

SURGICAL CASTRATION OF PIGLETS – CHALLENGES AND ALTERNATIVES – A REVIEW

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Abstract

The European Declaration on Alternatives to Surgical Castration of Pigs stipulated that from 2012, surgical castration could only be performed using anesthetics and/or analgesics, and that it would be completely abandoned by 2018. Many Member States disagreed with the conditions set out in the Declaration. The issue of surgical castration arouses serious controversy among consumers due to their concerns over animal welfare and rearing conditions. According to the Council Directive 2008/120/EC of 18 December 2008 laying down the minimum standards for the protection of pigs, surgical castration can be performed without anesthesia until the seventh day of a piglet's life. Castration is considered painful and can have many adverse health and production consequences. Alternatives to surgical castration include immunocastration or the fattening of entire male pigs. However, these methods also evoke many emotions in both consumers and pork producers. The most common concerns relate to the presence of boar taint in pork, and the appearance of aggressive and sexual behavior within herds. Despite ample literature sources from recent decades, it is difficult to definitively determine whether it is possible to completely eliminate the surgical castration of male pigs. While the use of anesthesia and/or analgesics appears to meet the welfare requirements for pigs, it also poses practical and economic challenges to producers.

Key words: pigs, welfare, castration, immunocastration, boar taint, meat quality

In many countries, pork is primarily sourced from fattened gilts and barrows. The fattening of entire male pigs raises concerns due to the potential occurrence of boar taint in meat and aggression within pens. When deciding which animals to select for fattening, producers cannot completely disregard consumer needs or the legal requirements applicable in different countries (Fàbrega et al., 2010; Di Pasquale et al., 2020). Intensive animal production, aimed at boosting production profitability, is controversial among consumers, who pay increasing attention to animal welfare and rearing conditions. Today's consumers are no longer satisfied with an assurance of good-quality meat; they want to be sure that it comes from animals raised in good welfare conditions (Sutherland et al., 2012; Czech et al., 2022). The surgical castration of piglets evokes significant emotional responses due to the stress and pain they experience (Mancini et al., 2017). Surgical castration is regulated by the Council Directive 2008/120/EC of 18 December 2008 laying down the minimum standards for the protection of pigs. In 2010, meetings were held between European representatives from the pork production chain, resulting in the development of The European Declaration on Alternatives to Surgical Castration of Pigs. It stipulated that starting from 1 January 2012, surgical castration would only be performed using anesthetics and/or analgesics. Furthermore, from 1 January 2018, the procedure was to

be completely discontinued. Failing to reach an agreement on the matter, many Member States chose not to sign and adhere to the conditions set out in the declaration (Lin-Schilstra and Ingeenbleek, 2021). Countries that decided to use anesthesia during the surgical castration of piglets include Norway and Sweden, while the use of analgesics has become the most common practice in France, Belgium, and Germany. In turn, the fattening of entire male pigs is a common practice in Spain and Portugal, whereas Ukraine, Poland, the Czech Republic, Italy, Croatia, Bulgaria, and Romania still predominantly use surgical castration without anesthesia. Differences in production strategies can be observed not only between countries but also within them. Belgium, Germany, Norway, Romania, and Ukraine also use immunocastration as an alternative solution; however, it is a rarely chosen method in this respect (Aluwé et al., 2020). In Norway, legal regulations prohibiting surgical castration without pain-relieving measures were implemented as early as in 2002. In Denmark, similar regulations were introduced in 2009, and in Sweden in 2016. In recent years, Germany and France have followed suit, establishing bans on performing the procedure without anesthesia starting in 2021. This variation in the timing of implementing respective regulations highlights the different pace at which European countries address this issue (Lin-Schilstra and Ingeenbleek, 2021).

Bearing the above in mind, the aim of this review article is to summarize findings from the available literature on alternatives to surgical castration in male pigs, as well as to discuss the associated challenges, controversies, and their impact on pig welfare and pork quality.

Surgical castration

According to the Council Directive 2008/120/EC of 18 December 2008, the surgical castration of piglets may be performed without anesthesia not later than the seventh day of piglet's life, and only by a veterinarian or a trained and experienced person using appropriate methods and maintaining hygiene. This decision may have stemmed from the long-standing – but now outdated – knowledge and belief about a lack of pain perception or reduced pain perception in neonates due to their immature nervous systems (Baysinger et al., 2021). However, certain research results have proved increased pain perception in neonates (Mellor and Stafford, 2004; Baysinger et al., 2021), as vertebrates, including pigs, have neuroanatomical structures related to pain perception similar to those in humans (Baars, 2001; Sneddon et al., 2014; Baysinger et al., 2021).

The surgical castration of entire male pigs without anesthesia is highly controversial due to its adverse impact on their welfare. The procedure not only triggers acute pain but may also lead to pain or discomfort that can persist for hours, days, or even weeks afterward (Rault et al., 2011). The specifics of the procedure may vary across countries. The procedure begins with restraining the piglet (by suspending it by its legs, placing it in a specialized castration stand, or holding it manually) to expose the anogenital region (Hay et al., 2003). Subsequently, the scrotum is incised, with either two vertical cuts or one horizontal cut. The testicles are then everted from the surrounding tissue, and the spermatic cord is severed using either a scalpel or an emasculator. A disinfectant is applied to the wound and sometimes antibiotics are additionally administered to prevent infection (Fredriksen et al., 2009; American Veterinary Medical Association, 2013). Despite repeated questioning of the use of antibiotics in animal production, they have been applied during the surgical castration of male piglets (Albernaz-Gonçalves et al., 2022). In a survey study conducted by Fredriksen et al. (2009), the respondents from 10 out of the 26 analyzed countries reported using antibiotics very often or always to prevent infections. Notably, in Italy, the Netherlands, and Estonia, this practice was reported by over 50% of the respondents. One of the risks posed to human health by the use of antibiotics is the continuously growing antibiotic resistance, arousing another controversy among consumers (Barton, 2014). In addition, the castration procedure may cause certain complications such as hemorrhaging, swelling, and infection, potentially affecting performance, posing health risks, and even leading to fatalities of piglets (Hay et al., 2003; Morales et al., 2017).

It is difficult to assess the degree of pain experienced by piglets during and after the procedure. As noted by

Bonneau and Weiler (2019), indicators of pain include increased vocalization, resistance, elevated heart rate, and heightened urine levels of stress hormones. Hay et al. (2003) evaluated pain responses induced by the castration procedure over five days post-operation. Piglets were randomly assigned to three groups of seven piglets each: three underwent castration, two underwent sham castrations, and two were not subjected to any procedures. The authors observed reduced interest in nursing (suckling and massaging the udder) among the castrated piglets for the first 2.5 hours post-procedure. The castrated piglets moved around the pen much more compared to non-castrated individuals. In addition, the castrates exhibited significantly more behaviors that were indicative of pain, such as stiffness and trembling, as well as scratching their rump and wagging their tails for at least two days, and maintained a huddled-up posture throughout the period. However, no significant differences were found in the levels of stress hormones in the urine of castrates and entire male piglets, which was, however, inconsistent with findings of other authors who have observed changes in stress-hormone levels in response to the procedure (Prunier et al., 2005; Marchant-Forde et al., 2009; Maršálek et al., 2011; Lonardi et al., 2015). In another experiment, Taylor and Weary (2000) studied pain responses based on vocalization: pigs in one of their groups were castrated, while sham castrations were performed in the other. The castration procedure was divided into stages: restraint, washing the anogenital region (stages performed in both groups), incision of the scrotum, and severing/pulling the spermatic cord (the last two stages performed only in the castrated group). The authors did not observe any differences in vocalization during the period when all piglets underwent the same treatments from the initial stages (first and second stage). However, the castrated piglets emitted significantly more high-frequency sounds. The pain experienced by piglets during surgical castration has been documented in the literature, and research is underway to validate methods for assessing pain scales in pigs (Ison et al., 2016; Viscardi et al., 2017; Luna et al., 2020; Trindade et al., 2023; da Silva et al., 2023; Robles et al., 2023).

