PIGLET CASTRATION AND ALTERNATIVES - SUMMARY

THE PROBLEM

Most male pigs around the world are surgically castrated, often without any pain relief. The main reason for castration is to prevent boar taint, the undesirable odour or taste in pork which arises from chemicals produced by sexually mature males. Castration also reduces aggression and sexual behaviours in male pigs which cause injury and affect welfare later in life.

Surgical castration is highly painful, and the pain lasts for days after the procedure. While pain relief can be provided to some extent with the use of anaesthesia and analgesia, it is not completely effective and carries additional costs for the producer. Two main alternatives exist to surgical castration in pigs: rearing entire males and vaccination to delay puberty.

REARING ENTIRE MALES

Rearing entire males entirely avoids the pain and stress of the castration procedure. Additionally, there are economic benefits to producers rearing entire males. Not only do they save on the labour and costs of surgical castration and any pain relief medications, but entire males are more efficient than barrows: they have an improved feed conversion rate meaning they require less feed to reach the same slaughter weight than surgically castrated pigs. For example, the net benefit of switching from castration to entire male production in Europe has been estimated as potentially over one billion euro. As a result of this better efficiency, entire male pig production has a substantially lower environmental impact than pig production with surgical castration.

However, rearing entire males can increase the risk of boar taint and undesirable aggressive and sexual behaviours in male pigs. There are a number of strategies which can mitigate these risks:

- Pre-pubertal slaughter: Slaughtering the pigs before they reach puberty is the most effective means of minimising the risk of boar taint and undesirable behaviours and renders castration unnecessary. This is already standard practice in some countries such as Ireland and the UK, and to some extent in Spain, Portugal, and Greece.
- Detection of boar taint at the slaughter line: Boar taint can be detected at the slaughter line and the carcasses can be used in heat-processed and cold-served meats, as processing destroys the pheromone responsible for the taint. The most promising approach for large slaughter plants is the automated combination of laser diode thermal desorption ion source and the mass spectrometry (LDTD-MS/MS) method as it can be performed at the slaughter line, is quick and accurate. For smaller slaughterhouses, sensory evaluation by the human

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nose is the most suitable method as it is fast, accurate, and more economical for smaller slaughterhouses.

- Management and Nutrition: Some management factors, such as improved housing conditions (more space, increased feeder space and more drinkers, group stability, organic manipulable enrichment), can help to reduce boar taint, and are hugely beneficial in reducing aggressive behaviour in male pigs. Others have no or limited effect on boar taint reduction, but do reduce aggression, such as increased space and straw provision. Nutritional factors can play a part in reduced boar taint. For example, supplementing feed with chicory root or feeding cereal grains in the 3-4 days before pigs are slaughtered can reduce one of the compounds which contribute to boar taint by half.
- Genetic Selection and Semen sexing: Selection against boar taint and semen sexing are two promising approaches to avoid the problem of boar taint altogether. Rearing female only herds has the additional benefit of reducing the undesirable sexual and aggressive behaviours. However, neither solution is currently commercially available.

VACCINATION TO DELAY PUBERTY

A vaccination protocol to suppress the male 'Gondaotrophic releasing hormone' (GnRH) leads to the delay of puberty, and can allow the rearing of heavier weight males without the risk of boar taint. This vaccination, also called immunocastration, has been developed by pharmaceutical company Zoetis under the brand Improvac® (known as Improvest® in the US). Delaying puberty is beneficial for welfare because it avoids the pain and stress of castration and reduces mounting behaviour in males, although more research is needed to establish the best vaccination protocol for very heavy weight males (~ 160kg). The vaccination has higher associated costs than surgical castration (with and without pain relief), some of which can be offset by the improved feed conversion ratio in immunocastrates compared with castrated pigs. While the environmental impact is greater than rearing entire males, it is still substantially lower than pig production with surgical castration. It has been shown there are no negative effects on meat quality or consumer acceptance.

RECOMMENDATIONS

- Surgical castration without any pain relief should be urgently banned.
- In a short interim period where surgical castration may still be performed, effective pain relief (anaesthesia and analgesia) should be systematically administered
- Risks of boar taint and undesirable sexual behaviours in non-surgically castrated pigs can be managed by:
  - Rearing entire males and slaughtering before they reach sexual maturity
  - Rearing entire males post-puberty and detecting boar taint at the slaughter line. Adapt management practices to reduce aggressive behaviours and risk of boar taint
  - Vaccination to delay puberty (Improvac©/Improvest©).

