



HAL
open science

Feeding strategy in organic pig farming as a lever to improve various quality dimensions of pork

Chloé Van Baelen, Lucile Montagne, Stéphane Ferchaud, Armelle Prunier, Bénédicte Lebret

► To cite this version:

Chloé Van Baelen, Lucile Montagne, Stéphane Ferchaud, Armelle Prunier, Bénédicte Lebret. Feeding strategy in organic pig farming as a lever to improve various quality dimensions of pork. *Animal*, 2024, 18 (7), pp.101190. 10.1016/j.animal.2024.101190 . hal-04582528v2

HAL Id: hal-04582528

<https://hal.inrae.fr/hal-04582528v2>

Submitted on 13 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



Feeding strategy in organic pig farming as a lever to improve various quality dimensions of pork



C. Van Baelen^{a,*}, L. Montagne^a, S. Ferchaud^b, A. Prunier^a, B. Lebret^a

^a PEGASE, INRAE, Institut Agro, 35590 Saint-Gilles, France

^b INRAE, GenESI, 86480 Rouillé, France

ARTICLE INFO

Article history:

Received 14 December 2023

Revised 6 May 2024

Accepted 7 May 2024

Available online 16 May 2024

Keywords:

Boar taint

Feed resources

Growth performance

Male pigs

Meat quality

ABSTRACT

Since 2022, European specifications for organic pig farming have evolved to distribute 100 % organic feed and to reinforce the link to the soil with feed resources that should primarily be obtained from the farm or the same region. Feeding strategy acts as a lever to improve various quality dimensions of organic (as well as conventional) pork, including intrinsic dimensions (carcass composition, nutritional, organoleptic, technological, sanitary qualities) and extrinsic dimensions related to animal farming (image). Diet may also influence the risk of undesirable odours or flavours that may be found in pork from non-castrated male pigs. This study aimed at evaluating the effects of a specific feeding strategy on several quality dimensions of organic meat from non-castrated male pigs. The experiment was conducted with 77 organic non-castrated male pigs (Piétrain NN × Large White) reared according to organic specifications and distributed in two batches. Within litters, male littermates were allocated at around 33 kg of live weight to either a Control group which received a Control feed (C) corresponding to the organic specifications or in a Bio+ group which received an organic test feed based mainly on French raw materials and which contained more fibres (faba bean and access to forages) and omega-3 fatty acids (linseed, camelina). All pigs were reared in the same building on deep straw bedding (1.3 m²/pig) with free outdoor access (1.0 m²/pig) using one pen per experimental group. Pigs were fed *ad libitum* until slaughter at about 125 kg live weight. Average daily gain, carcass weight and lean meat content did not differ significantly between C and Bio+ pigs. Compared to C, Bio+ pigs had higher ($P < 0.05$) ultimate pH in the loin (*Longissimus muscle*) and ham (*Gluteus medius*, and *Semimembranosus*) muscles, associated with a lower *Longissimus muscle* glycolytic potential ($P < 0.001$). Loin and ham meat from Bio+ vs. C pigs was lighter ($P < 0.05$) and had a more intense red colour ($P < 0.10$). The Bio+ strategy led to a lower *Longissimus muscle* n-6:n-3 fatty acid ratio ($P < 0.001$), indicating an improvement in pork nutritional value. Backfat skatole concentration was lower in Bio+ than in C pigs whereas backfat androstenone was higher in Bio+ than in C pigs ($P < 0.05$). Altogether, we demonstrated that the Bio+ strategy had positive impacts on several qualities of organic pork from non-castrated male pigs.

© 2024 The Authors. Published by Elsevier B.V. on behalf of The Animal Consortium. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Implications

Committing to organic farming means paying attention to feed resources and animal welfare. In organic and conventional pork production, the feeding strategy plays a key role in various quality dimensions (carcass composition, nutritional, organoleptic and technological properties of pork, and image of pig production). Compared to a feeding strategy that meets the minimal requirements of organic specifications, an organic feeding strategy mainly based on local resources, with a diet rich in fibre and omega-3 fatty

acids and with additional forage had positive impacts on several quality dimensions of organic pork from non-castrated male pigs.

Introduction

Health and sustainability are key considerations for consumers when it comes to food, especially food security, animal welfare and environmental impact (EU, 2020). Even though organic production is increasing, consumers still have doubts about what organic products really are (Crozet, 2022). Organic farming is a production system that aims to favour animal welfare, to preserve biodiversity and to strongly limit the use of inputs. These objectives are part of the European strategy farm to fork (EU, 2020). The organic specifications indicate to reinforce animal welfare (for example: *ad libitum*

* Corresponding author.

E-mail address: chloe.van-baelen@inrae.fr (C. Van Baelen).

access to forage) and to enhance the link to the soil for feeding resources (at least 30 % of local raw material for 100 % of organic feed ingredients) (EU, 2018). Feeding practices, in either organic or conventional systems, may affect several quality properties of pork, including the carcass composition and its commercial value, the organoleptic quality (texture, flavour) and the nutritional value (through the fatty acid (FA) composition) of pork (Lebret and Čandek-Potokar, 2022). The practices that meet organic farming specifications enhance the value of extrinsic dimensions (image) but their effects on other dimensions such as intrinsic ones (commercial, nutritional, organoleptic, technological) are controversial as they actually depend on husbandry factors within organic farming, such as pig genotype, housing conditions, and feeding level, among others (Prache et al., 2022).

The European regulations for organic farming stipulate that if piglets are castrated, this must be performed under adequate anaesthesia and/or analgesia to limit pain [Regulation EU, 2018/848]. However, anaesthesia and analgesia protocols used for piglet castration only partially relieve piglet pain (Prunier et al., 2020). With respect to animal welfare, one solution is to avoid the castration of male piglets and raise non-castrated males, while controlling the risk of undesirable flavours or odours of pork (von Borell et al., 2020). Androstenone and skatole are the main molecules responsible for this problem, also called boar taint. Androstenone is a steroid synthesised from cholesterol in the testicles with lipophilic properties (Robic et al., 2014; Zamaratskaia and Squires, 2009). Due to its lipophilic properties, androstenone is stored in adipose tissue and may give an urine-like odour typical of boar taint to the meat, even though this perception depends on the consumers (Bee et al., 2015; Lundström et al., 2009). Androstenone is principally related to sexual development which is largely due to genetic influence; thus, genetic selection is one efficient way of reducing the concentration of androstenone in adipose tissue (Zamaratskaia and Squires, 2009). Skatole is metabolised from tryptophan by gut bacteria and has lipophilic properties, thus also accumulates in the adipose tissue, leading to faecal odour in the meat (Lundström et al., 2009; Zamaratskaia and Squires, 2009). Every sexual type (female, male, non-castrated male) produces skatole from tryptophan in the colon but the testicular steroids reduce the liver metabolism of skatole, making its concentration higher in tissues of non-castrated compared with castrated males or female pigs (Zamaratskaia and Squires, 2009). Half-life of skatole is shorter than that of androstenone (few hours vs. few days) (Prunier et al., 2013). Diet is one of the most important factors influencing the concentration of skatole in adipose tissue because its synthesis and/or accumulation depends on the tryptophan availability in gut, the orientation of bacterial fermentation and the faecal excretion of skatole produced (Wesoly and Weiler, 2012). It was shown that adding more fermentable fibre to the diet of pigs could reduce the concentration of skatole (Wesoly and Weiler, 2012). Besides, it has been shown that including fibre in the pig diet could reduce muscle glycogen stores and thereby may increase meat's ultimate pH (Li et al., 2015).

Considering these issues, the pig feeding strategy can thus be considered as a lever to improve various quality dimensions of organic pork. The objective of this study was to evaluate the consequences of a feeding strategy combining a diet based on local (mainly French) raw materials, rich in fibre and in omega-3 FA (aimed at improving the pork's nutritional value) and the provision of forage in non-castrated organic pigs, on several quality dimensions of pork. The hypothesis is that, compared with a diet that strictly meets the organic specifications, this feeding strategy would (i) reduce skatole concentration and therefore the risk for boar taint, (ii) improve the nutritional value of pork and (iii) potentially improve pork technological quality through higher meat pH. However, the addition of forages could alter growth performance

which may limit protein digestibility (Noblet and Le Goff, 2001). The originality of this study lies in the simultaneous assessment of various quality properties of organic pork from non-castrated males, that are important for the farmers (growth performance, carcass commercial value), the processors (technological properties) and the consumers (organoleptic and nutritional properties).

Part of these results have been presented at international and national congresses (Van Baelen et al., 2023, 2024).

