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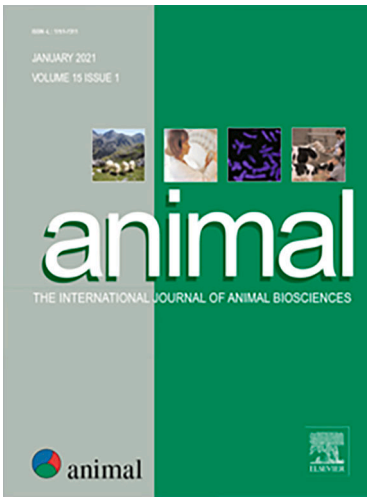

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Organic rearing of non-castrated male pigs: welfare indicators, carcass traits, pork quality and boar taint in Duroc and Pietrain crossbreds

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Highlights

- Male pigs in organic farming can show few health and welfare problems
- Fewer Duroc than Piétrain crossbred males have skin scratches or tail lesions
- Duroc and Piétrain crossbred males have similar growth rate and slaughter weight
- Duroc have less lean carcasses but more intramuscular fat than Piétrain crossbreds
- Meat quality but also boar taint risk are higher in Duroc than Piétrain crossbreds

Abstract

The main principles of organic farming as presented by the European organisation for organic food and farming are health, ecology, fairness and care, but intrinsic quality of products is also important for consumers. Pig genotype was tested as a lever to improve animal welfare and pork quality (meat tenderness, processing ability) of organic, non-castrated males while controlling the risk for boar taint. Non-

castrated Large White × Duroc (**D**, n = 47) or Large White × Pietrain NN (**P**, n = 34) males were involved in two batches, each including one group of pigs per genotype. Each group was reared in a pen from the same building on deep straw bedding (1.3 m²/pig), with a feeding zone (0.2 m²/pig) and an outdoor area (1.0 m²/pig), from 28 kg BW until slaughter at ca. 125 kg BW. All pigs received *ad libitum* the same growing and finishing diets, and hay. Overall, health and welfare indicators showed few problems, but the proportions of pigs with skin scratches, and tail lesions at the end of the finishing period, were lower in D than P pigs ($P < 0.05$). Growth rate and final BW did not differ between genotypes. The D pigs had lower carcass lean meat content ($P < 0.001$) and relative proportions of ham and loin ($P \leq 0.01$), and higher proportions of belly and backfat ($P \leq 0.001$) than P pigs. Compared to P, loin (*Longissimus* muscle) of D pigs was less light and exudative and had higher chroma ($P < 0.05$), but pH 24 h and glycolytic potential did not differ. Loin meat of D pigs had higher intramuscular fat content ($P < 0.001$) and tended to have a lower shear force ($P = 0.09$), but cooking loss did not differ. In the ham muscles, D pigs had higher chroma than P pigs in the *Gluteus medius*, whereas pH 24 h did not differ in the *Gluteus medius* and *Semimembranosus*. D pigs had higher backfat concentrations of androstenone ($P < 0.001$), and skatole and indole ($P < 0.05$) than P pigs, suggesting a higher risk of rejection by consumers due to boar taint. However, only one D carcass was detected as tainted by human nose test. Altogether, organic farming of non-castrated Duroc crossbred males appears to be favourable for animal welfare, technological and several sensory pork properties, provided that the risk of undesirable odours is limited through management practices.

Keywords: livestock farming system, pig genotype, growth performance, meat composition, androstenone

Implications

In organic farming, avoiding surgical castration of pig males is in line with the objectives of improved animal welfare. However, the risks of undesired behaviours of non-castrated males (mounting, aggressions), pork boar taint, and impairment of meat texture in relation to reduced intramuscular fat content have to be controlled. Rearing Duroc compared to Pietrain crossbred males allows to improve animal welfare and some quality dimensions of organic pork. However, the risk for boar taint is increased in Duroc crossbreds, and should be minimized by management practices for ending castration in good conditions for the animals, the farmers and the consumers.

Introduction

The main principles of organic farming are based on the use of practices that respect the environment, health and animal welfare (EU regulations 2018/848 and 2018/1584). In organic farming, the surface area available per pig is greater than in conventional farming, and pigs have access to bedding and roughage to fulfil their

behavioural needs and hence promote their welfare. Castration of male pigs is authorized up to 7 days of age if carried out with anaesthesia and analgesia, but considering animal welfare, it makes more sense not to perform this mutilation, especially as anaesthesia and analgesia only partially relieve the pain (Prunier et al., 2020). Non-castration of males improves growth efficiency (due to higher feed conversion ratio, protein retention and growth rate) thereby reducing environmental impacts of pig production, and improves carcass lean meat content and their commercial value (de Roest et al., 2009, Batorek et al., 2012). However, non-castrated males can express undesired, deleterious behaviours (aggression, sexual mounting) and their meat can present unpleasant odours, known as boar taint (Lundström et al., 2009; Lebret and Čandek-Potokar, 2022). Moreover, impairment of of some meat sensory traits, especially tenderness in relation to reduced intramuscular fat content could occur (Pauly et al., 2012).