PIGLET CASTRATION AND ALTERNATIVES – SCIENTIFIC REVIEW

How and why piglets are castrated

Surgical castration is usually performed within the first week of life – generally an incision is made in the scrotum of the piglet above each testicle which are then pulled out and the spermatic cord severed[1]. The purpose of castration is primarily to prevent boar taint[2], an unpleasant odour in meat due to the build-up of two compounds, androstenone and skatole, in the fat of male pigs. Castration can also reduce unwanted behaviours such as aggression and mounting, which increase with the onset of puberty in entire males[3], leading to a higher risk of injury, such as fight lesions and penile injuries[4–7] as well as being stressful for the recipients of these behaviours[8,].

Almost 75% of male piglets in Europe are surgically castrated (~ 100 million piglets/year)[9,10], nearly all male piglets in the US are castrated (= 94 million pigs annually)[11] and the situation is similar in Asia. Some countries do not routinely castrate (e.g., Spain, U.K., Ireland, Portugal) as the animals are slaughtered before they reach puberty. In other countries, national legislation requires castration to be performed only with pain relief (e.g., Switzerland, Denmark, Germany, France, the Netherlands). However, EU council directive 2008/120/EC allows surgical castration to be performed without any pain relief up to seven days of age, and in other leading pig producing regions, such as China and the USA, there is no legal requirement to provide pain relief during surgical castration. Thus, most male pigs around the world are castrated without any pain relief.

The effect of castration on piglet welfare

Due to the high level of innervation in the tissues of the testes and surrounding areas[12], surgical castration is highly painful. Pain can occur during the procedure itself (nociceptive pain), or while the resulting tissue damage is healing (inflammatory pain) but can also continue long after the tissues have healed (chronic pain)[12]. There is evidence of at least the first two categories of pain occurring in response to surgical castration in piglets.

Both vocalisations and spontaneous nociceptive motor responses are considered reliable behavioural indicators of pain during castration[13]. Piglets vocalise more often, more intensely and at a higher frequency and show more defensive body movements during the procedure compared to sham-castrated piglets[14–16]. Mean arterial blood pressure (MAP) is considered a sensitive physiological indicator of nociception in pigs[17], with a 20% increase during surgical procedures said to be sufficient to warrant additional pain relief[18]. MAP during surgical castration of piglets was found to increase by 24% during the incision and by 45% during the severing of the spermatic cord, suggesting significant pain during the procedure[19]. In line with these results, while piglets increase the volume of high-frequency calls during the incision, the highest volume of calls occurs during pulling and severing of the cords, indicating that this is the most painful part of the procedure. In the hours following castration, piglets may be more inactive and show reduced activity at the udder, whilst behaviours such as trembling, huddling, scratching at the rump and stiffness may last for days[20,21], indicating

that there is residual pain long after the procedure itself. Physiological indicators of stress, such as increased levels of the hormones cortisol, adrenocorticotropic hormone (ACTH) and lactate, also occur following castration[2,19].

The common practice of performing castration without pain relief is based on the incorrect assumption that neonates have a lower sensitivity to pain[5,22]. This assumption is evidenced in EU legislation which does not require pain relief for piglets castrated under seven days of age, while experimental evidence shows no differences in piglet pain perception[22] and cortisol responses before or after seven days of age[23].

Mitigating the pain and stress of castration

Where surgical castration cannot be avoided, the pain and stress experienced during surgical castration can be reduced with local or general anaesthetics to minimise pain during the procedure and analgesics to alleviate post operative pain. There is some debate as to the effectiveness of many anaesthetics[24,25]: some studies report that piglets still show evidence of pain or discomfort during the procedure[26,27], that the injection itself can be painful[19,27,28] and causes additional stress due to increased handling required[25]. While some general anaesthetics can be more effective than local anaesthetics in reducing pain during the procedure, they come with their own set of problems (see Table 1), and the recovery itself can be stressful for the piglets[29]. It is clear that anaesthesia alone is not effective in eliminating pain both during and after the procedure. EFSA in their recent report conclude that "*to achieve adequate pain relief a combination of analgesia and anaesthesia is needed*"[30]. However, currently there is no adequate method for providing long-term pain relief for the post-surgery period[25].