Material and methods

Animal measurements and observations

The experiment was conducted with 77 organic non-castrated male pigs (Piétrain NN (non-carrier of the n allele at the RYR1 gene) × Large White) distributed in two batches (n = 49 with birth from 03 November 2021 to 06 November 2021 for batch 1 and n = 28 pigs with birth from 14 December 2021 to 18 December 2021 for batch 2), during the winter and spring (first piglets born in November 2021 until last slaughter session in June 2022). Within each batch (10 litters from 9 boars and 8 litters from 8 boars were produced for batches 1 and 2, respectively), pairs of male littermates were preselected at weaning (7 weeks old, at 17 kg live weight (LW)) on the basis of their LW and growth rate from birth, and allocated to one of two pens where they stayed until the end of the experiment. At around 33 kg LW (11 weeks old, at the beginning of the experiment), each pen was randomly allocated to one experimental group (1 one group per pen): Control (C) (batch 1: n = 25 and batch 2: n = 12) and Bio+ (batch 1: n = 24 and batch 2: n = 16). Within batches, pigs from one litter were allocated as equally as possible between the two groups and, LW was considered in order to have groups with similar average and SD of LW at weaning, and LW was checked at the start of the experiment. However, it was not possible to strictly allocate pigs by pairs from the same litter since, for some litters, the number of available male pigs at weaning was not an even number. To avoid any social disturbances within pen, the number of pigs per group was not balanced. Within batches, pigs from each group were reared in a collective pen (total of four pens) from the same building on deep straw bedding (1.3 m²/pig), with fresh straw added weekly, having a free access to a covered outdoor area (1.0 m²/pig). 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 second batch had fewer pigs, the pen size was reduced using bales of hay to maintain the same available surface per pig (1.3 m²/pig). Pigs were weighed individually at the start of the experiment (at about 70 days of age and 33 kg LW), every 2 weeks during the experimental period corresponding to the growing phase (from about 33 to 66 kg LW) and finishing phase (from about 66 kg LW until slaughter), and the day before slaughter (at about 169 days of age and 128 kg LW). Average daily gain was calculated per pig during the growing and finishing phases and over the whole experimental period. Pigs were observed daily during the experimental period in order to evaluate pen and animal cleanliness, animal health (pigs with hernia, lameness, cough, skin wound, tail lesions) and overall agonistic behaviours (mounting). The ambient temperature was recorded hourly on both the building and the courtyard throughout the experiment.

Feeding strategy

Two feeding strategies were compared. Within each batch, one group of pigs received a Control feed (C) corresponding a minimum

to the organic specifications. The pigs of the other group received a test feed named Bio+ mainly based on French raw materials, containing faba bean and rich in omega-3 FA (linseed, camelina) (Table 1). In addition, the Bio+ pigs had a permanent access to forage distributed in a rack. The roughage used was grassland hay during the growing phase and clover wrapping during the finishing phase (Table 2). The FA composition of diets and roughages is detailed in Supplementary Table S1. All diets (based on barley, wheat, peas and soybean meal) were formulated by a private company (DFP Nutraliance), in order to fulfil animal nutritional requirements (Van Milgen and Noblet, 2002; Table 1) and were offered as pellets. Within each phase, the diets were isoenergetic and iso-proteic and contained similar lysine concentration. Animals were fed *ad libitum* throughout the experiment (distribution at 0900 h for pellets and 1000 h for forages). The distributed quantities of each diet, and of grassland hay and clover wrapping for Bio+ pigs, were determined per pen. All pigs had permanent access to water.

Slaughter and carcass measurements

Animals were slaughtered in a commercial slaughterhouse (Cooperl, 79800 Sainte-Eanne, France) at an average live weight of 125 kg. There were two series of slaughter per batch, each series including the same number of pigs from each experimental group. The heaviest half of the pigs in each pen were slaughtered in the first series and the other half, which remained in their original pen, in the second series. This was realised since LW is an important factor in determining carcass and meat characteristics. The second series occurred 2 weeks (batch 1) or 3 weeks (batch 2) after the first series. The day before slaughter, feed (and forage in Bio+ group) was removed at 1000 h. In the morning, pigs were individually weighed and transferred on a roofed platform where they remained in two pens, one for each feeding strategy (C and Bio+) without feed but with free access to water. Pigs from the same series were transported in a single truck to the slaughterhouse (maximum duration of 30 min). Pigs from the two experimental groups

Table 1
Composition of the experimental diets for pigs.

Ingredients (% as fed)	Feeding strategy ¹			
	Control		Bio+	
	Growing ²	Finishing ²	Growing ²	Finishing ²
Barley	39.9	45.1	40.9	39.7
Wheat	19.3	15.6	21.3	16.1
Maize	–	1.0	–	–
Pea	15.0	17.6	13.8	18.7
Wheat bran	5.0	8.0	–	–
Soybean meal	13.9	7.8	10.9	1.8
Camelina meal	–	–	5.0	–
Faba bean	–	–	2.9	8.0
Alfalfa	1.0	1.0	1.0	1.0
Sunflower meal	1.7	–	–	5.7
Extruded linseed	–	–	–	5.0
Macro-elements (salt, clay, phosphorous, lime carbonate)	3.89	3.69	3.92	3.72
Vitamin-mineral premix ³	0.25	0.25	0.25	0.25
Analysed chemical composition (% DM, unless otherwise stated) ⁴				
DM, % fresh feed	89.2	89.6	89.5	89.2
CP	17.2	15.7	16.9	15.9
Crude fat	3.1	2.6	3.3	4.1
NDF	17.1	18.3	17.6	16.8
ADF	6.1	6.2	6.1	7.4
ADL	1.1	0.9	1.0	1.2
Starch	47.2	47.9	47.2	47.9
Ash	6.7	6.9	6.5	6.6
Gross energy (MJ/kg)	18.1	17.9	18.2	18.2
Vitamin E (mg/100 g) ⁵	69.3	67.7	66.9	63.2
Fatty acid composition (% of identified FA) ⁶				
Saturated	19.2	21.8	19.2	16.5
Monounsaturated	26.8	11.9	22.1	36.5
Polyunsaturated	54.1	66.3	58.6	47.0
n-3	6	6.5	7.6	17.78
n-6	48.0	59.7	50.8	29.1
Calculated composition (% DM basis)				
Lysine (g/kg)	8.5	7.3	8.6	7.3
Net energy (MJ/kg)	9.44	9.33	9.45	9.34

¹ Feeding strategy given to the pigs with: Control feed based on the organic specifications and Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal).

² Growing phase: from 11 to 16 weeks of age, i.e. around 33–66 kg live weight. Finishing phase: from 16 weeks to around 24 weeks of age, i.e. 66 to around 125 kg live weight (slaughter).

³ Premix composition: Vitamin A (2 400 000 UI), Vitamin D3 (480 000 UI), Vitamin E (40 000 UI), Vitamin B1 (240 mg), Vitamin K3 (240 mg), Vitamin B2 (960 mg), sodium D-panthenate (2 800 mg), Vitamin B6 (360 mg), Vitamin B12 (8 mg), Niacinamid (4 800 mg), Biotin (36 mg), Folic acid (720 mg), Choline Chloride (96 000 mg), Copper (31 200 mg), Iron (3 600 mg), Zinc (28 800 mg), Manganese (14 400 mg), Iodine (120 mg), Selenium (84 mg), Endo-1,4-beta xylanase (440 000 UV), Endo-1,3(4) beta-glucanase (600 000 UV).

⁴ Analysed as described by Lebreton et al. (2021).

⁵ All samples were analysed by reversed-phase liquid chromatography, as described for Vitamin E concentration of muscle samples.

⁶ Fatty acid composition of diets was analysed by gas chromatography after chloroform–methanol extraction of lipids as described for FA composition of intramuscular fat.

Table 2
Analysed chemical composition of forages in the Bio+ feeding strategy for pigs.

	Hay	Clover wrapping
Analysed chemical composition (% DM, unless otherwise stated) ¹		
DM, % fresh feed	94.1	94.5
CP	9.66	13.63
Non proteic nitrogen	0.50	0.74
Crude fat	2.62	2.37
Starch	0.74	2.71
Crude fibre	29.2	34.9
NDF	56.0	57.5
ADF	29.0	39.7
ADL	2.35	8.61
Ash	9.08	8.79
Vitamin E (mg/100 g) ²	48.5	43.3
Gross energy (MJ/kg)	17.8	18.3
Fatty acid composition (% of identified FA) ³		
Saturated	31.3	33.1
Monounsaturated	6.0	10.2
Polyunsaturated	62.7	54.6
n-3	43.6	24.8
n-6	19.1	27.4

¹ Analysed as described by Lebret et al. (2021).

² All samples were analysed by reversed-phase liquid chromatography, as described for vitamin E concentration of muscle samples.

³ Fatty acid composition of diets was analysed by gas chromatography after chloroform-methanol extraction of lipids as described for FA composition of intramuscular fat.

were mixed just before loading to the truck and kept at the slaughterhouse in a single pen between 2 h 30 min and 9 h according to the slaughter session. Our experimental pigs were never mixed with other pigs. They were slaughtered in the early morning, by electrical stunning at high voltage and exsanguination. The hot carcass was weighed, and carcass lean meat content was determined using the CSB-Image-Meater device (CSB, Geilenkirchen, Germany), based on automatic measurements of muscle thickness at different spots (M3: minimal muscle thickness at the *Gluteus medius* muscle level; M4: average muscle thickness over four lumbar vertebrae) and backfat thickness on other spots (G3: minimal fat thickness over the *Gluteus medius* muscle; G4: average backfat thickness over four lumbar vertebrae) (Blum et al., 2014). Detection of boar taint (i.e. tainted or not tainted carcass) was undertaken on each carcass using the human nose methodology, by trained and experienced staff from the slaughterhouse. The carcasses were chilled at 4 °C, and after 24 h, the right carcass side was cut according to the standardised Dutch cut, and the ham, loin, shoulder, belly and backfat were weighed.

