post-mortem treatment. Pork muscles from the HB and HBES treatments were tougher than the CB treatment. PiVac wrapped muscles (HBPI and HBESPI) were more tender than HB muscle samples. Tenderness data (WBSF) was also supported by sensory analysis findings. Variable results were obtained from Duroc pigs (high IMF) where no differences in pH, tenderness or sensory analysis data were observed. Additional parameters such as protein degradation (SDS page), instrumental colour (CIE L*, a*, b*), drip loss and water holding capacity (WHC by NMR relaxometry (T22 population)) were not significantly influenced by post-mortem treatment or breed (low and high IMF).

Carcass hanging and ageing

Following slaughter, low (Pietrain) and high IMF content (Duroc) pig carcass sides were suspended conventionally by the achilles tendon or from the aitch bone (pelvic bone). Two hanging methods x two carcass sides resulted in four treatment groups. Carcass sides were chilled and pH and temperature measurements were measured (in LTL muscles) after 45 minutes, 3 and 24 hours post-mortem. Muscles (LTL, SM and BF) were excised 24 hours post-mortem, sliced into steaks, vacuum packaged, aged for 7 and 14 days at 4°C and frozen at -20°C until required for analysis. The rate of pH decline did not differ among the four treatment groups. Pig breed significantly influenced the fat content of BF muscle only. Surface redness and yellowness of LTL muscles were influenced by pig breed only. Cook loss, texture and water holding capacity measurements were not influenced by breed, hanging method or ageing time. Sensory analysis (cooked LTL muscle) indicated that pig breed, i.e. duroc, was the only factor to moderately enhance some of the pork quality sensory properties such as juiciness and overall acceptability descriptors.

Modified atmosphere packaging

Commercial pork striploin (LTL) slices were stored in six different modified atmosphere packaging (MAP) treatments for up to 14 days at 4°C as follows:

- 70% O_2 : 30% CO_2
- 70% N_2 : 30% CO_2
- 30% O_2 : 30% CO_2 : 40% N_2
- 40% O_2 : 60% CO_2
- 40% N_2 : 60% CO_2
- 20% O_2 : 60% CO_2 : 20% N_2

Apart from some minor significant differences related to the colour of pork in the absence of oxygen, none of the quality and shelf-life measurements or sensory analysis descriptors examined were influenced by MAP treatment.

Pork slices (LTL) were also stored in 70% O_2 : 30% CO_2 at three gas headspace to pork meat ratios (2:1, 1:1 and 0.5:1). No significant differences were detected in quality and shelf-life measurements between the packaging treatments. However, a reduction in gas headspace to meat ratio (from 2:1 to 0.5:1) significantly enhanced the eating quality of pork with respect to texture, juiciness, flavour and overall consumer acceptability.

Enhancement

Pork loins (LTL) were pumped (to 120% of original weight) with brine solutions, containing Aquamin or laboratory manufactured solubilized pork protein (SPP), using a multi-needle brine injector.

For the Aquamin trials, injection with water-based brine solutions containing phosphate, NaCl, aquamin or rosemary resulted in the following treatments (based on 20% uptake):

- 0.3% phosphate + 0.5% NaCl (0.3% Ph + 0.5% NaCl).
- 0.3% Aquamin + 0.5% NaCl (0.3% A + 0.5% NaCl).
- 0.5% Aquamin + 0.5% NaCl (0.5% A + 0.5% NaCl).
- 0.5% Aquamin + 0.5% NaCl + 0.01% Rosemary (0.5% A + 0.5% NaCl + 0.01% R).

Solubilised pork protein (SPP) was manufactured from pork LTL in the laboratory by acidification of pork slurries to pH 2.5 with phosphoric acid. Brine solutions containing phosphate, NaCl, SPP or rosemary resulted in the following treatments (based on 20% uptake):

- 0.3% phosphate + 0.5% NaCl (0.3% Ph + 0.5% NaCl).
- SPP + 0.5% NaCl (SPP + 0.5% NaCl).
- SPP + 0.5% NaCl + 0.01% Rosemary (SPP + 0.5% NaCl + 0.01% R).

Following injection, pork LTL, including non-injected controls (control group), were vacuum packaged and brine uptake was calculated. Pork LTL was cut into slices and packaged in MAP (70% O_2: 30% CO_2). Quality and shelf-life measurements were recorded at selected time intervals. The uptake of brine by pork LTL in both the Aquamin and SPP trials was ≥ 20% for the phosphate treatment (0.3% Ph + 0.5% NaCl). Brines containing Aquamin or SPP were not well retained well in pork post-injection where uptake ranged from approx. 4 – 8%. Aquamin reduced pork redness and exerted lipid pro-oxidant activity which was reduced by including rosemary in the enhancement brine solution. Aquamin also displayed antimicrobial activity. Aquamin moderately enhanced selected sensory properties of MAP pork however, off-flavours were detected by panellists during storage. Other physcio-chemical parameters were not positively influenced by Aquamin and overall, Aquamin did not represent a suitable replacement for phosphate in pork enhancement brines. Similarly, SPP did not perform as well as phosphate in brine enhancement solutions with respect to quality, texture, and sensory properties of MAP pork.