Despite substantial evidence indicating that the surgical castration worsens the welfare of male pigs, discontinuation of this procedure could have serious consequences, like the development of boar taint in pork, as well as increased aggression and sexual behavior within herds. Additionally, it might expose farmers to higher costs associated with implementing alternative methods. Surgical castration without anesthesia is considered an economical approach, and limiting the prophylactic use of antibiotics can further reduce its cost, which usually ranges from €0.78 to €2.99 (Škrlep and Batorek-Lukač, 2023).

Surgical castration with anesthesia and/or analgesia

A solution to mitigate pain during surgical castration may involve the use of anesthesia and/or analgesics. Pre-

ventative measures include general or local anesthesia. General anesthesia can be administered via inhalation using CO₂/O₂ or isoflurane, or intramuscularly using ketamine. While CO₂/O₂ anesthesia is cost-effective, it poses a challenge related to administering an appropriate dose – essential to ensure unconsciousness but not lethal. Isoflurane anesthesia is more costly due to the equipment required (Bonneau and Weiler, 2019). What is more, it elicits adverse environmental impacts because anesthetic gases are greenhouse gases that contribute to climate change, and isoflurane, in particular, contains a chlorine atom, which is implicated in ozone layer depletion and increases harmful ultraviolet radiation effects (Bara and Janczak, 2023). Piglets anesthetized via intramuscular injections using a combination of ketamine and azaperone experience prolonged recovery periods, during which they may suffer from motor coordination issues and low blood pressure. These conditions can lead to hypothermia or even crushing by the sow. Another method harnessed to alleviate pain during surgical castration is local anesthesia, administered directly into the testes or spermatic cord (Kluivers-Poodt, 2007). Lidocaine and procaine are the most commonly used agents, with procaine being less effective in some cases and the only approved local anesthetic for pigs in certain countries (Weiler and Bonneau, 2019). However, Skade et al. (2021) did not confirm its poorer efficacy in their study but observed that procaine injections caused greater discomfort in piglets compared to lidocaine injections. The efficacy of local anesthesia also depends on the technique of administration and the interval between injection and the procedure. Analgesic drugs are commonly administered in addition to general and local anesthesia. Meloxicam and flunixin are widely used to this end, though their standalone use does not alleviate pain during castration. Instead, they effectively reduce post-procedure pain (Bonneau and Weiler, 2019). Hansson et al. (2011) evaluated pain responses in piglets castrated with anesthesia and observed that lidocaine, administered directly to the testes, alleviated pain behaviors during the procedure, while meloxicam reduced responses afterward. Studies by Haga and Rønneheim (2005), Hansson et al. (2011), and Kluivers-Poodt et al. (2012) confirmed changes in the physiology and/or behavior of piglets subjected to surgical castration with anesthesia that indicated the pain-relieving effect. In contrast, Sutherland et al. (2010, 2012), Viscardi and Turner (2018) and Coutant et al. (2022 a, b) did not confirm any improvements in this regard. Opposite findings from these studies may be attributed to differences in the anesthetics and/or analgesics used, as well as in dosing and administration methods.

The use of pain-relieving measures during and after castration is limited due to their efficacy, legal requirements in different countries, and the costs borne by farmers. Courboulay et al. (2010) estimated that local anesthesia increased labor requirements by 39–52%. Similarly, Scollo et al. (2021) reported labor- and time-consumption increases of 56.5% and 76.8%, respectively, depend-

ing on the pain relief method used. They also calculated the costs: castration without anesthesia – €0.32 per piglet, castration using azaperone and meloxicam – €3.14, castration with procaine and meloxicam – €3.30.

Boar taint

Boar taint poses a challenge to the pork meat industry, forcing the use of, among other things, strategies to mask it (Martínez et al., 2016). Its occurrence supports the advisability of the castration practice. This unpleasant odor and flavor in the meat results from the accumulation of certain compounds in the adipose tissue, including primarily androstenone, skatole, and indole compounds. The odor is described as urinous and fecal, and also resembling the odor of sweat or naphthalene (Duarte et al., 2021). Androstenone (5 α -androst-16-en-3-one) is a steroid produced in the Leydig cells of the testes, with its synthesis regulated by the luteinizing hormone (LH), during sexual maturity and functions as a pheromone, influencing reproductive behaviors and indicating readiness for mating (Squires et al., 2020). It is metabolized in the liver and testes and then excreted in the urine. However, non-degraded androstenone accumulates in the adipose tissue (Duarte et al., 2021), and its odor is described as reminiscent of sweat, dirt, silage, and parsnip (Borrišer-Pairó et al., 2017). Skatole (3-methylindole) is produced in the large intestines of pigs of both sexes upon tryptophan degradation by bacteria and accumulates in the adipose tissue if not degraded. Its production depends on environmental factors, particularly diet and housing conditions, and, to a lesser extent, on genetic factors, and it is responsible for the fecal odor in pork (Duarte et al., 2021). Males cannot metabolize and eliminate it through the liver because their sex steroids inhibit these processes. Other compounds that potentially influence the presence of boar taint by enhancing the effects of skatole and androstenone include aldehydes, short-chain fatty acids, phenols (p-cresol, 4-ethylphenol), and 4-phenyl-3-buten-2-one (Squires et al., 2020).

Heyrman et al. (2021) investigated the frequency and impact of aggressive behaviors among male pigs, including related skin changes, as well as the influence of season of the year and lean meat content on the occurrence of boar taint in meat across 22 farms (16,791 male pigs). The average frequency of boar taint was 1.8 $\pm$ 0.8% and varied between and within farms, which, according to the authors, supported the hypothesis that the appearance of odor depended on various factors. They observed that aggressive behavior may contribute to an increased incidence of boar taint, and that the odor was more prevalent in the winter than in the summer. They attributed these observations to the shorter daylight hours and the associated increased testicular activity in the male pigs. Also, they found out that the boar taint was significantly less perceptible in the pigs with a higher lean meat content. Similarly, Thomsen et al. (2015) demonstrated increased androstenone level in the winter compared to the summer, while such season-dependent differences were not observed in skatole levels.