Meat ultimate pH was measured on the *Semimembranosus* (SM) at 5 cm from the tip of the hip bone, on the *Gluteus medius* (GM) and on the *Longissimus thoracis et lumborum* (LTL) between the 13th and 14th ribs (Ingold Xerolyt electrode, Mettler Toledo and Syleps pH meter, Lorient, France).

Colour was measured on the GM and LTL muscle. GM was exposed to artificial light right after cutting before measurement, close to the spot of pH measurement, of CIE colour coordinates L* (lightness), a* (redness), b* (yellowness), C* (saturation (chroma)) and h° (hue angle) using a chromameter (Minolta CR400, Osaka, Japan), with a D65 illuminant, a 1-cm diameter aperture and a 2° observer angle, after calibration against a white tile. A transversal slice of LTL (last and second to last rib level) was taken and bloomed (15 min, 4 °C, artificial light) before measurement of colour coordinates (average value of three different determinations per slice). Numerical total colour difference is 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).

Then, on the ventral part of the same slice, a subsample of LTL was taken with a 25 mm diameter punch, placed in a plastic tube (previously tarred) with inner fins (KB labor technic) and stored on a rack for 24 h at 4 °C. The next day, the tubes were weighed with and without the sample to calculate drip loss, according to the EZ drip loss method of Christensen (2003). After trimming, the remaining part of the LTL slice was grounded and kept for biochemical analyses.

Biochemical properties and fatty acid composition of the Longissimus muscle

At carcass cutting, a 2 cm thick slice of LTL muscle (first lumbar vertebra level) was taken and stored under vacuum at – 20 °C before lipid and FA profile determination. After thawing, slices were trimmed of external fat, grounded, and lipid concentration was determined from chloroform-methanol (2:1 v/v) extraction as described by Lebret et al. (2018). Then, between 0.025 and 0.035 g of extracted lipids were collected and stored under nitrogen flow at – 20 °C before determination of FA composition. After the methylation of FA with boron trifluoride methanol, FA composition was determined by gas chromatography as described by Lebret et al. (2021). Analyses were performed with a gas – chromatograph (Agilent Technologies 7890A, Santa Clara, CA, USA) equipped with an injector, a capillary column (30 m × 0.25 mm internal diameter) filled with a stationary phase containing 50 % cyanopropylphenyl and 50 % dimethylpolysiloxane (Agilent technologies) and a flame ionisation detector (280 °C). The carrier gas was hydrogen. The column temperature was increased from 150 °C up to 220 °C (+4 °C/min) and reached a plateau after 10.5 min. Heptadecanoic acid (C17:0) was used as the internal standard. Retention times and peak areas were determined for all samples. The identities of the peaks were determined by comparing them to the retention times of standard FA methyl esters. The amount of each FA was calculated as a function of the internal standard, and FA composition was expressed as a percentage of identified FA.

The LTL slice used for colour and drip loss measurement (described above in the “Slaughter and carcass measurements” section) was cut into two parts in the thickness direction. The section corresponding to the last rib level was trimmed of external fat and grounded, and one sub-sample was freeze-dried and pulverised before determination of protein (=6.25 × nitrogen) and water concentrations as previously described by Lebret et al. (2018). The other grounded sub-sample was stored at –20 °C before determination of glycolytic potential, defined as glycolytic potential = 2 × [(glycogen) + (glucose) + (glucose-6-phosphate)] + (lactate), and expressed as μmole equivalent lactate/g of fresh tissue. Free glucose, glucose 6-phosphate, glucose from glycogen hydrolysis by amyloglucosidase and lactate were determined enzymatically according to the methods described by Lebret et al. (2018).

The second part of the LTL slice remaining after colour measurement (i.e. corresponding to the second to last rib, sampled as described above) was vacuum packaged on the day after slaughter and aged for 7 days at + 4 °C. Then, a core sub-sample of LTL was taken, cut into small pieces, frozen in liquid nitrogen and stored at – 80 °C before the analysis of thiobarbituric acid reactive substances (TBARS) according to the method described by Lebret et al. (2018). The TBARS concentration was determined in duplicates after forced chemical oxidation induced by iron trichloride and sodium ascorbate for 0, 120, 240, 360 or 480 min, and expressed in μg of malondialdehyde (MDA) produced per g of tissue.

The day after slaughter, another transversal slice of LTL was taken at the level of third and fourth last ribs (12th dorsal verte-

brae) and cut into two parts in thickness direction. Both sections were vacuum packaged. The section corresponding to the third last rib was stored at -20°C ("non-aged meat") and the other one aged for 7 days at $+4^{\circ}\text{C}$ before freezing at -20°C . They were sent to Lanupro lab (Ghent University, Belgium) to perform an analysis of vitamin E, carnosine and anserine. Vitamin E analysis was performed on non-aged and aged meat samples according to an adaptation of the method described by Vossen et al. (2016). Vitamin E (α -tocopherol) concentration was determined by reversed-phase HPLC (GE Healthcare, Diegem, Belgium), using a Supelcosil LC18 column ($25\text{ cm} \times 4.6\text{ mm} \times 5\text{ }\mu\text{m}$; Sigma-Aldrich, Bornem, Belgium). The mobile phase was a mixture of methanol/water (97:3; v/v), and the elution was performed at a flow rate of 2.0 mL/min. UV detection was at a wavelength of 292 nm. The α -tocopherol concentration of the samples was determined by comparison of peak areas with those obtained from a standard curve of α -tocopherol. The concentration of dipeptides, carnosine and anserine as molecules with antioxidant properties were performed on non-aged LTL muscle samples (Kobe et al., 2011). Carnosine and anserine were analysed by HPLC (Agilent Technologies, 1200 series) with a Nucleosil 120-7 NH_2 column (aminopropyl column; Machery-Nagel, Düren, Germany), and UV detection at 210 nm. Samples concentrations in anserine and carnosine were determined by comparing with standard solutions of both anserine and carnosine with known concentrations between 0.02 and 0.10 mg/ml.

Backfat androstenone and skatole determinations

Twenty-four hours after slaughter, a piece of backfat (whole thickness, neck level) was taken, vacuum packaged and stored at -20°C for further measurement of androstenone and skatole concentrations by HPLC as previously described by Batorek et al. (2012). Briefly, backfat samples were melted (microwave) and the liquid lipids were centrifuged 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, $3.5\text{ }\mu\text{m}$, $4.6 \times 75\text{ mm}$, USA). Flow rate was 1.2 mL/min for skatole and 1.0 mL/min for androstenone. The detection limits were 0.08 $\mu\text{g/g}$ of liquid fat for androstenone and 0.02 $\mu\text{g/g}$ of liquid fat for skatole, and these values were assigned to pigs with concentrations below those limits.

Statistical analysis

Statistical analyses were performed with R studio software (version 4.3.0, The R Core Team, 2023). The pen was considered as the statistical unit for data on feed consumption and feed conversion ratio, and no statistical analyses were possible considering the very low number of data (two pens per experimental group). For the other measures, individual records were available; thus, the pig was considered as the statistical unit and data were analysed using an ANOVA, with the feeding strategy (two modalities), the batch (two modalities) and the slaughter day within batch (two modalities per batch) as fixed effects in the model (procedure lme followed by the procedure Anova of the car package). Distribution of residuals of the models was checked for normality, and lsmeans (Least-square means) were calculated per feeding strategy (emmeans package, Lenth et al., 2024). For androstenone, data were log-transformed to reach a normal distribution of the residuals and analysed with the same model as described above. For skatole data, the non-parametric Kruskal-Wallis test was used to assess the effect of the feeding strategy. All statistical models are described in Supplementary Material S1.

Results

In each pen, the resting area was considered clean during all the experiment (0–25 % of the pen was dirty). None of the pigs had wound or severe liquid faecal excretion. No signs of disease, mortality or mounting behaviour were observed during the animals' daily care periods. For batch 1, the ambient temperature was 10.4°C on average (varying from -1.5 to $+26^{\circ}\text{C}$) in the building and 9.2°C (varying from -3.1 to $+22.3^{\circ}\text{C}$) in the courtyard. For batch 2, the ambient temperature recorded for the building was 15.6°C on average (varying from 0 to $+32^{\circ}\text{C}$) and 14.0°C on average for the courtyard (varying from -2 to $+29.8^{\circ}\text{C}$).

Growth performances and carcass traits

Using local raw materials and adding fibre did not influence growth performance traits calculated on the total duration of the experiment. However, a higher average daily gain ($+76\text{ g}$; $P = 0.005$) was observed in pigs fed with the Control during the growing phase but a lower average daily gain during the finishing phase (-75 g ; $P = 0.003$; Table 3). The feed conversion ratio was similar in both experimental groups during the growing (2.55 vs. 2.58), finishing (2.95 vs. 2.80) and growing-finishing phases (2.81 vs. 2.81) for Control vs. Bio+ pigs, respectively. Bio+ pigs ate in average 65 g per day and per pig of fresh roughage during the growing phase, and 117 g per day during the finishing phase. Regarding the carcass parameters, the hot carcass weight, the carcass dressing, the lean meat content, the muscle and backfat thickness, and the relative proportion of primary cuts did not significantly differ between Bio+ and Control pigs (Table 3, $P \geq 0.088$).