Tainted meat, especially when heated, develops an off-flavour, that is aversive to most consumers. This defect is mainly ascribed to androstenone and skatole (and indole to a lesser extent) that accumulate in adipose tissue. Recently, another component: 2-aminoacetophenone has been shown to contribute also to boar taint and consumer rejection of pork products (Mörlein et al., 2024). Androstenone (a testicular steroid mainly related to sexual development) is largely under genetic influence (Robic et al., 2008; Mathur et al., 2013) but also depends on pigs' age at slaughter (Bonneau et al., 1987; Zamaratskaia et al., 2004). Androstenone is stored in adipose tissue and may give an urine-like odour to the meat, even though this perception depends on the consumers (Lundström et al., 2009; Bee et al., 2015). Skatole and indole are metabolized from tryptophan by gut bacteria and also accumulate in the adipose tissue, leading to faecal odour in the meat (Lundström et al., 2009; Zamaratskaia and Squires, 2009). The contribution of indole to boar taint is much lower than that of skatole, due to the lower sensitivity of consumers to this molecule (Moss et al., 1993). Even though every sexual type (female, castrated male, non-castrated male) produces skatole, its metabolism linked to testicular steroids explains why its concentration is higher in tissues of non-castrated males than in those of other sexes (Zamaratskaia and Squires, 2009). Skatole levels in backfat depend largely on pigs' farming conditions, with dirtiness (Hansen et al., 1994; Parois et al., 2017) and feeding (Wesoly and Weiler, 2012) being the most important determining factors.

In organic farming, fattening pigs must be fed 100% organic feed, without GMOs or synthetic amino acids. These regulations may affect the nutritional balance of diets, with possible consequences on carcass (lower lean meat content) and meat characteristics (Lebret and Čandek-Potokar, 2022; Prache et al., 2022a). Improving health, protecting the environment and promoting animal welfare are the main reasons why consumers buy organic food products in Europe, but quality and taste of products are also strong motivations (Baudry et al., 2017; Agence Bio, 2022; Kühl et al., 2023). The ethical (including animal welfare) and environmental dimensions related to pork production are part of the extrinsic (i.e. production-related) quality attributes of pork, and are increasingly important to consumers (Liu et al., 2023). Extrinsic and intrinsic (product-related, i.e. sensory, nutritional, technological...) quality attributes of pork result from multiple factors all along the value chain, from animal farming through slaughtering and processing, up to consumption of pork and products (Lebret and Čandek-Potokar, 2022; Prache et al., 2022b). Especially, the

pig breed or genotype, sex, and husbandry practices (e.g. castration/or not of males; feeding; age and/or weight at slaughter…) can directly affect or interfere to determine these pork quality attributes, whatever the farming system: conventional, 'alternative', or organic (Lebret and Čandek-Potokar, 2022; Prache et al., 2022a). Therefore, we investigated whether rearing Duroc compared to Pietrain crossbreeds could contribute to improving jointly the welfare and meat quality of non-castrated males in organic farming. Indeed, the most commonly used pig genotype in both organic and conventional farming are the Pietrain crossbreds free of the halothane sensitivity allele (NN) due to their efficiency for lean meat production and low boar taint risk, however they lead to pork of 'standard' sensory and technological quality. Compared to Pietrain, the Duroc crossbreds generally lead to better intrinsic pork quality (texture, pH, colour) (Edwards et al., 2003; Morales et al., 2013; Lebret et al., 2023a) but present a higher risk of boar taint (Werner et al., 2020a,b). In addition, behavioural differences between Duroc (purebred or crossbred) and Large White or Pietrain pigs (Terlouw and Rybarczyk, 2008), as well as lower prevalence of skin scratches on carcasses from Duroc than Pietrain crossbred males (Werner et al., 2020a), have been reported. Thus, our work aimed at evaluating whether, in organic farming, pig genotype could be a lever to improve animal welfare and meat quality of non-castrated male pigs, while avoiding boar taint and maintaining satisfactory growth performance and carcass composition. The objective of this study was to compare health and welfare indicators, growth performance, carcass composition, meat quality and boar taint risk of non-castrated male pigs in organic farming according to genotype: Duroc × Large White vs Pietrain NN × Large White. Part of these results were presented at an international conference (Lebret et al., 2023b) and at a national technical meeting (Lebret et al., 2024).

Material and methods

Animals and experimental design

The animal experiment was carried out at the INRAE Porganic (certified organic) experimental farm (INRAE GenESI, 86480 Rouillé, France; doi:10.15454/1.5572415481185847E12), following approval by local ethics committee and governmental authorization (see Ethics approval section below). The experiment involved a total of 81 non-castrated male pigs originating from Large White sows (INRAE Porganic herd) inseminated with semen from either Duroc boars (**D**; Nucléus, 35650 Le Rheu, France) or Pietrain NN boars (**P**; Nucléus, non-carriers of the hal mutation at the RYR1 gene and chosen for their low risk for boar taint). Pigs were produced in two batches (six weeks apart between batches 1 and 2), including 30 D (issued from 7 litters and 3 boars) and 22 P pigs (issued from 6 litters and 3 boars) for the first batch, and 17 D (issued from 6 litters and 5 boars) and 12 P pigs (issued from 3 litters and 3 boars) for the second batch. Experimental pigs were selected on the basis of their BW at 70 days (average BW and standard deviation were balanced between genotypes) and placed by genotype in a collective pen. Each pen included a resting area on deep straw bedding (1.3 m²/pig) with fresh straw added weekly, a feeding zone on concrete floor (0.2 m²/pig), and a covered outdoor area on a concrete floor (1.0 m²/pig). The four pens (one per genotype and per batch) were in the same animal building as represented in Figure 1. Within a batch,

