Department of Primary Industries
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A report into the recognised factors that affect pig response to carbon dioxide (CO_2) stunning.

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This document is principally a review of the scientific literature. Additionally, this report includes information obtained from industry sources and legislative and regulatory review both within Australia and internationally. This report is provided as information and its contents should not be construed as official NSW DPI policy. Mention of trade names, products, commercial practices, or organisations does not imply endorsement by NSW DPI.

Abstract

- Exposure to CO_2 is the most common method used to stun pigs prior to slaughter in Australian pig processing establishments.
- Exposure to CO_2 is recognised as being aversive to pigs during the stunning process, but there are many aspects of this method that are beneficial to pig welfare compared with other methods of stunning.
- Multiple on-farm and processing establishment factors were identified as affecting the degree of aversiveness of CO_2 experienced by pigs.
- Understanding of these factors, and development and implementation of best practice processes accordingly, will help to improve the welfare outcomes of pigs at processing establishments.
- Further research is required to better identify these factors and develop mitigation strategies to facilitate positive pig welfare at all stages of the slaughter process.

Background

According to the Food and Agriculture Organisation's (FAO) *Guidelines for humane handling, transport and slaughter of livestock, "*it is desirable to render an animal unconscious before it is slaughtered in order to eliminate pain, discomfort and stress from the procedure" (FAO,2001). Australia and several other countries/jurisdictions have a legislated requirement for livestock to be rendered unconscious via stunning prior to slaughter. Research has shown that the way in which a pig is stunned can impact

animal welfare, meat quality, and the efficiency and cost of slaughter (Marcon et al., 2019; Steiner et al., 2019).

There are three recognised methods of stunning pigs: mechanical (e.g., captive bolt), electrical, and controlled atmosphere (e.g., carbon dioxide (CO_2)) (Hewitt, 2022; Nielsen et al., 2020). In Australia, the *Model Code of Practice for the Welfare of Animals – Livestock at Slaughtering Establishments, 2002* deems it acceptable for pigs to be stunned using any of these three methods.

CO_2 stunning involves pigs being loaded into a gondola crate, which is lowered into a pit containing CO_2 gas. Pigs are rendered unconscious through oxygen deprivation within 30-60 seconds. The gondola containing the unconscious pigs is brought back up, unconsciousness is confirmed, they are shackled to the processing line, and bled out ('stuck') to ensure death.

All seven of Australia's export-accredited pig abattoirs use CO_2 stunning. Australian Pork Limited's website indicates that greater than 85% of pigs processed in Australia are stunned using CO_2 .

More than 97% of the pigs processed in NSW across multiple pork processing facilities are stunned in this manner, while the remaining pigs processed at other, smaller domestic abattoirs are stunned via captive bolt or electrical stunning.

Research has established that there are clear advantages to CO_2 stunning systems over other stunning systems. Advantages include that they reliably result in unconsciousness, allow the stunning of multiple animals at once, and require less handling and restraint of the pigs than other stunning methods. Conversely, there are negative aspects to the use of CO_2 including that exposure to CO_2 does not cause instantaneous unconsciousness, and it can cause a range of aversive responses in pigs (Hewitt & Small; Steiner et al., 2019).

This literature review aims to identify factors which contribute to the responses of pigs to CO_2 stunning, and to identify best-practice CO_2 stunning methods that will support the implementation of best practice in pig processing establishments to improve animal welfare outcomes.

Review of science / literature

It is recognised that many factors can alter the response of pigs to stress. Additionally, it is recognised that reducing stress improves welfare outcomes for the animals during the slaughter process, and the eating quality of the final product. Pig breed, genetics, and handling during early life and at the abattoir, can affect how pigs respond to stressful situations, including exposure to CO_2 during the stunning process.

Under legislation, it is required that CO_2 concentration be above 80% to ensure rapid insensibility. However, CO_2 is aversive to pigs at any concentration above 15% (Llonch et al., 2012; Steiner et al., 2019). Therefore, modifying the concentration of CO_2 used in the stunning process only partially affects the degree of aversiveness experienced by the pigs.