Meat quality traits of loin and ham muscles

Meat quality traits were affected by the feeding strategy (Table 4). In the loin (LTL muscle), Bio+ pigs had a higher ultimate pH ($P = 0.011$), lower lightness ($P = 0.02$) and a tendency for lower h° value ($P = 0.08$) (Table 4). The calculated difference in meat colour between the Control and Bio+ strategy was of 1.2. Differences in drip loss between feeding strategies were not significant. For ham muscles, greater differences between feeding strategies were observed. Compared to Control pigs, the Bio+ pigs had higher ultimate pH in both SM and GM muscles ($P < 0.05$). Values of colour parameters of the GM showed less light (-2.4 point, $P = 0.001$) and redder meat (i.e. lower hue angle, $P < 0.01$) in Bio+ than Control pigs.

Biochemical composition of the Longissimus muscle

The effect of feeding strategy on the biochemical composition of the LTL muscle is presented in Table 5. Muscle protein concentration was higher in Bio+ than Control pigs ($P < 0.01$) but water and lipid concentrations did not differ between the feeding strategies. Glycolytic potential was lower in Bio+ than Control pigs ($P < 0.001$). Regarding vitamin E, there was no difference between feeding strategies on day 1 and day 7 after slaughter. Bio+ pigs had a higher concentration of anserine than Control ones ($P < 0.01$) whereas carnosine concentration did not significantly differ between Bio+ and C pigs. The kinetics of lipid oxidation according to feeding strategy showed higher MDA concentrations in Bio+ than Control pigs at T360, with greater differences at T480 min ($P < 0.001$; Fig. 1). The effect of the feeding strategy on the FA composition of the LTL muscle is presented in Table 6, and detailed in Supplementary Table S2. Regarding the proportions of saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids, the feeding strategy did not significantly influence

Table 3
Effect of the feeding strategy on growth performance and carcass traits in pigs.

	Feeding strategy ¹				P-value		
	Control (n = 37) ²		Bio+ (n = 40) ²		Feeding strategy	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
Growing phase performance³							
Initial live weight (kg)	33.9	0.90	34.6	0.86	0.593	0.009	0.026
Initial age (days)	70	0.3	70	0.2	0.460	0.353	0.057
Average daily gain (g)	977	20.4	901	19.4	0.005	0.148	0.050
Finishing phase performance⁴							
Initial live weight (kg)	68.1	1.43	66.1	1.36	0.265	0.018	0.018
Initial age (days)	112	0.3	112	0.2	0.460	0.353	0.057
Average daily gain (g)	1 024	19.0	1 099	18.1	0.003	0.266	0.383
Growing and finishing performance							
Slaughter age (days)	168	1.1	170	1.0	0.101	<0.001	<0.001
Final live weight (kg)	127	1.5	129	1.4	0.403	0.568	0.886
Average daily gain (g)	1 007	16.0	1 025	15.2	0.365	0.169	0.157
Carcass traits							
Hot carcass weight (kg)	97.4	1.12	99.9	1.06	0.089	0.465	0.927
Carcass dressing (%)	77	0.3	77.5	0.3	0.275	0.645	0.159
Lean meat content (%)	59.9	0.3	60.5	0.29	0.103	0.258	0.164
G3 (mm) ⁵	13.5	0.56	13.6	0.52	0.817	0.535	0.603
M3 (mm) ⁶	73.9	1.61	75.4	1.49	0.412	0.725	0.906
G4 (mm) ⁵	23.3	0.68	23.9	0.63	0.446	0.473	0.932
M4 (mm) ⁶	55.7	1.08	56.7	1.00	0.437	0.815	0.782
Carcass composition (%)⁷							
Ham	25.1	0.47	24.3	0.45	0.165	0.613	0.020
Loin	26.4	0.35	26.6	0.33	0.657	0.604	0.008
Shoulder	21.1	0.56	21.9	0.53	0.288	0.689	0.164
Belly	15.1	0.19	15.1	0.18	0.721	0.152	<0.001
Backfat	5.2	0.13	5.0	0.13	0.412	0.788	0.455

Abbreviations: lsmeans = least-square means.

¹ Feeding strategy given to pigs with: Control feed based on the organic specifications and Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal).

² P-values of effects of feeding strategy, batch and slaughter day within a batch.

³ around 33 (70 days of age) to 66 kg live weight.

⁴ around 66–128 kg (at about 165 days of age) live weight.

⁵ Backfat thickness measured with the CSB-Image Meater device, G3: minimal fat thickness over the *Gluteus medius* muscle; G4: average backfat thickness over four lumbar vertebrae.

⁶ 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.

⁷ Calculated as a relative percentage of the weight of the cold right carcass side.

Table 4
Effect of the feeding strategy on meat quality indicators in pigs.

	Feeding strategy ¹				P-value		
	Control (n = 37) ²		Bio+ (n = 40) ²		Feeding strategy	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
Loin: <i>Longissimus thoracis et lumborum</i> muscle							
pH 24 h (ultimate pH) ³	5.50	0.015	5.55	0.014	0.011	0.133	0.113
Drip loss (%)	4.46	0.352	4.02	0.334	0.332	0.978	0.089
Colour							
Lightness, L*	50.4	0.42	49.1	0.40	0.020	0.036	0.200
Redness, a*	6.8	0.18	6.7	0.17	0.917	0.335	0.901
Yellowness, b*	4.9	0.16	4.6	0.15	0.307	0.125	0.705
Chroma, C*	8.4	0.22	8.2	0.21	0.653	0.206	0.913
Hue angle, h°	35.6	0.58	34.3	0.55	0.084	0.247	0.616
Ham muscles							
pH 24 h <i>Gluteus Medius</i>	5.55	0.017	5.59	0.017	0.037	0.445	0.429
pH 24 h <i>Semimembranosus</i>	5.57	0.015	5.62	0.015	0.019	0.041	0.498
Colour							
Lightness, L*	49.6	0.55	47.2	0.53	0.001	0.018	0.144
Redness, a*	10.0	0.27	10.3	0.26	0.453	0.125	0.059
Yellowness, b*	7.4	0.25	6.9	0.24	0.185	0.034	0.086
Chroma, C*	11.6	0.35	11.3	0.33	0.612	0.457	0.323
Hue angle, h°	36.4	0.66	34.2	0.62	0.009	0.050	0.519

Abbreviations: lsmeans = least-square means.

¹ Feeding strategy given to pigs with: Control feed based on the organic specifications and Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal).

² P-values of effects of feeding strategy, batch and slaughter day within batch.

³ ultimate pH: measured 24 h after slaughter, defined as the amplitude of *postmortem* pH fall.

Table 5
Effect of the feeding strategy on biochemical composition of the *Longissimus* muscle in pigs.

	Feeding strategy ¹				P-value	Batch	Slaughter day within batch
	Control (n = 37) ²		Bio+ (n = 40) ²				
	lsmeans	SE	lsmeans	SE			
Water (%)	75.1	0.10	75.0	0.09	0.443	0.909	0.767
CP (%)	22.0	0.09	22.4	0.08	0.004	0.754	0.634
Lipids (%)	2.27	0.113	2.14	0.107	0.371	0.237	0.747
Glycolytic potential (μmol eq.lactate/g)	178	3.4	159	3.2	<0.001	0.443	0.790
Vitamin E D1 ³ (μg α-tocopherol/g)	2.33	0.088	2.29	0.084	0.737	0.054	0.051
Vitamin E D7 ⁴ (μg α-tocopherol/g)	2.05	0.085	2.06	0.080	0.895	0.391	0.908
Carnosine D1 ³ (mg/100 g of meat)	410	4.9	403	4.6	0.229	0.385	0.524
Anserine D1 ³ (mg/100 g of meat)	33.3	0.60	35.5	0.57	0.005	0.525	0.597

Abbreviations: lsmeans = least-square means.

¹ Feeding strategy given to pigs with: Control feed based on the organic specifications and Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal).

² P-values of effects of feeding strategy, batch and slaughter day within batch.

³ D1: non-aged meat (sampled 1 day after slaughter).

⁴ D7: meat aged 7 days at + 4 °C under vacuum.