Marination

Experimental trials were conducted to the compare the efficacy of Aquamin and laboratory manufactured solubilised pork protein (SPP) to phosphate in pork marinating solutions (brines). Sliced LTL pork was marinated in vacuum pouches with brines resulting in the following ingredient concentrations for each packaged treatment:

- No marinade (control group).
- 0.3% phosphate + 0.5% NaCl (0.3% Ph + 0.5% NaCl).
- SPP + 0.5% NaCl (SPP + 0.5% NaCl).
- SPP + 0.5% NaCl + 0.01% Rosemary (SPP + 0.5% NaCl + 0.01% R).
- 0.5% Aquamin + 0.5% NaCl (0.5% A + 0.5% NaCl).
- 0.5% Aquamin + 0.5% NaCl + 0.01% Rosemary (0.5% A + 0.5% NaCl + 0.01% R).

All steaks were stored for up to 8 days at 4°C. A range of experimental measurements and sensory analysis ('blind tasted' and 'halo assessed') was carried out. Apart from some minor differences related to moisture, colour and cook loss, the majority of the physcio-chemical parameters measured were not influenced by marination treatment. In 'blind tasted' pork, positive effects of the SPP + 0.5% NaCl treatment were observed on days 2 and 7 of storage with respect to flavour and overall sensory acceptability descriptors. In addition, positive effects of the phosphate (0.3% Ph + 0.5% NaCl) and Aquamin (0.5% A + 0.5% NaCl) treatments were observed on day 7 of storage. Similar findings were reported for the 'halo'

assessed marinated pork on days 2 and 7 of storage. Minor differences in off-odour, texture and juiciness descriptors were observed in selected treatments between 'blind tasted' and 'halo assessed' vacuum packaged pork. Overall, it was concluded that Aquamin and SPP treatments did not out-perform phosphate in marinated pork meat.

4. Impact of the Research

This research increased the scientific knowledge, capability and know-how related to post-mortem interventions for improving pork eating quality. Useful data was obtained on the use of pre-rigor processing/intervention techniques, packaging, enhancement and marination techniques for enhancing pork tenderness and quality. The data and research findings can be used as a baseline on which to build future development and innovation related to these processes.

Pi Vac processing offered protection against the negative effects of hot boning which would be of interest to pork primary processing companies. Advantages of hot boning include reductions in weight loss during chilling, drip losses during storage and reduced chilling costs. Electrical stimulation, either alone or combined with PiVac offered no benefit which would simplify the application of PiVac technology in the pork meat management chain. From a research perspective, positive findings related to the fact that PiVac packaged hot boned pork was as tender as cold boned control pork implies future potential for this line of research, previously abandoned due to the risk of PSE in pork.

Optimised modified atmosphere packaging conditions (gas mixture and headspace to meat ratio) were identified for pork meat which is of interest to both meat processors, the consumer, and the scientific community.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

This research project enhanced and strengthened the ongoing collaboration between Teagasc Ashtown and UCC in the areas of meat science and packaging research. Additional collaborative links were developed with Marigot Ltd (Cork), the supplier of Aquamin as a potential phosphate replacer for the enhancement/marination trials, Hermitage AI (Kilkenny) for low and high IMF pigs and Ballyburden Meats (Cork) for the supply of commercial pork striploins.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

The project was classified as an applied type within the research continuum but was still pre commercial. Key data was generated using existing technologies and processes in each participating institution. To satisfy task objectives, technologies and processes were modified as appropriate. Research findings will underpin future research in this area to product superior quality pork and associated products.

(iii) Outcomes with economic potential

Pork meat accounts for approximately 40% of global meat consumption. Technologies which enhance pork quality and saleable shelf-life offer considerable economic advantages to pork processors and the pig meat industry. The demonstrated potential of hot boning in combination with Pi Vac wrapping can result in reduced muscle weight and drip losses and lower chilling costs for pork processors.
Previous reports have indicated that the gas headspace in MAP must be 1.5 – 2 times the meat volume in order to prevent pack collapse. Others suggested that the gas headspace should be no less than 2 – 3 times the meat volume. Project research findings demonstrated that a reduction in the gas headspace to meat ratio was possible for pork meat packed in high oxygen MAP, without negatively influencing the eating quality of pork. Potential benefits of reducing the gas headspace to meat ratios in MAP include a reduction in retail pack size which would result in lower manufacturing, transport and storage costs for the meat industry.

