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

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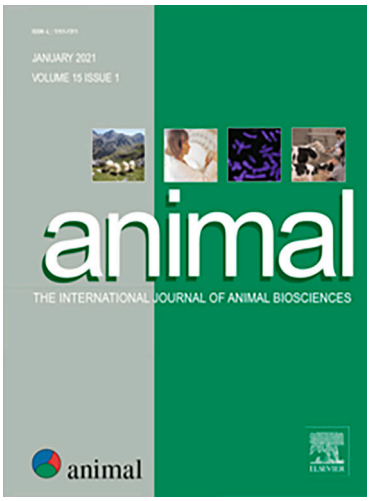

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Highlights

- Non-castration of males and organic farming contribute to societal image of pork
- Feeding strategy is a way to improve many quality dimensions of organic pork
- Feeding improves technological quality without impairing growth of organic pigs
- Linseed, camelina meal and roughage improve fatty acid n-3 and n-6 profile of pork
- Modulating quality dimensions concerns many stakeholders along pork chain value

Abstract

Since 2022, European specifications for organic pig farming have evolved to distribute 100 % organic feed, 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 roughages) 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 to a lower *Longissimus muscle* glycolytic potential ($P < 0.001$). Loin and ham meat from Bio+ *vs* C pigs was less light ($P < 0.05$) and had a more intense red color ($P < 0.10$). The Bio+ strategy led to 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 C pigs whereas backfat androstenone was higher in Bio+ than C pigs ($P < 0.05$). Altogether, we demonstrated that the Bio+ strategy had positive impacts on several qualities of organic pork from entire male pigs.

Keywords**:** Male pigs, Feed resources, Growth performance, Boar taint, Meat quality

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 on 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 roughage 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 aim 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 indicates to reinforce animal welfare (for example : *ad libitum* access to roughage) 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 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). In respect to animal welfare, one solution is to avoid 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 of this problem, also called boar taint. Androstenone is a steroid synthesized 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 under 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 in the diet

of pigs could reduce the concentration of skatole (Wesoly and Weiler, 2012). Besides, it has been shown that including fibre in pig diet could reduce muscle glycogen stores and thereby may increase meat 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 nutritional value) and the provision of roughage 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., 2024, 2023).

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 03/11/2021 to 06/11/2021 for batch 1 and n = 28 pigs with birth from 14/12/2021 to 18/12/2021 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 pre-selected 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 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 standard deviation 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, number of pigs per group

was not balanced. Within batches, pigs from each group were reared in a collective pen (total of 4 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 two 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 roughage distributed in a rack. The roughage used were 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 9:00 am for pellets and 10:00 am for roughage). 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 realized since LW is an important factor determining carcass and meat characteristics. The second series occurred two weeks (batch 1) or three weeks (batch 2) after the first series. The day before slaughter, feed (and roughage in Bio+ group) was removed at

10:00 am. In the morning, pigs were individually weighed, 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 were mixed just before loading to the truck and kept at the slaughterhouse in a single pen between 2 hours 30 min and 9 hours 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 the standardized Dutch cut and the ham, loin, shoulder, belly and backfat were weighed.

Meat ultimate pH was measured on the ***Semimembranous* (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 color 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 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 hours 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 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 ionization 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 (heptadecanoic acid, C17:0), and FA composition was expressed as percentage of identified FA.

The LTL slice used for color and drip loss measurement (described above in the "Slaughter and carcass measurements" section) was cut in two parts in 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 pulverized 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 x [(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 color 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 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 vertebrae) and cut in 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 7 days at + 4 °C before freezing at - 20 °C. They were sent to Lanupro lab (Ghent University, Belgium) to perform 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 cm × 4.6 mm × 5 µm; 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 antioxidants 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 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 µm, 4.6x75 mm, USA). Flow rate was 1.2 mL/min for skatole 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 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 of feed consumption and feed conversion ratio and no statistical analyses were possible considering the very low number of data (2 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 analysis of variance, with the feeding strategy (2 modalities), the batch (2 modalities) and the slaughter day within batch (2 modalities per batch) as fixed effects in the model (procedure lm followed by the procedure Anova of the car package). Distribution of residuals of the models were 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 Kruskall-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 °C) in the building and 9.2 °C (varying from - 3.1 to + 22.3 °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 °C) and 14.0 °C on average for the courtyard (varying from - 2 to + 29.8 °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 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 at day 1 and day 7 after slaughter. Bio+ pigs had 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 ($P < 0.001$; Figure 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 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 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 Figure 2. Androstenone concentration was higher in Bio+ than 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 was significantly lower in Bio+ than 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 farming 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 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 animals. 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 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 its variability of organic feed ingredients, compared to conventional ones (Roinsard et al., 2021, 2018). Some studies show that growth performances of pigs reared in organic farming system were lower to 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 organic system (Prache et al., 2022). The presence of roughage 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). Beside, 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 roughage, suggesting that it was too fermented or even rotten. The pigs probably did not find it palatable and did not eat much roughage 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 pHu (ultimate pH measured 24h 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 pHu of the formers, based on the well-established relationships