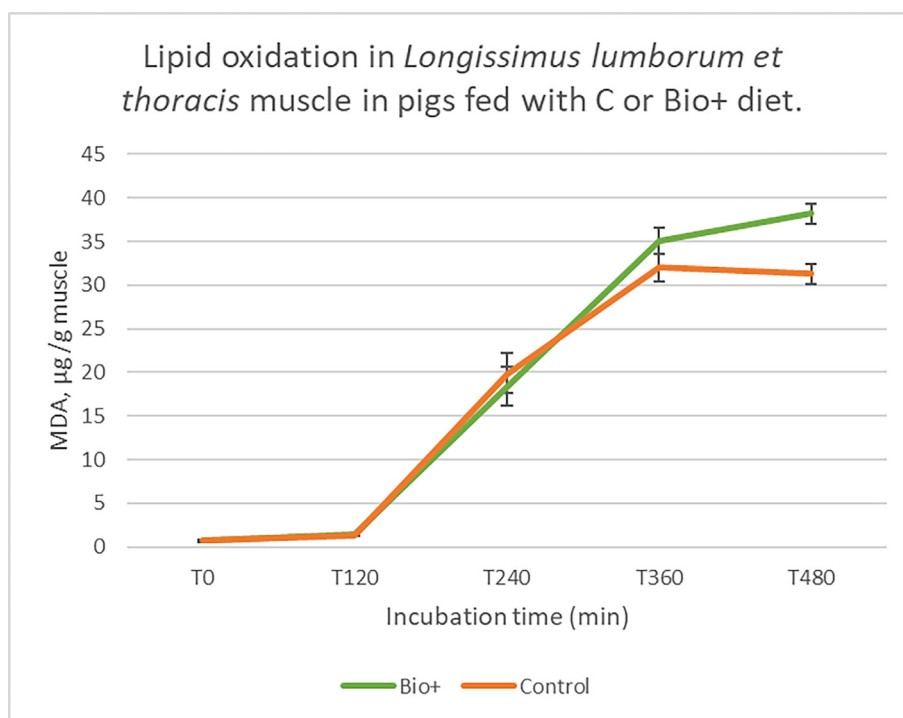


Fig. 1. Lipid oxidation in pig *Longissimus lumborum et thoracis* muscle aged 7 days according to the feeding strategy. Thiobarbituric acid reactive substances (TBARS) were assessed after 0, 120, 240, 360 or 480 min of incubation in oxidising conditions, and values were expressed in μg of malondialdehyde (MDA) per g of muscle. Data are least-square means (lsmeans) and SE calculated from raw data. Pigs were fed following either a Control (feed based on the organic specifications) or a Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acid sources (camelina meal or linseed extruded meal). ANOVA showed significant effects of the feeding strategy on average MDA concentration at 360 ($P < 0.05$) and 480 ($*** P < 0.001$) min of incubation.

any of them. However, the Bio+ feeding strategy led to a lower proportion of n-6 PUFA ($P = 0.012$) and a higher proportion of n-3 PUFA ($P < 0.001$), compared to Control pigs. The ratio LA:ALA was then much lower in Bio+ than in Control pigs ($P < 0.001$).

Boar taint components in adipose tissue

Androstenone and skatole concentrations in adipose tissue according to the feeding strategy are showed in Fig. 2. Androstenone concentration was higher in Bio+ than in Control pigs (with lsmeans values of 0.84 for Bio+ vs. 0.51 μg/g liquid fat for C, $P = 0.03$). Concentrations of skatole were significantly lower in Bio+ than in Control pigs, in which more pigs had skatole concentration values above 0.02 μg/g liquid fat ($P = 0.02$). Given consumer

rejection thresholds of 3 μg/g of liquid fat for androstenone and 0.15 μg/g of liquid fat for skatole, only two Bio+ pigs exceeded the androstenone threshold and two others the skatole threshold, while two Control pigs exceeded the skatole threshold. Zero carcasses were detected as odorous by human nose at the slaughterhouse.

Discussion

The originality of this study was to simultaneously assess the impact of a potentially ameliorative feeding strategy (Bio+) on several quality dimensions of pork from organic, non-castrated male pigs. This feeding strategy, implying the addition of fibres and paying attention to local raw material while being in an organic farm-

Table 6
Effect of the feeding strategy on the fatty acid composition of *Longissimus* muscle in pigs.

Fatty acid composition (% of identified fatty acid)	Feeding strategy ¹				P-value		
	Control (n = 37) ²		Bio+ (n = 40) ²		Feeding strategy	Batch	Slaughter day within batch
	lsmeans	SE	lsmeans	SE			
Saturated fatty acids	35.3	0.27	34.7	0.26	0.098	0.057	0.036
Monounsaturated fatty acids	47.2	0.50	47.6	0.47	0.576	0.306	0.153
Polyunsaturated fatty acids	17.5	0.63	17.7	0.60	0.777	0.981	0.831
n-6	15.5	0.56	13.7	0.53	0.012	0.938	0.823
n-3	1.62	0.12	3.72	0.11	<0.001	0.743	0.864
C18:2 linoleic acid (LA): C18:3 α -linolenic acid (ALA)	20.18	0.69	6.18	0.65	<0.001	0.343	0.730

Abbreviations: lsmeans = least-square means.

¹ Feeding strategy given to pigs with: Control feed based on the organic specifications and Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal).

² P-values of effects of feeding strategy, batch and slaughter day within batch.

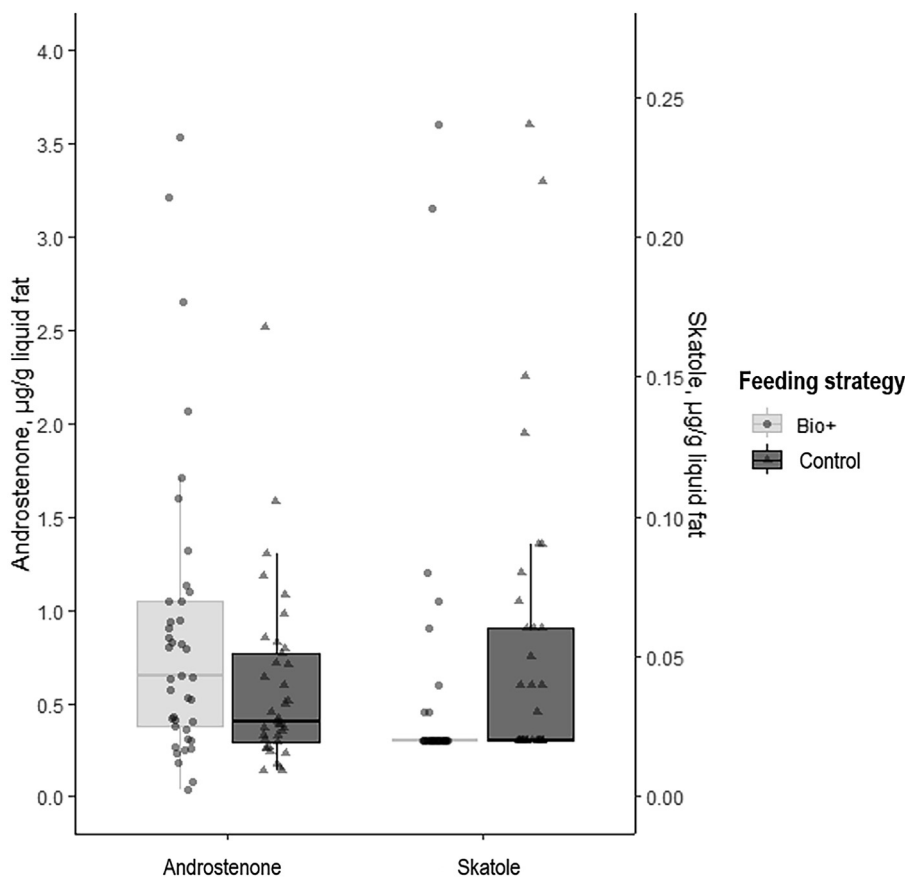


Fig. 2. Effect of feeding strategy on androstenone and skatole concentrations in backfat. Pigs were fed following either a Control (feed based on the organic specifications) or a Bio+ feed based on the organic specifications and mainly based on French raw materials, containing faba bean and omega-3 fatty acids sources (camelina meal or linseed extruded meal). The horizontal lines represent (from top to bottom) the 3rd quartile, the median and the 1st quartile. The effect of feeding strategy was found significant for androstenone ($P = 0.029$) and skatole concentrations ($P = 0.027$).

ing with non-castrated male pigs, should certainly have a positive image to the consumers. It has also several benefits on pork quality traits including skatole concentration and boar taint risk, and muscle glycogen stores and technological quality. Several factors were considered while having in mind the specific feature to identify either synergistic or antagonistic links. The further approach details the different quality dimensions from farm to fork, the overall societal image and the environmental properties of pork from non-castrated male pigs in organic farming. In our experimental design, the treatment was applied at the pen level since all pigs from a given pen received the same experimental diet

(Bio+ or Control). However, measures related to growth, carcass composition and meat properties were performed at the animal level. Animals were fed *ad libitum* in a collective feeder and were housed in an enriched environment in accordance with organic specifications (straw on the floor that was regularly refreshed, large space, access to an outdoor run) so that competition for resources and, especially for feed, was low within pens. Indeed, very few agonistic behaviours were observed in the pens. Therefore, we consider that interactions between animals do not, or very hardly, influence the application of the treatment, and hence, that measurements are independent of any interactions between ani-

mals. As a consequence, we considered the animal as the statistical unit.