Aside from the limited effectiveness in terms of pain relief, some studies have reported higher pre-weaning mortality in piglets castrated with pain relief compared to piglets castrated without (treated piglets received either intramuscular injections of meloxicam and azaperone; or an intramuscular injection of meloxicam and a subcutaneous injection of procaine hydrochloride and adrenaline tartrate)[31] and compared to uncastrated piglets (treated piglets received only meloxicam)[32]. In many cases, it was the lower weight piglets that had a higher risk[31,32].

The use of anaesthesia and analgesia also increases the amount of labour and the costs required; castration with anaesthesia and analgesia has been estimated to cost between ~7-10 times more per pig than surgical castration without pain relief[33,34] and require 59% longer to perform[34]. In addition to this, castrated pigs perform poorer than entire males in both meat quality and efficiency metrics[35] as well as on environmental metrics[36] (Table 3).

Table 1: Overview of approaches to pain relief in piglets during surgical castration. Summarised from EFSA (2022) and Bonneau & Weiler (2019)[3,37]

	Method of administration	Examples	Pros	Cons
Local Anaesthesia	Intratesticular Injection	lidocaine, mepivacaine, procaine, bupivacaine	• Can be effective in reducing pain during procedure	• Only minimal peri-operative analgesia • Intratesticular injection is painful. • Not all drugs are equally effective • Timing between injection and surgery determines effectiveness • Need to be combined with analgesics to achieve post operative pain relief
General Anaesthesia	Injectable	Opioids (butophanol, buprenorphine)	• More potent analgesic effects than NSAIDS and local anaesthetics	• Strong sedative effect: increased risk of crushing • Controlled substances
	Injectable	Ketamine and azaperone	• Effective in pain relief	• Long recovery time: Increased risk of crushing and hypothermia • Controlled substances
	Inhalable	CO_2 and CO_2 mixtures	• Faster recovery time than other general anaesthetics • Cheap	• Does not suppress pain • CO_2 inhalation is aversive to pigs • Lethal risk: Easy to overdose
	Inhalable	Isoflurane (Inhalation + Air/O_2)	• Rapid loss of consciousness • Quick Recovery time. • Not aversive.	• Does not suppress pain • Potent greenhouse gas - Environmental effects • Reports of headaches dizziness in stockpeople • Expensive equipment needed
Analgesia	Intramuscular Injection	NSAIDS (e.g. Meloxicam, Ketoprofen, Flunixin)	• Improves efficiency of pain reduction when paired with anaesthesia • Some pain relief post-surgery provided	• Does not reduce pain during procedure unless paired with anaesthesia • Post operative pain relief only temporary (<24h) • Repeated doses required • Repeated handling stress

Alternatives to surgical castration

The 'European Declaration on alternatives to surgical castration of pigs' was put forward in 2010 by the European Commission. This declaration brought together various stakeholders from farming and industry to researchers, veterinarians, and NGOs to voluntarily agree to phase out surgical castration entirely by 2018 in the EU and all European Free Trade Association countries[38,39].While this goal has not been achieved, much research into the alternatives has been done in the meantime. A 2022 EFSA

report on the welfare of pigs on farm concluded that because of the "*short and medium-term negative welfare consequences including soft tissue lesions and integument damage, handling stress, fear, and pain*", surgical castration without anaesthesia or analgesia should no longer be performed[30]. Currently, the most feasible alternatives to surgical castration are to raise entire males, or vaccination to delay puberty (immunocastration)[3,37].

Rearing entire male pigs

The pain and stress of the castration procedure and subsequent recovery period can be entirely avoided by rearing entire males.

Benefits to People: On top of the welfare benefits for the pigs themselves, rearing entire males can save on the labour and costs associated with the procedure (estimated to cost ~€0.32-0.39 per pig without pain relief or ~€2.83-€3.30 with pain relief[31,40]). In addition, rearing entire males can have further economic benefits as boars have a better growth rate (+13% better), eat less (up to 9% less), have a better feed conversion rate (up to +14% better), and the meat is leaner (up to 20% more lean) than castrates[35,41] so sells at a higher price. The better feed conversion rate has been valued at €7.11 per pig for entire males (cited in a report published by the EU Commission in 2019[42]). The French Pork industry (IFIP) have developed an online tool to simulate the overall financial impact of rearing entire males compared to various alternatives which takes into account the current market situation[43]. In November 2022, this tool indicates that raising entire males with an appropriate feed diet results in savings of between €6.46 compared to castration with local anaesthesia, and €6.99 compared to castration with general anaesthesia[43] per pig. In a report released by the European Commission, the net benefit of switching from castrated to entire male production in Europe has been estimated as potentially over one billion euro[44].

