Pig Welfare and Pork Provenance

This Food Agility CRC project developed a cost effective solution to better manage pig health and welfare, and accurately trace product through the supply chain.

By Dr Megan Trezona, Dr Michael Garrett, Elizabeth Jackson, Dr Karen Moore, Dr Rodrigo Pires, Lily Tao, and Grant Gilmour

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PROJECT DESCRIPTION

Project aim: To develop a cost effective Xiot Health Tag which can be widely adopted by large scale commercial piggeries to better manage pig health and welfare, and by pork processors to accurately trace product and provide information on provenance through the pig supply chain.

PROJECT PARTNERS

Partner	Description
Curtin University	Curtin is an innovative, global university known for its high-impact research, strong industry partnerships and commitment to preparing you for jobs of the future.
Xsights Digital	Technology Partner - The Xsights Mission is 'To empower decision making through affordable data collection and insight reporting". Since incorporation, Xsights has developed scalable 'plug and play' solutions that collect valuable real-time location data on assets using Internet of Things (IoT) devices, offered as a SaaS ('Sensing as a Service') subscription. Xsights is committed to raising awareness for our award winning Xsights IoT Tag (Xiot Health Tag), for the global agricultural industry, as a scalable solution for Provenance & Traceability of Agrifood, and Health & Wellbeing Monitoring of Livestock. Xsights is also committed to ensuring we continue to establish new partnerships and collaborations, expand our customer base, and secure new funding opportunities to build new markets within the Agri-tech community for the Xiot Health Tag solution.
Craig Mostyn Group	Industry Partner - Craig Mostyn Group (CMG) is one of Australia's oldest, largest, and most trusted family-owned food and agricultural businesses. With a history tracing back to 1923, Craig Mostyn Group has established itself as the trusted source,

	consistently delivering high quality produce to local and international markets. We produce fresh pork, beef, lamb, abalone, protein meal and tallow for our food service, retail and wholesale customers domestically and abroad. The CMG vision is to be the trusted source of food for families in Australia and around the world.
WA Department of Primary Industries and Regional Development Department of **Primary Industries and Regional Development** GOVERNMENT OF WESTERN AUSTRALIA	The Department of Primary Industries and Regional Development (DPIRD) is the Western Australian government agency responsible for supporting primary industries and regional economies. DPIRD's mandate brings together agriculture, food, fisheries, and regional development under a single framework to ensure coordinated policy, regulation, and research. DPIRD's mission is to grow, protect, innovate. Grow covers the efforts to expand and diversify agriculture, aquaculture, and food industries, alongside broader regional economic development. Protect covers DPIRD's statutory responsibilities to biosecurity, pest and disease control, natural resource stewardship, and fisheries management, ensuring that industry growth does not compromise environmental or community resilience. Innovate reflects DPIRD's role in applied science and technology, using research facilities and field stations to develop and extend new knowledge across crops, livestock, aquaculture, and climate adaptation.
Pork Innovation WA PIWA Pork Innovation WA	Pork Innovation WA Inc (PIWA) is a not-for-profit research and development provider led by the WA pork industry. PIWA aims to promote the research, development and extension of science to improve the efficiency, productivity and sustainability of the

	WA pork industry. It does this through bringing together stakeholders to conduct research projects and disseminate research outcomes and promote the uptake of new technologies.
Beanstalk AgTech BEANSTALK	Beanstalk is a leading ventures and advisory firm dedicated to driving profitable and sustainable agrifood systems. Bold founders and innovative agribusinesses turn to us for insights, capital and connections. In an uncertain world, we work together to harness technology and meet the challenges of the future. From the field to boardroom, concept to scale, Beanstalk delivers impact to power resilience in agriculture.
Food Agility CRC foodagility	Innovation Partner - Food Agility makes innovation easier. We broker, design and deliver innovation programs for the Australian agrifood industry, ensuring maximum impact for investment. We specialise in using data and digital technology to increase profits and improve sustainability. We have a strong track record, with a $400m+ portfolio that includes discrete, agile research projects through to major initiatives of national and global significance. Our team, board and network of 117 project partners span the agrifood, technology, research and government sectors.

EXECUTIVE SUMMARY

This report provides a comprehensive overview of the **3Ps: Pig welfare, production decision support and pork provenance in supply chains** project (Project No. FA119), a three-year, multidisciplinary research initiative. The project's core objective was to use advanced digital technology to address critical challenges facing the Australian pork industry, including economic losses from pig mortalities and the need for enhanced traceability and verifiable provenance throughout the supply chain.

This work is of paramount importance as it provides a scalable solution for an industry that must differentiate its high-quality products from cheaper imports by demonstrating a commitment to animal welfare and sustainable practices. The research delivers a technological framework that not only improves on-farm productivity but also creates a data-driven narrative that can be communicated to consumers, building trust and potentially commanding a market premium. The technology partner, Xsights Digital, leveraged the project as a real-world laboratory to iteratively refine its Xiot Health Tag and associated data platform. The research and its resulting technology stand to benefit a wide array of stakeholders.

The value model identified that:

- **Pork producers and the pork industry** could gain significant economic value, with projections indicating a potential value of up to $9.3m p.a. for the industry partner through improved sow management and reduced post-wean mortality.
- **Pork processors and food exporters** could benefit from a system that provides accurate, end-to-end traceability from the farm to the abattoir, offering a potential market advantage.
- **Consumers** could benefit from enhanced transparency, enabling them to make more informed purchasing decisions based on verifiable data regarding food safety and ethical practices.
- **Policymakers and regulators** could benefit from objective, continuous data that can be used to inform animal welfare standards.

Key results from the project include the development of a robust Xiot Health Tag with a ~1% failure rate for grower pigs, the successful validation of a scalable data pipeline, and the establishment of a "human-in-the-loop" machine learning framework. The research also provided profound consumer insights, revealing that while consumers value animal welfare, their purchasing behaviour is most strongly influenced by direct human benefits like food safety and environmental sustainability cues.

Methodology and Key Results

The project's methodology was characterised by a phased, iterative approach across four distinct workstreams, each contributing to the development of a comprehensive and commercially viable solution.

On-farm Data Collection and Technological Innovation

The project developed low-cost Xiot Health Tags to measure surface ear temperature and activity in a commercial setting. The design of the grower tag (Xiot-G) was iteratively refined to be robust and durable, achieving a low failure rate of approximately 1%. In contrast, the gilt/sow tag (Xiot-S) faced higher rates of damage from the animals, necessitating further improvements for future deployments.

A key outcome was the successful demonstration of post-farm gate traceability. By strategically deploying gateway hardware at the farm and the abattoir, the project proved that it was technically viable to track the identity of every tagged pig from the farm to the next stage of the supply chain without the need for manual inputs.

Scalable and Reliable Data Pipeline

The project focused on developing a data architecture capable of handling the immense volume of data from thousands of pigs. The system evolved from an initial, less scalable setup to a highly robust and reliable architecture for large-scale trials. For the full-batch trials, Edge Computers were deployed on-farm to aggregate and preprocess data before uploading it to a fully-managed, elastic data warehouse in the Cloud. The system handled nearly 14 million rows of temperature and activity data from a single 18-week trial with no outages, demonstrating its commercial readiness.

The "Human-in-the-Loop" Machine Learning Model

This workstream transformed raw data into actionable insights for farm management. The approach involved developing both a statistical method and a machine learning model, with the most significant aspect being the implementation of a "human-in-the-loop" (HITL) approach. A dedicated mobile application surfaced a daily task list of pigs predicted to have health issues based on the tag data. Farm personnel would then use the Xsights Livestock Management (XLM) app to locate the pig, evaluate its condition, and provide a response, generating training labels for the machine learning model. The statistical model demonstrated a high true positive rate, with approximately 79% of the pigs flagged for review being confirmed as having observable symptoms of illness by farm staff. The machine learning model showed reduced accuracy (67.6%) when compared to the statistical method but demonstrated high recall (0.89) and F1-score (0.74), indicating reliable performance in imbalanced datasets. The model performed well at identifying sick and injured animals, finding almost 9 out of 10 cases. However, its predictions come with trade-offs: about two-thirds of the alerts are correct, and it still raises some false alarms. The balance between catching every sick/injured case and avoiding unnecessary alerts depends on how the model threshold is optimised and operational needs of the farm.

Commercialisation and Value Creation
A three-phase commercial analysis identified where the Xiot Health Tag could add the most value within the supply chain. The analysis provided a strategic prioritisation of opportunities, revealing that while a reduction in post-wean mortality represented the largest single economic opportunity, improved sow management was the highest-impact short-term opportunity due to its lower implementation complexity. The potential value from full implementation was estimated to be between $2.8m and $9.3m p.a. for the industry partner, providing a compelling business case for adoption.

Consumer Insights and Recommendations
A critical component of the project was the consumer research, which provided a nuanced understanding of how to effectively communicate the value of digitally monitored animal welfare (DMAW) to the end consumer. The research revealed a significant disconnect between what consumers say they value and what actually drives their purchase decisions. While consumers express strong ethical beliefs and prioritise attributes like humane processing and stress-free environments, a behavioural experiment revealed that their actual choices were most strongly influenced by direct, human-focused benefits such as food safety and health assurance. The research also found that sustainability is a decisive factor, as the absence of environmental information from a product dropped the likelihood of a consumer choosing it by approximately 28%.