The feeding strategy did not impact the growth performance during the whole growing-finishing period or the carcass characteristics. Overall, the values obtained for growth and carcass traits in this experiment have a similar order of magnitude to those found by several authors in organic systems (Millet et al., 2006; Quander-Stoll et al., 2022). This suggests that both strategies meet the nutritional needs of non-castrated males to develop their potential for lean tissue growth, despite some uncertainty in the evaluation of the nutritive values of organic raw materials compared to conventional ones, in particular for amino acid digestibility. Indeed, there is a low number of studies assessing the nutritive value and variability of organic feed ingredients, compared to conventional ones (Roinsard et al., 2018, 2021). Some studies show that the growth performances of pigs reared in organic farming system were lower than that of pigs reared under conventional conditions due to insufficient coverage of animal requirements, which are boosted by the increased physical activity and energy requirements for thermoregulation due to the increase of the surface area available and to outdoor access in the organic system (Prache et al., 2022). The presence of forage rich in fibre did not impact the pig performances in our study, despite the well-known negative effect of dietary fibre on performances due to lower digestibility of dietary energy and protein (Noblet and Le Goff, 2001). Besides, adding fibre just before slaughter can lead to an extension of the digestive tract and therefore a decreased carcass dressing (Asmus et al., 2014; Urbańczyk et al., 2005). The absence of such impact may be explained by the low intake of forage by the animals as also observed by Kelly et al. (2007). In our experiment, storage problems were observed with the wrapped forage, suggesting that it was too fermented or even rotten. The pigs probably did not find it palatable and did not eat much forage during the finishing phase. Unfortunately, no further measurement or analysis has been performed to address this hypothesis.

Farmer remuneration is influenced by the carcass weight and lean meat content, and the carcass yield and relative weights of high-value cuts are important for actors of slaughtering and first processing. Our results on growth performance and carcass composition suggest that the Bio+ strategy did not reduce the commercial value of pigs for farmers, or of carcasses or cuts for slaughter and first processing actors.

Technological quality refers to the meat's ability to be processed into pork products, and feeding strategy is a way to enhance some technological properties of pork (Lebret and Čandek-Potokar, 2022). The Bio+ strategy slightly increased the pH_u (ultimate pH measured 24 h after slaughter) of the loin and ham muscles, which can be explained by the reduction in the muscle glycolytic potential of Bio+ pigs. Some literature data show that the incorporation of fibre into the diet can lead to a reduction in muscle glycogen reserves (Li et al., 2015). Despite differences in meat pH between both feeding strategies, drip loss was not significantly modified. The improvement in meat colour (less light, redder hue) in Bio+ pigs compared with Control pigs may be explained by the higher pH_u of the formers, based on the well-established relationships between these traits (Rosenvold et al., 2001). Choosing the organic housing conditions means higher pig space allowance and outdoor access, leading to lower ambient temperature (in our experimental conditions) and greater physical activity for pigs than encountered in "conventional" indoor housing conditions. These can influence muscle metabolic properties including higher glycogen concentration, leading to the risk of lower meat ultimate pH, lighter and more exudative meat, and impaired pork technological quality (Lebret and Čandek-Potokar, 2022). However, the values found for LTL glycolytic potential, drip loss, and ultimate pH and colour

of loin and ham muscles in our experiment correspond to the range of values generally reported for pigs in conventional farming, and indicate satisfactory meat quality traits (Warner et al., 2017). Altogether, these results indicate that organic pork was overall of satisfactory quality, and that when compared with the Control, the Bio+ feeding strategy had positive impacts on the technological quality of the meat.

No carcass was detected as tainted by the human nose test at slaughterhouse, consistent with the relatively low androstenone and skatole concentrations in backfat in our experiment regardless of feeding strategy. Moreover, only two Bio+ pigs were above the rejection threshold by consumers of 3.0 µg/g of liquid fat for androstenone as reported by Bonneau and Chevillon (2012). Two other Bio+ pigs and two Control pigs exceeded the rejection threshold of 0.15 µg/g of liquid fat for skatole (Moerlein et al., 2012). The rejection threshold values for androstenone and skatole concentrations are controversial in the literature and a matter of debate for many reasons (high individual variation of consumer's sensitivity, especially to androstenone; boar taint perception depending on product's fat proportion and methods of preparation or consumption and differences between methods of measure of the odorous compounds) (Ampuero Kragten et al., 2011; Bee et al., 2015). Using thresholds of 1.5 µg/g of liquid fat for androstenone and 0.20 µg/g for skatole, as suggested by Mörlein et al. (2016), six Bio+ pigs would be above the consumer rejection thresholds for androstenone, and two Bio+ and two Control pigs would be above the threshold for skatole. The relatively low backfat androstenone concentration in our experiment can be explained by the fact that Piétrain boars (Piétrain NN; Nucleus, Le Rheu, France) used to inseminate sows were chosen for their low risk of androstenone-related odours. Adding regularly fresh straw allowed to maintain clean the bedding area all along the experiment, which could have contributed to limit the concentration of skatole in backfat (Prunier et al., 2013). Even though diet is not the main factor of variation of backfat androstenone, it can be affected by the distribution of fibre-rich feedstuffs. For example, pigs fed with 9 % chicory (rich in fermentable carbohydrates, including inulin) in the diet for 2 weeks before slaughter had higher backfat androstenone concentration (Zammerini et al., 2012). A slight even though the non-significant increase in backfat androstenone was also found with the addition of 10 % inulin to the diet (Aluwé et al., 2009) whereas Martins et al. (2023) found no significant effect of the distribution of a high fibre diet (including beet, lupin, peas and malt rootlets) compared to a control diet, on backfat androstenone concentration of Alentejano male pigs raised outdoors. Adding fermentable dietary fibres is known to reduce the backfat concentration in skatole, which is produced by the breakdown of tryptophan in the colon (Wesoly and Weiler, 2012; Zammerini et al., 2012). Fermentable fibre could have stimulated microbial fermentation and growth, leading to more incorporation of tryptophan in microbial protein, thus decreasing its availability for skatole production (Jensen, 2006). The ingestion of forage but also straw, rich in insoluble fibre, might have also increased the faecal transit speed that is another factor limiting the degradation of tryptophan into skatole. In agreement, compared with Control, the Bio+ strategy has reduced the backfat skatole concentration and the number of pigs with values above 0.02 µg/g liquid fat, even though the number of carcasses above the threshold rejection for consumers (>0.15 µg/g) was similar in both feeding strategies. Despite their higher backfat androstenone (which remained low overall), the Bio+ pigs had lower backfat skatole indicating that in a commercial context, the Bio+ feeding strategy would limit the risk for boar-tainted carcasses due to skatole and their downgrading at slaughterhouse.

Diet is the major way to influence the FA composition of pork and feeding pigs with an enriched n-3 FA diet has been largely used

to contribute to produce healthier food (Dugan et al., 2015). The Bio+ diets included extruded linseed and camelina meal that contain respectively 53.8 and 33.2 % omega-3 PUFA (INRA CIRAD AFZ) and the forages also contained high proportions of n-3 PUFA (e.g., 43.2 and 25.5 % of C18:3n-3 in of hay and clover wrapping, respectively, as presented in Supplementary Table S2). Adding more omega-3 FA in the Bio+ feeding strategy, had a positive impact on the meat PUFA composition as expected, with a marked increase in n-3 PUFA proportion at the expense of n-6 PUFA (Corino et al., 2014; Wood et al., 2008), without any changes in the relative proportions of total SFA, MUFA, PUFA. This led to a decrease in LA:ALA ratio up to values close to nutritional recommendations (ANSES, 2011), demonstrating that the Bio+ feeding strategy enhanced the nutritive value of the meat regarding its composition in FA.

Whatever the feeding strategy of the pigs, the pork meat was well protected from oxidation because the premix included vitamin E. Overall, vitamin E concentration in the loin was lower after 7 days of ageing than in meat sampled on the day after slaughter, in agreement with the decrease in α -tocopherol in pork loin after 8 d ageing (Vossen et al., 2016). It suggests that vitamin E actually played an antioxidant role during meat ageing and storage in our experiment. Indeed, the feeding strategy did not influence TBARS concentration in the LTL until 240 min of forced chemical oxidation, indicating that the Bio+ feeding strategy would not affect lipid oxidation of meat stored in usual conditions.

Carnosine and anserine are dipeptides known to prevent damages caused by oxidative stress due to antioxidant capacities (Peiretti et al., 2011). Thus, Bio+ diet moderately increased anserine concentration, which could contribute to limit lipid oxidation and/or protein oxidation (not measured) (Goethals et al., 2020).

The daily observation of animals during the experiment showed similar behaviour of non-castrated male pigs whatever the feeding strategy or the batch (results not shown). An enriched environment with straw bedding is known to reduce agonistic behaviour such as mounting and biting (Prunier et al., 2013). In that way, having access to forage (straw bedding, roughage...) might be a solution to reduce aggressive behaviour that could be observed with non-castrated male pigs (Høok Presto et al., 2009). As explained below, the mean amount of roughage intake was very low in this experiment and we cannot here explore the consequence of the presence of forage on aggressive behaviour.

Conclusion

A feeding strategy based on the use of local sources of protein, on fibre and omega-3 FA enrichment and additional forages for non-castrated male pigs reared in organic farming is a guarantee of a high level of image quality for consumer. Compared with a more classical feed that meets a *minima* of the organic specifications, such an ameliorative strategy did not affect pig growth performance or carcass traits and therefore their commercial value for farmers. The Bio+ strategy improved some indicators of the technological and nutritional properties of pork and would contribute to reduce the risk of boar taint due to skatole, which are of interest to the processors and consumers. The consequences of the feeding strategy tested on other pork quality properties, in particular environmental impacts, need to be further quantified.