Pig breed and genetic makeup

- The halothane gene in pigs is the cause of Porcine Stress Syndrome (PSS) (also known as Malignant Hyperthermia) (Driessen et al., 2020; Grandin, 2022). Pigs homozygous (nn) for the halothane allele are more prone to exhibiting responses which range from excessive

excitability during handling, to death in stressful situations such as transport. Also, nn-pigs have leaner carcasses but frequently display the pale, soft exudative (PSE) meat condition(Driessen et al., 2020; Grandin, 2022).

- Information on the performance of the heterozygote pig (Nn) is equivocal. The quantity of lean meat in the carcass of the Nn pig tends to be intermediate between the nn and NN segregants, but this varies with breed and growing environment.
- Under conditions of stress, some of the undesirable conditions of the nn type being PSS and PSE, appear to be expressed in the Nn animal (McPhee, 1992).
- Crossbreeding and selection for pigs with lean, heavy muscling before recognition of this genotype meant that the halothane gene became established in commercial pig herds around the world.
- Also, certain breeds had a higher incidence of the halothane gene and thus a higher prevalence of PSS (Hampshire, Yorkshire, Pietrain) whilst other breeds were less predisposed (Duroc, Large White) and had noticeably calmer temperaments (Grandin, 1992).
- The development of a reliable test to identify halothane positive pigs has largely eradicated these pigs, with Australian commercial herds considered free of the gene in 2011 (Channon & Warner in (Jose, 2017)). However, it is possible that halothane positive pigs remain in smaller, boutique herds and/or free-range systems where the typical commercial breeds are less prevalent than 'heritage' breeds.
- Troeger & Woltersdorf (1991) found that while the reactions of pigs to CO_2 exposure depended on the gas concentration used, and the halothane genotype was the most determinant factor. When the CO_2 concentration is relatively low (<80%), homozygous halothane positive pigs (nn) showed a more vigorous uncoordinated motoric activity during the excitation phase. Also, their muscle could be predisposed to extremely rapid postmortem glycolysis in comparison with halothane negative (NN) and heterozygous pigs (Nn).
- Despite the claim that commercial Australian herds are halothane gene free, there may be some remaining affected lines.

On farm rearing

- In her work on reducing stress in pigs pre-slaughter, Grandin (1999) found that accustoming pigs to human interaction in the weaning to finishing period greatly reduced their excitability, even in pigs carrying the halothane gene.
- Walking through pens and driving groups of pigs up laneways daily reduced fearful behaviour, whilst hitting or kicking pigs increased fear. This daily handling resulted in the pigs becoming easier to handle both during transport and processing, and ultimately resulted in better quality carcases (Grandin, 1999).
- Additionally, Terlouw (2005) found that behavioural characteristics of the pig, established early in life, along with genetic background and slaughter conditions, explained a large part of variability in several technological meat quality parameters.
- Behavioural, physiological and metabolic responses to aversive situations depended on genetic background and prior experience of the animals (Terlouw, 2005).
- In Australian pork abattoirs, Jongman et al (2021) found that latency to loss of posture following CO_2 exposure was associated with farm of origin, highlighting the role of background farm factors in the response of pigs to CO_2 stunning

- Further research is recommended to investigate the specific factors relating to the farm, such as genetics, previous experience, and transport conditions, on the pigs' susceptibility to succumb to CO_2 (Jongman et al., 2021).