Based on these findings, the report offers clear, actionable recommendations for producers and marketers to effectively commercialise the technology. Marketing strategies should go beyond purely ethical claims about animal welfare and should balance these with direct human benefits. Producers should leverage the technology itself as a signal of transparency and integrate environmental information to maximise appeal and purchase intent.

Conclusions and Forward-Looking Recommendations
The 3Ps project has successfully demonstrated the viability and significant potential of a digitally monitored animal welfare system for the Australian pork industry. The research has not only delivered a robust and reliable technology but has also provided a strategic roadmap for its commercial adoption.

Summary of Key Findings

- The Xiot Grower Health Tag is a durable and effective tool for continuous, large-scale pig monitoring in a commercial farming environment.
- The project's data pipeline is scalable and reliable, capable of ingesting and processing millions of data points to support advanced analytics.
- The "human-in-the-loop" machine learning model is a viable and highly effective approach for on-farm decision support, leveraging the expertise of farm personnel to achieve a high rate of accuracy in identifying compromised pigs and providing valuable labelled data for model training and evaluation.
- The technology creates a compelling economic value proposition for producers.
- Consumer research revealed that while ethical motivations are central, purchasing decisions are primarily driven by personal benefits, credibility, and sustainability cues. This highlights the need for a nuanced marketing strategy that connects animal welfare to tangible human and environmental benefits.

Recommendations for Future Development and Commercialisation

- **Phased Deployment:** New deployments should be structured in a phased manner - familiarisation, validation, and data enrichment - to ensure the consistent collection of high-quality training labels from farm personnel.
- **Continued Hardware Refinement:** Further research and development is recommended for the gilt/sow tags to improve their durability and functionality, which is crucial for unlocking the high-value sow management opportunities identified in the research.
- **Market-Facing Commercialisation Strategy:** The project partners should develop a clear go-to-market strategy that leverages the consumer insights by framing animal welfare within a broader narrative of food safety, health, and environmental stewardship, communicated through credible and transparent technology signals.

INDUSTRY IMPACT METRICS

The Industry Impact Metrics selected for the research project are as follows:

Impact metric	Goal	Result
Key result 1: Tag & pig health data are highly correlated	> 75%	The statistical model achieved ~ 79% accuracy based on pigs predicted to be compromised being verified as sick or injured by personnel on-farm (Pilot wean trial 3).
Key result 2: Number of tag features that are highly correlated	2 or more	Activity Index & Temperature, Activity Index & Accelerometer. Model features used for statistical and machine learning methods for identifying compromised pigs were consistent.
Key result 3: Predictive accuracy of tag alerts: compromised pigs	> 90%	Potentially achievable using machine learning methods assuming the presence of regular and reliable observational records as inputs (training labels).
Key result 4: % of compromised pigs identified via tag alerts saved by CMG	> 50% pa	Requires further tag deployments to be conducted with full engagement by farm personnel to accurately quantify.
Key result 5: Total opportunity value enabled by tags for CMG	$4m pa	$2.5m - $9.4m p.a. for all opportunities. $1m - $3.4m p.a. for post-wean and sow opportunities
Key result 6: Understanding of pork characteristics relevant to end users	List of characteristics	Advanced welfare cues, intrinsic product safety/quality, extrinsic cues - price/ package, features tied to human benefits.

IMPACT STATEMENTS

INDUSTRY PARTNER

Name: Dr Megan Trezona
Job title: Biosecurity, Animal Welfare & Research Manager
Organisation: Craig Mostyn Group Pty Ltd

The **FA119 3Ps: Pig Welfare, Production Decision Support and Pork Provenance in Supply Chains** project has generated valuable insights into indicators of pig health and demonstrated the value of accurate data capture. It has also highlighted the workflow changes required on-farm to ensure records are collected reliably and efficiently.

Through the research collaboration, innovative ear tag technology, associated infrastructure and digital tools were developed and tested to monitor individual animal health and provide an early warning system for compromised pigs. The digital tools, including the Xsights Livestock Management (XLM) app and computer dashboards, were helpful in supporting management decision-making. Together, these technologies enable real-time health monitoring while also providing precise location and traceability information, key for production, welfare, and compliance outcomes.

Several notable achievements in the development of the tag and its technology included the addition of a light to enable easy identification of potentially compromised pigs and an RFID chip which enabled accurate medication logs to be collected in real time. While initial use has slowed daily health checks and treatment, the long-term benefits of accuracy, compliance, and data integration provide a strong platform for further refinement.

Beyond individual animal care, the project demonstrated opportunities to expand data insights to herd-level management. For sow herds in particular, the desktop findings suggest potential benefits for health, welfare, and reproductive performance, while also pointing to possible pathways for improved return on investment and advancement in precision livestock farming.

TECHNOLOGY PARTNER

Name: Dr Michael Garrett
Job title: Solutions Architect
Organisation: Xsights Digital Pty Ltd

The work completed during this project has significantly advanced our understanding of the key technological considerations in using electronic ear tags (XioT Health Tags) in commercial piggeries to enhance health and wellbeing outcomes and support traceability of every pig at scale. Being able to uniquely identify each pig and monitor its current status, developmental history, and key events on a continual basis provides a range of benefits with the potential to meaningfully enhance industry outcomes.

Developing and evaluating the technology *in situ* with large numbers of pigs on a real commercial pig farm has been pivotal in this regard. Spreading deployments out over the duration of the project, including multiple preliminary pilots, has enabled the design of the Xiot Health Tag, associated infrastructure deployed on-farm, and data processes to be iteratively refined over time as new knowledge and understanding has been acquired.

The project identified a series of impactful objectives which necessitated new solutions to be developed that had not previously been used in industry settings. These solutions were developed using a multidisciplinary approach, incorporating industry, research, and technological perspectives in the implementation and validation of the technology. This included input from operatives working on the farm themselves, which was pivotal in understanding how the technology could be aligned with existing operational practices to enhance outcomes.

RESEARCH PARTNER

Name: Dr Elizabeth Jackson and Dr Heerah Jose
Position: Associate Professor of Supply Chain Management & Logistics and Research student, respectively
University: Curtin University

The Australian pork industry is a leader in innovation when it comes to evidence-based decision making, leadership in science, adoption of technology and constantly improving animal welfare throughout its production systems. It operates in a fiercely competitive environment with disparate consumer attitudes continually demonstrating competing objectives in demanding high-quality, high-welfare products at low prices. As such, consumer-centric products are essential for Australian pork producers to remain competitive when cheaper, lower-quality products are readily available from nearby overseas countries.

Innovation focused on animal welfare will continue to thrive in the Australian pork industry because keeping pigs in good conditions is a priority of the entire supply chain. This project exemplifies this ethos through the collaborative efforts of all the research partners. The project objective around harnessing digital innovations to improve on-farm pig husbandry has been extended to consider mid-chain operational and logistics needs and also consumer perceptions of on-farm digital systems that support animal welfare. Overall, this project has been an authentic supply chain collaboration with animal welfare at its heart.

It has been a privilege for Curtin University to collaborate with this team to make a significant difference to how pig welfare systems are developed by the integration of farming systems practice into low-cost, high-value digital technology.

INNOVATION PARTNER

Name: Dr Mick Schaefer
Position: CEO
Organisation: Food Agility CRC

The 3Ps Project has been a great example of how collaboration across multiple organisations can drive impactful research and innovation.

Over the past three years, this project has delivered practical, data-driven solutions that improve not only the welfare of individual animals, but also the overall productivity and sustainability of the pork industry.

By leveraging novel digital technologies and combining these with research insights, the 3Ps Project has enabled commercial producers to monitor and manage animal health more effectively, reduce stress factors, and create environments that support better outcomes for pigs.

This initiative demonstrates the power of collaboration between industry, researchers, and technology partners. Together, the project has driven sustainability and ethical practices, reinforcing the pork industry's commitment to high welfare standards and environmental stewardship. For Food Agility CRC, this project exemplifies our mission in delivering real-world impact through innovation that benefits animals, producers, and consumers alike.

END-USER PROFILE

STOCKPERSON, CRAIG MOSTYN GROUP:

What does your daily role look like?
As a stockperson in a commercial piggery, the daily routine involves monitoring, treating, and managing the welfare of thousands of pigs. The job demands speed, accuracy, and compassion, often under tight time constraints.

What is the problem that needs to be addressed?
Managing large groups (e.g. 200-1000 head) of pigs can make it difficult to identify early signs of compromised pigs. Current methods rely on physical observations of signs of illness, injury and changes in behaviour. Identification of pigs which require a course of medication is by spray marking which can potentially lead to missed treatments.

How do you see technology like the Xiot Health Tag and Xsights Livestock Management (XLM) app addressing the problem?
Critical to maintaining and demonstrating good health and welfare outcomes in commercial piggeries is early detection and management. The ability to be directed toward animals that

need extra attention, and potential intervention, could help with improving work efficiencies. With additional refinement the technology developed in the project could help us in this endeavour.

What other advantages do you see the technology bringing to your business?
Pigs in large groups can be difficult to count with accuracy. This technology provides the ability to know the current location and stock inventory in real time.

