Journal homepage: http://www.sasas.co.za/journals

South African Journal of Animal Science 2018, 48 (No. 6)

Pig diet with bioactive compounds influences quality of meat and smoked ham

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(Received 16 February 2018; Accepted 16 July 2018; First published online 5 December 2018)

Abstract

The application of novel meat sources to the production of traditional smoked premium ham was evaluated. Various feeding strategies were designed for 90 Duroc x (Duroc x Landrace) pigs. The experiment was conducted to investigate the effects on the quality of meat and smoked ham when supplementing the diet of slaughter pigs with linseed oil and rapeseed oil and with the addition of vitamin E. Proximate composition, pH, texture and colour parameters of the *quadriceps femoris* muscles (raw pork and pork ham) were determined. The multivariate analysis of these traits demonstrated that the 3% addition of linseed oil to pigs' diet caused a decrease in the fat content in meat, and in higher meat tenderness and protein content. Diet supplementation with 3% linseed oil caused a significant increase in the technological yield of ham production (20.3%), but only in products with high fat content (8.30%). Data allowed the authors to conclude that diet supplementation with 3% linseed oil, coupled with 100 mg vitamin E, is the best form of supplementing a diet for fatteners that are reared in compliance with the rigorous principles of the pork quality system.

Keywords: Lineseed oil, rapeseed oil, pork, texture
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Introduction

Between 2006 and 2050, the global human population is estimated to increase by 37% (United Nations, 2007). This will necessitate a food production increase. In 2050, the global production of pork meat is estimated to exceed 465 million tons, which is twice as much as that produced in 1999 (Steinfeld *et al*., 2006). Today, the possibility that these predictions will come true is exceptionally high because pork represents 49% of total consumed meat, and 70% of meat products in Europe (European Commission, 2013). Such a high increase in meat production compared with previous years is the result of strong intensification of production and reduced costs of animal rearing. An increase in pig population, however, is not linked to a higher number of farms being involved in pig production, but to the boosted production of pork by leading producers from China and Denmark. Today, consumers pay increasing attention to meat quality, animal welfare and the impact of mass production on the environment. It is therefore important to increase production effectiveness and to modernize technological systems. Several research studies have proved that the quality of pork depends on the choice of an appropriate genotype of animal and conditions of feeding and rearing (Bosi & Russo, 2004; Ventura *et al*., 2012; Okrouhlá *et al*., 2013; Zhou *et al*., 2014; Đorđević *et al*., 2016).

One of the most effective methods of modernized animal production is to introduce quality systems involving the producer, the processor, the salesperson and the consumer. For example, the Pork Quality Assurance Plus® (PQA Plus) system was implemented in the US in 2007 (National Pork Board, 2010), and the Pork Quality System® (PQS) was implemented two years later (11 December 2009) in Poland (Guzek *et al*., 2013). Of course, rigorous obedience to PQS principles is a prerequisite to obtaining a production certificate, but it does not prevent a producer from enacting successive improvements of these principles and pursuing even better results, as well as a higher quality of manufactured product and greater safety.

The most popular food product from pork is ham (Jimenez-Colmenero *et al*., 2010). The processing includes smoking and scalding, which prolong its shelf life. The manufacturing of smoked meat products has a long-established tradition in Europe. There are many types of these products, and they are manufactured

URL: http://www.sasas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science http://dx.doi.org/10.4314/sajas.v48i6.5