between these traits (Rosenvold et al., 2001). Choose 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 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. As example, pigs fed with 9% chicory (rich in fermentable carbohydrates, including inulin) in the diet for two weeks before slaughter had higher backfat androstenone concentration (Zammerini et al., 2012). A slight even though 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 FA composition of pork and feeding pigs with 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 C18:3 n-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 positive impact on the meat PUFA composition as expected, with an 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 roughage (straw bedding, roughage…) might be a solution to reduce aggressive behaviour that could be observed with non-castrated male pigs (Høøk 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 roughage on aggressive behaviour.

Conclusion

A feeding strategy based on the use of local source 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 high level of image quality for consumer. Compared with a more classical feed that meets *a minima* 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 technological and nutritional properties of pork and would contribute to reduce the risk for boar taint due to skatole, which are of interest for 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.

Ethics approval

The experiment was performed in the INRAE experimental facilities (GenESI Porganic, 86480 Rouillé, France), DOI :

https://www.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 authorized 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

The authors did not use any artificial intelligence assisted technologies in the writing process.

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Declaration of interest

None.

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Table 1 Composition of the experimental diets for pigs

Item	Feeding strategy [1]			
	Control		Bio+	
	Growing [2]	Finishing [2]	Growing [2]	Finishing [2]
Ingredients (% as fed)				
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/100g) [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 to 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 Lebret 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 roughages in the Bio+ feeding strategy for pigs

Item	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/100g) [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

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

	Feeding strategy [1]						
	Control (n=37) [2]		Bio+ (n=40) [2]		*P*-value		
Item	lsmeans	SE	lsmeans	SE	Feeding strategy	Batch	Slaughter day within batch
Growing phase performance [3]							
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 performance [4]							
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)	1024	19.0	1099	18.1	0.003	0.266	0.383
Growing and finishing performance							
Slaughter age (days)	198	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)	1007	16.0	1025	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 to 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]						
	Control (n=37) [2]		Bio+ (n=40) [2]		*P*-value		
Item	lsmeans	SE	lsmeans	SE	Feeding strategy	Batch	Slaughter day within batch
Loin : *Longissimus thoracis et lumborum* muscle							
pH 24 h (ultimate pH) [3]	5.5	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 24h *Gluteus Medius*	5.55	0.017	5.59	0.017	0.037	0.445	0.429
pH 24 h *Semimembranous*	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 *post mortem* pH fall

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

	Feeding strategy [1]						
	Control (n=37) [2]		Bio+ (n=40) [2]		*P*-value		
Item	lsmeans	SE	lsmeans	SE	Feeding strategy	Batch	Slaughter day within batch
Water (%)	75.1	0.10	75.0	0.09	0.443	0.909	0.767
Crude protein (%)	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/100g of meat)	410	4.9	403	4.6	0.229	0.385	0.524

Anserine D1 [3] (mg/100g 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 one day after slaughter)

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

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

	Feeding strategy [1]						
	Control (n=37) [2]		Bio+ (n=40) [2]		*P*-value		
Item	lsmeans	SE	lsmeans	SE	Feeding strategy	Batch	Slaughter day within batch
Fatty acid composition (% of identified fatty acid)							
Saturated fatty acids	35.3	0.27	34.7	0.26	0.098	0.057	0.036
Monounstaurated 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. 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 minutes of incubation in oxidizing 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 acids 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.

Fig. 2 Effect of feeding strategy on androstenone and skatole concentrations in backfat

Androstenone and skatole concentrations in backfat according to the feeding strategy. 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 ($P = 0.027$).