What have you learnt from being involved in this project?

i) **Workflow Impact:** While some tasks may take longer initially, the XLM app creates efficiencies elsewhere, especially in decision-making and follow-up.
ii) **Real-World Testing:** Trialling the technology in commercial settings has been essential to uncover limitations and refine usability.
iii) **ROI Considerations:** The project has shown that returns vary between sow herds and grower herds, guiding future investment decisions.
iv) **Patience is Key:** Innovation takes time. Results may not align with initial expectations, but long-term gains in welfare and productivity are clear. While initial use has slowed daily health checks and treatment, the long-term benefits of accuracy, compliance, and data integration provide a strong platform for further refinement.

OBJECTIVES

Objective 1: Identify data measured by the XioT Health Tags that accurately reflect the health status of pigs.

Objective 2: Utilise machine learning to predict the welfare and health of animals.

Objective 3: Evaluate and evolve provenance systems that allow pork supply chain customers to observe pork characteristics (e.g. welfare).

METHODOLOGY

Workstream 1 – On-farm data collection

Workstream 1 Lead: Dr Megan Trezona (Craig Mostyn Group)

Workstream 1 Objectives:

- Identify relationships between data measured by the Xiot Health Tag against standard measures used to assess pig health/welfare and environmental conditions (3 batches x 1,000 progeny pigs and 120 pregnant gilts).

- Undertake broad scale pilot testing of the Xiot Health Tag and customised user interface to determine:
    - If predictions of health and welfare are accurate.
    - Whether detection of variation and associated alerts can assist with day to day pig management (3 batches x 1,000 progeny pigs).

Workstream 1 Methodology:

- Xiot Health Tags are low cost, electronic ear tags developed to collect measurements from pigs to assess their health and welfare. Temperature (as measured on the surface of the ear) and activity measures are provided for each pig with a Xiot Health Tag at regular intervals and broadcast via Bluetooth Low Energy (BLE). Xiot Health Tags also include an RFID chip to accommodate individual identification and the ready collection of data.

- Commercial-Off-The-Shelf (COTS) hardware, including data receivers (gateways), networking infrastructure, and Edge Computing devices were deployed to collect data that was broadcast via the Xiot Health Tags. The collected data was then uploaded to Cloud computing systems for further processing with the intention of identifying those tagged pigs with health or welfare problems which could be subsequently validated by personnel on the farm via a dedicated software application running on a mobile device.
    - Temporary hardware deployments at an abattoir were used to capture and evaluate data from pigs with Xiot Health Tags after they left the trial farm site.

- A series of deployments on a commercial pig farm (Craig Mostyn Group) located in the Wheatbelt region of Western Australia were used to evaluate the hypothesis. For each deployment, a small group of focus pigs was used to collect manual measurements of health and welfare, including weight, body condition, and recording of any symptoms of disease or injury. This was supplemented by standard farm records which identified mortality events and the number of pigs moved to the sick pen throughout each tag deployment. Tag deployments for grower pigs were focused on the Nursery phase, which lasted from four to ten weeks of age (with pigs tagged after weaning at four weeks of age):
    - **4 x Preliminary pilots** - used to evaluate (i) the performance of initial versions of the Xiot Health Tag deployed on small numbers of pigs (n = 20), and (ii) infrastructure deployed on the farm for the purposes of collecting data from the Xiot Health Tag.
    - **3 x Batch trials** - used to evaluate later iterations of the Xiot Health Tag design and infrastructure deployed on the farm for data collection, where each Batch trial featured a full batch of grower pigs (n = ~ 1000 pigs) tagged concurrently.
    - **3 x Pilot weaner trials** - used to evaluate further refinements to the Xiot Health Tag and farm infrastructure design for full grower batches (each batch comprising approximately 1000 pigs) during the Nursery phase.
        - Extending on the Batch trials, the first two Pilot weaner trials focused on collecting measures of tagged pig health and welfare captured by trained personnel on-farm.
        - The third (and final) Pilot weaner trial was used as a 'soft launch' to evaluate the use of the mobile application to manage a full batch of tagged pigs in a way that approximated day-to-day operations on the farm. In addition to recording observations of pig health and welfare, farm personnel also evaluated pigs that were predicted to have health/welfare issues based on analysis of data provided by their Xiot Health Tags.
        - These activities were accommodated via a dedicated software application running on a mobile device that personnel carried with them when engaging with the pigs.

- **Gilt trials** - 119 gilts were tagged with Xiot-S Health Tags (gilt/sow tags) that included an accelerometer and larger battery. The intention was initially to determine if there were relationships between data collected from the tag and the health and reproductive outcomes during the gestation period. However, during the project it was evident that the focus needed to evolve into developing the Xiot-S design *in situ* and demonstrating that data could be collected from gilts during the production cycle.

Workstream 2 – Data storage and processing for analytics

Workstream 2 Lead: Dr Michael Garrett (Xsights)

Workstream 2 Objectives:

- Build an on-boarding process for the pig health and welfare data collected through CMG's supply chain (i.e. Workstream 1 data).
- Build a data storage solution that can scale and accommodate desired applications of data for pig production planning and husbandry responsiveness to optimal pig health and welfare.
- Refine and scale the solution to CMG production and supply chain requirements.

Workstream 2 Methodology:

- COTS hardware deployed in the rooms used for tag deployments at the farm site, together with Cloud computing infrastructure, was used to store and process Xiot data from tagged pigs for the purposes of surfacing actionable insights into health and welfare.
- For the Preliminary pilots (with small numbers of tagged pigs), Xiot Health Tag data collected by the receivers deployed on the farm (gateways) was uploaded directly to a Cloud endpoint via a cellular modem. However, for the Batch, Pilot wean, and Gilt trials (which featured much larger numbers of tagged pigs), Edge Computers were deployed on the farm to aggregate Xiot Health Tag data from the gateways and upload this to a fully-managed, elastic data warehouse in the Cloud for permanent storage and further processing.
- Temporary hardware deployments at the abattoir were used to verify the presence of pigs tagged for the third Pilot wean trial as they were unloaded from the transport truck and moved into lairage. This was cross-referenced against records of tagged pigs generated as pigs left the farm Loading Shed.
- A detailed feasibility assessment was conducted with regards to deploying gateway and networking hardware onto transport trucks to monitor tagged pigs as they were

moved to the farm to the abattoir. This assessment indicated it was infeasible due to inherent technical challenges and limitations which would require considerable amounts of equipment to be deployed onto the trucks to operate effectively.

Workstream 3 – Machine learning analysis and reporting

Workstream 3 Lead: Dr Michael Garrett (Xsights)

Workstream 3 Objectives:

- Further develop the on-boarding process for the pig health and welfare data collected through CMG's supply chain (i.e. Workstream 1 data) for machine learning analysis and reporting.

- Establish the foundation for data-driven predictions using machine learning models and reporting for end-users in a way that is impactful and adds value to CMG's supply chain:
    - Determine correlations between automatically recorded data and physical observations to develop a pattern for healthy pigs on an individual and herd basis (identify which of the parameters measured by the Xiot Health Tags most accurately predict the current health status of the pig).
    - Apply machine learning algorithms to predict welfare and health of pigs, and detect and alert for variations in activity, feeding and health (determine the rules that are to be associated with the measures, that is what constitutes a normal health status vs what indicates a change (decline) in health and welfare status).

- Establish a framework for ongoing training and refining of models and deploying these into production environments in accordance with selection criteria:
    - Develop a user interface/mobile platform which initiates alerts and automated actions based on real-time data.

Workstream 3 Methodology:

- The data pipeline incorporated a fully-managed, elastic data warehouse (Cloud-based) for the purposes of permanently storing Xiot Health Tag measures. This platform also provides comprehensive processing and analysis capabilities which enable data models and algorithms to be developed using the same platform that stores the data. This is of particular importance given the quantity of Xiot Health Tag data being collected.

- Two methods were developed for assessing pig health/welfare from Xiot Health Tag measures (ear surface temperature and activity) with the objective of identifying pigs that were most likely to require attention or intervention by farm personnel:
    - Statistical method - identifies sick/injured pigs based on sustained statistical deviations in their temperature or activity data. This was the baseline method and was focused on maximising the true positive rate to provide farm personnel with confidence in the system to support adoption.
    - Machine learning method - relies on farm personnel to 'label' pigs that are sick/injured, where these labels support the training of a model which can identify previously unseen instances of sick pigs/injured.
        - Experimental algorithm trained exclusively from previous 3Ps Pilot wean batches. It employs a more expansive approach compared to the statistical method to enable a greater number of training labels to be collected (via observational responses from 3Ps team on-farm) to support continuous improvement moving forward.

- For the three Pilot wean trials, observations were collected three times weekly for the first five weeks, then once weekly during the final week of the Nursery Phase by trained personnel:
    - A standardised disease and injury matrix was used to evaluate body condition, diarrhoea, respiratory issues, lameness, skin lesions, and tail bites on a 0–4 severity scale.
    - For the third Pilot wean trial, pigs that were predicted to be sick/injured based on their Xiot Health Tag data were surfaced for review by personnel on-farm via a dedicated mobile app. This was presented using a daily task list workflow where personnel would locate each pig (using the LED light on the Xiot Health Tag to confirm identity), evaluate the condition of the pig, and then submit a response (sick or not sick).

Workstream 4 – Downstream supply chain traceability

Workstream 4 Leads: Grant Gilmour (Beanstalk) & Elizabeth Jackson (Curtin University)

Workstream 4 Objectives:

- Identify the value proposition of traceability and welfare attributes for CMG across its supply chain.

- Assess key risks and enablers of traceability technology across people, process and existing technology.

