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Review

The effect of oil plants supplementation in pig diet on quality and nutritive value of pork meat*

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The aim of the current study was to provide the updated knowledge about the influence of supplementation of pig diets with oil plants on the quality and nutritive value of pork meat. The use of feed rich in PUFAs in pig diet including plant oils, such as linseed, rapeseed or sunflower is beneficial for consumers health since these acids improve the dietetic value of meat. They especially increase the proportions of n-3 fatty acids like linolenic acid in pig muscle, but don't influence the proportion of DHA and EPA. Among oil plants especially the use of linseed in pig diet seems to be a good source of n-3 PUFA, due to its nutritive, economic and technical sustainability as well as ALA content (50% of fatty acids). However, a higher share of PUFAs has a negative influence on technological properties of pork meat and its oxidative stability, as well as sensory characteristics. Thus, the use of antioxidants in the pig diet including vitamins A, C, E and selenium can reduce the formation of initiating lipid radicals and protect the unsaturated fatty acids in pork from an increased lipid oxidation.

KEY WORDS: fatty acid profile / feeding / lipid oxidation / plants oils / pork meat

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Introduction

Pork meat is an important component of human diet in many countries in the world. The average consumption of this meat and its products *per capita* in Europe is generally around 40 kg per year, whereas in China 32 kg and in USA over 23 kg (MEATS - OECD-FAO Agricultural Outlook 2016-2025 [Edition 2016]. In order to retain this tendency among the modern health-conscious consumers, strong expectations of the meat highest quality with enhanced nutritional and health-promoting properties including vitamins, minerals, and polyunsaturated fatty acids [Poławska *et al.* 2011, Horbańczuk *et al.* 2015] have to be addressed. For example, the fatty acid composition of pork meat is very important for human health, especially in western countries, where pork constitutes a large part of the total meat consumption [Skiba *et al*. 2012]. However according to Blicharski *et al*. [2015] there is a great variability in content of fatty acids in particular pork cuts and pork products (Tab. 1). It should also be noted that such PUFAs as C18:3 n-3 (ALA) cannot be synthetized *de*

Table 1. Energy value, fat and fatty acid composition of chosen pork cuts and pork products [Blicharski *et al.* 2015]

Item	Part of pork and pork products						
	pork chop	meat skimmed	ham	blade-bone	pork neck	ribs	bacon
Energy value (kcal)	152	122	118	145	213	309	322
Fat (%)	7.69	1.92	3.31	7.5	16.47	28.17	29.43
Fatty acids (mg/100g)							
C14:0 (myristic)	126	64	48	100	631	500	444
C16:0 (palmitic)	1655	751	687	1563	3202	6154	7225
C16:1 (palmitoleic)	193	86	72	170	360	662	886
C18:0 (stearic)	980	464	460	1047	2427	4178	4298
C18:1 n-9 (oleic)	2509	1145	1097	2820	5119	8915	8939
C18:1 n-7 (rumenic)	235	111	103	244	474	751	924
C18:2 n-6 (linoleic)	574	236	239	518	1371	2154	2318
C18:3 n-3(α-linolenic)	107	43	28	65	230	427	146
Σ n-6	640	274	252	518	1549	2351	2557
Σ n-3	142	56	28	65	282	504	426
Σ PUFA	783	330	281	583	1831	2855	2982
Σ MUFA	2937	1342	1272	3234	5953	10328	10749
Σ SFA	2838	1316	1331	2737	6659	11391	12213

Table 2. Composition of SFA, MUFA and PUFA in selected plant oils [Pieszka 2007]

Total fatty acids (%)	Linseed oil	Rapseed oil	Sunflower oil
SFA	11.28	7.46	8.48
MUFA	24.41	59.86	24.78
PUFA	64.30	32.68	66.74
PUFA *n-6*	27.20	25.12	66.19
PUFA *n-3*	36.84	5.95	0.30

novo by mammals [Ogłuszka *et al*. 2017]. They must be derived directly from either animal or plant products, as the human physiological requirement for long chain (LC) n-3 PUFA can be well met by the consumption of plant foods containing the ALA precursor [Jóźwik *et al*. 2010, Brzozowska and Oprządek 2016, Czech *et al*. 2017].

One of the methods of improving the dietetic value of pork meat, through modification of the fatty acid composition, is the supplementation of pig diets with oil plants for example linseeds, rapeseed or sunflower (Tab. 2).

However, the increased content of PUFA in pork may adversely affect its quality due to the susceptibility of n-3 PUFA to oxidation [Lyberg *et al.* 2005, Kerr *et al.* 2015]. The aim of the current review was to summarize and update the current knowledge about the impact of supplementation of pig diets with oil plants on the quality and nutritive value of pork meat.