Supplementary material

Supplementary material to this article can be found online at <https://doi.org/10.1016/j.animal.2024.101190>.

Ethics approval

The experiment was performed in the INRAE experimental facilities (GenESI Porganic, 86480 Rouillé, France), <https://www.https://doi.org/10.15454/1.5572415481185847E12> in compliance with EU directive 2010/63/EU for animal experiments, French legislation and organic specifications. This facility is certified organic by "Certipaq Bio". The technical and scientific staff had individual accreditation from the French Minister to experiment on living animals. The methods for animal experiment were approved by the local Committee on Ethics in animal experimentation and the present animal experimentation was authorised by the French Ministry of Higher Education, Research and Innovation (APAFIS #34201-2021113014545668 v6).

Data and model availability statement

None of the data were deposited in an official repository. The data/models that support the study findings are available from the authors upon request.

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

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

C. Van Baelen: <https://orcid.org/0009-0001-2625-1057>.

L. Montagne: <https://orcid.org/0000-0002-9540-1872>.

S. Ferchaud: <https://orcid.org/0009-0004-9364-8785>.

A. Prunier: <https://orcid.org/0000-0003-3070-6613>.

B. Lebret: <https://orcid.org/0000-0001-5435-0389>.

CRedit authorship contribution statement

C. Van Baelen: Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. L. Montagne: Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. S. Ferchaud: Resources, Methodology, Investigation. A. Prunier: Writing – review & editing, Validation, Project administration, Methodology, Funding acquisition, Conceptualization. B. Lebret: Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of interest

None.

Acknowledgements

The authors thank D. Grivault, S. Moreau and T. Terrasson from Porganic, INRAE GenESI, 86480 Rouillé France for animal care and sample collection, N. Bonhomme, S. Daré, M. Paupe and S. Tacher from UMR PEGASE, INRAE, L'Institut Agro Rennes Angers, 35590 Saint-Gilles, France for laboratory analysis, and S. De Smet, E. Kowalski and E. Vossen, Lanupro, Gent University, Belgium for their welcome and complementary analysis. The authors would also like to thank D. Renaudeau (UMR PEGASE, INRAE) for his contribution to the formulation of experimental diets and his advice on part of the discussion section.

Financial support statement

This work was supported by Institut national de recherche pour l'agriculture, l'alimentation, et l'environnement (INRAE) and Casdar FARINELLI. This project is part of a PhD (C. Van Baelen) co-funded by INRAE (METABIO métagramme) and the Brittany region. The first author also received a mobility grant (Rennes Métropole and the Brittany region) for carrying out part of the laboratory analyses at Gent University, Belgium.

References

- 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 Science* 82, 346–352. <https://doi.org/10.1016/j.meatsci.2009.02.001>.
- Ampuero Kragten, S., Verkuylen, B., Dahlmans, H., Hortos, M., Garcia-Regueiro, J.A., Dahl, E., Andresen, O., Feitsma, H., Mathur, P.K., Harlizius, B., 2011. Inter-laboratory comparison of methods to measure androstenone in pork fat. *Animal* 5, 1634–1642. <https://doi.org/10.1017/S1751731111000553>.
- ANSES, 2011. Actualisation des Apports Nutritionnels Conseillés pour les acides gras - Version intégrant les modifications apportées par l'erratum du 28 juillet 2011. France. Retrieved on 01/06/2023 from <https://www.anses.fr/fr/content/actualisation-des-apports-nutritionnels-conseilles-c3%A9s-pour-les-acides-gras-version-int%C3%A9grant-0>.
- Asmus, M.D., DeRouche, J.M., Tokach, M.D., Dritz, S.S., Houser, T.A., Nelssen, J.L., Goodband, R.D., 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. *Journal of Animal Science* 92, 119–128. <https://doi.org/10.2527/jas.2013-6679>.
- Batorek, N., Škrlep, M., Prunier, A., Louveau, I., Noblet, J., Bonneau, M., Čandek-Potokar, M., 2012. Effect of feed restriction on hormones, performance, carcass traits, and meat quality in immunocastrated pigs. *Journal of Animal Science* 90, 4593–4603. <https://doi.org/10.2527/jas.2012-5330>.
- Bee, G., Chevillon, P., Bonneau, M., 2015. Entire male pig production in Europe. *Animal Production Science* 55, 1347–1359. <https://doi.org/10.1071/AN15279>.
- Blum, Y., Monziols, M., Causeur, D., Dumas, G., 2014. New calibration of the main method for classifying pig carcasses in France. *Journées Recherche Porcine* 46, 39–44.
- Bonneau, M., Chevillon, P., 2012. Acceptability of entire male pork with various levels of androstenone and skatole by consumers according to their sensitivity to androstenone. *Meat Science* 90, 330–337. <https://doi.org/10.1016/j.meatsci.2011.07.019>.
- Christensen, L.B., 2003. Drip loss sampling in porcine m. longissimus dorsi. *Meat Science* 63, 469–477. [https://doi.org/10.1016/S0309-1740\(02\)00106-7](https://doi.org/10.1016/S0309-1740(02)00106-7).
- Corino, C., Rossi, R., Cannata, S., Ratti, S., 2014. Effect of dietary linseed on the nutritional value and quality of pork and pork products: systematic review and meta-analysis. *Meat Science* 98, 679–688. <https://doi.org/10.1016/j.meatsci.2014.06.041>.
- Crozat, A., 2022. Baromètre des produits biologiques en France - 2022, l'observatoire Société & Consommation-Agence Bio. ed. France. Retrieved on 31/05/2023 from https://www.agencebio.org/wp-content/uploads/2023/03/Rapport-complet_Barometre-Bio-Edition-2023.pdf.
- Dugan, M.E.R., Vahmani, P., Turner, T.D., Mapiye, C., Juárez, M., Prieto, N., Beaulieu, A.D., Zijlstra, R.T., Patience, J.F., Aalhus, J.L., 2015. Pork as a source of omega-3 (n-3) fatty acids. *Journal of Clinical Medicine* 4, 1999–2011. <https://doi.org/10.3390/jcm4121956>.
- EU, 2018. Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007. *Official Journal of the European Union*, Brussels, Belgium.
- EU, 2020. Communication from the commission to the european parliament, the council, the european economic and social committee of the regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system., *Official Journal of the European Union*, Brussels, Belgium.
- Goethals, S., Van Hecke, T., Vossen, E., Vanhaecke, L., Van Camp, J., De Smet, S., 2020. Commercial luncheon meat products and their in vitro gastrointestinal digests contain more protein carbonyl compounds but less lipid oxidation products compared to fresh pork. *Food Research International* 136, 109585. <https://doi.org/10.1016/j.foodres.2020.109585>.
- Høok Presto, M., Algers, B., Persson, E., Andersson, H.K., 2009. Different roughages to organic growing/finishing pigs – influence on activity behaviour and social interactions. *Livestock Science* 123, 55–62. <https://doi.org/10.1016/j.livsci.2008.10.007>.
- Jensen, B.B., 2006. Prevention of boar taint in pig production. factors affecting the level of skatole. *Acta Veterinaria Scandinavica* 48, S6. <https://doi.org/10.1186/1751-0147-48-S1-S6>.
- Kelly, H.R., Browning, H.M., Day, J.E., Martins, A., Pearce, G.P., Stopes, C., Edwards, S. A., 2007. Effect of breed type, housing and feeding system on performance of growing pigs managed under organic conditions. *Journal of the Science of Food and Agriculture* 87, 2794–2800. <https://doi.org/10.1002/jsfa.3060>.
- Kobe, R., Ishihara, Y., Takano, J., Kitami, H., 2011. Simultaneous determination of anserine and carnosine in chicken meat by hydrophilic interaction chromatography on an aminopropyl bonded silica gel column. *Bunseki Kagaku* 60, 859–863. <https://doi.org/10.2116/bunsekikagaku.60.859>.
- Kowalski, E., Vossen, E., Millet, S., Ampe, B., Callens, B., Van Royen, G., De Smet, S., Aluwé, M., 2020. Performance and carcass, loin and ham quality in crossbreds from three terminal sire lines. *Meat Science* 167, 108158. <https://doi.org/10.1016/j.meatsci.2020.108158>.
- Lebret, B., Batonon-Alavo, D.I., Perruchot, M.-H., Mercier, Y., Gondret, F., 2018. Improving pork quality traits by a short-term dietary hydroxy methionine supplementation at levels above growth requirements in finisher pigs. *Meat Science* 145, 230–237. <https://doi.org/10.1016/j.meatsci.2018.06.040>.
- Lebret, B., Čandek-Potokar, M., 2022. Review: pork quality attributes from farm to fork. part i. carcass and fresh meat. *Animal* 16, 100402. <https://doi.org/10.1016/j.animal.2021.100402>.
- Lebret, B., Lenoir, H., Daré, S., Fonseca, A., Fève, K., Riquet, J., Mercat, M.J., 2021. Finishing season and feeding resources influence the quality of products from extensive-system Gascon pigs. part 1: carcass traits and quality of fresh loin. *Animal* 15, 100240. <https://doi.org/10.1016/j.animal.2021.100240>.
- Lenth, R.V., Bolker, B., Buurkner, P., Giné-Vázquez, I., Herve, M., Jung, M., Love, J., Miguez, F., Riebel, H., Singmann, H., 2024. emmeans: Estimated Marginal Means, aka Least-Squares Means [R package emmeans version 1.10.0]. URL <https://cran.r-project.org/web/packages/emmeans/index.html> (Posted 01.23. 24).
- Li, Y., Li, J., Zhang, L., Yu, C., Lin, M., Gao, F., Zhou, G., Zhang, Y., Fan, Y., Nulndali, L., 2015. Effects of dietary energy sources on post mortem glycolysis, meat quality and muscle fibre type transformation of finishing pigs. *PLoS ONE* 10, e0131958.
- Lundström, K., Matthews, K.R., Haugen, J.-E., 2009. Pig meat quality from entire males. *Animal* 3, 1497–1507. <https://doi.org/10.1017/S1751731109990693>.
- Martins, J.M., Varino, R., Charneca, R., Albuquerque, A., Garrido, N., Neves, J., Freitas, A., Costa, F., Marmelo, C., Ramos, A., Martin, L., 2023. Outdoor finishing of intact male Portuguese Alentejano pigs on a sustainable high-fiber diet: impacts on blood, growth, carcass, meat quality and boar taint compounds. *Animals* 13, 2221. <https://doi.org/10.3390/ani13132221>.
- Millet, S., Ongena, E., Hesta, M., Seynaeve, M., De Smet, S., Janssens, G.P.J., 2006. The feeding of ad libitum dietary protein to organic growing-finishing pigs. *The Veterinary Journal* 171, 483–490. <https://doi.org/10.1016/j.tvjl.2005.01.002>.
- Moerlein, D., Grave, A., Sharifi, A.R., Buecking, M., Wicke, M., 2012. Different scalding techniques do not affect boar taint. *Meat Science* 91, 435–440. <https://doi.org/10.1016/j.meatsci.2012.02.028>.
- Mörlein, D., Trautmann, J., Gertheiss, J., Meier-Dinkel, L., Fischer, J., Eynck, H.-J., Heres, L., Looft, C., Tholen, E., 2016. Interaction of skatole and androstenone in the olfactory perception of boar taint. *Journal of Agricultural and Food Chemistry* 64, 4556–4565. <https://doi.org/10.1021/acs.jafc.6b00355>.
- Noblet, J., Le Goff, G., 2001. Effect of dietary fibre on the energy value of feeds for pigs. *Animal Feed Science and Technology* 90, 35–52. [https://doi.org/10.1016/S0377-8401\(01\)00195-X](https://doi.org/10.1016/S0377-8401(01)00195-X).
- Peiretti, P.G., Medana, C., Visentin, S., Giancotti, V., Zunino, V., Meineri, G., 2011. Determination of carnosine, anserine, homocarnosine, pentosidine and thiobarbituric acid reactive substances contents in meat from different animal species. *Food Chemistry* 126, 1939–1947. <https://doi.org/10.1016/j.foodchem.2010.12.036>.
- Prache, S., Lebret, B., Baeza, E., Martin, B., Gautron, J., Feidt, C., Medale, F., Corraze, G., Raulet, M., Lefevre, F., Verrez-Bagnis, V., Sans, P., 2022. Review: quality and authentication of organic animal products in Europe. *Animal* 16, 100405. <https://doi.org/10.1016/j.animal.2021.100405>.
- Prunier, A., Brillouët, A., Merlot, E., Meunier-Salaün, M.C., Tallet, C., 2013. Influence of housing and season on pubertal development, boar taint compounds and skin lesions of male pigs. *Animal* 7, 2035–2043. <https://doi.org/10.1017/S1751731113001596>.
- Prunier, A., Devillers, N., Herskin, M., Sandercock, D., Sinclair, A., Tallet, C., von Borell, E., 2020. Husbandry interventions in suckling piglets, painful consequences and mitigation. In: Farmer, C. (Ed.), *The Suckling and Weaned Piglet*. Wageningen Academic Publishers, Wageningen, NL, pp. 107–138. https://doi.org/10.3920/978-90-8686-894-0_4.
- Quander-Stoll, N., Bautze, D., Zollitsch, W., Leiber, F., Früh, B., 2022. Effects of 100% organic feeding on performance, carcass composition and fat quality of fattening pigs. *Biological Agriculture & Horticulture* 38, 271–284. <https://doi.org/10.1080/01448765.2022.2119889>.
- R Core Team, 2023. R: A language and environment for statistical computing. MSOR connections. R Foundation for Statistical Computing, Vienna, Austria.
- Robic, A., Faraut, T., Prunier, A., 2014. Pathways and genes involved in steroid hormone metabolism in male pigs: A review and update. *The Journal of Steroid Biochemistry and Molecular Biology* 140, 44–55. <https://doi.org/10.1016/j.jsbmb.2013.11.001>.
- Roinsard, A., Heuzé, V., Juin, H., Renaudeau, D., Tran, G., 2018. Chemical and nutritional value of organic feedstuffs : a need to address in 100% organic feeding of organic monogastric animals. In: *Proceedings of the 69th European Federation of Animal Science*, 27–31 August 2018, Dubrovnik, Croatia, session 48.
- Roinsard, A., Früh, B., De Simone, A., 2021. Organic knowledge network on monogastric animal feed : ration planning tool, Ok net ecofeed. https://ok-net-ecofeed.eu/wp-content/uploads/2020/12/D4.3_Ration-planning-tools_OK_Net_EcoFeed_template_deliverable-compressed.pdf (Posted 12.14.20).
- Rosenvold, K., Petersen, J.S., Lwerke, H.N., Jensen, S.K., Therkildsen, M., Karlsson, A. H., Møller, H.S., Andersen, H.J., 2001. Muscle glycogen stores and meat quality as affected by strategic finishing feeding of slaughter pigs. *Journal of Animal Science* 79, 382. <https://doi.org/10.2527/2001.792382x>.