- Convert tag trigger points into actionable steps to derive value throughout CMG's pig supply chain.

- Specify changes to existing practices required to derive direct and indirect value from the adoption of traceability technology.

Workstream 4 Methodology:

- There were three key phases to analyse how the Xiot Health Tag could improve welfare and unlock benefits for the industry. These included:
  - Phase 1: Current state analysis – mapping of CMG pork value chain.
  - Phase 2: Pain point and possibility analysis – highlighting areas along the value chain where movement and temperature tracking can add value.
  - Phase 3: Future supply chain – mapping of the possible future CMG pork supply chain with a deep dive on the risks and enablers across the people, processes and technology domains.

- Xiot Health Tags broadcast data at regular intervals (approximately every one second) via Bluetooth Low Energy (BLE) which can be received by gateways that are deployed within sufficient proximity. The collection and processing of this data enables the inventory of any room with Xiot tagged pigs to be determined autonomously and in real time. Similarly, movements of Xiot tagged pigs between any room with deployed gateways on a farm can be identified and recorded autonomously. This includes any external facilities that are part of the supply chain (such as an abattoir), providing the foundation for reliable and accurate traceability at scale with no need for manual inputs or effort from personnel.

- The initial methodology for Workstream 4 aimed to evaluate the on-farm technology in the supply chain context by tracing pigs through the abattoir and boning room via Xiot Health Tags applied on-farm. Initial observations of tag retention and opportunities for tracking individual pigs throughout the abattoir were insufficient to warrant this element proceeding. Instead, a desktop review of traceability challenges at CMG's Linley Valley Pork (LVP) abattoir was undertaken to document the processing of pigs with the specific aim of determining how far along the supply chain an individual pig could be traced and therefore carry its own unique provenance story.

- Downstream work to understand consumer perceptions of digitally monitored animal welfare was conducted by the project's research student, Heerah Jose, under the supervision of Associate Professor Elizabeth Jackson, Professor Billy Sung and Dr Patrick Duong at Curtin University. The research aimed to identify factors that influence consumers' perception of DMAW and whether any attitude difference exists while consuming pork products at-home vs. out-of-home. The research also determined whether digital intervention in animal welfare practices motivates consumers to purchase pork products and how these digital interventions can be communicated effectively. A mixed-method approach was taken to the research with two-out-of-three phases completed at the time of submitting this report. Further details of the research and its outputs are provided in subsequent sections of this report.

RESULTS

Workstream 1 – On-farm data collection

The focus of Workstream 1 was to establish a foundation for continuous collection of data from large numbers of pigs which could be used to identify those with health or wellbeing issues in a way that aligned with daily operations on a commercial pig farm.

The key results for Workstream 1 are as follows:

Xiot Health Tags

- The design of the Xiot Health Tag evolved in response to learnings from successive deployments on pigs at the trial farm. Two versions of the Xiot Health Tag were developed - a tag for grower pigs (Xiot-G) followed by a tag for gilts/sows (Xiot-S).
    - The Xiot-G tag form factor, housing, and material composition went through successive iterations to account for environmental challenges, improve durability, and reduce deployment time. Preliminary issues with tag firmware and batteries were overcome, and later versions featured further weight reductions and refinements to the housing design such that only a single male barb was required to attach the tag to the ear (a compatible sleeve for receiving the barb was built into the Xiot-G tag).
        - The final Xiot-G tag design version used for the 3 x Pilot wean trials featured a recorded average failure rate of ~ 1% (damage from pigs including tag detachments, isolated instances of hardware failure).
    - The Xiot-S tag form factor, housing, and material composition went through successive iterations in response to the additional stressors imposed by sows.
        - Tagged gilts were found to damage and destroy their tags at a much higher rate compared to grower pigs with Xiot-G tags.
        - With considerably lower numbers of Xiot-S tags deployed compared to Xiot-G tags, there were fewer opportunities to iterate on the design.
        - Of the last batch of Xiot-S tags deployed on gilts at the test farm, ~15% remain functional (subsequent improvements to the form factor and material design for deployments outside of this project have seen a tag functionality rate in excess of 85%).

- A calibration process was developed for the Xiot Health Tag temperature sensor to account for individual differences and reduce measurement errors. This was applied to all temperature measures collected during the three Pilot wean trials.

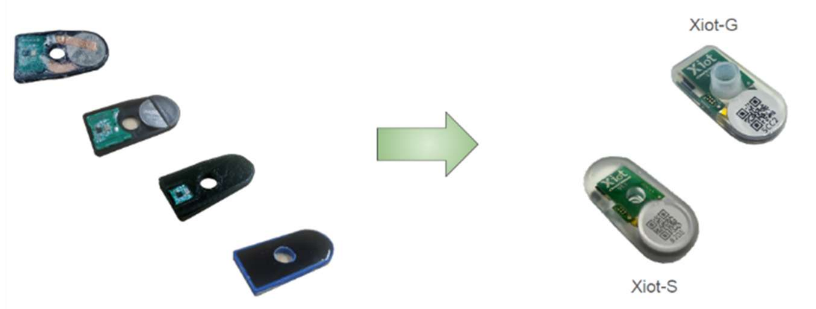

Figure 1: Evolution of the Xiot-G and Xiot-S tags.

Hardware for data collection and processing

- The hardware infrastructure deployed at the farm for the purposes of collecting data also evolved over time to enhance reliability, cost-effectiveness, and scalability across successive Xiot Health Tag deployments.
    - The quantity of gateway hardware that was required to be deployed was reduced over time as a better understanding of their capabilities within a commercial pig farm developed.
    - Experiments with a second type of gateway which provided Xiot Health Tag localisation capabilities (angle of arrival method) demonstrated insufficient accuracy for the purposes of evaluating feed intake.
    - Gateway hardware needs to be sufficiently resilient to survive cleaning with high pressure water hoses.
    - Edge Computers provided an efficient and cost effective solution for initial collection and processing of Xiot Health Tag data, as well as a basis for configuring and monitoring equipment remotely.
    - Starlink was used to connect each Edge Computer deployed on Farm to the Internet. This provided sufficient bandwidth and reliability for regular data uploads and remote monitoring and management.
    - Environmental conditions were monitored throughout each Xiot Health Tag deployment trial through the use of low-cost sensors which provided continual measures of ambient temperature and humidity.

Figure 2: Hardware infrastructure deployed at the farm.

Post farm gate monitoring of Xiot tagged pigs (Farm => Abattoir)

- Experiments with gateway and networking hardware deployed temporarily at the abattoir demonstrated the viability of tracking Xiot tagged pigs from the farm to other locations.
    - Data provided by gateways deployed in the farm Loading Shed was cross-referenced against data records captured at the abattoir. The number and identities of the Xiot tagged pigs leaving the farm matched those arriving at the abattoir (tested on two separate occasions with pigs from the third Pilot wean trial).

- The metal structure of the livestock trailer constrains the ability to capture information broadcast by the Xiot Health Tags therefore monitoring tagged pigs in transit is not likely to be technically or commercially viable. This is of questionable value given that the gateways deployed at the Loading Shed in conjunction with temporary hardware deployed at the Abattoir provided a reliable means for comparing departing and arriving pigs during testing.

Mobile app for data capture and management of pigs

- A dedicated mobile (Xsights Livestock Management, XLM) app was developed to enable personnel on the farm to capture observations and interactions with pigs. Individual pigs were identified via the LED light functionality of the Xiot Health Tag, where the XLM app would scan for and establish connections with tags for this purpose. Data records for specific pigs could also be retrieved and added by scanning the unique QR code or RFID chip on each Xiot Health Tag, with the RFID scanning being the most practical in real world conditions.
  - The XLM app underwent multiple revisions to address performance challenges when scanning and connecting to tags that arise when large numbers of BLE-enabled devices (Xiot Health Tag) are in close proximity. Metal surfaces present in the environment and the pigs themselves also impacted the strength of signals broadcast by the Xiot Health Tags.
    - These were mitigated through improvements to the method used by the XLM app to scan and connect to Xiot Health Tags together with the adoption of a daily task list-based workflow. This workflow used a ‘Management list’ to display the pigs that were predicted to be sick/injured, where users would then work through this list methodically. The intent was to align the workflow with practices that could feasibly be undertaken by personnel working on a farm (number of pigs on the Management list was capped at 30 each day and ranked in order of severity).

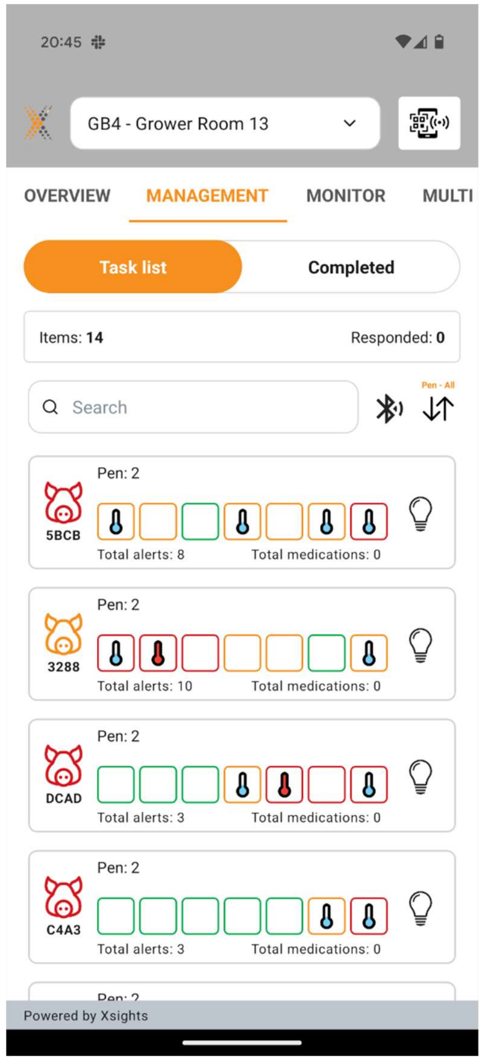

Figure 3: XLM mobile app for data capture and management of pigs.