the two pens dedicated to the experiment were adjacent, identical and separated by a solid partition of 1 m high (indoor pen) and horizontal bars (courtyard) that allowed olfactory, auditory and some physical contacts among pigs. As the number of pigs was lower for D than P pigs, and at the second than first batch in both genotypes, the pen size was reduced using bales of hay to maintain the same available indoor surface per pig (1.3 m²/pig). All animals were fed *ad libitum* the same organic growing (from 10 until 16 weeks of age) and then finishing diets (from 16 weeks of age until slaughter at around 25 weeks of age). The diets were formulated by a private company (DFP Nutraliance, Sadroc, France), in order to fulfil animal nutritional requirements (Van Milgen and Noblet, 2003) and were offered as pellets. Their composition and nutritional value are described in Table 1. The diets were distributed with 2 feeders of 1 m length per pen, with quantities varying progressively between 1.5 and 2.6 kg/d and per pig during growing and 2.5 to 3.6 kg/d and per pig during the finishing period. Each morning the animal technicians checked the feeders. If they were empty, the quantity of feed distributed was increased. Moreover, in each pen and all along the experiment, pigs had free access to hay harvested from permanent grassland that was provided daily in a rack, and had permanent access to water. Quantities of feed and hay distributed were recorded and assuming that they were all consumed, their average consumption were calculated per pen and per growing or finishing period, taking into account the actual number of pigs in each pen and each day all along the experiment. Pigs were weighed individually at start of the experiment, every two weeks during the experiment, and the day before slaughter. Average daily gain was calculated per pig during the growing and finishing phases and over the whole experimental period. The ambient temperature was recorded hourly in both the building and the courtyard throughout the experiment. All traits assessed on the living animals, as well as on carcasses or pork (described below) during the experiment, are described according to references of Animal Trait Ontology for Livestock (https://www.umrh.inrae.fr/ontologies/visualisation/public/) in the Supplementary Table S1.

Observations of behaviour and health on the farm

Observations of the animals were performed at three times in each pen during the course of the experiment: two weeks after the start of the growing period, at the end of the growing period (corresponding to the middle of the whole experimental period) and at the end of the week preceding the first departure for slaughter, i.e. at an average age of 84, 111 and 161 days, respectively. These observations and measurements, based on the Welfare Quality® protocol (2009), aimed at evaluating cleanliness, welfare and health (list of indicators detailed in Table 2 and Supplementary Table S1). Some parameters were observed at the animal level and from these observations, we calculated the numbers of pigs: dead, in poor general condition (severe health problems requiring treatment), with retarded growth (1/3 lighter than the other pigs of the pen), dirty (≥ 50 % of one side of the body covered with faeces), with hernia, with lameness (no support on at least one limb), with large wound (≥ 5 cm in diameter), with skin scratches (more than 15 recent scratches on at least one side of the body), with signs of skin irritation (redness) or presence of external parasites (e.g. lice), with difficult breathing, with a lesion(s) on at least one ear or tail, or pigs exhibiting straw exploration (as sign of ‘positive welfare’). Other parameters were observed at the pen level: cleanliness of feeding and drinking troughs, distribution of resting pigs in the pen (huddled : ≥ 50 % of pigs are lying with

at least half of their body in contact with another pig; scattered : ≥ 50 % of pigs are lying on their sides without touching each other), presence of liquid faeces on pen walls or floor, presence of coughing or sneezing, and pig approach time (time taken for at least one pig to approach and touch an unfamiliar observer after entering the pen) to assess the human-animal relationship.

Slaughter and measurements of carcass and meat quality traits

Pigs were slaughtered in a commercial abattoir (Cooperl, 79800 Sainte-Eanne) at an average BW of 125 kg. There were two series of slaughter per batch, each series including half of the pigs from each genotype. The heaviest half of the pigs in each genotype (i.e., pen) were slaughtered in the first series and the other half, which remained in their original pen, in the second series that occurred two weeks (batch 1) or three weeks (batch 2) after the first series to reach the targeted average BW at slaughter. Feed and hay were removed at around 8:00 am on the day before slaughter. Pigs were individually weighed, grouped within genotype to form two sub-groups that were placed on a roofed platform without feed but with free access to water. During the following night, pigs from the two sub-groups were mixed just before loading into the truck but not with non-experimental animals, and transported in the same truck to the slaughterhouse (maximum duration of 30 min). There they were all placed in a single pen (still without mixing with other animals) for 50 min to 2 hours according to the slaughter session, with free access to water. Pigs were slaughtered in the early morning by electrical stunning at high voltage and exsanguination.

Just after slaughter, the hot carcass (trimmed of digestive, reproductive and respiratory tracts and of perirenal fat) was weighed. Carcass yield was calculated as the percentage of hot carcass weight to final BW. Carcass lean meat content was determined using the automatic grading CSB-Image Meater device (CSB, Geilenkirchen, Germany) and prediction equations (Commission Regulation 2017a, 2017b), based on automatic measurements of muscle thickness (**M3**: minimal muscle thickness at the *Gluteus medius* muscle level; **M4**: average muscle thickness over four lumbar vertebrae) and backfat thickness (**G3**: minimal fat thickness over the *Gluteus medius* muscle; **G4**: average backfat thickness over four lumbar vertebrae) (Blum et al., 2014). Each carcass was submitted to a human nose test by trained and experienced staff from the slaughterhouse, to detect boar taint (i.e. tainted or not tainted carcass). The number of recent (i.e., red) skin scratches (≥ 2 cm) was counted on each carcass (except head, throat, feet and tail) by a single trained operator all along the experiment.

After chilling (24 h at 4 °C), the weight of wholesale cuts from the right carcass side (ham, loin, backfat, shoulder, and belly) was recorded, and the proportion (relative weight) of each carcass cut to the cold right carcass side was calculated. Muscle pH was measured 24 h after slaughter in the *Semimembranous* at 5 cm from the tip of the hip bone, in the *Gluteus Medius* (**GM**) (on the fresh cut after ham cutting) and in *the Longissimus thoracis et lumborum* (**LTL**) between the 13th and 14th ribs (Ingold Xerolyt electrode, Mettler Toledo and Syleps pH meter, Lorient, France) (one measure per muscle). Meat colour was determined on the GM and the LTL by measurement of colour coordinates CIE **L***: lightness, a*: redness, **b***: yellowness, **C***: saturation (chroma) and **h°**: hue using a chromameter Minolta CR 400 (Osaka,

Japan) with a D65 illuminant, a 1-cm diameter aperture and a 2° observer angle. GM was exposed to artificial light right after cutting before measurement, and colour coordinates were measured (single measurement of each coordinate) close to the spot of pH measurement. A transversal section of LTL (12th lumbar vertebra level) was taken and bloomed for 15 min at 4 °C under artificial light before measurement of colour coordinates at three different sites of the slices and the average of L*, a*, b*, C* and h° values were calculated. Numerical total colour difference defined as : $\sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$ was calculated. The instrumental CIE L*a*b* results are considered as visually detectable when the numerical total colour difference rose above 2 (Kowalski et al., 2020).