Attempts have been made to reduce the incidence of boar taint by modifying pigs' diets based on the assumption that feeding may play a role in regulating the levels of the compounds responsible for the odor—skatole and indole. Among other factors, diet can influence a reduction in tryptophan availability by modifying the endogenous microbiome, as well as gastrointestinal transit time, and, thereby, the rate of absorption of skatole and indole (Bee et al., 2020). Hansen et al. (2008) investigated the impact of administering high-fiber diets for one or two weeks before slaughter on the occurrence of boar taint. In their experiment, pigs were fed organic feed containing additives: dried chicory roots (10–13.3%) in the first group and blue lupine (25%) in the second group. They showed that the diet supplemented with lupine reduced the levels of skatole in blood and fat, but had a negative impact on growth rate and feed conversion. In turn, a reduced concentration of indole was determined in the pigs fed with chicory. Feeding male pigs dried chicory and lupine for two weeks before slaughter reduced the sensory perception of boar taint in the meat more effectively than the feeding for only seven days. Other studies have also investigated the effect of dried chicory root on reducing boar taint, reporting positive results regarding its ability to lower skatole levels (Hansen et al., 2006; Maribo et al., 2010; Li et al., 2019). Additionally, various strategies aimed at controlling skatole and indole levels have been explored as well. For instance, Zamaratskaia et al. (2005 c) observed a reduced level of skatole in the fat of entire male pigs fed raw potato starch. Similarly, Chen et al. (2007), using the same additive, noted a decrease in skatole levels in fat and plasma but no effect on indole levels. Büttner et al. (2020) showed a reduced concentration of skatole in uncastrated male pigs of the Piétrain breed by adding 10% native potato starch to their diet one month before slaughter. Zamaratskaia et al. (2006) demonstrated reduced levels of both skatole and indole in the liver of female pigs fed raw potato starch. In contrast, Aluwé et al. (2009) did not observe a reduction in boar taint after administering diets with varying percentages of raw potato starch. While et al. (2012) found decreased skatole concentrations in the large intestine and adipose tissue when using a diet with dried Jerusalem artichoke. Similar results indicating reduced skatole levels in fat were achieved by Okrouhlá et al. (2020) when feeding pigs Jerusalem artichoke. Reduced skatole levels in fat were also observed when administering flaxseed to female pigs (Kouba et al., 2003). However, skatole and indole concentrations were higher in the adipose tissue of pigs fed a diet supplemented with garlic essential oil, with levels increasing as the additive concentration increased (Leong et al., 2011). Marro et al. (2024) studied the effect of plant extracts on skatole levels in blood and fat tissue. They also observed an increased skatole concentration in pigs administered garlic essential oil, whereas oregano essential oil did not significantly affect the skatole concentration in either blood or fat.

Meier-Dinkel et al. (2013) and Borrissier-Pairó et al. (2017) investigated consumer sensitivity to boar taint in meat. They observed significant subjectivity in odor assessment, with evaluations of consumer varying depending on their sensitivity to odors. Borrissier-Pairó et al. (2017) found out that consumers with a high sensitivity to androstenone were more likely to reject meat with boar taint. Their study also examined the impact of meat processing methods (vacuum-cooked versus fried/breaded with garlic and parsley) on consumer evaluation. The frying/breading method was found to increase the acceptance of meat from entire male pigs, even among consumers highly sensitive to androstenone. These proposed methods suggest potential solutions for the meat industry, such as implementing a classification system for tainted meat in slaughterhouses and using it in specific products where the unpleasant odor can be masked. Literature works indicate that there are varying thresholds for androstenone and skatole contents that are acceptable to consumers. In the 1990s, these thresholds were reported at 0.5 to 1 µg/g of fat for androstenone and 0.2 to 0.25 µg/g of fat for skatole. However, later consumer studies have shown that an androstenone level exceeding 1 µg/g of melted fat was still acceptable for pork tenderloin (Meier-Dinkel et al., 2013).

When deciding to forgo surgical castration, it is crucial to pay particular attention to the methods for controlling and detecting boar taint in meat. New investigations on detection methods (Font-i-Furnols et al., 2020; Burgeon et al., 2021) and on methods for reducing the odor (Squires et al., 2020; Duarte et al., 2021) still appear in literature, highlighting the ongoing relevance of this issue.

Aggression and sexual behavior in pens

The emergence of aggression and sexual behavior within herds can pose a significant problem for swine production and has a substantial adverse impact on animal welfare. The fattening of entire male pigs may exacerbate the occurrence of aggressive and sexual behaviors due to the accumulation of sex hormones. Uncastrated individuals are more likely to fight for dominance within a group, by biting, chasing, or striking, which may result in wounds, cuts, and abrasions. In addition to aggression, sexual behaviors are also problematic as uncastrated males may experience leg injuries and lameness due to mounting behavior (Fredriksen et al., 2008). When comparing the aggressive and sexual behaviors of females and uncastrated males, Rydhmer et al. (2004) observed more injuries among entire male pigs, with 15% of all males and 6% of females exhibiting issues related to lameness or leg injuries. Beside limb injuries, mounting can also lead to penile injuries. Weiler et al. (2016) examined the penises of entire male pigs from both experimental and commercial farms. They noted that 76.6–91.3% of entire male pigs from the experimental farms had scars and/or fresh wounds on their organ, while this problem was observed in 64.0–94.9% of entire male pigs from the

commercial farms. In addition to exhibiting aggression towards other individuals, uncastrated males can pose a threat to the workers who handle them (Palmer et al., 2018). Producers can minimize the problem of aggression by ensuring sufficient space in pens, unlimited access to feed, grouping in pens by sex, early socialization in groups, rare mixing between pens, and also by providing natural materials that enrich the environment the pigs are kept in (Borell et al., 2020).

Considering the impact of surgical castration of entire male pigs on their welfare, the behavioral and health consequences that may arise from aggressive and sexual behaviors cannot be overlooked. Foregoing surgical castration, while improving the welfare of piglets, may impair the welfare of adult individuals, triggering aggression, attacks, and an increased frequency of injuries (Rydmer et al., 2006).

Immunocastration

Immunocastration is one of several known alternatives to surgical castration. It is performed by administering Improvac® (Zoetis, Belgium) in two injections (Wicks et al., 2013). This product was approved for market use in the EU in May 2009 (Zamaratskaia and Rasmussen, 2015). According to the manufacturer's recommendations, it should be administered subcutaneously using safe devices designed for this purpose. The first dose of the product is given to uncastrated males at the age of eight to nine weeks, and the next dose no earlier than four weeks after the first, but four to six weeks before slaughter.

Immunocastration induces an immune response against the endogenous gonadotropin-releasing factor (GnRF), which is responsible for regulating testicular function through the gonadotropic hormones LH and FSH. It is expected to inhibit testicular development, and thus reduce sex hormone production (Bonneau and Weiler, 2019). The full effect of immunocastration is achieved only after the second dose of the product. Although the first dose does not modify testicular functions, it prepares the animal for the immune response to GnRF upon administration of the second dose (Weiler et al., 2021).

The reduction in sex hormone production resulting from immunocastration decreases the frequency of boar taint occurrence. An experiment by Fazarinc et al. (2023) demonstrated that the concentration of androstenone exceeded the threshold of 0.5 µg/g in 81.8% of the commercial, hybrid entire male pigs, while in a group subjected to immunocastration, the percentage was only 4.3% of the males. Results confirming reduced levels of sex hormones in entire male pigs of the WBP (Polish Large White) breed slaughtered at a body weight of 120 kg were obtained in an experiment by Pawlicki et al. (2022). In the blood serum and testes of immunocastrated males, lower levels of androstenone, testosterone, and estradiol were found. Reduced hormone levels were also demonstrated by Brunius et al. (2011), Metz et al. (2002), and Han et al. (2019) who reported lower skatole

concentrations in the adipose tissue and androstenone in immunocastrated than entire males.