on a commercial scale in the division of high-value food products (Resano *et al*., 2007). Scalded and smoked meat products are usually manufactured in a traditional way from the whole hind leg or from separated muscles with fat and skin, and with such basic ingredients as rock salt and water. Then they are smoked with the wood of deciduous trees. The modern processing is based on strict parameters of time, temperature, humidity, with the addition of osmotically active and flavour-enhancing substances (Feng *et al*., 2013). The quality of smoked pork products is influenced by many factors, of which the most important are the quality of the raw materials and the processing, which must be conducted appropriately (Jimenez-Colmenero *et al*., 2010). The content and quality of fat are determinants of the final sensory characteristics of ham, namely flavour, texture, juiciness and appearance (Safa *et al*., 2017). Today, producers tend to manufacture food products with increased nutritional value and all the necessary properties of functional foods. The use of linseed oil and rapeseed oil, coupled with vitamin E supplementation, as feed additives, which improve the quality of meat from fatteners, resulted from long-lasting studies that show their undeniably positive effects on, primarily, the texture, lipid profile and oxidative properties of pork (Matthews *et al*., 2000; D'Arrigo *et al*., 2002; Musella *et al*., 2009; Kralik *et al*., 2010; Więcek *et al*., 2010, Horbańczuk *et al*., 2015). Data from literature point to the significant effect of raw material properties, (particularly the content of intramuscular fat) and processing (i.e. duration of brining and pickling) on the quality of long-ripening smoked meat products (Cila *et al*., 2006). For scalded smoked meat products, however, a need has emerged for extensive research.

This study therefore focused on the analysis of the effects of modification of pig diet in compliance with PQS standards through the addition of vitamin E and linseed (L_I and L_{II}) or rapeseed oil (R) on the proximate composition, colour and texture (firmness and tenderness) of the *quadriceps femoris* muscle and of scalded smoked ham made from it. Pig diet supplementation, coupled with rigorous compliance with PQS standards for livestock production, will provide an opportunity to create new functional meat products of the highest possible quality.

Materials and Methods

The experiment was conducted on pig production farms in Wronie, Kujawsko-Pomorskie Province, Poland. The pigs were in commercial production following PQS standards. According to Directive 2003/65/EC of the European Parliament and of the Council of 22 July 2003 amending Council Directive 86/609/EEC on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes (Text with EEA relevance) (Directive 65/EC, 2003). The production was not an experimental procedure and did not require application to and consent of the National Ethical Commission at the Ministry of Science and Higher Education in Poland.

A total of 360 pig hybrids (Duroc x (Duroc x Landrace) were reared in compliance with PQS standards, which are presented in Table 1. Hogs, aged 10 weeks (70 ± 2 days) (after weaning) and meeting the weight criterion (30 ± 2.0 kg), were randomly assigned to four dietary treatments. Each experimental group consisted of 90 animals (six replicates of 15 animals each). They were kept on straw litter in pens with a stocking density of 1 m^2/pig. The pens were equipped with objects that attracted attention and prevented aggression, for example hanging chains and balls. At the first stage of fattening, which is until pigs have reached 50 kg live weight (50 ± 2.5 kg; 79 ± 2 days old), all porkers were fed ad libitum the same feed mixture containing 3400 kcal/kg of digestible energy and 16% crude protein. The second stage of fattening (60 ± 3.5 kg; 95 ± 2 days of old) involved feeding the porkers ad libitum with the experimental feed mixtures, namely the control diet (C); a diet supplemented with 2.0% linseed oil and 100 mg vitamin E α-tocopherol (L_I); a diet supplemented with 3.0% linseed oil and 100 mg vitamin E, α-tocopherol (L_{II}); and a diet supplemented with 3.0% rapeseed oil and 100 mg vitamin E, α-tocopherol (100 mg vitamin E = 100 IU = 100 mg equivalent ethyl α-tocopherol) (R) (Tables 2 and 3).

The body weight of individual fatteners was measured (50 ± 2.5 kg) before the onset of the first stage of fattening to select animals with bodyweights within a specified range, at the start of the second stage of fattening and at the end of the experiment. Feed intake (kg/pig per day) was controlled in each group by weighing the administered feed and subtracting the leftovers. The results of feed intake determination and bodyweight measurements allowed the feed conversion ratio (FCR) (kg feed/kg live weight gain) to be calculated.

After five weeks in the second stage of fattening, 12 porkers with body weights ranging from 95 to 105 kg were selected from each experimental group, resulting in two pigs from each replication.