In terms of human health and wellbeing, leaner meat is healthier and consumer demand has moved towards choosing healthier options[45]. Rearing entire males is also likely to benefit the wellbeing of the producers themselves. A study among pig producers in Belgium demonstrated that farmers who were given practical experience of the different alternatives saw entire male production as a valid alternative to surgical castration due to the increased profitability and reduced labour costs[46].

Benefits to the Environment: This better efficiency in entire males also results in environmental benefits: one study found a reduced carbon footprint of the feed intake (9-22% lower), increased nitrogen and phosphorus efficiency (9-14% and 9-17% higher, respectively), and lower nitrogen and phosphorus excretion (14-27% and 14-31% lower, respectively) compared with castrates[47].

Managing boar taint and undesirable behaviours

Rearing entire males increases the risk of boar taint in the carcass. Androstenone is produced in the testis of male pigs at sexual maturity[45] while skatole, although produced in the hind gut of both male and female pigs, accumulates in the fat of male pigs as its breakdown is inhibited by hormones produced in the testes[48]. Rearing intact males can also increase the risk of undesirable aggressive and sexual behaviours[49]. Entire males show more sexually motivated mounting behaviour[5] which is likely very stressful for the recipient[8], and can result in more skin lesions[50]. Penile injuries are also a problem which increases with age in entire males due to penis biting with reported incidence of 64-95% of

male pigs being affected, up to 9% to a severe degree[4]. Various strategies are available to reduce the risk of both boar taint and these undesirable injurious behaviours (summarised in Table 2).

Pre-pubertal slaughter: EFSA (2022) state that the most effective means of minimising the risk of boar taint in entire males is to slaughter the animals before they reach sexual maturity (5-7 months)[37]. This renders castration unnecessary as the aggressive sexual behaviours and the chemicals primarily responsible for boar taint do not present themselves in high levels until the peri- and post-pubertal period[51]. This means that slaughtering before puberty has the added benefit of reducing the unwanted aggressive and sexual behaviours in entire male pigs. This has been the standard practice in Ireland and the UK where almost 100% of males are left entire, and common in commercial production in Spain, Portugal, and Greece[3].

Detection of boar taint at the slaughter line: Estimates of tainted carcasses vary widely; high androstenone content is reported in between 5.5-56% of carcasses, while high skatole content has been reported in 6.6-34% of carcasses[52]. However, since the odour is only detected during cooking, the carcass can be used in heat-processed meats (such as cooked hams, luncheon meat and cooked sausages) and meats that are served cold[53], as well as processed in a way to mask the flavour, such as through smoking[3], providing it can be isolated and removed off the slaughter line. As various methods were developed to detect and quantify the amounts of androstenone and skatole in pig carcasses at the slaughter line, but few were validated across studies, the European Commission published a report in 2014 detailing a reference method by which more rapid approaches could be tested against[54]. A number of aspects need to be taken into account while evaluating the best available methods, such as the speed and capacity, accuracy, whether it can be performed on or at the slaughter line, the potential for automation, and the costs involved[52]. Taking all these factors into account, a review of available methods has found that the most promising approach for large slaughter plants is the tandem between the laser diode thermal desorption ion source and the mass spectrometry (LDTD-MS/MS) where the sampling and sample pre-treatment are automated, which measures both androstenone and skatole, can be performed at the slaughter line, and is quick and accurate. Sensory evaluation through the human nose method is also appropriate as it is both fast and accurate. For smaller slaughterhouses, the sensory evaluation, through human nose, is the most suitable method due to the cost of the LDTD-MS/MS approach[52].