Meat sampling and biochemical and texture analyses

After colour measurement, a sub-sample of the LTL slice was taken with a 25 mm diameter punch on the ventral part of the slice, weighed and placed in a plastic tube (previously tarred) with inner fins for 24 h at 4°C. The next day, the tubes were weighed with and without the sample to determine drip loss (EZ method; Christensen, 2003). The remaining part of the LTL slice was trimmed of external fat and connective tissue, minced and homogenized. A sub-sample was freeze-dried and powdered before determination of protein and water contents. Protein was determined from nitrogen concentration (Dumas method, AOAC, 1990) assessed in duplicates with a Rapid N cube (Elementar, Villeurbanne, France) and using a multiplication factor of 6.25. Water content was determined in duplicates on freeze-dried LTL samples before and after drying at 103 °C. Protein and water contents were expressed as a percentage of fresh muscle considering water loss of each muscle sample during freeze-drying. The remaining part of homogenized LTL was stored at -20 °C until determination of glycolytic potential (= 2 × [(glycogen) + (glucose) + (glucose-6-phosphate)] + [lactate]) expressed as micromoles equivalent lactate/g of fresh tissue, as detailed by Lebret et al. (2018).

The same day, another section of LTL was taken (last rib level), vacuum packaged and stored at -20 °C until determination of lipid (intramuscular fat: **IMF**) content. After thawing, the slice was trimmed of external fat, minced and homogenized and IMF content was determined by chloroform-methanol (2:1 v/v) extraction (Lebret et al., 2018). A third section (200 g) of LTL (10th -11th lumbar vertebrae) was removed, vacuum packaged, kept at 4 °C and shipped to the IDELE laboratory (14310, Villers-Bocage, France) for shear force measurements. After 7 to 8 days of vacuum packaged ageing at 4°C, the meat section was cut into two similar pieces of 100 g which were cooked in an oven at 250 °C up to a piece core temperature of 70 °C, and cooled. Then, a 1 cm thick slice was removed from the 6 sides of each meat piece and the core pieces were used to prepare 10 rectangular cut stripes of 1 cm² parallel to fibre axis per pig. Shear force was determined perpendicularly to muscle fibres with a Warner-Bratzler cell fitted on a texturometer Instron 3343 (Norwood, MA, USA). The average of shear force measurements was calculated per pig and used for statistical analyses.

Backfat sampling and biochemical analyses of boar taint components

Twenty-four hours after slaughter, a piece of backfat (whole thickness, neck level) was taken, vacuum packaged and stored at -20 °C until determination of

androstenone, skatole and indole concentrations by HPLC, as previously described by Batorek et al. (2012). Briefly, backfat samples were melted (microwave), centrifuged and the liquid phase was removed and stored at -20 °C for 2 weeks. All samples were analysed by HPLC (Agilent Technologies, 1200 series, Santa Clara, Ca, USA) with a C18 column (waters sunfire, 3.5 µm, 4.6 × 75 mm, USA). Flow rate was 1.2 ml/min for skatole and indole and 1.0 ml/min for androstenone. The detection limits were 0.08 µg/g of liquid fat for androstenone and 0.02 µg/g of liquid fat for skatole and indole, and these values were assigned to pigs with concentrations below those limits.

Statistical analyses

Statistical analyses were performed with the R software (version 4.3.3, The R Core Team, 2024). Observations and measurements of animal welfare and health indicators assessed at the pen level were not statistically analysed, as the sample size was too small (two pens per genotype). To analyse the effect of genotype on individual observations and measurements of welfare and health, we calculated the total numbers of pigs (the two batches were considered together) in each of the two modalities per parameter, and we performed a 2Î test, derived from Chi2 and better suited to small sample sizes with some classes having less than 5 individuals (Arbonnier, 1966). For data of feed consumption and feed conversion ratio that were assessed at the pen level, no statistical analyses were possible (two pens per genotype). For data on individual growth, carcass and meat quality traits and biochemical tissue composition, the pig was considered as the statistical unit. Data were analysed using an ANOVA including the genotype (n = 2), the batch (n = 2) and the slaughter day within batch (n = 2 per batch) as fixed effects in the model (*lm* procedure and *Anova* procedure of the *car* package). The normality of the distribution of the residuals was checked for each variable, and least square means (**lsmeans**) as well as the SE of the lsmeans were calculated per genotype using the *lsmeans* procedure of the *emmeans* package. A square-root transformation was applied to the number of skin scratches assessed at slaughterhouse and a log transformation was applied to the concentration of androstenone to reach a normal distribution of the residuals. These data were then analysed with the same model as described above, and lsmeans (and SE) of data were back calculated per genotype using the *lsmeans* procedure and specifying “type = response”. Data of backfat skatole and indole, whose residuals did not follow a normal distribution (even after log or square root transformations) were analysed by non-parametric Kruskal and Wallis test. All statistical models are described in Supplementary Material S1.