Table 1 Meat quality requirements in the Polish Pork Quality System

Trait	Description
Pig genetic requirements	Animals free from the homozygous form of the recessive gene of susceptibility to stress RYR1T (nn), a gene responsible for increased incidence of PSE type meat defects (pale, soft and exudative) Exploitation of the genetic potential of these breeds: Polish landrace, Polish Yorkshire and Pulawska[2] for maternal components, and Duroc, Hampshire and Pietrain for sire components. These breeds are characterized by high meat content in the carcass, low fat content, appropriate meat quality, and a beneficial level of intramuscular fat. The ban on the use of pure-bred Pietrain pigs in the production of fatteners due to the linkage of this breed's susceptibility to stress and the occurrence of muscular hypertrophy with a high frequency of PSE meat defects. Pigs of the Pietrain breed may be used in the PQS only as one of the sire components in the form of a hybrid from crossing with Duroc or Hampshire breeds
Nutrition requirements	Balanced and two-stage feeding allowing for the maximum exploitation of the genetic potential of animals during muscle development. It prevents meat quality defects and excessive intramuscular fat deposition Ban on the use of fish meal in the last stage of fattening (the last month prior to slaughter) and reduction of maize content in a feed ration to maximally 20%) Ban on the use corn in the last stage of fattening. Maize, negatively affects the quality of backfat. Corn fat is characterized by a high proportion of unsaturated fatty acids. In backfat of pigs fed with excessive quantities of maize, there are large amounts of linoleic and oleic acid, so that the fat turns yellow and unsolid.
Welfare requirements	Eliminating or minimizing stress factors in pre-slaughter handling that may induce irreversible metabolic reactions that lead to meat quality defect development, in particular PSE and DFD (dark, firm and dry) Slaughter of fatteners at BW of 100 kg (± 15 kg), which corresponds to the obligation of slaughtering animals at the age of 5-6 months
Meat quality requirements	Meat colour: L* = 43-56, Water holding capacity (WHC), determined by drip loss method: WHC = 2-5% Intramuscular fat content: IF= 0.8 – 2.5% pH = 5.8 – 6.4 Meat content in carcass exceeding the average meat content of carcasses from the mass purchase and reaching not less than 55% on average Backfat colour: white or white with creamy or slightly pink shade Firm consistency of fat Meat free of fish odour

[1] PQS was established by POLSUS in cooperation with Polish Meat Association. On 11 December 2009 it was officially recognized by the Polish Minister of Agriculture as a national food quality system. PQS is in accordance with EU regulation EC No 1974/2006.
[2] One of Polish heritage breeds

The animals were transported at night (120 km, 2 h) to a slaughter house (ZM Olewnik, Sierpc, Poland). They were slaughtered according to the standard procedure under veterinarian control. After evisceration, half-carcasses were cooled with the shock method in counter current until the temperature of the meat reached *ca.* 4 °C. The *quadriceps femoris* (QF) muscles were cut from the chilled half-carcasses 12 hours post slaughter, and their weights were measured (1.05 ± 0.1 kg). The muscles sampled from the right half-carcasses were used for a physicochemical analysis of the meat, and those cut from the left half-carcasses, which had similar weight (42.5 ± 0.5 kg) were used to produce Polish traditional smoked ham.

The processing of ham production was started by injecting a brine solution of 3% NaCl and 100 ppm $NaNO_2$ using an injector (Injector Universal, Delitech Dagema, Willich, Germany) in 20% of muscle mass. The muscles were then plasticized using a vacuum tumbler (LPM 20, Glass, Paderborn, Germany) for 40 minutes in an interval programme: 50% work time and 50% relaxation, using a cooling system (4 °C) in the working chamber. Next, the products were air-dry smoked for 2.5 hours with beech chips, with fraction sizes ranging from 4.0 to 12.0 mm, with the temperature of the working chamber in the smokehouse reaching 40 °C (UW-150, Borniak, Borne Sulinowo, Polska). The smoked meat was scalded in a convection-vapour furnace (CPE 110, Kuppersbuch, Gelsenkirchen, Germany) at 95 °C with full steaming of the working chamber. The finished meat product was cooled to 2 °C and stored at 0 ± 1 °C.