Management: While it was previously thought that wallowing in excrement could lead to skatole absorption through skin[55], more recent evidence indicates that while this can occur, it does not lead to high concentrations of skatole[56]. There is evidence that improved housing (more space, more feeder space and drinkers, organic/chewable enrichment, and stable groups) is associated with reduced androstenone[57], but straw provision alone had no effect[58]. Improved housing and enrichment are also hugely beneficial to animal welfare. Other factors such as group size and stability, reduced stocking density, and increased feeder space bring animal welfare benefits, and some are also associated with reduced boar taint. Importantly, reduced aggression and stress in male pigs has been associated with lower prevalence of boar taint[59].

Nutrition: One way to reduce boar taint is to select dietary ingredients that reduce the production of the compounds associated with boar taint. The Innovative Approaches for Pork Production with Entire Males (IPEMA) research network, funded by the EU, was created to find solutions to the issues raised by switching to alternatives to surgical castration in pigs. They produced a summary of all nutritional factors found to be related to boar taint and concluded that nutritional strategies were

more effective in reducing skatole, but not andrestenone[60]. In short, dietary supplementation with chicory root, likely due to inulin, or feeding pure cereal grains in the 3-4 days before slaughter can reduce skatole by 50-60%[61–64]. Other promising approaches are the addition of raw potato starch or hydrolysable tannins in the feed. However, it is more difficult to incorporate starch into the diet and the appropriate dose of tannins has not yet been established[61]. In terms of welfare, it is important that the diet meets the nutritional requirements of entire males, which differs from castrated males, and that feed restriction, which can increase antagonistic behaviours[65,66], is avoided.

Genetic Selection: Androstenone and skatole have moderate to high heritability (depending on detection method) and candidate genes have been identified. Boar taint can also differ between breeds[67].Some breeding companies have incorporated boar taint as a factor in selection methods[68,69].

Rearing Female only herds: Rearing only female herds would require ability to reliably sex boar semen in large volumes. However currently this method is not considered viable as sperm sexing is difficult and can lead to reduced fertility in pigs[3,70,71]. The only commercially available method relies on separating X and Y sperm based on their DNA content using high-speed flow cytometers. As porcine X and Y chromosomes differ in DNA content by only a little (3.6%), this method is too slow to produce the quantity of sperm of sufficient purity required for one AI dose[72]. Alternative methodologies are being developed[73], and improvements in AI technology ensuring that the sperm reaches the site of fertilisation can make up for the issues around low doses[70]. In terms of welfare, however, there may be increased risks of pain and discomfort for female pigs during insemination as a more invasive deep intrauterine insemination technique is required when using sexed semen compared with more traditional AI methods[55].

Table 2. Overview of strategies to reduce boar taint and undesirable behaviours in entire male pigs

Strategies	Effect on Boar Taint	Effect on Animal Welfare
Reduced age at slaughter	++	++
Detection of boar taint at the slaughter line	++	=
Management	+	++
Nutrition	+	=
Genetic Selection against boar taint	+	=
Rearing Female only herds	++	-

In many countries, preferred cuts of meat require pigs to be reared to greater slaughter weights (>120kg - post-puberty). For some continental meats, a higher fat content is required which can only be achieved through rearing to even greater slaughter weights; for example, one of the most well-known cured hams from Italy, Parma Ham, must come from pigs aged over 9 months with an average weight of 160kg±10% [74,75]. This brings with it problems of increased risk of boar taint and aggressive and sexual behaviours, which pose legitimate welfare concerns. The rearing of these males intact may not always be appropriate, and alternatives must be sought.

Vaccination to delay puberty

Another alternative to surgical castration consists of vaccinating male pigs to delay puberty. This vaccination, also called immunocastration, has been developed by pharmaceutical company Zoetis under the brand Improvac® (known as Improvest® in the US). Improvac is an active immunisation (vaccination) against gonadotropin-releasing hormone, which inhibits testicular functioning limiting the release of androstenone. Skatole levels are also reduced as an indirect consequence. Improvac can postpone the onset of puberty for at least 10 weeks. While it does require repeated handling and injection, correct handling can minimise the stress associated with the procedure[55] and the injection method is less painful than surgical castration, and likely less painful than castration using local anaesthetics which have to be injected intratesticularly. Improvac injection is an aqueous preparation which produces little reaction at the site of injection[76] and research shows an occurrence of inflammation in ~6% of treated pigs[77]. Research has shown that pigs given Improvac show less aggressive behaviour, mount their penmates less and are without skin lesions when compared to entire males[78,79], and that this effect can last up to 22 weeks after the second dose[80]. Penile injuries were also found to be fewer and less severe in immunocastrates[81]. When properly administered, the risk of pigs not responding to the vaccine is very low, although this risk is actually likely to be higher due to conditions in which it is administered in practice[3]. This risk is reported to be between 0-3% and can be due to poorly administered/missed vaccinations or underlying health problems in the animals[82,83]. This means that there is always a small risk of negative behaviours compared with surgically castrated pigs, but this risk is far lower than entire males.