In addition to the positive impact on reducing boar taint, immunocastration also minimizes the consequences of sexual behavior. Zoels et al. (2020) compared the frequency of penile injuries in entire male pigs and immunocastrated pigs. They showed that 91.7% of the entire males exhibited signs of injuries, while in the immunocastrated individuals, this percentage ranged from 16.7% to 41.7%. Similar results were obtained in an experiment by Reiter et al. (2017), where the number of penile injuries in entire males was 75.8%, compared to 48.4% recorded in the immunocastrated individuals. Zamaratskaia et al. (2008) compared the behaviors of entire males and immunocastrates, and showed no significant differences in the time spent sleeping, walking, or eating. However, they observed that the immunocastrated males exhibited fewer aggressive behaviors (biting the tails or ears of other pigs), social behaviors (pigs interacting non-aggressively), and manipulative behaviors (nibbling, pushing). Reducing aggressive behaviors not only positively affects pig welfare but may also decrease water consumption (Muniz et al., 2021).

Despite the many proven positive effects of immunocastration, this method has certain drawbacks. These include the costs associated with purchasing the product, as well as the labor required for the injections (Bonneau and Weiler, 2019). De Roest et al. (2009) estimated the cost of immunocastration at €3 to €3.36 per pig, depending on the country. Another issue is the social acceptance of immunocastration; consumers have concerns about the potential presence of residues in meat (Fredriksen et al., 2011; Kress et al., 2019). Their critical stance was confirmed by the results of a study by Heid and Hamm (2012), which analyzed the attitudes of German consumers towards immunocastration and showed that the respondents were worried about, among other things, hormone residues in the meat they consumed. Additionally, handling heavy pigs for subsequent injections can be challenging, prompting some farmers to consider the method impractical (Brunius et al., 2011). Lin-Schilstra and Ingenbleek (2022) conducted a scenario analysis for implementing immunocastration as a single solution for piglet castration. In their study, two extreme scenarios were constructed in which all the ambiguous issues regarding immunocastration were viewed either positively or negatively. The authors concluded that there was a low likelihood that immunocastration could be implemented as the sole alternative to surgical castration in entire male pigs.

An important aspect is providing an appropriate diet for immunocastrated pigs. Nutrition plays a crucial role in growth performance, carcass quality, and overall health. Bee et al. (2020) highlighted the specific dietary needs of immunocastrates, particularly their amino acid requirements. Decreased levels of sex hormones after the second vaccine dose trigger metabolic changes, which was confirmed by lysine requirements decrease by up to

30% in the immunocastrated pigs compared to the entire male pigs. Muniz et al. (2019) found out that also the immunocastrated pigs required more lysine than the surgically castrated males.

Fattening entire male pigs

Besides unwanted consequences such as boar taint and aggression, fattening entire male pigs has also positive outcomes. The feed conversion of entire male pigs is more efficient and ensures higher lean meat deposition, thereby boosting production profitability (Daxanberger et al., 2001; De Roest et al., 2009; Škrlep et al., 2020).

Kress et al. (2020), who compared carcass quality based on sex (entire male pigs, gilts, barrows), showed that the carcasses of entire male pigs contained the most lean meat and had thinner backfat compared to those of the castrated individuals. They also showed that the combined mass of valuable carcass elements in entire male pigs was 48.33 ± 0.16 kg/carcass, which was not statistically significantly higher compared to immunocastrates or barrows, but significantly lower than in gilts.

Aaslyng et al. (2019) reported that the carcasses of entire male pigs showed a higher meat content compared to castrates, but that the meat obtained from entire males was less tender and had a lower protein content. Opposite observations were made by Lundström et al. (2009), who stated that the carcasses of entire males were characterized by better quality and higher protein content of the meat than those of the castrates. Aaslyng and Hviid (2020) studied meat quality in the Danish pig population by randomly selecting entire male pigs, gilts, and barrows from various slaughterhouses. They demonstrated that the meat from the pigs of each sex was of high quality with a low coefficient of variation for pH and color. In addition, they observed increased drip loss from the meat of entire male pigs and higher shear-force values. Another important aspect concerning entire male pigs, besides the quality of meat, is in using their meat in processing and as raw material. An experiment by Škrlep et al. (2016), which tested the suitability of meat from entire male pigs and immunocastrates for dry-cured ham production, showed that hams from the entire males had higher processing losses than those from the immunocastrated males. This could be related to a higher muscle mass and a lower intramuscular fat (IMF) content, making the hams from the entire males drier, less marbled, tougher, and more intensely colored.

Despite the information available in the literature indicating the presence of boar taint in the meat from entire male pigs, it may be utilized for processing. Wauters et al. (2017) suggested that meat affected by boar taint could be used to produce cold-served meat products. In turn, Mörlein et al. (2019) stated that up to 33% of the meat and fat from carcasses in which the melted fat had skatole concentrations of up to $0.3 \mu\text{g/g}$ and androstenone concentrations of up to $3.8 \mu\text{g/g}$, could be used in the production of high-fat sausages.

To address the issue of boar taint in meat from intact male pigs, researchers have examined the link between its occurrence and the sexual maturity of these animals. This correlation arises from the increasing synthesis of androstenone with sexual development. A similar relationship has been observed for skatole levels, likely due to the inhibition of skatole degradation by androstenone and other sex steroids (Larzul, 2021). A correlation between skatole and androstenone levels was also demonstrated by Zamaratskaia et al. (2004). Babol et al. (2004) examined the impact of maturation on skatole levels in plasma. They observed low skatole levels at 150–180 days of age, which increased during the 180–190 to 240–360-day range, depending on the pig breed. In another study, Zamaratskaia et al. (2005 a) noted a relationship between body weight and plasma levels of compounds responsible for boar taint. Skatole and testicular steroid levels in plasma were higher in the pigs weighing 115 kg compared to those with lower body weights (90 and 100 kg). Further on, Zamaratskaia et al. (2005 b) found associations between skatole and androstenone levels and factors related to maturation, such as gonadal hormone levels and reproductive organ size. Slaughtering pigs at lower body weights can also influence carcass and meat quality. Fàbrega et al. (2011) showed that the meat from pigs slaughtered at 105 kg exhibited significantly higher lightness (L^*) and higher drip loss compared to the meat from pigs slaughtered at 130 kg. Additionally, carcasses from the pigs slaughtered at a live weight of 105 kg had a higher percentage of lean meat.

Despite findings indicating a relationship between sexual maturity and boar taint, there is no universal age or body weight at which boar taint-free meat can consistently be obtained from entire male pigs.