- Urbańczyk, J., Hanczakowska, E., Świątkiewicz, M., 2005. The effect of organic feeding on carcass and meat quality of fattening pigs. *Journal of Animal and Feed Sciences* 14, 409–412. <https://doi.org/10.22358/jafs/70592/2005>.
- Van Baelen, C., Montagne, L., Ferchaud, S., Prunier, A., Lebret, B., 2023. Feeding strategy in organic farming as a lever to improve various quality dimensions or pork. In: Proceedings of the 74th European Federation of Animal Science, 26 August - 1 September 2023, Lyon, France, poster session 45.
- Van Baelen, C., Montagne, L., Ferchaud, S., Prunier, A., Lebret, B., 2024. Quelles sont les conséquences de la stratégie alimentaire sur les qualités des produits porcins issus de l'agriculture biologique ? *Journées Recherche Porcine* 56, 1–6.
- Van Milgen, J., Noblet, J., 2002. Partitioning of energy intake to heat, protein, and fat in growing pigs. *Journal of Animal Science* 81 (suppl_2), E86–E93.
- von Borell, E., Bonneau, M., Holinger, M., Prunier, A., Stefanski, V., Zols, S., Weiler, U., 2020. Welfare aspects of raising entire male pigs and immunocastrates. *Animals* 10, 2140. <https://doi.org/10.3390/ani10112140>.
- Vossen, E., Claeys, E., Raes, K., van Mullem, D., De Smet, S., 2016. Supra-nutritional levels of α -tocopherol maintain the oxidative stability of n-3 long-chain fatty acid enriched subcutaneous fat and frozen loin, but not of dry fermented sausage: Effect of α -tocopherol on n-3 fatty acid enriched meat products. *Journal of the Science of Food and Agriculture* 96, 4523–4530. <https://doi.org/10.1002/jsfa.7668>.
- Warner, R.D., Dunshea, F.R., Channon, H.A., 2017. Producing consistent quality meat from the modern pig. In: Mathew, A. (Ed.), *Achieving Sustainable Production of Pig Meat*. Burleigh Dodds Science Publishing, Cambridge, UK.
- Wesoly, R., Weiler, U., 2012. Nutritional Influences on Skatole Formation and Skatole Metabolism in the Pig. *Animals* 2, 221–242. <https://doi.org/10.3390/ani2020221>.
- Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Sheard, P.R., Richardson, R.I., Hughes, S. I., Whittington, F.M., 2008. Fat deposition, fatty acid composition and meat quality: a review. *Meat Science* 78, 343–358. <https://doi.org/10.1016/j.meatsci.2007.07.019>.
- Zamaratskaia, G., Squires, E.J., 2009. Biochemical, nutritional and genetic effects on boar taint in entire male pigs. *Animal* 3, 1508–1521. <https://doi.org/10.1017/S1751731108003674>.
- Zammerini, D., Wood, J.D., Whittington, F.M., Nute, G.R., Hughes, S.I., Hazzledine, M., Matthews, K., 2012. Effect of dietary chicory on boar taint. *Meat Science* 91, 396–401. <https://doi.org/10.1016/j.meatsci.2012.01.020>.