Table 2 Composition of control and supplemented linseed or rapeseed oil in the pig diets

Diet composition	Treatment groups			
	C	L_I	L_{II}	R
Soybean meal, E46%	11.0	11.5	12.00	11.5
Triticale, %	31.5	31.0	30.0	31.0
Wheat,%	30.0	30.0	30.0	30.0
Barley, four row, %	25.0	23.0	22.5	23.0
Linseed oil,%	-	2.00	3.00	-
Rapeseed oil,%	-	-	-	3.00
Premix[1],%	2.50	2.50	2.50	2.50
Supplement vit. E (IU)[2]	100	100	100	100
Vitamin E with oil (IU) [3]	-	3.50	5.25	8.02

C: control group; L_I: diet supplementation with 2% linseed oil and 100 mg vitamin E; L_{II}: diet supplementation with 3% linseed oil and 100 mg vitamin E; R: diet supplementation with 3% rapeseed oil and 100 mg vitamin E
[1]Premix: vitamin E 100 mg, vitamin A 10 500 IE, vitamin D_3 1 300 IE, vitamin K 3.50 mg, vitamin B_1 2.00 mg, vitamin B_2 3.75 mg, vitamin B_{12} 25 µg, nicotinic acid 25 mg, pantothenic acid 15 mg, zinc 100 mg, iron 125 mg, manganese 100 mg, copper 16.25 mg, Iodine 3.75 mg, cobalt 0.75 mg, phytase – 500.00 FTU
[2] Vitamin E content in diet in IU α-tocopherol in supplementation premix
[3] Vitamin E content in diet in IU α-tocopherol in linseed and rapeseed oil according to Kunachowicz *et al.* (2017)

Table 3 Nutritional value of the control and supplemented linseed or rapeseed oil pig diets*

Diet composition		Treatment groups			
		C	L_I	L_{II}	R
Metabolizable energy	MJ	14.00	14.07	14.11	14.11
Crude protein	%	15.70	15.70	15.70	15.70
Lysine	%	1.07	1.07	1.07	1.07
Cys+ met	%	0.64	0.64	0.64	0.64
Threonine	%	0.68	0.68	0.68	0.68
Tryptophan	%	0.18	0.18	0.18	0.18
Crude fibre	%	4.00	4.00	4.00	4.00
Crude fat	%	2.59	4.59	5.59	5.59
Starch	%	56.32	52.99	53.22	53.22
Sugar	%	3.52	3.51	3.51	3.51
Calcium	%	0.54	0.54	0.54	0.54
Available phosphorus	%	0.36	0.36	0.36	0.36
Sodium	%	0.18	0.18	0.18	0.18
Magnesium	%	0.22	0.22	0.22	0.22

*According to Grala & Skomiał (2014)
C: control group; L_I: diet supplementation with 2% linseed oil and 100 mg vitamin E; L_{II}: diet supplementation with 3% linseed oil and 100 mg vitamin E; R: diet supplementation with 3% rapeseed oil and 100 mg vitamin E

In raw meat, pH measurements were taken 24 hours after slaughter, but in the finished products these were taken after the processing of production was completed on the cooled samples. Analyses were carried out in three replications according to the methodology described by Wyrwisz *et al.* (2016). Using a pH-meter

(205, TESTO, Lenzkirch, Germany), measurements of the pH value were performed at three sites on a slice of ham.

A 100 g slice of the sample (muscle or ham) was homogenized in a Buchi B-400 homogenizer. The homogenate was distributed onto a Petri dish and analysed three times with a near-infrared (NIR) spectroscopy in a NIRFlex solids apparatus (N-500, Büchi, Flawil, Switzerland) for contents (%) of water, protein, fat, connective tissue and ash.