Results and Discussion

Health, behaviour and welfare during the rearing period

Regarding pig environmental conditions, for batch 1, the ambient temperature was 8.7 °C on average (varying from -1.5 to +21.5 °C) in the building and 6.9 °C (varying from -4.1 to +18.8 °C) in the courtyard. For batch 2, the ambient temperature recorded for the building was 8.6 °C on average (varying from -1.5 to + 24.0 °C) and 7.4 °C on average for the courtyard (varying from -4.1 to + 21.5 °C). Overall, few

health and welfare problems were detected in pigs of either genotype, although some indicators showed more favourable results for Duroc crossbreds (Table 2). Indeed, a lower percentage of pigs with skin scratches was observed in D than P crossbreds at all three observation stages during the experiment ($P < 0.01$). A lower number of skin scratches was also observed on carcasses from D than P crossbreds (lsmeans (SE) of 27 (2.6) vs 36 (3.5), respectively, $P = 0.037$). However, D and P pigs were mixed in the same pen during the pre-slaughtering period and carcass scratches may have been caused by the pigs from the other genotype during fights in response to mixing (Terlouw et al., 2021). These results are in line with those obtained on carcasses of organic, non-castrated male pigs issued from Duroc compared with Pietrain sire lines and Large White × Landrace maternal lines (Werner et al., 2020a). As skin lesions can result from bites during fights or hoof marks during sexual mounting, present data suggest a lower frequency of one or both of these behaviours in D than P pigs. Another favourable indicator is the lower frequency of tail lesions at the end of the finishing period in D than P pigs ($P < 0.05$). Pig mortality was numerically lower in D pigs but did not significantly differ between genotypes. However, it should be noted that the number of pigs was small. The other health and welfare indicators observed at the pig level did not differ between genotypes. At the pen level, a shorter approach time was found for D pigs at all three observation stages, indicating a lower fear of humans. A shorter approach time and a greater frequency of contacts with an unfamiliar human were also observed in castrated pure-bred Duroc males compared with castrated pure-bred Large White males (Terlouw and Rybarczyk, 2008).

Growth performance and carcass traits

Average growth rate during growing, finishing and across the entire experimental period, as well as final BW did not differ between D and P pigs (Table 3). Average individual feed consumption over the entire experimental period, calculated per pen, was similar for D (2.73 kg/d) and P (2.80 kg/d) pigs, as well as feed conversion ratio (D: 2.85; P: 2.88) and individual hay consumption (D: 109, P: 120 g/d). Hot carcass weight did not differ between genotypes, despite a slightly lower carcass yield in D than P pigs ($P < 0.05$) (Table 4). Carcass lean meat content was lower in D than P pigs (-1.9 points, $P < 0.001$). This was related to lower M3 and M4 muscle ($P < 0.001$) and higher G3 and G4 backfat thicknesses ($P < 0.05$). In line with these results, lower proportions of loin and ham ("lean" wholesale cuts; $P \leq 0.01$) and higher proportions of belly and backfat ($P \leq 0.001$) were found for D than P pigs, whereas relative proportion of shoulder did not differ between genotypes. The growth performance of D and P pigs is satisfactory compared to that found in organic farming for non-castrated or castrated males or female crossbred pigs issued from Duroc or Pietrain boars and Large White (Ferchaud et al., 2022) or Large White × Landrace sows (Werner et al., 2020a; Quander-Stoll et al., 2021, 2022). The lack of growth difference between D and P pigs is at odds with previous studies showing lower growth rate in Duroc than Pietrain NN crossbred female pigs (Lebret et al., 2023a). Conversely, other authors have reported higher growth rate associated to higher feed intake in females and castrated male crossbreds or pure-bred Duroc than Pietrain pigs (Edwards et al., 2006; Morales et al., 2013; Kowalski et al., 2020; Werner et al., 2020a). These differences could be explained by the use of different Duroc and/or Pietrain sire lines in the different studies (Kowalski et al., 2020). The lower carcass yield of D than P pigs is in agreement with Werner et al. (2020a) and confirms our previous results in female pigs (Lebret et al., 2023a), although the

difference observed in the present experiment was smaller. The lower carcass lean meat content of D pigs, associated with their lower muscle thickness and proportion of lean cuts and their higher adiposity, is consistent with numerous studies comparing D and P NN crossbred pigs (Edwards et al., 2006; Morales et al., 2013; Kowalski et al., 2020; Lebret et al., 2023a) or pure-breds (Plastow et al., 2005; Ciobanu et al., 2011).

Meat quality traits of loin and ham

In the loin (LTL muscle), the pH 24 h did not differ between genotypes, but meat from D pigs had lower drip loss and L* ($P < 0.05$) and slightly higher a* and C* values ($P < 0.05$) (Table 5). Cooking loss did not differ, but shear force tended to be lower for meat from D than P pigs ($P = 0.09$). In the ham *Semimembranous* and GM muscles, the pH 24 h did not differ between genotypes. In the GM, D pigs showed higher a* and b* values leading to higher C* ($P < 0.05$), whereas L* and h° did not differ between D and P pigs. Pig genotype affected LTL biochemical composition, with lower water and protein contents ($P \leq 0.05$) and especially higher IMF content (+ 0.6 points; $P < 0.001$) in D than P pigs, while glycolytic potential did not differ (Table 6).

The lower drip loss in D than P pigs, as indicator of better technological quality, is in line with the literature (Edwards et al., 2003; Kowalski et al., 2020; Lebret et al., 2023a). These authors also reported a higher pH 24 in meat from D than P pigs, which was not observed here. This difference may be linked to the fact that the glycolytic potential was relatively high for both D and P pigs in the present study, compared with previous results from conventional farming (Lebret et al., 2023a). This could be due to the low ambient temperature to which pigs were subjected during the experimental period, as it has been shown that low ambient temperature compared to thermoneutral conditions during the growing-finishing period of pigs (i.e. 12 °C vs 23 °C) leads to higher glycogen stores in the LTL muscle (Faure et al., 2013). The lower lightness of loin from D pigs can be explained by their lower drip loss (Monin, 2003). In contrast to our results, several studies have shown no difference in LTL lightness between D and P pigs, and the effect of genotype on a*, b* and C* values varies from study to study but is generally low (Edwards et al., 2003; Kowalski et al., 2020; Lebret et al., 2023a). The numerical total colour differences between D and P pigs (LTL muscle, D – P = 0.03; GM, D – P = 0.12) were very small, indicating that they would not be visually noticeable by consumers (Kowalski et al., 2020). Unlike drip loss, cooking loss did not differ according to genotype, in agreement with Morales et al. (2013) and Kowalski et al. (2020).