Other alternatives

In addition to the most commonly used alternatives to surgical castration of male pigs (immunocastration and fattening of entire males), other methods are being investigated that could potentially minimize the consequences of abandoning the procedure. However, these methods should not be regarded as viable solutions to the problem, as they remain in the research phase. One of these is genetic selection aimed at reducing the compounds responsible for boar taint. This is possible due to the highly heritable nature of androstenone (0.55–0.88) and skatole (0.23–0.55) (Duarte et al., 2021). As a result, it seems feasible to select individuals in which boar taint is reduced (Tajet et al., 2006; Squires, 2006; Parois et al., 2015). However, this method carries the risk of reproductive losses because androstenone synthesis is linked to other testicular steroids, which can adversely impact sexual maturity (Duarte et al., 2021).

Another method entails the use of sexed semen, which would allow for the fattening of gilts only, potentially eliminating the problem of boar taint entirely (Čandek-Potokar and Batorek-Lukač, 2015). Although technologies for differentiating sperm based on sex chromosomes

do exist, there are issues related to the availability of this semen for commercial production. Performing deep intrauterine insemination requires a large number of sperm cells (Waberski et al., 2019). Additionally, such sperm cells are more susceptible to damage, and their use in fertilization is characterized by lower efficiency (Gaudy, 2014; Quelhas et al., 2023). This method is particularly costly and requires skilled personnel to execute (Quelhas et al., 2023).

Conclusions

Surgical castration causes pain to piglets and negatively impacts their welfare. Consumer pressure has forced producers and administrative bodies to take steps to introduce alternative methods. The most popular alternatives include the use of pain-relieving methods, immunocastration, and the fattening of entire male pigs. Each of these methods has certain consequences, such as increased production costs, changes in behavior and welfare of individuals, handling difficulties, the presence of boar taint, and negative impacts on the quality of pork. Therefore, it is essential to choose a method that considers pig welfare, does not significantly increase production costs compared to barrow fattening, and allows consumers to consume pork in line with their sensitivity to pig rearing conditions.

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References

- Aaslyng M.D., Hviid M. (2020). Meat quality in the Danish pig population anno 2018. *Meat Sci.*, 163.
- Aaslyng M.D., Støier S., Lund B.W., Nielsen D.B. (2019). Slaughtering of entire male pigs seen from the slaughterhouse perspective. *IOP Conf. Ser: Earth Environ. Sci.*, 333: 1–6.
- Albernaz-Gonçalves R., Antillón G.O., Hötzel M.J. (2022). Linking animal welfare and antibiotic use in pig farming – a review. *Animals*, 12: 216.
- Aluwé M., Millet S., Nijs G., Tuytens F.A.M., Verheyden K., De Brabander H.F., De Brabander D.L., Van Oeckel M.J. (2009). Absence of an effect of dietary fibre or clinoptilolite on boar taint in entire male pigs fed practical diets. *Meat Sci.*, 82: 346–352.
- Aluwé M., Heyrman E., Almeida J.M., Babol J., Battacone G., Čitek J., Font i Furnols M., Getya A., Karolyi D., Kostyra E., Kress K., Kušec G., Mörlin D., Semenova A., Škrlep M., Stoyanchev T., Tomašević I., Tudoreanu L., Van Son M., Żakowska-Biemans S., Zamaratskaia G., Van den Broeke A., Egea M. (2020). Exploratory survey on European consumer and stakeholder attitudes towards alternatives for surgical castration of piglets. *Animals*, 10.
- American Veterinary Medical Association. (2013). Literature review on the welfare implications of swine castration. Available online: <https://www.avma.org/resources-tools/literature-reviews/welfare-implications-swine-castration>
- Baars B.J. (2001). There are no known differences in brain mechanisms of consciousness between humans and other mammals. *Anim. Welfare*, 10: 31–40.
- Babol J., Zamaratskaia G., Juneja R.K., Lundström K. (2004). The effect of age on distribution of skatole and indole levels in entire male pigs in four breeds: Yorkshire, Landrace, Hampshire and Duroc. *Meat Sci.*, 67: 351–358.
- Bara M., Janczak A. (2023). Toxicity of anesthetic gases: exposure in operating rooms and influence on the environment. *Prospect. Pharm. Sci.*, 21: 1–5.
- Barton M.D. (2014). Impact of antibiotic use in the swine industry. *Curr. Opin. Microbiol.*, 19: 9–15.
- Baysinger A., Webb S.R., Brown J., Coetzee J.F., Crawford S., DeDecker A., Karriker L.A., Pairis-Garcia M., Sutherland A.M., Viscardi A.V. (2021). Proposed multidimensional pain outcome methodology to demonstrate analgesic drug efficacy and facilitate future drug approval for piglet castration. *Anim. Health Res. Rev.*, 22: 163–176.
- Bee G., Quiniou N., Maribo H., Zamaratskaia G., Lawlor P.G. (2020). Strategies to meet nutritional requirements and reduce boar taint in meat from entire male pigs and immunocastrates. *Animals*, 10.
- Bonneau M., Weiler U. (2019). Pros and cons of alternatives to piglet castration: Welfare, boar taint, and other meat quality traits. *Animals*, 9.
- Borell E.V., Bonneau M., Holinger M., Prunier A., Stefanski V., Zöls S., Weiler U. (2020). Welfare aspects of raising entire male pigs and immunocastrates. *Animals*, 10.
- Borriesser-Pairo F., Panella-Riera N., Gil M., Kallas Z., Linares M.B., Egea M., Garrido M.D., Oliver M.A. (2017). Consumers' sensitivity to androstenone and the evaluation of different cooking methods to mask boar taint. *Meat Sci.*, 123: 198–204.
- Brunius C., Zamaratskaia G., Andersson K., Chen G., Norrby M., Madej A., Lundström K. (2011). Early immunocastration of male pigs with Improvac® – Effect on boar taint, hormones and reproductive organs. *Vaccine*, 29: 9514–9520.
- Burgeon C., Debliquy M., Lahem D., Rodriguez J., Ly A., Fauconnier M.L. (2021). Past, present, and future trends in boar taint detection. *Trends Food Sci. Technol.*, 112: 283–297.
- Büttner S., Heidbüchel K., Höinghaus K., Baldinger L., Weissmann F., Bussemas R. (2020). Fattening of entire male pigs as an alternative to piglet castration. *Thünen Institut of Organic Farming*, 15.
- Čandek-Potokar M., Batorek-Lukač N. (2015). Alternatives to surgical castration of pigs. *Bulg. J. Anim. Husbandry*, 52: 41–51.
- Chen G., Zamaratskaia G., Andersson H.K., Lundström K. (2007). Effects of raw potato starch and live weight on fat and plasma skatole, indole and androstenone levels measured by different methods in entire male pigs. *Food Chem.*, 101: 439–448.
- Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs (codified version).
- Courboulay V., Hemonic A., Gadonna M., Prunier A. (2010). Castration avec anesthésie locale ou traitement anti-inflammatoire: quel impact sur la douleur des porcelets et quelles conséquences sur le travail en élevage. *Journées Rech. Porcine*, 42: 27–33.
- Coutant M., Malmkvist J., Kaiser M., Foldager L., Herskin M.S. (2022 a). Piglets' acute responses to local anesthetic injection and surgical castration: Effects of the injection method and interval between injection and castration. *Front. Vet. Sci.*, 9.
- Coutant M., Malmkvist J., Kaiser M., Foldager L., Herskin M.S. (2022 b). Piglets' acute responses to procaine-based local anesthetic injection and surgical castration: Effects of two volumes of anesthetic. *Front. Pain Res.*, 3.
- Czech A., Kusior G., Zięba G., Łukaszewicz M., Grela E.R. (2022). Effect of immunocastration on the steroid hormones content, serum lipid profile, and fatty acid profile in tissues of porkers fed dry or wet diet. *Anim. Sci. Pap. Rep.*, 40: 171–184.
- da Silva G.V., Pivato G.M., Peres B.G., Luna S.P.L., Pairis-Garcia M.D., Trindade P.H.E. (2023). Simplified assessment of castration-induced pain in pigs using lower complexity algorithms. *Sci. Rep.*, 13.
- Daxenberger A., Hageleit M., Kraetzl W.D., Lange I.G., Claus R., Le Bizec B., Meyer H.H. (2001). Suppression of androstenone in entire male pigs by anabolic preparations. *Livest. Prod. Sci.*, 69: 139–144.
- De Roest K., Montanari C., Fowler T., Baltussen W. (2009). Resource