(iv) Outcomes with national/ policy/social/environmental potential

The overall objective of this research (production of pork with consistently good eating quality) aligns with the Department of Agriculture, Food and the Marine Food Wise 2025 strategy for the Irish agri-food sector. Strengths of the Irish pig meat sector, identified in Food Wise 2025, included a premium quality product with value-added capability. Innovation by producers and processors is key in order to maintain competitiveness in the International marketplace. The outcomes of this project provide a platform on which future pork quality research, development and innovation projects may be based. An acceptable reduction in gas headspace to meat ratio, and consequently pack size, for pork stored in MAP was identified during this project. This has beneficial environmental implications and is in line with Ireland's National Waste Policy 2020-2025 (A Waste Action Plan for a Circular Economy) with respect to packaging waste prevention measures etc.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

Keenan, D.F. (2016). Pork Meat Quality, Production and Processing on. In *Encyclopedia of Food and Health*, Caballero, B., Finglas, P.M. and Toldrá F., eds., vol. 4, pp. 419-431. Oxford: Academic Press.

(ii) Popular non-scientific publications and abstracts including those presented at conferences

Keenan, D.F., Kerry, J.P. and Allen, P. (2016). Effect of hot boning, electrical stimulation and pi-vac post mortem interventions on the physico-chemical characteristics and eating quality of pork *M. Longissimus thoracis et lumborum* muscles from Pietrain and Duroc pig breeds. Poster presented at the 62nd *International Congress of Meat Science and*

Technology (ICoMST): Meat for Global Sustainability, Bangkok, Thailand, August 14 – 19, 2016.

(iii) National Report

N/A

(iv) Workshops/seminars at which results were presented

Novel Technologies Gateways - November 23rd 2016: Conversations with industry regarding PiVac and other interventions.

Meat Gateways - August 16th 2017: Phosphate replacement was discussed.

Science Week - November 18th 2017: The role of phosphate in pork products and the challenges in their replacement was discussed through a processed meat demonstration.

Waterford Institute of Technology – November 9th 2017: 'The role of techno-functional ingredients in processed meat' was presented with emphasis on project outcomes specifically the difficulty in replacing phosphates in pork products.

(v) Intellectual Property applications/licences/patents

N/A

(vi) Other

N/A

5. Scientists trained by Project

Total Number of PhD theses: __0__

Total Number of Masters theses (minor dissertations): __2__

Heaphy, E. (2015). Optimisation of modified atmosphere packaging to enhance fresh pork quality. Minor dissertation submitted (August 2015) in fulfilment of the requirements of the taught MSc programme in Food Science in University College Cork.

Corcoran, S. (2016). Influence of varying the gas headspace to meat ratio in modified atmosphere packaging on the quality and sensory properties of pork. Minor dissertation submitted (August 2016) in fulfilment of the requirements of the taught MSc programme in Food Science in University College Cork.

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
Teagasc	2	1.56
UCC	1	0.78
Total	**3**	**2.34**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	2	4.87
Total	**2**	**4.87**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
N/A	

9. Project Expenditure

Total expenditure of the project:	€409,816.37
Total Award by DAFM:	€444,908.00
Other sources of funding including benefit in kind and/or cash contribution(specify):	€0

Breakdown of Total Expenditure

Category	Teagasc, Ashtown	UCC	Total
Contract staff	83,337.58	181,768.00	190,105.58
Temporary staff	-	-	-
Post doctorates	-	-	-
Post graduates	-	-	-
Consumables	16,844.72	27,882.69	44,727.41
Travel and subsistence	1,898.37	1,594.30	3,492.67
Sub total	102,080.67	211,244.99	313,325.66
Durable equipment	-	-	-
Other	1,372.53	2,410.80	3,783.33
Overheads	30,624.20	62,083.18	92,707.38
Total	**134,077.40**	**275,738.97**	**409,816.37**

10. Leveraging

N/A

11. Future Strategies

According to Food Wise 2025, global meat consumption is projected to increase by 1.6% p.a. through the next decade. "Global forecasts for increased demand for protein, in particular protein from meat, and increased economic prosperity in many emerging markets present opportunities for increased exports of high quality, safe and sustainable Irish meats to international markets". Both fresh and processed Irish pork products are a source of high-quality protein. The nutritional quality, palatability and versatility of pork meat render it suitable to meet this demand. "Research and targeted promotional work being carried out by a wide range of stakeholders, together with the acknowledgement of the quality, sustainability and competitiveness of Irish pig meat will help to position the pig meat sector in the future" (Food Wise, 2025).
Experimental protocols employed and technologies utilised have enhanced the research capacity and expertise of UCC and Teagasc in the area of pork-based muscle foods research. The data generated in this project will be used to inform future research and studies focussed on improving the eating quality of Irish pork. Additional research on the use of novel ingredients and/or phosphate replacers in pork products is required which may form the basis research project proposals submitted to DAFM in the future.