Standard measures of pig health/welfare

- The focus of the Batch trials was on validating the Xiot Health Tag design, hardware infrastructure deployed on-farm, and pipeline for continuous ingestion and storage of data. Observations of pig health and welfare were collected during these trials as a reference point whilst the Xiot Health Tag design and mobile application were still under development.

- For the Pilot wean trials, the focus shifted to the regular collection of observational data to provide a continuous record of those pigs with health or welfare issues. The first two Pilot weaner trials were focused on observational data collection exclusively to provide a basis for developing methods for identifying sick/injured pigs (statistical and machine learning method). The third introduced a validation component with respect to predictions surfaced from the Xiot Health Tag data.

- For Pilot weaner trial 3, the statistical method identified pigs that were suspected to have health or welfare issues and added these to a list (Management list) on the XLM app for review by personnel on-farm. **Approximately 79%** of the pigs that were added to the Management list were confirmed to have observable symptoms of illness by personnel on-farm. Considerable uplift was achieved midway through the trial when the activity metric was incorporated into the statistical model.
  - These predictions were based on a statistical algorithm that looked for sustained deviations in temperature and activity data provided by each Xiot Health Tag over time, with an emphasis on rolling statistical features (mean, standard deviation, and variation).
- Note that the statistical method was calibrated to maximise the proportion of pigs on the Management list that would be confirmed to have observable symptoms of illness. It was not calibrated to maximise coverage of sick/ injured pigs within the tagged population in the room as the objective was to support adoption in accordance with a daily management context.

Workstream 2 – Data storage and processing for analytics

The focus of Workstream 2 was to develop and validate a scalable and reliable system for data ingestion which could accommodate large numbers of pigs with Xiot Health Tags within a commercial farming setting.

The key results for Workstream 2 are as follows:

- The data ingestion and processing pipeline evolved over the course of the project to accommodate greater volumes of data, improve reliability, and support the development of data insights:
  - Version 1 (Preliminary trials) - a single cellular modem provided a suitable means of uploading Xiot Health Tag data payloads from gateways to the Cloud. However, this required the installation of a dedicated antenna to provide connectivity with the nearest cellular tower. Remote monitoring capabilities were minimal.
  - Version 2 (Batch trials) - Edge Computers and more capable networking infrastructure was deployed on-farm to accommodate the increased volume of data. The Edge Computers performed preliminary processing of Xiot Health Tag data to produce metrics which also decreased data upload

volume. Deployed hardware could be monitored manually via remote connection.
    - Version 3 (Pilot wean trials and Gilt trials) - Fully-managed, elastic data warehouse in the Cloud added as endpoint for permanent storage and further processing.

- Version 3 of the data ingestion and processing pipeline proved to be a highly robust and reliable solution for ingesting and storing large volumes of Xiot Health Tag data metrics (no outages).
    - As an example, for the 3Ps pilot weaner/grower 3 trial (1050 pigs tagged), nearly **14 million rows** of temperature and activity metric data was collected across the 18 weeks the pigs were at the farm.

- Statistical and machine learning models were developed working directly with the acquired Xiot Health Tag data metrics on the same Cloud platform. These outputs were then used to populate the Management list with predicted sick/injured pigs for review by personnel on-farm throughout the third Pilot wean trial.

Workstream 3 – Machine learning analysis and reporting

The focus of Workstream 3 was to establish the necessary foundation for developing and validating machine learning models which predicted pigs with health and welfare issues based on Xiot Health Tag data.

The key results for Workstream 3 are as follows:

- Pigs with observable health and welfare issues were recorded manually by personnel on the days they were at the farm for the Pilot weaner trials using a standardised disease and injury matrix.

- For the third Pilot weaner trial, pigs with observable health and wellbeing issues were also recorded through the mobile XLM app. This included pigs that were responded to on the Management list as well as additional sick/injured pigs that weren't on the list. This observational data was stored in the Cloud data warehouse alongside the Xiot Health Tag temperature and activity metric data for ready model development.
    - This workflow provides the necessary basis for machine learning based on a human-in-the-loop approach, where the expertise and judgement of farm personnel is used to provide labels for training the models on a continuous

basis. This workflow was successfully utilised by farm personnel throughout the Nursery Phase for the third Pilot wean trial.

- For the machine learning model development, a comprehensive set of 49 temporal features was engineered from 10 minute ear tag temperature data streams, capturing rolling behaviour over 3 to 48 hours, historical lags, change signals, and trend components from Seasonal-Trend decomposition using Loess (STL) decomposition.
  - To deal with the time series nature of the data and potential leakage challenges, a strict temporal split with a single global cutoff was enforced (to eliminate leakage and to reflect the conditions of predicting on future unseen farm data).
  - Using cross validation, a diverse set of models/learners was benchmarked, from linear baselines to tree-based ensembles, focusing on precision–recall characteristics (i.e., precision shows how many of the model's positive results are actually correct, while recall shows how many of the true positives it managed to find). These measures are especially important when one outcome is much rarer than the other which is reflected as operational costs of false alarms.
  - Two machine learning models, gradient boosting (XGBoost) and bagging (Random Forest), were then fine-tuned using nested resampling and conservative search spaces designed to reduce overfitting and to improve performance (i.e., minimising the false positive rate). The best performing model (XGBoost) was selected for the production deployment.
  - Building on these results, we delivered an integrated end-to-end inference workflow that sources new data from the Cloud warehouse and produces per observation (10 minute interval) predictions.
  - These predictions were then weighted, proportionally to the total of records/day for each animal, and an aggregated daily alert was produced. The daily health alert summaries, which are suitable for deployment, were then integrated into the Xsights Livestock Management (XLM) app.

- Regarding feature importance, the deployed model (XGBoost) relies heavily on the STL decomposition trend feature. After that, the 48-hour rolling statistics (maximum, standard deviation, average, minimum, and range) were the next most influential features. These capture medium-term variation in the data and play a key role in predictions. Features calculated over 24 hours and 30 hours (like rolling min, max, and average) also contribute, but less strongly. Shorter-term windows (12h, 6h, and 3h) rank much lower, suggesting the model finds longer time horizons more useful for distinguishing patterns.

- Results from live deployment show that the XGBoost model resulted in about 67.6% accuracy on the daily alert data. The model showed high recall (89%), meaning it correctly identifies most sick/injured animals, but precision is moderate (64%), so around one-third of the "sick" alerts are false alarms. The XGBoost confusion matrix showed that the model correctly identified 697 sick, 297 healthy animals but missed 84 sick animals (false negatives) and raised 393 false alarms (healthy flagged as sick, false positives).

- This highlights the need to decide what matters more in practice: minimising missed cases to protect animal welfare, or avoiding false alarms to reduce unnecessary interventions and potentially trust in the tool. Adjusting the classification threshold can tilt this balance, but it always comes at the cost of one metric over the other.

- A framework for ongoing training and refining of machine learning models was established, utilising performance and user engagement metrics to drive which models would be utilised in production settings.

Workstream 4 – Downstream supply chain traceability

The focus of Workstream 4 was to identify the value proposition of traceability and welfare attributes for CMG across its supply chain and better understand attitudes towards digitally monitoring animal welfare.

The key results for Workstream 4 are as follows:

- **Improving Sow Management is likely the highest impact opportunity in the short term**. Sow management is the most valuable group of opportunities and the implementation most feasible. This is due to the relative smaller number of sows in the herd, longer planned lifespans and existing individual tracking capability.

- **Reducing Post-Weaning Disease Mortality is the largest, single, opportunity, but more difficult to achieve**. The biggest single opportunity that ear tag technology can effect is the reduction of post-weaning disease mortality. This is more difficult to implement than changes to sow management due to the number of animals that require tracking.

- **Underlying technology and personnel remain a key risk to realising value from the tags**. Opportunities exist across CMG's operations to implement technology driven welfare and production improvements. A logical implementation process exists where the quick wins are pursued before the higher value, but more difficult, opportunities are engaged.

- **Identified Potential benefits enabled by the Xiot Health Tag**. Several opportunities were identified that an ear tag could enable, including:
    - **Improved Sow Management**: Improve Farrowing rate, Lower Sow Replacement Rate, Increase Farrowing Frequency, Reduced still births, Reduced Crushing.
    - **Avoidable Post-Weaning Mortality**: Reduced post-weaning disease incidence, reduced vice (including tail and flank biting), reduced suboptimal feed intake.
    - **Improved Feed Use Efficiency**:
    - **Product Traceability**: Enable paddock to processor traceability and processor to plate traceability.
    - **Production planning**: Improve tracking of pigs to enable optimise production decisions.
    - **Optimised Medication & Vaccination Use**: Reduce overmedication, under-medication/vaccination and efficacy of delivered medicines/vaccines. Ability to confirm if medication withholding periods have been met.