The lower water and protein contents and the higher IMF content of the LTL in D than P pigs confirm our recent findings (Lebret et al., 2023a). The higher IMF content of D compared to P pigs is well established both in crossbreds (Kowalski et al., 2020; Morales et al., 2013; Werner et al., 2020b) and purebreds (Plastow et al. 2005; Ciobanu et al., 2011), although there is a high variability among Duroc lines for this trait (Schwob et al., 2020). The higher IMF content may partly explain the lower shear force of the meat from D pigs (Listrat et al., 2016). The average content of 2.50 % in the meat from D pigs corresponds to that above which a difference in IMF has a perceptible, positive effect on meat texture (Lebret, 2009). Thus, our results suggest a better tenderness and/or juiciness of meat from D than P pigs, which should be validated by sensory tests.

Boar taint components in backfat

The androstenone concentration in backfat was higher ($P < 0.001$) in D than P pigs; backfat skatole and indole concentrations were also higher for D than P pigs ($P < 0.05$), even though genotype differences were of smaller magnitude (Figure 2). The higher androstenone content in D than P crossbred pigs is in agreement with Werner et al. (2020b) and other studies reporting higher backfat androstenone in purebred Duroc compared to Landrace or Yorkshire pigs (Xue et al., 1996; Oskam et al., 2010, Grindflek et al., 2011). In accordance with our results, Dalmau et al. (2019) reported higher skatole and indole contents in backfat of D than P crossbred pigs. On the opposite Werner et al. (2020b) found a lower skatole, but a similar indole concentration in the backfat of D than P crossbred pigs. In pure-bred pigs, Xue et al. (1996) reported higher skatole in Duroc and Yorkshire compared with Landrace pigs, whereas Oskam et al. (2010) found lower skatole and indole, and Grindflek et al. (2011) lower skatole content in backfat of Duroc compared to Landrace pigs. This lack of consistency agrees well with the assumption that genetic factors have generally a lower influence on skatole and indole concentrations than that of environmental factors as indicated by Zamaratskaia and Squires (2009) and Parois et al. (2018) in their literature reviews. Boar taint risk due to skatole (and indole, even of much lower contribution) is considered as low when pigs are fed appropriately (Wesoly and Weiler, 2012), kept in good environmental conditions including clean bedding, moderate ambient temperature and proper ventilation (Hansen et al., 1994; Thomsen et al., 2015; Parois et al., 2018).

Considering consumer rejection thresholds for consumers of 3 µg/g liquid fat for androstenone as suggested by Bonneau and Chevillon (2012) who performed their androstenone measures in the same laboratory and with the same method as us, and of 0.15 µg/g liquid fat for skatole as suggested by Mörlein et al. (2012), and that only one of the two thresholds should be reached for rejection, 8 carcasses from D pigs (17 %) and 3 from P pigs (9 %) would be defective. However, at the slaughterhouse, only one carcass from D pigs was found to be odorous by the human nose test. It was the carcass with the highest skatole concentration (0.80 µg/g liquid fat). In agreement with our results, Mathur et al. (2013) showed that many carcasses with concentrations exceeding the thresholds used in our study were not classified as odorous by the human nose test in abattoirs. Similarly, Xue et al. (1996) reported more pigs exceeding the threshold concentration of 1.5 µg/g 16-androstenes in backfat, than those identified as tainted by a sensory analysis undertaken with panellists qualified to identify androstenone. Finally, it should pointed out that our androstenone concentrations were expressed in µg/g of liquid fat and that a ratio of 1.7 should be applied to estimate the concentrations expressed in µg/g of fat tissue according to Pauly et al. (2008). Applying this ratio, our threshold limit corresponds to 1.76 µg/g of fat tissue (or 1.76 ppm).

Conclusions

In our experimental conditions under organic specifications, some animal welfare and health indicators were improved for non-castrated Duroc crossbred males compared with non-castrated Pietrain crossbred male pigs, even if overall, these indicators

revealed few problems of health and welfare. Growth performance and final BW did not differ between genotypes, but carcasses from D pigs had a lower lean meat content, indicating a lower carcass value, compared to carcasses from P pigs. Meat from D pigs had a higher technological quality. The higher IMF content and tendency for lower shear force of cooked meat from D compared to P pigs suggest a more tender meat for the D pigs. However, the risk for boar taint especially due to androstenone was higher for meat from D than P pigs. Altogether, our results indicate it is possible to rear organic, non-castrated males under field/commercial conditions, provided that the risks for boar taint and aggressive behaviour are controlled by breeding and farming practices.

Ethics approval

All procedures contributing to this work complied with the French legislation on animal experimentation and were approved by the local Committee for Consideration of Ethics in Animal Experimentation. On these bases, the present animal experimentation was authorized by the French Ministry of Higher Education, Research and Innovation (Authorization: APAFIS#30357-202103041121621 v4 delivered on July 2, 2021).

Data and model availability statement

Data set and list of variables have been deposed in the national repository Recherche Data Gouv: https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/SCSMVX and are publicly available.

Declaration of generative AI and AI-assisted technologies in the writing process

Authors declare they did not use generative AI nor AI-assisted technologies in the writing process of the present manuscript.

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Declaration of interest

None.