The standard protocol for normal weight pigs requires two doses at least four weeks apart, while more doses are recommended for heavy pigs (pigs which are slaughtered at much higher body weights, i.e. 160 kg on average, over 9 months of age)[74]. Recent research however, looking at the welfare and behaviour of heavy pigs, found that pigs which received Improvac were more active and had a higher percentage of lesions compared to castrates until after two doses were given, and up to five doses were required to ensure the welfare of the pigs in the study[82].

Benefits to People: This approach has higher associated costs than surgical castration with and without pain relief (Improvac is estimated to cost between €1.40 and €1.50 per dose resulting in costs of €2.80-€3.00 for two doses[42)]. In addition, labour costs can add to this expense; administering two doses plus labour is estimated at €3-4 per pig[83]. For heavy weight pigs, immunocastration is estimated to cost between €4.01 - €5.34[40,42], and this may be higher if more than three doses are required. Additionally, further labour may be required to detect non-responders after the second dose[3]. However, some of this additional cost can be offset by the improved feed conversion ratio in immunocastrates compared with castrated pigs and the higher percentage of lean meat[84]. According to the French Pork Industry costs calculation tool, the overall costs of rearing immunocastrates (two doses for standard weight pigs) is only €2.52 more per pig than for rearing entire males, far less than the almost €7 difference with surgical castration with pain relief[43].

In terms of meat quality, there is little difference to that of meat from either females or castrated males[85], and even for traditional products with larger weight pigs, it is considered a good alternative[83]. Carcasses are also less likely to be rejected than entire males where higher fatness is required[86]. The levels compounds which lead to boar taint were found to be similar in

immunocastrated pigs compared to surgically castrated pigs after two doses[51], and in heavy pigs three doses were found to be sufficient to control boar taint[87]. Due to the risk of non-responders, carcass rejections may be higher than for surgically castrated pigs.

In terms of human health and wellbeing, the handling required to give the vaccine, particularly at heavier weights may cause some practical difficulties[69]. This may be particularly relevant for producers of heavy pigs which require at least three (and in some cases up to five[82]) doses of the vaccine. Uptake of this alternative by producers is also limited due to concerns around consumer perception[88,89], which is in turn affected by lack of knowledge of the issue. While there are regional differences in consumer acceptance of this alternative (for example Italian consumers rated it more positively while German consumers were more cautious[83]), an EU-wide study found that 71% of respondents approved of immunocastration as an alternative to surgical castration[90].

Benefits to the Environment: The impact on the environment of pork production using immunocastrates is said to be intermediate to that of surgical castrates and entire males[36,83]. An experimental study found that, compared to surgically castrated pigs, immunocastration resulted in a reduced carbon footprint of the feed intake (9-16% lower), increased nitrogen and phosphorus efficiency (7-10% and 6-14% higher, respectively), and lower nitrogen and phosphorus excretion (14-19% and 14-24% less, respectively) compared with castrates[36].

Table 3: Summary of pros and cons of surgical castration compared with rearing entire males and immunocastration