- efficiency and economic implications of alternatives to surgical castration without anaesthesia. *Animal*, 3: 1522–1531.
- Di Pasquale J., Vecchio Y., Martelli G., Sardi L., Adinolfi F., Nannoni E. (2020). Health risk perception, consumption intention, and willingness to pay for pig products obtained by immunocastration. *Animals*, 10.
- Duarte D.A.S., Schroyen M., Mota R.R., Vanderick S., Gengler N. (2021). Recent genetic advances on boar taint reduction as an alternative to castration: a review. *J. Appl. Genet.*, 62: 137–150.
- Fàbrega E., Velarde A., Cros J., Gispert M., Suárez P., Tibau J., Soler J. (2010). Effect of vaccination against gonadotrophin-releasing hormone, using Improvac®, on growth performance, body composition, behaviour and acute phase proteins. *Livest. Sci.*, 132: 53–59.
- Fàbrega E., Gispert M., Tibau J., Hortós M., Oliver M.A., Font i Furnols M. (2011). Effect of housing system, slaughter weight and slaughter strategy on carcass and meat quality, sex organ development and androstenone and skatole levels in Duroc finished entire male pigs. *Meat Sci.*, 89: 434–439.
- Fazarinc G., Batorek-Lukač N., Škrlep M., Poklukar K., Van den Broeke A., Kress K., Labussière E., Stefanski V., Vrecl M., Čandek-Potokar M. (2023). Male reproductive organ weight: criteria for detection of androstenone-positive carcasses in immunocastrated and entire male pigs. *Animals*, 13.
- Font-i-Furnols M., Martín-Bernal R., Aluwé M., Bonneau M., Haugen J.E., Mörlein D., Panella-Riera N., Škrlep M. (2020). Feasibility of on/at line methods to determine boar taint and boar taint compounds: An overview. *Animals*, 10.
- Fredriksen B., Lium B.M., Marka C.H., Mosveen B., Nafstad O. (2008). Entire male pigs in farrow-to-finish pens – Effects on animal welfare. *Appl. Anim. Behav. Sci.*, 110: 258–268.
- Fredriksen B., Font i Furnols M.F., Lundström K., Migdal W., Prunier A., Tuytens F.A., Bonneau M. (2009). Practice on castration of piglets in Europe. *Animal*, 3: 1480–1487.
- Fredriksen B., Johnsen A.M.S., Skuterud E. (2011). Consumer attitudes towards castration of piglets and alternatives to surgical castration. *Res. Vet. Sci.*, 90: 352–357.
- Gaudy J. (2014). Alternatives to surgical castration in pigs: a review. *Indian J. Anim. Prod. Mgmt.*, 30: 1–6.
- Haga H.A., Ranheim B. (2005). Castration of piglets: the analgesic effects of intratesticular and intrafunicular lidocaine injection. *Vet. Anaesth. Analg.*, 32: 1–9.
- Han X., Zhou M., Cao X., Du X., Meng F., Bu G., Kong F., Huang A., Zeng X. (2019). Mechanistic insight into the role of immunocastration on eliminating skatole in boars. *Theriogenology*, 131: 32–40.
- Hansen L.L., Mejer H., Thamsborg S.M., Byrne D.V., Roepstorff A., Karlsson A.H., Hansen-Møller J., Jensen M.T., Tuomola M. (2006). Influence of chicory roots (*Cichorium intybus* L.) on boar taint in entire male and female pigs. *Anim. Sci.*, 82: 359–368.
- Hansen L.L., Stolzenbach S., Jensen J.A., Henckel P., Hansen-Møller J., Syriopoulos K., Byrne D.V. (2008). Effect of feeding fermentable fibre-rich feedstuffs on meat quality with emphasis on chemical and sensory boar taint in entire male and female pigs. *Meat Sci.*, 80: 1165–1173.
- Hansson M., Lundeheim N., Nyman G., Johansson G. (2011). Effect of local anaesthesia and/or analgesia on pain responses induced by piglet castration. *Acta Vet. Scand.*, 53: 1–9.
- Hay M., Vulin A., Génin S., Sales P., Prunier A. (2003). Assessment of pain induced by castration in piglets: behavioral and physiological responses over the subsequent 5 days. *Appl. Anim. Behav. Sci.*, 82: 201–218.
- Heid A., Hamm U. (2012). Consumer attitudes towards alternatives to piglet castration without pain relief in organic farming: Qualitative results from Germany. *J. Agr. Environ. Ethics*, 25: 687–706.
- Heyrman E., Millet S., Tuytens F.A.M., Ampe B., Janssens S., Buys N., Wauters J., Vanhaecke L., Aluwé M. (2021). On-farm prevalence of and potential risk factors for boar taint. *Animal*, 15.
- Ison S.H., Clutton R.E., Di Giminiani P., Rutherford K.M. (2016). A review of pain assessment in pigs. *Front. Vet. Sci.*, 3.
- Kluivers-Poodt M. (2007). Castration under anaesthesia and/or analgesia in commercial pig production. *Anim. Sci. Group*, 85: 1–2.
- Kluivers-Poodt M., Houx B.B., Robben S.R.M., Koop G., Lambouij E., Hellebrekers L.J. (2012). Effects of a local anaesthetic and NSAID in castration of piglets, on the acute pain responses, growth and mortality. *Animal*, 6: 1469–1475.
- Kouba M., Enser M., Whittington F.M., Nute G.R., Wood J.D. (2003). Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. *J. Anim. Sci.*, 81: 1967–1979.
- Kress K., Millet S., Labussière E., Weiler U., Stefanski V. (2019). Sustainability of pork production with immunocastration in Europe. *Sustainability*, 11.
- Kress K., Hartung J., Jasny J., Stefanski V., Weiler U. (2020). Carcass characteristics and primal pork cuts of gilts, boars, immunocastrates and barrows using AutoFOM III data of a commercial abattoir. *Animals*, 10.
- Larzul C. (2021). How to improve meat quality and welfare in entire male pigs by genetics. *Animals*, 11.
- Leong J., Morel P.C., Purchas R.W., Wilkinson B.H. (2011). Effects of dietary components including garlic on concentrations of skatole and indole in subcutaneous fat of female pigs. *Meat Sci.*, 88: 45–50.
- Li X., Jensen B.B., Canibe N. (2019). The mode of action of chicory roots on skatole production in entire male pigs is neither via reducing the population of skatole-producing bacteria nor via increased butyrate production in the hindgut. *Appl. Environ. Microb.*, 85.
- Lin-Schilstra L., Ingenbleek P.T. (2021). Examining alternatives to painful piglet castration within the contexts of markets and stakeholders: A comparison of four EU countries. *Animals*, 11.
- Lin-Schilstra L., Ingenbleek P.T. (2022). A scenario analysis for implementing immunocastration as a single solution for piglet castration. *Animals*, 12.
- Lonardi C., Scollo A., Normando S., Brscic M., Gottardo F. (2015). Can novel methods be useful for pain assessment of castrated piglets? *Animal*, 9: 871–877.
- Luna S.P.L., de Araújo A.L., da Nóbrega Neto P.I., Brondani J.T., de Oliveira F.A., Azerêdo L.M.D.S., Telles F.G., Trindade P.H.E. (2020). Validation of the UNESP-Botucatu pig composite acute pain scale (UPAPS). *PLoS One*, 15.
- Lundström K., Matthews K.R., Haugen J.E. (2009). Pig meat quality from entire males. *Animal*, 3: 1497–1507.
- Mancini M.C., Menozzi D., Arfini F. (2017). Immunocastration: Economic implications for the pork supply chain and consumer perception. An assessment of existing research. *Livest. Sci.*, 203: 10–20.
- Marchant-Forde J.N., Lay D.C., McMunn K.A., Cheng H.W., Pajor E.A., Marchant-Forde R.M. (2009). Postnatal piglet husbandry practices and well-being: the effects of alternative techniques delivered separately. *J. Anim. Sci.*, 87: 1479–1492.
- Maribo H., Magnussen C.C., Jensen B.B. (2010). Effect of 15% dried chicory root in feed for male pigs. *Meddelelse*, 876.
- Marro P., Wesoly R., Stefanski V. (2024). Influence of different plant extracts on CYP-mediated skatole and indole degradation in pigs. *Animals*, 14: 888.
- Maršálek P., Svoboda M., Smutná M., Blahová J., Večerek V. (2011). Neopterin and biopterin as biomarkers of immune system activation associated with castration in piglets. *J. Anim. Sci.*, 89: 1758–1762.
- Martínez B., Rubio B., Viera C., Linares M.B., Egea M., Panella-Riera N., Garrido M.D. (2016). Evaluation of different strategies to mask boar taint in cooked sausage. *Meat Sci.*, 116: 26–33.
- Meier-Dinkel L., Sharifi A.R., Tholen E., Frieden L., Bücking M., Wicke M., Mörlein D. (2013). Sensory evaluation of boar loins: Trained assessors' olfactory acuity affects the perception of boar taint compounds. *Meat Sci.*, 94: 19–26.
- Mellor D.J., Stafford K.J. (2004). Animal welfare implications of neonatal mortality and morbidity in farm animals. *Vet. J.*, 168: 118–133.
- Metz C., Hohl K., Waidelich S., Drochner W., Claus R. (2002). Active immunization of boars against GnRH at an early age: consequences for testicular function, boar taint accumulation and N-retention. *Livest. Prod. Sci.*, 74: 147–157.
- Morales J., Dereu A., Manso A., de Frutos L., Piñeiro C., Manzanilla