Instrumental measurement of Warner-Bratzler shear force (WBSF) (N) was conducted using a universal testing machine, Instron (model 5965, MA, USA) with a Warner-Bratzler shear attachment consisting of a v-notch blade, according to Wyrwisz *et al*. (2016). Six cores (1.27 cm in diameter and 2.5 ± 0.2 cm in length) were obtained from each sample slice parallel to the orientation of the muscle fibre. A 500-N load cell was used, and the crosshead speed was set at 200 mm/min.

Colour parameters of raw and smoked FQ muscles were measured at the surface of the muscle cross section, always in the same area, and starting from the head of the muscle. Results of the meat colour analyses were presented in the CIE-L*a*b* scale where the L* value designates lightness, ranging from 0 for black to 100 for white, and a* and b* are colour coordinates (+a*: red, -a*: green, +b*: yellow, -b*: blue) (Commission Internationale de l'Eclairage). The muscle was left to bloom for 30 minutes. Afterwards, 10 measurements of colour value were performed with an illuminant D_{65}, 2° standard observer. The diameter of the measuring head was 8 mm (Minolta Chroma Meter CR-400, Osaka, Japan) on the surface of the freshly cut muscle.

Mean values were compared between groups with a one-way analysis of variance and Duncan's multiple comparison test. If assumptions of the variance analysis were not met, owing to a lack of normality of distribution based on the Shapiro-Wilks test or an inequality of variance based on Levene's test, means were compared between groups with a Kruskal-Wallis test. Multivariate differences in meat quality were evaluated between groups using a cluster analysis. The analyses were based on squared Euclidean distances for standardized variables, and Ward's method was used for agglomeration. Results were presented in the form of dendrograms. Multivariate differences between groups were also evaluated with a multi-way analysis of variance (MANOVA), and the F-test was based on Wilks' lambda. The statistical analysis was carried out using Statistica 10.0 software (StatSoft, 2011) and SPSS Statistics 23 (IBM, 2015) and assumed values to be significant at P <0.05 or P <0.001 for MANOVA.

Results and Discussion

Table 4 summarizes the results of the meat quality analysis conducted for fatteners produced in the PQS system with diet modifications and of the quality analysis of the finished meat product, smoked ham.

The supplementation of pig diet with linseed oil influenced the pH value of the meat compared with the results obtained for groups C and R. One per cent difference in linseed oil addition did not affect the pH between L_I and L_{II} groups. Linseed oil supplementation significantly increased water content and protein in raw meat compared with C and R groups (P <0.05). Of all the analysed groups, the highest tenderness for meat and ham samples was observed in L_{II}. Linseed oil supplementation had no effect on the L* parameter of meat, whereas L_{II} ham was characterized by a higher lightness compared with C. Regarding the saturation level of red a* and yellow b*, supplementation of linseed oil significantly influenced the intensity of the colour of meat compared with C and R groups (P <0.05). In hams, the results for these parameters have decreased. These results are consistent with earlier reports (Okrouhlá *et al*., 2013). Diet supplementation with linseed oil contributed to a significant decrease in fat content of meat (P <0.05). This observation corresponds to results reported earlier by Dostálová *et al*. (2012), because they demonstrated a significant decrease in the fat content of Pietrain meat, and to findings published by Václavková *et al*. (2014) regarding the meat of Prestice Black-Pied pigs as a result of diet supplementation with 7% linseed oil. In contrast, Huang *et al*. (2008) demonstrated an increase in the content of intramuscular fat, but this occurred at significantly higher diet supplementation with linseed oil (10%). In turn, Bečková & Václavková (2010) showed no change in the chemical composition of meat from pigs fed a diet supplemented with linseed oil. Therefore, it may be speculated that the discrepancy of the results obtained in the chemical composition of meat from pigs fed a diet with additional linseed oil is because of the use of different genetic groups of animals. The meat of pigs administered linseed oil was characterized by lower values of the b* parameter and higher values of the a* parameter (P <0.05) in opposition to other experimental groups. Ham made from L_{II} was characterized by lower saturation of red colouring (a*) (P <0.05). Diet L_I resulted in a decreased content of ash (P <0.05), an increased value of the b* parameter (P <0.05) in the raw meat, and decreased fat content (P <0.05) and increased protein content (P <0.05) in the ham. Diet L_{II} had no effect (P >0.05) on the values of those parameters. Compared with the control group, pig diet L_{II} decreased the content of connective tissue (P <0.05) in raw meat and improved tenderness (↓WBSF) of raw meat and smoked ham (P >0.05).