Pre-slaughter handling

- At processing plants, Grandin (1999) identified many factors that reduced stress in pigs, making them easier to handle through the facility and ultimately resulting in improved welfare outcomes, carcase quality and reduced wastage.
- Resting of pigs for 2-4 hours following transport, preventing heat stress, not over-crowding pens and chutes, removal of distractions along races, and most importantly, avoiding the use of electric prodders, are advocated.
- The last 15 minutes in the stunning period is considered by Grandin as the most critical time when quiet handling is required to reduce stress and maintain carcase quality (Grandin, 1999).
- For pigs heterozygous for the halothane gene (Nn), Driessen et al. (2020) found that a total of 4763 fattening pigs were transported from a single farm to a commercial slaughterhouse (distance 110 km) in 121 transports. Effects of farm management, climate parameters during transport, transport and slaughterhouse conditions on pork quality were assessed. The researchers found that avoiding the mixing of unfamiliar pigs during the transport process and providing sufficient lairage time could reduce stress and thus improve meat quality (Driessen et al., 2020).
- Further, in Australian abattoirs, Jongman et al. (2021) examined the effect of on-plant handling of pigs and their response to CO_2 stunning. Behavioural responses during handling in lairage, through races and chutes, and to CO_2 once pigs were loaded into the gondola, were recorded, and included escape attempts, crawling, mounting, response to detection of CO_2, gasping, time to loss of posture and presence of convulsions.
- Findings from this study included:
    - Crawling, escape attempts and mounting behaviour are likely conscious reactions and indicative of an aversive reaction. The presence of these behaviours in the gondola were associated with either the sex composition of the lairage pen, or sex of the focal pig, with females being less likely to display these behaviours than males, and mounting in the gondola being much more likely in pigs from lairage pens of mixed sexes (Jongman et al., 2021).
    - Also, the likelihood of mounting in the gondola increased with greater amounts of highly aversive handling in the race by the stockperson or after being trapped by the automatic gates. Interestingly and incongruously, the likelihood of crawl and escape attempts in the gondola decreased with greater amounts of highly aversive handling and electric prodding in the race (Jongman et al., 2021).
    - Gasping is considered to occur at the onset of breathlessness. CO_2 exposure is likely to lead to severe air hunger, which is reported to be the most unpleasant sensation of breathlessness. However, gasping persisted beyond isoelectric EEG, and therefore may not necessarily be indicative of consciousness. The occurrence of gasping during the CO_2 stunning process was correlated with higher pen activity in lairage, and higher fresh skin injuries, indicating a possible effect of lairage conditions (Jongman et al., 2021).

- Jongman et al. (2021) concluded that the variation in outcomes between abattoirs and stunning systems, and the relationships between preslaughter handling and behavioural outcomes indicated that improvements can be made to reduce aversive responses to CO_2 stunning. In particular, avoiding mixing pigs of different sexes in lairage and aversive handling in the race may reduce aversive response to CO_2 stunning. Further, theynoted that one abattoir had minimal crawl, escape attempts, mounting behaviour and the lowest cortisol concentration. This abattoir anecdotally ran at lower-than-normal gondola capacity during the experiment, loading 3 pigs rather than the typical 8 pigs per gondola (Jongman et al., 2021).
- Söderquist et al. (2023) examined the effect of companionship of a familiar or unfamiliar pig on behaviours in 72 nine-weeks old pigs during exposure to air-filled foam. Escape attempts were observed in 75% of solitary pigs, 42% of pigs with unfamiliar conspecifics, and 33% of pigs with familiar conspecifics.
- Familiar pig pairs clearly preferred social contact during foam exposure, whereas this was not as clear in unfamiliar pig pairs, whose behaviour ranged from contact-seeking to aggression.
- Their results highlighted the importance of contact with conspecifics when studying animal welfare and suggest that familiarity between pigs is important for social support, thus emphasizing the importance of maintaining social groups to reduce stress in pigs at slaughter (Söderquist et al., 2023).

Facility design

- Several aspects of the CO_2 stunning system are designed to reduce stress in pigs. Positive aspects of the system allow small groups of pigs to be efficiently moved towards the stunning unit using mechanical push gates, which minimizes the handling stress involved with human contact. Additionally, allowing pigs to remain in groups during preslaughter-handling and stunning respects the natural herd instincts in pigs to remain in social contact with one another, thereby minimizing fear and stress caused by isolation and close human contact. In contrast, close human contact and restraint of pigs individually during electrical or captive bolt stunning was associated with causing preslaughter handling stress and product quality defects, such as PSE meat and blood splash (Atkinson et al., 2020).
- In a two-part study, Jongman et al. (2000) examined the relative aversiveness of electric shock or CO_2 exposure to pigs and compared the aversiveness of a CO_2 gondola to the aversiveness of a V-belt restrainer used for electrical stunning.
    - In the first part of the experiment pigs were trained to walk into the empty gondola for a food reward. After the training period, they were exposed to one of three aversive stimuli: either CO_2 (at 60% concentration, where pigs remained conscious, or 90% concentration, where pigs became unconscious) or an electric prodder, or a control treatment of no stimulus at the bottom of the CO_2 pit. Researchers found that the pigs found the application of the electric prodder significantly more aversive than the control treatment and both CO_2 treatments. There was only slight difference in pig response between control and CO_2 exposure at either 60% or 90% concentration, suggesting that while pigs found electric shock highly aversive, exposure to CO_2 was only slightly aversive.
    - In the second experiment, pigs were trained to either walk into a stationary CO_2 gondola or onto a stationary V-restrainer belt, for a food reward. Then, the pigs were placed either into the gondola or on the restrainer which were set in motion, without a food reward.