- E.G., Wuyts N. (2017). Surgical castration with pain relief affects the health and productive performance of pigs in the suckling period. *Porcine Health Manage.*, 3: 1–6.
- Mörlein J., Meier-Dinkel L., Gertheiss J., Schnäkel W., Mörlein D. (2019). Sustainable use of tainted boar meat: Blending is a strategy for processed products. *Meat Sci.*, 152: 65–72.
- Muniz H.D.C.M., da Rocha L.T., Kunzler J.S., Ceron M.S., Fraga B.N., Bottan J., de Quadros A.R.B., de Oliveira V. (2019). Evaluation of factorial methods to estimate lysine requirements for barrows and immunocastrated pigs. *Livest. Sci.*, 227: 68–74.
- Muniz H.D.C.M., Klein D.R., dos Santos M.D.S., Schneider L.I., Ceron M.S., de Quadros A.R.B., Eliseu C., de Oliveira V. (2021). Water intake and wastage during the growing–finishing period of immunocastrated and surgically castrated pigs. *Anim. Prod. Sci.*, 61: 1385–1392.
- Okrouhlá M., Čítek J., Švejtil R., Zadinová K., Pokorná K., Urbanová D., Stupka R. (2020). The effect of dietary *Helianthus tuberosus* L. on the populations of pig faecal bacteria and the prevalence of skatole. *Animals*, 10: 693.
- Palmer C., Pedersen H.G., Sandøe P. (2018). Beyond castration and culling: Should we use non-surgical, pharmacological methods to control the sexual behavior and reproduction of animals? *J. Agr. Environ. Ethics*, 31: 197–218.
- Parois S.P., Prunier A., Mercat M.J., Merlot E., Larzul C. (2015). Genetic relationships between measures of sexual development, boar taint, health, and aggressiveness in pigs. *J. Anim. Sci.*, 93: 3749–3758.
- Pawliski P., Galuszka A., Pardyak L., Tuz R., Plachno B.J., Malopolska M., Dubniewicz K., Yang P., Kotula-Balak M., Tarasiuk K. (2022). Leydig cells in immunocastrated Polish Landrace pig testis: differentiation status and steroid enzyme expression status. *Int. J. Mol. Sci.*, 23.
- Prunier A., Mounier A.M., Hay M. (2005). Effects of castration, tooth resection, or tail docking on plasma metabolites and stress hormones in young pigs. *J. Anim. Sci.*, 83: 216–222.
- Quelhas J., Pinto-Pinho P., Lopes G., Rocha A., Pinto-Leite R., Fardilha M., Colaço B. (2023). Sustainable animal production: exploring the benefits of sperm sexing technologies in addressing critical industry challenges. *Front. Vet. Sci.*, 10.
- Rault J.L., Lay D.C., Marchant J.N. (2011). Castration induced pain in pigs and other livestock. *Appl. Anim. Behav. Sci.*, 135: 214–225.
- Reiter S., Zöls S., Ritzmann M., Stefanski V., Weiler U. (2017). Penile injuries in immunocastrated and entire male pigs of one fattening farm. *Animals*, 7.
- Robles I., Luna S.P.L., Trindade P.H.E., Lopez-Soriano M., Merenda V.R., Viscardi A.V., Tamminga E., Pairis-Garcia M.D. (2023). Validation of the Unesp-Botucatu pig composite acute pain scale (UPAPS) in piglets undergoing castration. *PloS one*, 18.
- Rydmer L., Zamaratskaia G., Andersson H.K., Algers B., Lundström K. (2004). Problems with aggressive and sexual behaviour when rearing entire male pigs. *Proc. 55th Annual Meeting of the European Association for Animal Production*, Bled, Slovenia, 4.
- Rydmer L., Zamaratskaia G., Andersson H.K., Algers B., Guillemet R., Lundström K. (2006). Aggressive and sexual behaviour of growing and finishing pigs reared in groups, without castration. *Acta Agric. Scand. Section A*, 56: 109–119.
- Scollo A., Galli M.C., Contiero B., De Benedictis G.M., Orlandi B., Gottardo F. (2021). Analgesia and/or anaesthesia during piglet castration – part II: practicability of farm protocols, resource efficiency and economic implications. *Ital. J. Anim. Sci.*, 20: 472–478.
- Skade L., Kristensen C.S., Nielsen M.B.F., Diness L.H. (2021). Effect of two methods and two anaesthetics for local anaesthesia of piglets during castration. *Acta Vet. Scand.*, 63.
- Škrlep M., Batorek Lukač N. (2023). Advantages and drawbacks of rearing entire male and immunocastrated pigs. *Proc. 14th International Symposium Modern Trends in Livestock Production*.
- Škrlep M., Čandek-Potokar M., Lukač N.B., Povše M.P., Pugliese C., Labussièrre E., Flores M. (2016). Comparison of entire male and immunocastrated pigs for dry-cured ham production under two salting regimes. *Meat Sci.*, 111: 27–37.
- Škrlep M., Tomašević I., Mörlein D., Novaković S., Egea M., Garrido M.D., Linares M.B., Peñaranda I., Aluwé M., Font-i-Furnols M. (2020). The use of pork from entire male and immunocastrated pigs for meat products – An overview with recommendations. *Animals*, 10.
- Sneddon L.U., Elwood R.W., Adamo S.A., Leach M.C. (2014). Defining and assessing animal pain. *Anim. Behav.*, 97: 201–212.
- Squires E.J. (2006). Possibilities for selection against boar taint. *Acta Vet. Scand.*, 48.
- Squires E.J., Bone C., Cameron J. (2020). Pork production with entire males: Directions for control of boar taint. *Animals*, 10.
- Sutherland M.A., Davis B.L., Brooks T.A., McGlone J.J. (2010). Physiology and behavior of pigs before and after castration: effects of two topical anesthetics. *Animal*, 4: 2071–2079.
- Sutherland M.A., Davis B.L., Brooks T.A., Coetzee J.F. (2012). The physiological and behavioral response of pigs castrated with and without anesthesia or analgesia. *J. Anim. Sci.*, 90: 2211–2221.
- Tajet H., Andresen Ø., Meuwissen T.H.E. (2006). Estimation of genetic parameters of boar taint; skatole and androstenone and their correlations with sexual maturation. *Acta Vet. Scand.*, 48.
- Taylor A.A., Weary D.M. (2000). Vocal responses of piglets to castration: identifying procedural sources of pain. *Appl. Anim. Behav. Sci.*, 70: 17–26.
- Thomsen R., Edwards S.A., Jensen B.B., Rousing T., Sorensen J.T. (2015). Weight and season affects androstenone and skatole occurrence in entire male pigs in organic pig production. *Animal*, 9: 1577–1586.
- Trindade P.H.E., Lopez-Soriano M., Merenda V.R., Tomacheuski R.M., Pairis-Garcia M.D. (2023). Effects of assessment method (real-time versus video-recorded) on a validated pain-altered behavior scale used in castrated piglets. *Sci. Rep.*, 13.
- Vhile S.G., Kjos N.P., Sørum H., Øverland M. (2012). Feeding Jerusalem artichoke reduced skatole level and changed intestinal microbiota in the gut of entire male pigs. *Animal*, 6: 807–814.
- Viscardi A.V., Turner P.V. (2018). Use of meloxicam or ketoprofen for piglet pain control following surgical castration. *Front. Vet. Sci.*, 5.
- Viscardi A.V., Hunniford M., Lawlis P., Leach M., Turner P.V. (2017). Development of a piglet grimace scale to evaluate piglet pain using facial expressions following castration and tail docking: a pilot study. *Front. Vet. Sci.*, 4.
- Waberski D., Riesenbeck A., Schulze M., Weitze K.F., Johnson L. (2019). Application of preserved boar semen for artificial insemination: Past, present and future challenges. *Theriogenology*, 137: 2–7.
- Wauters J., Verplanken K., Vercruysse V., Ampe B., Aluwé M., Vanhaecke L. (2017). Sensory evaluation of boar meat products by trained experts. *Food Chem.*, 237: 516–524.
- Weiler U., Bonneau M. (2019). Why it is so difficult to end surgical castration of boars in Europe: Pros and cons of alternatives to piglet castration. *IOP Conf. Ser.: Environ. Earth Sci.*, 333.
- Weiler U., Isernhagen M., Stefanski V., Ritzmann M., Kress K., Hein C., Zöls S. (2016). Penile injuries in wild and domestic pigs. *Animals*, 6.
- Weiler U., Font-i-Furnols M., Tomasevič I., Bonneau M. (2021). Alternatives to piglet castration: from issues to solutions. *Animals*, 11.
- Wicks N., Crouch S., Pearl C.A. (2013). Effects of Improvac and Bo-Priva on the testicular function of boars ten weeks after immunization. *Anim. Reprod. Sci.*, 142: 149–159.
- Zamaratskaia G., Rasmussen M.K. (2015). Immunocastration of male pigs – situation today. *Procedia Food Sci.*, 5: 324–327.
- Zamaratskaia G., Babol J., Andersson H., Lundström K. (2004). Plasma skatole and androstenone levels in entire male pigs and relationship between boar taint compounds, sex steroids and thyroxine at various ages. *Livest. Prod. Sci.*, 87: 91–98.
- Zamaratskaia G., Babol J., Andersson H.K., Andersson K., Lundström K. (2005 a). Effect of live weight and dietary supplement of raw potato starch on the levels of skatole, androstenone, testosterone and oestrone sulphate in entire male pigs. *Livest. Prod. Sci.*, 93: 235–243.
- Zamaratskaia G., Rydhmer L., Chen G., Madej A., Andersson H.K., Lundström K. (2005 b). Boar taint is related to endocrine and