  This work has identified between $2.7m and $9m p.a. in potential value from full implementation of the tag technology across all CMG farms. This is by-no means the actual realisable value that will be achieved by, rather it is the value at-stake that will guide investment decisions into each key opportunity area.

- The desktop review of challenges for individual-pig traceability at CMG's Linley Valley Pork abattoir, for the purpose of providing a provenance story to consumers, found that traceability back to the farm is possible, but not for an individual pig.
    - At present individual ear tags are removed at an early stage on the slaughter floor and prior to carcass grading. Provided an ear tag is not dislodged on the slaughter floor (specifically in the water bath and burner), then it could be linked to a RFID attached to the skid or gamble that is holding the carcass. This information could be transferred to the tag applied at the time of grading. A form of bar code stamp on the product would then need to be used in the boning room to track an individual pig, provided it did not interfere with throughput and product appearance.
    - The cost of developing and implementing such technology would need to be balanced against the value of knowing the origin of a product back to the property or individual animal.

- See the following section 'Higher Degree by Research Students' for interim results of Heerah Jose's PhD project titled *Consumers' Attitude Towards Digitally Monitored Animal Welfare (DMAW) in the Western Australian Pork Industry*.

HIGHER DEGREE BY RESEARCH STUDENTS

Student: Heerah Jose

Supervisors: Associate Professor Elizabeth Jackson, Professor Billy Sung and Dr Patrick Duong

Project title: Consumers' Attitude Towards Digitally Monitored Animal Welfare (DMAW) in the Western Australian Pork Industry

Project duration: 2023 - 2026

Background and introduction:

Industry challenges:

- Understanding the attitude of WA's pork consumers is essential and is an under-studied area of inquiry.
- Changes in consumption patterns among Australian consumers.
- Change in consumption context.

The solution addresses the following:

- Understanding consumer attitudes towards DMAW.
- What attributes do consumers associate with DMAW?
- How much importance do consumers give these attributes?
- What's the worth or perceived value consumers see in these attributes?
- Are consumers ready to accept DMAW products?
- What attributes would consumers like to see on DMAW product labels?

Research gap: There is no existing research to indicate what attributes consumers associate with DMAW products.

Research question: What attributes reflect DMAW for end-consumers in the context of at-home vs. out-of-home consumption?

Research objective: To investigate the attributes that various consumers consider as DMAW in the contexts of at-home vs. out-of-home consumption.

Detailed research objectives, research design and analytical techniques:

	Research Objective	**Theory/Data Collection/Analysis**
Phase I	• To investigate the attributes that various consumers consider as DMAW in the contexts of at-home vs. out-of-home consumption.	Laddering technique. 20 interviews (end consumers)
Phase II	• To identify the influence of perceived importance which the end consumers assign to attributes on perceived value. • To evaluate the effect of perceived value in formulating the consumers' attitude towards DMAW. • To identify whether there are differences in perceived value based on consumers' personal values. • To investigate whether consumers' perceived value changes with their innovativeness.	Structural Equation Modelling/ Multi-group analysis. 628 end consumers.
Phase III	• To evaluate which combination of appeal encourages consumers to have a positive attitude towards DMAW products.	Discrete Choice Modelling. 716 end consumers.

Results:

Phase I: This phase investigated consumer attitudes toward digitally monitored animal welfare practices, aiming to understand their acceptance and the values they associate with these practices. It investigated the role of digital technology in enhancing consumer decision-making by addressing animal welfare concerns. A hierarchical value chain (see Appendix Figure 1) was developed using the LadderUX software to simplify and clarify the relationships between attributes, consequences, and values. The findings indicate that consumers prioritise attributes such as animal diets, stress-free environments, humane processing practices, and health conditions, linking these to both ethical and hedonic values. Intrinsic attributes like product appearance and freshness are crucial for at-home consumption decisions, while sustainable packaging also plays a role. The study also found differences in consumer behaviour based on the consumption context, with ethical decision-making often shifting to restaurateurs when dining out.

The research underscores the importance of transparency, ethical practices and product quality in influencing consumer decisions, providing actionable insights for marketing strategies that promote ethical consumption and improve animal welfare standards.

Phase II: Building on these qualitative insights, Phase II employed Theory of Consumption Value (TCV) and the Perceived Value (PERVAL) model to examine how consumers evaluate DMAW-labelled pork products. These frameworks extend beyond narrow economic considerations by recognising multiple value dimensions: functional, emotional, epistemic, conditional, social, and price, thereby capturing the ethical, emotional, and personal significance of animal welfare innovations. A conceptual path model (see Appendix Figure 2) was developed to test how specific welfare cues (e.g., clean water provision, heart-rate monitoring, temperature regulation, humane processing) map onto the perceived value dimensions and shape consumer attitudes.

Findings show that emotional value is the strongest driver of positive attitudes, followed by functional, epistemic, and price value. In contrast, social value exerted a negative effect in the private, at-home consumption context, suggesting that welfare-related choices are less about social signalling and more about personal reassurance. These results underline the importance of marketing strategies that foreground transparency, personal benefit, and technology-enabled credibility, rather than relying on social approval cues. Moreover, segmentation opportunities arise by appealing to consumers who prioritise universalist or stimulation values, or who are more innovation-oriented. As digital traceability becomes mainstream, these insights reinforce the potential of DMAW practices to build consumer trust and accelerate the adoption of ethically aligned production systems.

Phase III: To examine how consumers make real-world trade-offs when purchasing pork products, this study employed a Discrete Choice Experiment (DCE). Unlike Phases I and II, which focused on attitudes and value perceptions, Phase III investigated how DMAW attributes and market cues influence actual choice behaviour. Respondents evaluated product profiles featuring varying combinations of welfare claims, certification logos, and sustainability information (see Appendix Figure 3).

Preliminary findings show that consumers are most responsive to human-focused benefits such as food safety and health assurance, particularly when reinforced by credible DMAW verification logos. In contrast, claims centred solely on animal benefits had limited influence unless supported by other cues, such as certification, clear product descriptions, or sustainability assurances. A critical insight is the role of sustainability: when environmental information was absent, the likelihood of consumers choosing the product dropped by around **28%**, highlighting sustainability as a decisive element in consumer decision-making.

These results underscore that while ethical motivations and emotional reassurance are central, choice behaviour is strongly moderated by credibility and personal relevance. Digital monitoring technologies enhance this credibility by signalling transparency and control, but only when communicated through logos, traceability markers, and clear consumer-facing benefits. Marketers should therefore prioritise labelling strategies that balance ethical and functional assurances to appeal to both value-driven and pragmatic segments.

CONCLUSIONS AND RECOMMENDATIONS

Workstream 1 – On-farm data collection

- The Xiot Health Tag provides a robust, durable, and reliable means for continuous monitoring of large numbers of pigs within a commercial farming setting.
    - Tag calibration of the temperature sensor is a critical step for reliable measurement.

- Suitable hardware can be deployed on commercial pig farms for the purposes of ingesting Xiot Health Tag data and uploading it to a designated endpoint for further processing and analysis.
    - Strategic deployment of hardware supports full traceability of every Xiot tagged pig, both within the farm as they move between locations and external to the farm, such as the abattoir.
    - Environmental conditions, such as the ambient temperature and humidity in a shed, can be measured by low-cost sensors and captured using the same hardware.

- Analysis of the outcomes from the third Pilot wean trial indicated that temperature and activity metrics derived from Xiot Health Tag data can be used to identify pigs with health/welfare issues for management by farm personnel.
    - The continuous nature of Xiot Health Tag data is well suited to statistical methods that leverage sustained data deviations as a basis for identifying pigs with potential issues. However, there are limitations if a particular illness or ailment does not affect surface ear temperature or activity in a way that differs from that of a normal, healthy pig.
    - A dedicated mobile XLM app and task-list based workflow provides a viable means for personnel working on a farm to locate and respond to pigs that are predicted to be sick/injured as well as capture any observations or interactions of value to the farm (e.g. medication records).
    - Further deployments with farm personnel engaged with the system on an ongoing basis will provide additional evidence from which to evaluate the relationship between Xiot Health Tag data metrics and standard measures of

pig health and welfare, as well as its impact on daily operational and management practices.

Workstream 2 – Data storage and processing for analytics

- Edge Computers and associated networking infrastructure deployed on-farm provide a viable solution for collecting large quantities of Xiot Health Tag data to efficiently monitor full batches of pigs.
    - These devices provide additional benefits in terms of managing upload bandwidth requirements through preprocessing of data, as well as remote monitoring capabilities to support large scale deployments.

- A fully-managed, Cloud-based solution for ingesting and processing Xiot Health Tag data metrics provides the necessary scalability to accommodate large numbers of tagged pigs concurrently, consistent with what would be expected on commercial farms.
    - The collection of large quantities of Xiot Health Tag data provides the necessary foundation for identifying insights into pig health and welfare.

Workstream 3 – Machine learning analysis and reporting

- Analysis of the outcomes from the third Pilot weaner trial indicated that a machine learning model could be trained from observational data to predict pigs with health or welfare issues. However, accuracy was limited by the observational records that were available for training and evaluating the model.