Table 4 Effect of diet supplementation with linseed and rapeseed oil and with vitamin E on the chemical and physical properties of raw pork and pork ham (*quadriceps femoris muscle*)

Variable	Raw				SEM	Ham				SEM
	C	L_I	L_{II}	R		C	L_I	L_{II}	R	
pH_{24}	6.17^{ab}	6.04^{a}	6.09^{ab}	6.25^{b}	0.05	6.42^{b}	6.17^{a}	6.16^{a}	6.27^{ab}	0.03
Technological process yield	-	-	-	-	-	72.23^{b}	70.24^{b}	79.70^{c}	60.90^{a}	1.54
Chemical composition (%)										
Water	70.56^{b}	72.83^{c}	73.67^{c}	69.11^{a}	0.48	66.53^{a}	67.95^{b}	67.96^{b}	68.65^{b}	0.42
Fat	8.27^{b}	5.88^{a}	5.03^{a}	9.77^{b}	0.56	9.21^{c}	5.49^{a}	$8.30b^{c}$	7.61^{b}	0.43
Protein	19.83^{ab}	19.89^{ab}	20.05^{b}	19.52^{a}	0.16	22.08^{a}	23.85^{b}	21.35^{a}	21.48^{a}	0.26
Ash	1.21^{b}	1.09^{a}	1.17^{b}	1.40^{c}	0.03	0.65^{a}	1.18^{b}	1.27^{c}	1.48^{d}	0.03
Connective tissue	1.56^{b}	1.59^{b}	1.38^{a}	1.87^{c}	0.03	0.431^{a}	0.508^{ab}	0.403^{a}	0.623^{ab}	0.066
Salt	-	-	-	-	-	0.66^{a}	1.77^{c}	1.27^{b}	1.48^{bc}	0.02
Texture										
WBSF (N)	41.50^{b}	38.15^{ab}	35.02^{a}	37.71^{ab}	1.96	13.97^{c}	13.46^{bc}	11.19^{a}	12.12^{ab}	0.62
Colour										
Lightness L*	40.24^{a}	40.76^{a}	41.05^{a}	41.16^{a}	0.32	69.81^{a}	71.09^{a}	73.81^{b}	73.68^{b}	0.52
Redness a*	15.65^{a}	18.91^{b}	15.79^{a}	15.59^{a}	0.35	13.38^{c}	11.70^{b}	10.58^{a}	10.98^{ab}	0.29
Yellowness b*	5.69^{c}	3.75^{a}	5.08^{b}	6.89^{d}	0.19	8.69^{d}	7.90^{c}	7.37^{a}	7.65^{b}	0.09
MHG[1]	c	b	a	d		a	b	d	c	

a-c- Means within a row without a common superscript differ significantly (*P* <0.05)
C: control group; L_I: diet supplementation with 2% linseed oil and 100 mg vitamin E; L_{II}: diet supplementation with 3% linseed oil and 100 mg vitamin E; R: diet supplementation with 3% rapeseed oil and 100 mg vitamin E
WBSF: Warner-Bratzler Shear Force
[1]Multivariate homogeneous groups. Results based on MANOVA and pairwise multivariate comparisons where F-test is based on Wilks's lambda; values without a common letter in the row are significantly different, *P* <0.001.