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Table 1

Composition and nutritional value of the organic feeding regimen distributed to pigs[1]

	Growing period[2]	Finishing period[2]
Ingredients (%, as fed basis)		
Barley	45.77	45.06
Wheat	14.50	15.60
Maize	-	1.00
Peas	14.40	17.60
Wheat bran	4.20	8.00
Soybean meal	14.50	7.80
Alfalfa	1.00	1.00
Sunflower meal	1.50	-
Calcium carbonate	1.34	1.15
Bentonite clay	1.00	1.00
Salt	0.84	1.17

Monocalcium phosphate	0.40	0.37
Sodium bicarbonate	0.30	-
Mineral-vitamin mix[3]	0.25	0.25
Chemical composition (% to fresh feed)		
DM	89.59	88.90
CP	16.01	14.07
Crude fat	3.09	2.36
Crude fibre	5.26	5.08
Starch	41.65	44.72
Ash	6.63	6.37
Digestible lysine	0.70	0.60
Net energy (MJ/kg)	9.44	9.33

[1] Feeding regimen were formulated and manufactured, and their chemical composition determined by DFP – NUTRALIANCE (Moulin Beynel, Sadroc, France)

[2] Growing period: from 10 to 16 weeks of age, i.e around 27 to 60 kg BW; finishing period: from 16 to around 25 weeks of age, i.e. 60 to around 127 kg BW (slaughter).

[3] Premix composition: Vitamin A (2400000 UI), Vitamin D3 (480000 UI), Vitamin E (40000 UI), Vitamin B1 (240 mg), Vitamin K3 (240 mg), Vitamin B2 (960 mg), sodium D-panthenate (2800 mg), Vitamin B6 (360 mg), Vitamin B12 (8 mg), Niacinamid (4800 mg), Biotin (36 mg), Folic acid (720 mg), Choline Chloride (96000 mg), Copper (31200 mg), Iron (3600 mg), Zinc (28800 mg), Manganese (14400 mg), Iodine (120 mg), Selenium (84 mg), Endo-1,4-beta xylanase (440000 UV), Endo-1,3(4) beta-glucanase (600000 UV)

Table 2

Influence of genotype on indicators of health and welfare of non-castrated male pigs in organic farming

	Start of growing			End of growing			End of finishing		
	D[1]	P[2]	Sign.[3]	D[1]	P[2]	Sign.[3]	D[1]	P[2]	Sign.[3]
Observations at pig level (% of pigs)									
Number of pigs observed	47	35		47	34		47	33	
Mortality since start of growing	0	0	ns	0	3	ns	0	6	ns
Pigs in poor general condition	0	0	ns	2	0	ns	0	0	ns
Pigs with retarded growth	6	6	ns	4	6	ns	0	0	ns
Dirty pigs	0	0	ns	0	0	ns	2	0	ns
Pigs with hernia	0	0	ns	0	0	ns	2	0	ns
Pigs with lameness	0	3	ns	0	3	ns	0	0	ns
Pigs with large wound	2	3	ns	2	6	ns	0	0	ns
Pigs with skin scratches	0	20	<0.001	0	35	<0.001	0	18	<0.01
Pigs with signs of skin irritation or external parasites	0	0	ns	0	0	ns	0	0	ns
Pigs with gasping breathing	0	0	ns	0	0	ns	0	0	ns
Pigs with ear lesion(s)	0	0	ns	0	0	ns	0	0	ns
Pigs with tail lesion(s)	2	0	ns	4	6	ns	0	9	<0.05

Pigs handling straw	64	64	ns	47	38	ns	36	49	ns
Observations at pen level (% of pens)									
Number of pens observed	2	2		2	2		2	2	
Soiled drinking or feeding troughs	0	0		0	0		0	0	
Distribution of pigs									
huddled	50	50		0	0		0	0	
scattered	0	0		0	0		0	0	
Presence of liquid faeces	100	50		50	100		0	0	
Presence of coughing or sneezing	100	100		100	100		100	100	
Approach time (s)	34	57		11	32		9	21	

Abbreviations:

[1] D: Large White × Duroc crossbred males.

[2] P: Large White × Pietrain crossbred males.

[3] Signification: *P*-value of genotype effect, ns: $P > 0.10$.

Table 3

Influence of genotype on growth performance of non-castrated male pigs

	Genotype[1]		*P*-value[2]		
	Duroc crossbreds	Pietrain crossbreds	Genotype	Batch	Slaughter day within batch

	lsmeans	SE	lsmeans	SE			
n	47		34				
Body weight (BW) at start of growing period (kg)	27.9	0.58	27.8	0.68	0.90	<0.001	<0.001
BW at start of finishing period (kg)	61.1	1.08	60.9	1.25	0.91	0.49	<0.001
BW at end of finishing period (kg)	127	1.81	128	2.10	0.75	0.44	0.008
Final age (d)	176	0.2	175	0.2	0.046	<0.001	<0.001
Average daily gain (ADG) during growing (g)	852	19.4	850	22.6	0.95	0.041	<0.001
ADG during finishing (g)	1027	18.2	1033	21.2	0.82	0.22	<0.001
ADG during growing-finishing (g)	963	14.7	967	17.1	0.86	0.077	<0.001

Abbreviations: lsmeans = least-square means.

[1] Duroc crossbreds: Large White × Duroc, Pietrain crossbreds: Large White × Pietrain.

[2] *P*-values of the fixed effects of genotype, batch, and slaughter day within batch, obtained from ANOVA applied to raw data.