- Using machine learning to reliably identify pigs with health or welfare issues requires personnel working with the pigs to record all instances where pigs are observed to be sick/injured to provide the necessary inputs for model training.
    - This engagement needs to be accurate, reliable, and ongoing to provide the necessary inputs for training machine learning models according to a Human-In-The-Loop approach. This leverages the judgement and experience of personnel on-farm to identify all instances of pigs with observable symptoms of illness at regular points in time (e.g. each day), as well as their feedback in validating model outputs (i.e. predictions), to support model training.
        - As per Pilot wean trial 3, the XLM app provides a viable and efficient means for supporting this process.
    - Further accuracy can be achieved where the dataset available for model training features high quality training labels encompassing enough of the

variation for a given set of conditions (e.g. seasonal changes, environmental conditions, disease outbreak patterns, age effects, etc.).
    - A recommended approach for new tag deployments would be as follows:
        - Phase 1 - Deploy initial batch of tags, focus on technology and workflow familiarisation to ensure farm personnel can provide reliable observations of pigs with health/welfare issues (training labels), and develop a preliminary machine learning model based on these inputs.
        - Phase 2 - Deploy second batch of tags, focus on collecting further training labels and validating the outputs of the model (with the goal of achieving a given target accuracy rate).
        - Phase 3 - Incorporate any additional information of relevance that describes the individual characteristics of each farm and variations therein (e.g. weather, environmental conditions data, age, pig birth weights, genetics, etc.) to provide a richer dataset and retain and validate again.

Workstream 4 – Downstream supply chain traceability

- Improving sow management is likely the highest impact opportunity for the Xiot Health Tag in the short term, while reducing post-weaner disease mortality is the largest, single, opportunity. Underlying technology and personnel remain a key risk to realising value from the tags.

- The potential value from full implementation of the tag technology across all CMG farms is between $2.7m and $9m p.a., representing the value at-stake that will guide investment decisions into each key opportunity area.

- Individual-pig traceability at CMG's Linley Valley Pork abattoir, for the purpose of providing a provenance story to consumers, is currently not possible. Future investment in this regard would need to be balanced against the value of knowing the origin of individual animals.

- The three-phase consumer research provides a comprehensive understanding of consumer responses to Digitally Monitored Animal Welfare (DMAW) practices in pork production. Phase I revealed the ethical and hedonic values consumers associate with welfare practices, highlighting attributes such as humane processing, animal diets, and stress-free environments. Phase II demonstrated how these attributes map onto multiple consumption value dimensions, identifying emotional value as the strongest predictor of attitudes in at-home consumption. Finally, Phase

III showed that while consumers express concern for animal welfare, their actual purchase decisions are most influenced by transparent, credible labels that link DMAW practices to human benefits (safety, health, quality) and environmental sustainability.

- Recommendations include:

    1. **Emphasise Advanced Welfare Cues**: Marketing should highlight DMAW features such as health monitoring, humane treatment, and stress-free environments, framed in ways that connect to emotional reassurance.

    2. **Leverage Technology for Credibility**: Use logos, blockchain traceability, and certification to translate monitoring data into consumer trust signals.

    3. **Highlight Human Benefits Alongside Ethical Claims**: Campaigns should balance "doing good for animals" with direct consumer benefits like safety, quality, and environmental protection.

    4. **Adopt Value-Based Segmentation**: Target universalist and hedonist consumers with ethical-emotional narratives, while appealing to pragmatic or innovative consumers with functional and technological benefits.

    5. **Tailor** to **Consumption Contexts**: At-home marketing should emphasise reassurance and emotional value, while out-of-home contexts should foreground safety and price-sensitive positioning.

- By combining insights across qualitative, quantitative, and behavioural methods, this project provides a roadmap for producers, marketers, and policymakers to foster ethical, credible, and consumer-aligned adoption of digitally monitored animal welfare practices.

NEXT STEPS

- Xsights will continue with further commercial and research trials over the next 12+ months, working with a range of large-scale operators and research institutions across the world.

- Recommendations for future development and commercialisation include:

  - **Phased Deployment:** New deployments should be structured in a phased manner - familiarisation, validation, and data enrichment - to ensure the consistent collection of high-quality training labels from farm personnel.

  - **Continued Hardware Refinement:** Further research and development is recommended for the gilt/sow tags to improve their durability and functionality, which is crucial for unlocking the high-value sow management opportunities identified in the research.

  - **Market-Facing Commercialisation Strategy:** The project partners should develop a clear go-to-market strategy that leverages the consumer insights by framing animal welfare within a broader narrative of food safety, health, and environmental stewardship, communicated through credible and transparent technology signals.

PROJECT TEAM

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PUBLICATIONS LIST

Peer reviewed papers:
Jose, H., Jackson, E. L., Duong, C., & Sung, B. (2025). Ethical food consumption in the digital age: Consumer attitudes towards digitally monitored animal welfare in pork products. *Appetite*, *207*, 107853. https://doi.org/10.1016/j.appet.2025.107853

Garrett, M., Wildisen, B., Geyer, K., Moore, K.L., Ho, L., & Trezona, M. (date TBC). Evaluating the activity patterns of weaned pigs using low-cost electronic ear tags. *animal – science proceedings,* (edition TBC). *Paper accepted for publication*.

Pires, R., Wildisen, B., Garrett, M., Brabant, O., Trezona, M., Ho, L., & Moore K.L. (date TBC). Near real-time animal health monitoring in weaned pigs using Internet of Things sensors and machine learning. *animal – science proceedings*, (edition TBC). *Paper accepted for publication*.

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Note: Two further papers are planned for Heerah Jose's consumer work (~February and May 2026)

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Peer reviewed conference papers:
Jose, H., Jackson, E.L., Duong, P & Sung, B. (2025). Consumer Evaluation of At-Home Digitally Monitored Animal Welfare, Australian and New Zealand Marketing Academy Conference (ANZMAC), Sydney, Australia, 1-3 December 2025, Macquarie University. *Paper accepted for delivery.*

Jose, H., Jackson, E.L., Duong, P & Sung, B. (2025). Ethical Food Consumption in the Digital Age: Consumer Attitudes Towards Digitally Monitored Animal Welfare in Pork Products. Global Marketing Conference, Hong Kong, 24-27 July 2025.

Jose, H., Jackson, E.L., Duong, P & Sung, B. (2024). Consumer Attitude Towards Digitally Monitored Animal Welfare, Australian and New Zealand Marketing Academy Conference (ANZMAC), Hobart, Tasmania, 4-6 December 2024, University of Tasmania.

ACRONYMS & ABBREVIATIONS

BLE	Bluetooth Low Energy
CMG	Craig Mostyn Group
COTS	Commercial-Off-The-Shelf
DMAW	Digitally Monitored Animal Welfare
DPIRD	Department of Primary Industries and Regional Development
HITL	Human-In-The-Loop
IoT	Internet of Things
LED	Light Emitting Diode
LVP	Linley Valley Pork
PIWA	Pork Innovation WA
RFID	Radio-Frequency Identification
SaaS	Sensing as a Service
STL	Seasonal-Trend decomposition using Loess
XioT	Xsights Xiot Health Tag
XLM	Xsights Livestock Management (app)

APPENDICES

Figure 1: Hierarchical Value Map (HVM) for factors consumers want to capture while using digital monitoring.