The differences observed in raw meat quality between groups (L_I and L_{II}) were limited to a higher content of ash (P <0.05), a higher value of the b* parameter (P <0.05), a lower content of connective tissue (P <0.05) and a lower value of the a* parameter (P <0.05) in meat from L_{II}. Smoked ham made from the meat of the fatteners from group L_{II} contained more fat and salt, but less protein (P <0.05) than that produced from the L_I fatteners. In addition, the higher dose of linseed oil contributed to greater tenderness (P <0.05), a lighter colour (↑L*; P <0.05) and lower values of a* and b* colour parameters in the smoked ham. The yield of the processing was highest in meat from fatteners administered (L_{II}), compared with meat from fatteners in groups C (P <0.05) and L_I (P <0.05). It is difficult to have a comparative discussion about the effect of diet supplementation with linseed oil on the yield of the technological process and quality of smoked and scalded pork ham because of the lack of published data.

Raw meat from the pigs fed diet (R) had a lower water content and contents of ash and connective tissue (P <0.05) than the meat from diet C. Diet R contributed to higher values of the b* parameter regarding meat colour, but had no effect on the values of the L* and a* coordinates (P >0.05). The smoked ham produced from the meat from pigs in group R was characterized by higher pH value, higher contents of water and salt and a lower fat content (P <0.05). In addition, it was more tender (P <0.05) and its colour was lighter (↑L*), but was less saturated with red (↓a*) and yellow (↓b*) colouring (P < 0.05), compared with ham from pigs that did not receive the R additive (P < 0.05). Compared with fatteners whose diets were supplemented, regardless of supplementation level, the raw meat of fatteners fed the diet supplemented with R contained less water (P = 0.039), but more fat and connective tissue (P <0.05), and was characterized by a higher value of the b* parameter (P <0.05). In addition, compared with the L_{II}, the diet supplemented with 3% R resulted in decreased protein content for the raw meat (P <0.05), but caused no reduction in the protein content of the ham. In contrast, linseed oil addition in a dose of 2% had no effect on the protein content in raw meat, but caused a significantly lower protein content in the ham (P <0.05) compared with R 3%. The yield of the processing was lowest in the meat from fatteners whose diet was supplemented with 3% R, compared with the meat from all other experimental groups (P <0.05). Rapeseed contains 36% to 40% fat and oil, which, when added to diets, increases their energy value and, simultaneously, is a carrier of glucosinolates, which disturb the functions of the thyroid gland through their negative effect on iodine metabolism. Exceeding the content of glucosilanes in a feed in a dose above 2.5 mM/kg feed reduces daily bodyweight gain, especially for younger animals weighing 30–60 kg. On the other hand, this dose of glucosilanes causes significant increase in the weight of internal organs, mainly the thyroid, liver and kidneys, which results in lowering thyroid hormone concentration in the blood. Those disorders may lead to inappropriate conformation of the half-carcasses, with their excessive adiposity caused by a reduced growth rate, and to a significant increase in the energy value of the diet (Schöne *et al*., 1990).

Table 5 Results of multi-way analysis of variance for all analysed traits of raw pork and pork ham from the *quadriceps femoris* muscle

	Treatment groups	**C**	**L_I**	**L_{II}**	**R**
Raw	C		20.0	11.9	27.0
	L_I	<0.001		7.3	21.7
	L_{II}	<0.001	<0.001		18.4
	R	<0.001	<0.001	<0.001	
Ham	C		32.6	45.0	64.8
	LI	<0.001		15.2	55.8
	LII	<0.001	<0.001		6.4
	R	<0.001	<0.001	<0.001	

P-values are below and F statistics above the diagonal
C: control group; L_I: diet supplementation with 2% linseed oil and 100 mg vitamin E; $L_{II:}$ diet supplementation with 3% linseed oil and 100 mg vitamin E; R: diet supplementation with 3% rapeseed oil and 100 mg vitamin E

The results of MANOVA and a pairwise comparison of the feeding groups are presented in Table 5 and Figure 1. The multivariate analysis demonstrated that the four groups of pigs did not differ significantly (P <0.001) in the quality traits of raw meat and the processed product. The greatest distance to group C was noted for group R in raw meat (D^2 = 27.0) and smoked ham (D^2 = 64.8). If all the traits are considered, the most similar result to the meat of the control was the raw meat of pigs fed a diet supplemented with L_{II} (D^2 = 11.9). In smoked ham, the most similar result came from the product made from the meat of pigs fed a diet supplemented with L_I (D^2 = 32.6). Of all the groups, the least total difference was demonstrated between the ham produced from the meat of pigs from groups L_{II} and R (D^2 = 32.6), and the greatest between the ham from pigs from groups C and R (D^2 = 64.8).