Finally, the pigs were moved towards either the crate or restrainer they had previously been exposed to, and ease of moving them was recorded. Pgs were less willing to initially enter the CO_2 gondola compared with the V-restrainer suggesting they found it slightly more aversive, although this difference disappeared with training.

Domestic & international jurisdictions

Jurisdiction	**CO2 stunning of pigs – permitted or not; relevant legislation/guidelines; comments**
Australia Permitted	Permitted For abattoir accreditation (domestic) in all states, processors must meet *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption)* (the Australian Standard) (AS 4696:2007) These standards require animals to be stunned (unconscious and insensible to pain) prior to sticking/death, but do not prescribe stunning methods or best practice of these. Recognised industry guideline: *Model Code of Practice for the Welfare of Animals - Livestock at Slaughtering Establishments* (2001) *"2.6.2.10 Stunning pigs by exposure to mixtures of air and carbon dioxide are also acceptable. The mixture recommended in Europe is currently 70% carbon dioxide by volume, and exposure is recommended for 60 seconds. These recommendations may need to be modified for Australian conditions as experience with local conditions increases."* In addition to the Australian Standard, the NSW Food Authority mandates that all domestic NSW red meat abattoirs (which includes pig abattoirs) meet the *Industry Animal Welfare Standard for Livestock Processing Establishments Preparing Meat for Human Consumption ed 3* (Industry Animal Welfare Standard). Annex E outlines the permitted method that applies to pigs in controlled atmosphere (CO_2) stunning and states that equipment must be used according to manufacturer's recommendations in relation to dwell time and gas concentration. Compliance with this Standard is voluntary for domestic abattoirs in other jurisdictions. Domestic jurisdictions with pig processing establishments as of 1 June 2023: NSW, Victoria, Queensland, South Australia, Western Australia
New Zealand Not conducted	Not conducted *The Code of Welfare Commercial Slaughter (2018)* (the Code), issued under the Animal Welfare Act 1999 (the Act) is intended for all persons responsible for the welfare of animals that are commercially slaughtered and identifies the minimum standards they must achieve to meet their obligations under the Act. The Code states, regarding the stunning of large mammals including pigs: *"Stunning must be applied using one of the following:* *i) a captive bolt firearm; or* *ii) an electrical stunner; or* *iii) a suitable firearm* *Note - Controlled atmosphere stunning of large mammals is not currently carried out in New Zealand."*
UK	Not permitted

Not permitted (Slaughter permitted)	*The Welfare of Animals at the Time of Killing (England) Regulations 2015* **29.**(1) *No person may stun pigs by exposure to gas unless each pig is exposed to the gas for long enough to ensure it is killed.*
Canada Stunning permitted	Permitted Safe Food for Canadian Regulations 2018 "*before bleeding a food animal, other than a game animal, a licence holder must render it unconscious in a manner that prevents it from regaining consciousness before death or slaughter. Exposing it to a gas or a gas mixture in a manner that causes a rapid loss of consciousness is an accepted method*."
USA Stunning not permitted Slaughter permitted	Not permitted *Code of Federal Regulations: Title 9 – Animals and Animal Products*, Subchapter A, last updated 2023, (under the Food Safety and Inspection Service, an agency of the US Department of Agriculture) Electrical is the only type of stunning mentioned. *In swine, carbon dioxide may be administered only to induce death in the animals before they are shackled, hoisted, thrown, cast, or cut.*
EU Stunning permitted Slaughter permitted	Permitted *Council Regulation (EC) No. 1099/2009 on the protection of animals at the time of killing.* "*In the case of pigs, mustelids and chinchillas, the minimum concentration of 80 % of carbon dioxide shall be used*."