	PROS			CONS		
	Animals	People	Planet	Animals	People	Planet
SURGICAL CASTRATION NO ANAESTHESIA OR ANALGESIA	• ↓ Risk of undesirable and injurious behaviours	**Economic:** • Meat quality: Eliminates risk of boar taint; higher intramuscular fat content, lower risk of dark, firm, dry meat, higher pH, meat firmer and less prone to turning rancid	• ↓ Risk of meat being discarded or wasted due to boar taint	• ↑ Pain and stress	**Economic:** • ↓ Selling price per carcass (Higher fat content) • ↑ Costs (time, labour, feed) **Human Wellbeing:** • Unhealthier meat (↑ saturated fat) • Unpleasant procedure for farmers	• ↑ Carbon Footprint of Feed Intake • ↑ Nitrogen & Phosphorus excretion • ↓ Nitrogen & Phosphorus efficiency
SURGICAL CASTRATION WITH ANAESTHESIA AND ANALGESIA	• ↓ Risk of undesirable and injurious behaviours • ↓ Peri- and post-operative pain	**Economic:** • Meat Quality: Eliminates risk of boar taint; higher intramuscular fat content, lower risk of DFD, higher pH, meat firmer and less prone to turning rancid	• ↓ Risk of meat being discarded or wasted due to boar taint	• Pain not eliminated • Method can be aversive/painful • Stressful handling • Effectiveness of approaches to pain relief varies • Risk of mortality	**Economic:** • ↓ Selling price per carcass (Higher fat content), • ↑ Costs (drugs, time, labour, feed) **Human Wellbeing:** • Unhealthier meat (↑ saturated fat) • Unpleasant procedure for farmers	• ↑ Carbon Footprint of Feed Intake • ↑ Nitrogen & Phosphorus excretion • ↓ Nitrogen & Phosphorus efficiency
REARING ENTIRE MALES	• No painful or stressful procedure	**Economic:** • ↑ Selling price per carcass (leaner meat). • ↓ Costs (drugs, time, labour, feed) **Human Wellbeing:** • Leaner heathier meat. • Potential Improved farmer wellbeing – increased profitability	• ↓ Carbon footprint of feed intake • ↓ Nitrogen & phosphorus excretion • ↑ Nitrogen & phosphorus efficiency	• ↑ Risk of undesirable injurious behaviours around puberty.	**Economic:** • ↑ Risk of boar taint	• ↑ Risk of meat being discarded or wasted due to boar taint
VACCINATION TO DELAY PUBERTY	• Minimal pain compared with surgical castration • ↓ Risk of undesirable and injurious	**Economic:** • ↓ Risk of boar taint • Higher selling price per carcass (leaner meat) • Overall costs less than castration with pain relief for standard weight pigs • Generally high level of consumer acceptance **Human Wellbeing:** • Leaner heathier meat	• ↓ Carbon Footprint of Feed Intake • ↓ Nitrogen & Phosphorus excretion • ↑ Nitrogen & Phosphorus efficiency	• Repeated handling stress for each dose required • Some pain due to injection	**Economic:** • Cost of treatment, particularly when more than 2 doses required • Risk of non-responders • Consumer acceptance **Human Wellbeing:** • Practical concerns about dosing heavier pigs	• Environmental impact of pork production with immunocastrates higher than with boars.

Conclusions and recommendations

Surgical castration is painful for pigs, both as the procedure is being performed and in the days after the procedure. While pain relief can be provided to some extent with the use of anaesthesia and analgesia, it is not completely effective. The two main alternatives to surgical castration are rearing entire male pigs and vaccination to delay puberty. Rearing entire males avoids the pain and stress associated with castration, has both economic and health benefits for people, and is the most sustainable form of pork production across a number of environmental metrics.

To minimise the risk of boar taint in the meat, and to reduce the occurrence of unwanted sexual and aggressive behaviours in entire males, there are a number of strategies that can be implemented. Most effective on both counts is reducing the age at slaughter. Where pigs are slaughtered at larger weights, the most effective strategy currently is to have a reliable and fast method for detection of boar taint on the slaughter line so that boar tainted meat can be processed in a way to minimise losses. Genetic, nutritional, and management strategies may also help to reduce the risk of boar taint and in some cases have positive benefits for animal welfare in terms of reducing aggressive and sexual behaviours.

A final alternative is the vaccination against puberty using Improvac, which greatly reduces the risk of boar taint as well as the occurrence of unwanted aggressive and sexual behaviour. This alternative does require repeated dosing of pigs which may be stressful for both the animals and the people performing the doses, although this can be minimised with good management practices. This is a more costly alternative than entire male production, but some performance benefits can offset these costs. Pork production with immunocastrates also performs better on a number of environmental metrics compared to production with surgical castration, although to a lesser extent than entire male production. While immunocastration is effective in reducing the risk of boar taint in heavy weight pig production (~160kg), more work needs to be done to refine the protocol to reduce aggression around puberty.

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