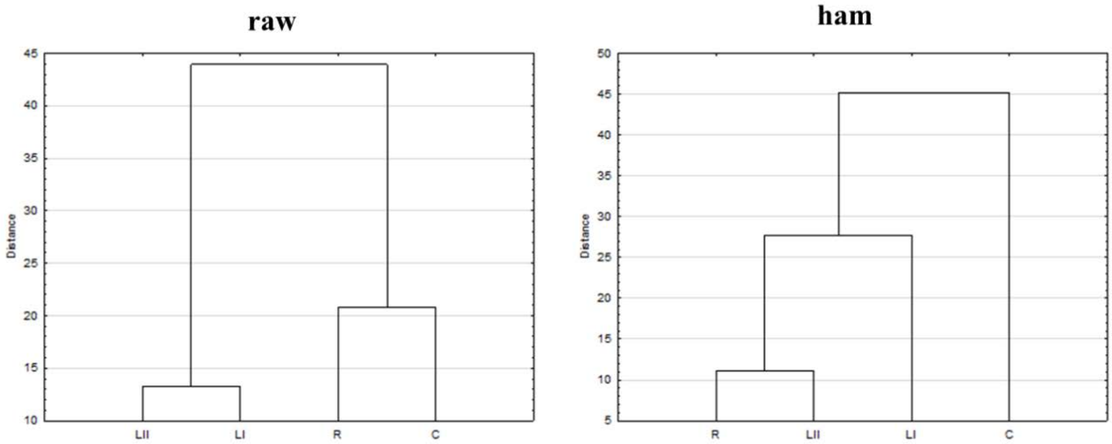

Figure 1 Dendrograms presenting multivariate similarity of raw pork and ham quality attributes based on cluster analysis
Each line on the dendrogram represents a treatment group; C: control group; L_I: diet supplementation with 2% linseed oil and 100 mg vitamin E; L_{II}: diet supplementation with 3% linseed oil and 100 mg vitamin E; R: diet supplementation with 3% rapeseed oil and 100 mg vitamin E. The percentage similarity coefficient is indicated on the graduated bar at the left side of each panel

Conclusion

The most beneficial effect on the quality of raw pork was observed with supplementation at L_I as it resulted in the lowest content of fat, the highest content of protein, and the lowest firmness of meat compared with meat obtained from all other dietary treatments. The highest technological yield of the product from the meat of pigs from group L_{II} suggests it would be the most desirable by the meat industry. The high fat content of ham may be unwanted. However, because fat is the main carrier of flavour, its high content in the finished product may be preferable to consumers. In addition, the higher content of fat had a considerable effect on the increased tenderness of L_{II} ham. Based on these results, it may be concluded that the least beneficial type of pig diet supplementation is the addition of 3% R. The meat of pigs fed this diet had a high content of fat and a low content of protein and generated the greatest losses in the processing of smoked ham production. High weight losses would contribute to a significant increase of the price of the finished product, and the exceedingly low content of fat in this product, which was lost in the scalding process, would affect its taste negatively.

Acknowledgements

Research was realised in a Project BIOFOOD - Innovative, Functional Products of Animal Origin, no. POIG.01.01.02-014-090/09 co-financed by the European Union from the European Regional Development Fund in the Innovative Economy Operational Programme 2007-2013 and research financed by Polish Ministry of Science and Higher Education with funds of Faculty of Human Nutrition and Consumer Sciences, Warsaw University of Life Science (WULS), for scientific research.

Authors' contributions

AS: writing manuscript, analysing results, laboratory work; JW: statistical analysis, laboratory work; and AW: consultancy about manuscript

Conflict of interest

Authors do not indicate any conflict of interest.

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