Table 4

Influence of genotype on carcass traits of non-castrated male pigs

	Genotype[1]				*P*-value[2]		
	Duroc crossbreds		Pietrain crossbreds		Genotype	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
n	47		34				
Hot carcass weight (kg)	96.8	1.41	98.5	1.64	0.44	0.16	0.023
Carcass yield (%)	76.1	0.22	76.8	0.26	0.041	0.005	0.006
Muscle thickness[3]							
M3 (mm)	67.6	0.94	74.0	1.05	<0.001	0.63	0.99
M4 (mm)	52.1	0.72	55.8	0.81	<0.001	0.89	0.96
Backfat thickness[4]							
G3 (mm)	15.3	0.52	13.4	0.58	0.015	0.64	0.008
G4 (mm)	25.0	0.50	22.2	0.56	<0.001	0.50	0.020
Lean meat content (%)[5]	58.9	0.27	60.8	0.32	<0.001	0.59	0.011
Carcass composition (%)[6]							
Ham	25.3	0.13	25.8	0.15	0.010	0.22	0.012

Loin	26.2	0.15	27.0	0.17	0.001	0.79	0.79
Shoulder	23.5	0.11	23.7	0.13	0.20	0.78	0.095
Belly	16.1	0.11	15.4	0.13	<0.001	<0.001	0.68
Backfat	6.0	0.12	5.4	0.14	0.001	0.22	<0.001

Abbreviations: lsmeans = least-square means.

[1] Duroc crossbreds: Large White × Duroc, Pietrain crossbreds: Large White × Pietrain.

[2] *P*-values of the fixed effects of genotype, batch, and slaughter day within batch, obtained from ANOVA applied to raw data.

[3] Muscle thickness measured with the CSB-Image Meater device, M3: minimal muscle thickness at the *Gluteus medius* muscle level, M4: average muscle thickness over four lumbar vertebrae.

[4] Backfat thickness measured with the CSB-Image Meater device, G3: minimal fat thickness over the *Gluteus medius* muscle, G4: average fat thickness over four lumbar vertebrae.

[5] Carcass lean meat content was determined from automatic measurements of muscle (M3 and M4) and backfat (G3 and G4) thicknesses with the CSB-Image Meater device (Blum et al., 2014).

[6] Calculated as relative percentage of the cold right carcass side.

Table 5

Influence of genotype on meat quality traits of non-castrated male pigs

	Genotype[1]				*P*-value[2]		
	Duroc crossbreds		Pietrain crossbreds		Genotype	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
n	47		34				

Loin: *Longissimus thoracis et lumborum* muscle

pH 24 h	5.51	0.008	5.51	0.010	0.25	0.087	0.040
Drip loss (%)	4.7	0.25	5.7	0.29	0.015	0.085	0.036
Colour							
Lightness (L*)	48.9	0.32	50.0	0.37	0.028	0.40	<0.001
Redness (a*)	7.5	0.15	7.0	0.17	0.034	0.002	<0.001
Yellowness (b*)	5.2	0.11	4.9	0.13	0.12	<0.001	<0.001
Chroma (C*)	9.1	0.17	8.6	0.20	0.037	<0.001	<0.001
Hue angle (h°)	34.9	0.47	34.9	0.55	0.95	0.013	0.009
Cooking loss (%)	34.2	0.63	33.8	0.72	0.62	<0.001	0.001
Shear Force (N/cm²)	33.3	0.69	35.1	0.80	0.090	0.006	<0.001
Ham muscles							
pH 24 h *Semimembranosus*	5.58	0.012	5.59	0.017	0.63	0.12	0.17
pH 24 h *Gluteus medius*	5.48	0.010	5.48	0.013	0.89	0.34	0.50
Colour *Gluteus medius*							
Lightness (L*)	51.6	0.46	51.2	0.55	0.59	0.001	<0.001
Redness (a*)	10.0	0.23	9.2	0.27	0.033	0.92	<0.001
Yellowness (b*)	8.4	0.17	7.5	0.21	0.002	0.18	<0.001

Chroma (C*)	13.0	0.26	11.9	0.31	0.005	0.53	<0.001
Hue angle (h°)	39.9	0.55	39.1	0.66	0.31	0.35	0.008

Abbreviations: lsmeans = least-square means.

[1] Duroc crossbreds: Large White × Duroc, Pietrain crossbreds: Large White × Pietrain.

[2] *P*-values of the fixed effects of genotype, batch, and slaughter day within batch, obtained from ANOVA applied to raw data.

Table 6

Influence of genotype on biochemical composition of the *Longissimus thoracis et lumborum* muscle of non-castrated male pigs

	Genotype[1]				*P*-value[2]		
	Duroc crossbreds		Pietrain crossbreds		Genotype	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
n	47		34				
Water (%)	74.7	0.09	75.2	0.11	<0.001	<0.001	0.002
Proteins (%)	21.9	0.07	22.2	0.08	0.005	0.011	0.35
Lipids (%)	2.50	0.078	1.90	0.090	<0.001	0.002	0.004
Glycolytic potential (µmol eq lactate/g)	176	2.2	173	2.6	0.37	0.34	0.27

Abbreviations: lsmeans = least-square means.

[1] Duroc crossbreds: Large White × Duroc, Pietrain crossbreds: Large White × Pietrain.

[2] *P*-values of the fixed effects of genotype, batch, and slaughter day within batch, obtained from ANOVA applied to raw data.

Fig. 1. Diagram of the animal building and experimental pens for organic pigs (Porganic experimental farm, INRAE)

Fig. 2. Concentrations of androstenone, skatole and indole in backfat of non-castrated males according to pig genotype: Large White × Duroc (D), or Large White × Pietrain (P) crossbreds. The horizontal bars represent (from top to bottom) the third quartile, the median, and first quartile. The effect of pig genotype on androstenone concentration was assessed using an ANOVA on log-transformed values, and on skatole and indole concentrations using a non-parametric test. Effect of genotype was found as significant for androstenone ($P < 0.001$), skatole ($P = 0.040$) and indole ($P = 0.030$) concentrations.