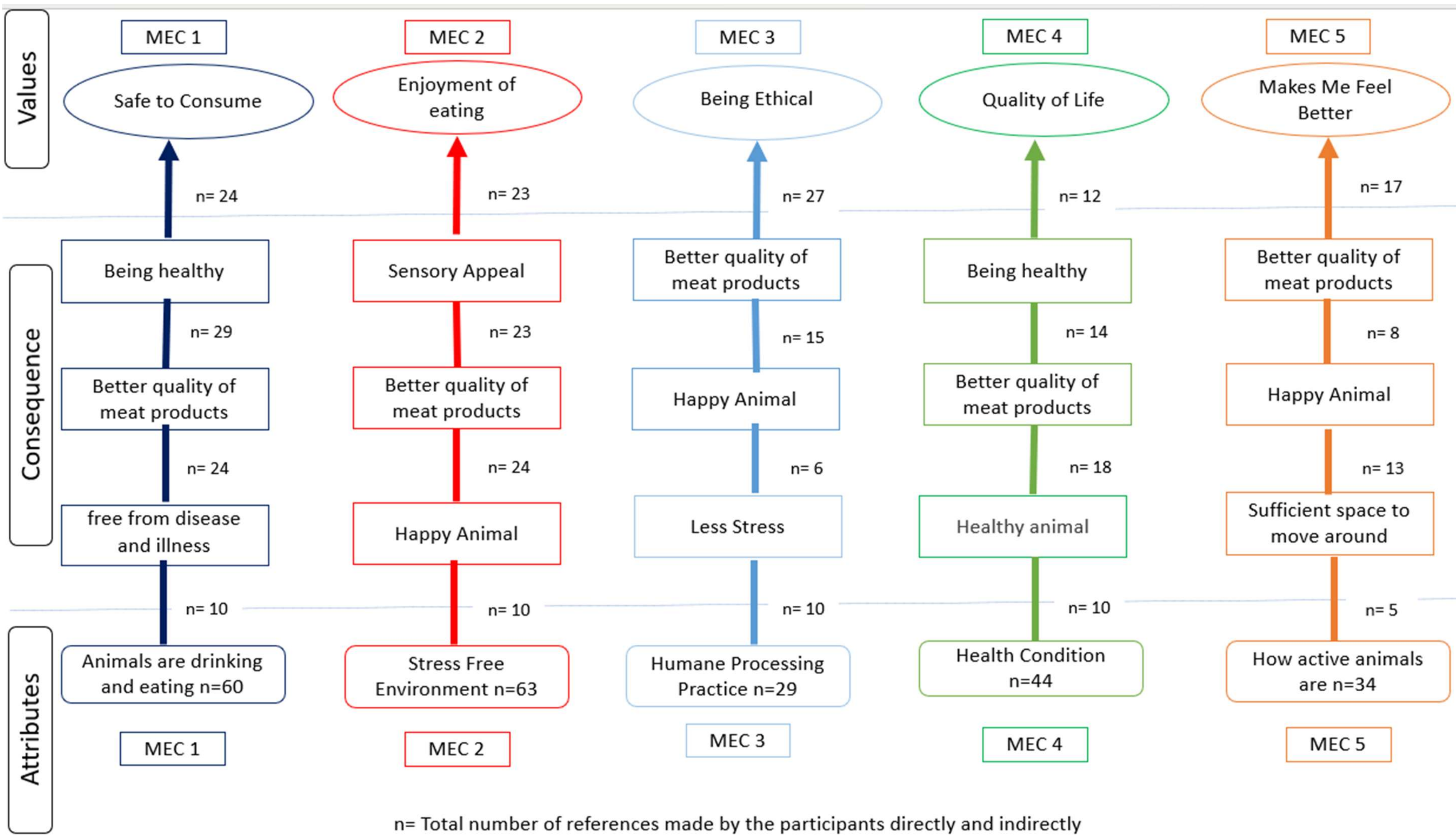


Figure 2: Path diagram of hypotheses for Phase II.

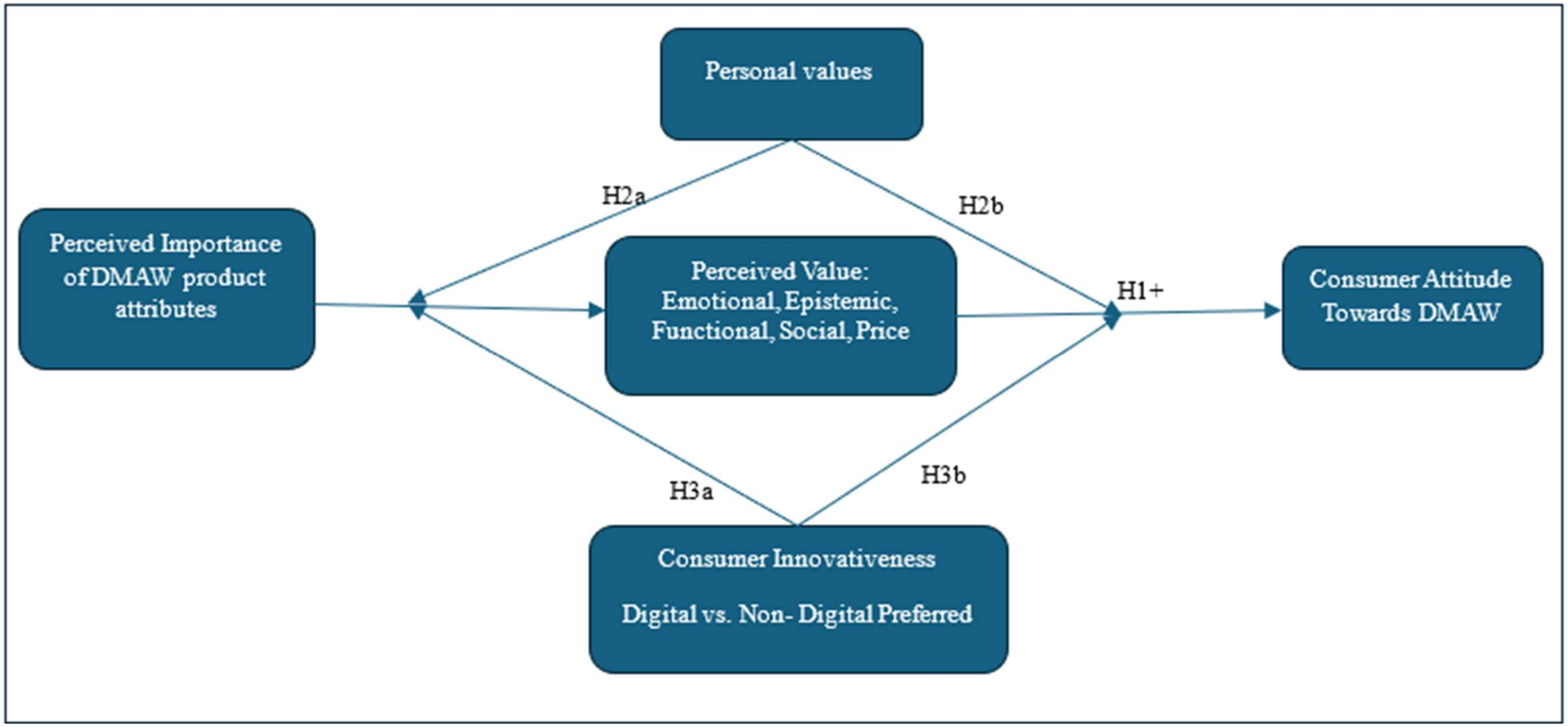
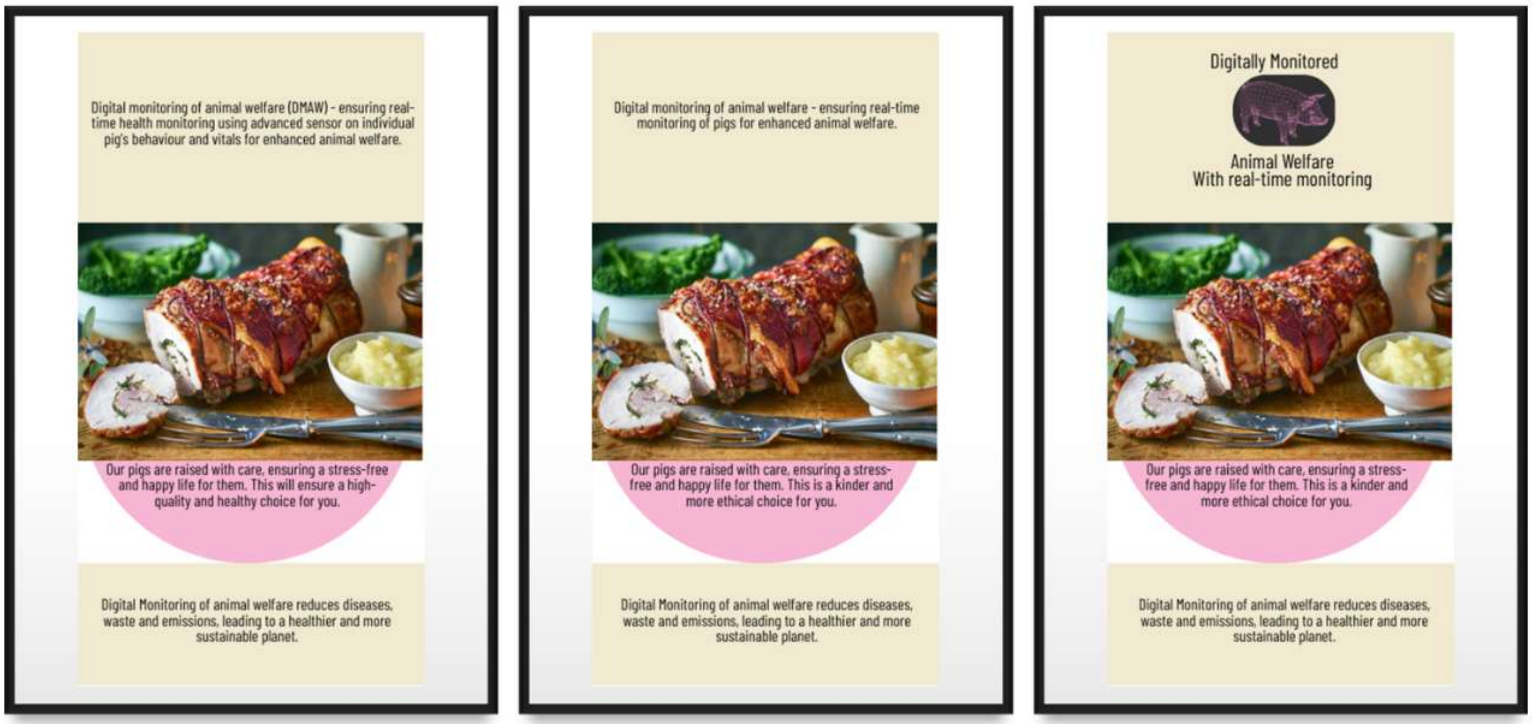


Figure 3: Sample product label developed for Discrete Choice Experiment- Phase III.



3Ps: Pig welfare, production decision support and pork provenance in supply chains

By Dr Megan Trezona, Craig Mostyn Group; Dr Michael Garrett, Xsights; Associate Professor Elizabeth Jackson, Curtin University; Dr Karen Moore, Craig Mostyn Group; Dr Rodrigo Pires, Department of Primary Industries and Regional Development; Lily Tao, Beanstalk AgTech; Grant Gilmour, Beanstalk AgTech

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