- anatomical changes at puberty but not to aggressive behaviour in entire male pigs. *Reprod. Domest. Anim.*, 40: 500–506.
- Zamaratskaia G., Squires E.J., Babol J., Andersson H.K., Andersson K., Lundström K. (2005 c). Relationship between the activities of cytochromes P4502E1 and P4502A6 and skatole content in fat in entire male pigs fed with and without raw potato starch. *Livest. Prod. Sci.*, 95: 83–88.
- Zamaratskaia G., Chen G., Lundström K. (2006). Effects of sex, weight, diet and hCG administration on levels of skatole and indole in the liver and hepatic activities of cytochromes P4502E1 and P4502A6 in pigs. *Meat Sci.*, 72: 331–338.
- Zamaratskaia G., Rydhmer L., Andersson H.K., Chen G., Lowagie S., Andersson K., Lundström K. (2008). Long-term effect of vaccination against gonadotropin-releasing hormone, using Improvac™, on hormonal profile and behaviour of male pigs. *Anim. Reprod. Sci.*, 108: 37–48.
- Zoels S., Reiter S., Ritzmann M., Weiß C., Numberger J., Schütz A., Lindner P., Weiler U. (2020). Influences of immunocastration on endocrine parameters, growth performance and carcass quality, as well as on boar taint and penile injuries. *Animals*, 10.

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