Industry

Australian Meat Industry Council

- The Industry Animal Welfare Standard (ed 3) was developed in 2020, effective 1 January 2022, to reflect the expectations of both the Australian meat processing industry and the community, regarding the management of livestock at Australian livestock processing establishments.
- The Standard was developed by industry representatives, animal welfare scientists, researchers and technical experts, standards writing and conformity assessment experts, non-governmental organizations, and regulators with an interest in animal welfare.
- This Standard adds to the pre-existing quality assurance systems all livestock processing establishments have in place to address issues associated with food safety and meat quality.
- Auditing against this standard is voluntary for domestic abattoirs, except in NSW where compliance with this Standard is mandatory.
- The addition of animal welfare principles to these systems provides a more comprehensive holistic approach and assists industry to prioritise and demonstrate continually improving animal welfare outcomes.

Australian Pork Limited (APL)

- APL do not have their own standards or policies that prescribe CO_2 stunning; they refer to the Model Code of Practice for Livestock at Slaughtering Establishments (2001) and the Industry Animal Welfare Standard.
- Currently, APL is focussing on developing resources that will enhance training and competency of abattoir staff to ensure all pre-stun animal handling processes are operated at the highest standards.
- The ProHand Pigs and Pork Abattoir programs were designed to drive positive animal welfare across the supply chain. This online program was developed by the Animal Welfare Science Centre in collaboration with Temple Grandin with funding from Australian Pork Limited and the Australian Meat Processor Corporation.

Other stakeholders

RSPCA Australia

- The knowledgebase article 'Is carbon dioxide stunning of pigs humane?' recognises that CO_2 exposure is aversive to pigs, but that stunning with CO_2 gas offers benefits over electrical stunning including the ability to stun animals in groups, with minimal restraint, less handling, and therefore potentially less stress before stunning.
- They recommend that stunning/killing pigs with high concentrations of CO_2 should be phased out and replaced with more humane alternatives.
- Additionally, they state that further research is urgently needed to develop stunning systems which retain the benefits of group CO_2 stunning while minimising the disadvantages.

Australian Veterinary Association

- CO_2 stunning of pigs is not specifically mentioned in the AVA's policy 'Humane Slaughter of Livestock'
- However, AVA do advocate that the slaughter of animals for food must be carried out in a humane manner and that prior to slaughter animals must be humanely and immediately rendered unconscious via stunning, and remain unconscious until death occurs. Arrangements must be in place so that animals are spared unnecessary excitement, pain, stress or suffering during movement, restraint, stunning and slaughter.

Conclusion

It is a legislated requirement in Australia and numerous other countries that livestock, including pigs, be rendered unconscious via stunning prior to slaughter. While CO_2 is recognised as being aversive to pigs, there are several aspects of the CO_2 stunning method that provide advantages to pig welfare compared with other methods of stunning.

These aspects include the ability to stun pigs in groups, with minimal restraint and handling, all of which reduce the stress experienced by pigs prior to stunning. Reduction of stress in pigs prior to their exposure to CO_2 minimises their aversive response to CO_2, in addition to improving carcase quality.

On-farm factors that were identified to reduce stress in pigs and their aversive response to CO_2 stunning include:

- Pig breed and genetic make-up
- Habituation of pigs to human interaction
- Training and managing pigs using low-stress stock handling techniques

Management practices at processing establishments that have been identified to minimise stress to pigs and therefore aversiveness to CO_2 include:

- Resting of pigs post transport
- Avoidance of overcrowding
- Avoidance of mixing pigs of different sexes in lairage
- Maintenance of social groupings to prevent mixing of unfamiliar pigs
- Minimising direct human contact
- Low stress handling of pigs prior to stunning, including avoiding the use of electric prodders.

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