Oil plants

There is scientific evidence about the positive effect of using oil plants in the pig diet on the nutritional value of raw pork meat and pork products. The FA composition of the carcass lipid depots in monogastric animals can be altered by dietary manipulation, so that diet fed can decrease saturated fatty acids (SAT) and increase PUFA in pork [Nuernberg *et al.* 2005, Realini *et al.* 2010, Ranucci *et al.* 2015]. For example, in Spain fat sources high in oleic acid are available from the olive oil industry, and have been effectively used by Iberian pig producers to modify the fatty acid profile of pork products [Gonzalez *et al.* 2005].

Linseed

Linseed enrichment of the pig diet is an important determinant of the extent of improvement in intramuscular fat deposition [Huang *et al*. 2008], due to alterations in the expression of genes involved in adipogenesis [Luo *et al.* 2009]. Data from the meta-analysis carried out by Corino *et al*. [2014] demonstrated that no differences have been reported for pH, drip loss, cooking loss as well colour in pork meat supplemented with linseed into the pig diet (except for Juarez *et.al.* [2011]). The authors also confirmed that linseed supplementation of pig diets may improve the nutritional quality of pork by increasing the n-3 FA concentration in muscle and adipose tissue. According to Raes *et al*. [2004] dietary linseed allows ALA in muscle to compete more effectively with LA for the pathways responsible for producing LC PUFA. Moreover, the use of linseed in pig diets seems to be a good source of n-3 PUFA, also due to its economic and technical sustainability and ALA content (50% of fatty acids). In pigs approximately one-third of the supplied n-3 that was deposited, resulted from the conversion of ALA to EPA and DHA. [Kloareg *et.al* 2007]. In the human organism n-3 FA, especially ALA, EPA and DHA play a very important role [Strzałkowska *et al.* 2009, Poławska *et al*. 2013, Szostak *et al*. 2016, Wojtasik-Kalinowska *et al.* 2016] since they possess anti-inflammatory, antimicrobic and antioxidant properties [Jóźwik *at al.* 2010,]. Moreover, DHA can contribute to the development of infant brain and liver [Horbańczuk and Wierzbicka 2016]. However, Bečkova and Vaclavkova [2010] demonstrated that feeding the linseed diet increased the content of n-3 PUFA in adipose tissue, but DHA was not altered by the diet.

Selected types of oil plants

In pigs fed with oil plants (linseed, rapeseed) as well as fish oil and lard the content of the PUFA's in the back fat and in the part of raw muscle differed depending on the type of supplemented fat [Lisiak *et al*. 2012]. The highest amounts of n-3 and the best n-6/n-3 ratio were reported in the group supplemented with a higher share of linseed (ca. 3:1) as compared to animals fed with a greater portion of rapeseed or fish oils (about 5.5:1). Bertol *et al*. [2013] aimed at evaluating the effect of genotype and dietary oil sources: soybean, canola and canola + flax on pork quality, and fatty acid composition. They observed that genotype affected the technological quality of pork (color, intramuscular fat) and the fatty acid profile (n6/n-3 ratio). Kralik *et al.* [2010] compared the effect of dietary supplementation with rapeseed, linseed and sunflower oils on the fatty acid composition in pork meat. The highest content of n-3 PUFA and the most favorable ratio of n-6/n-3 was reported for the group fed with linseed oil ($P<0.001$). Similar results regarding the improved composition of FA (n-3) in pork after linseed supplementation of the diet were obtained by Nuernberg *et al.* [2005], however the sensory characteristics of meat were also somewhat affected. The overall flavor of the combined meat/ back fat sample seems to be negatively affected by linseed oil supplementation. Increasing the n-3 content in pork can also be problematic due to off-odours and flavors resulting from oxidation of the PUFA's, what can affects the muscle palatability [Juarez et al., 2011]. The impact of dietary fat sources (soybean oil, calcium soaps of palm oil, animal fat,) on meat quality, fatty acid composition and sensory attributes in pork was analyzed by Alonso *et al*. [2012]. According to the cited authors, dietary fat supplementation did not significantly affect ultimate pH, colour, sensory attributes or SFA. Pigs fed soya bean oil had the lowest proportion of MUFA and the highest of PUFA. Moreover, dietary fat sources could be recommended for inclusion in diets, at these levels, with no detrimental effect on consumption quality. However the dilemma between a high sensory quality and consumer health still exists, even at these low levels of inclusion of different fat sources [Alonso *et al.* 2012].

The pig meat fatty acid composition was affected by feeding, since high-oleic sunflower oil supplementation resulted in a higher oleic acid content of pork meat, whereas no significant differences in FA composition were found when α-tocopheryl acetate was added to the feed [Cardenia *et. al.* 2011]. In turn, Wojtasik *et al*. [2012] analyzed the effect on meat quality and fatty acid profile of intramuscular fat and subcutaneous tissue fat of different fat mixtures in the diet: diet A: rapeseed oil, fish oil, and lard; diet B: rapeseed and linseed oil and diet C linseed and fish oil. Fat mixtures in the diet did not affect performance, but changed the PUFA concentration. The authors stated that supplementation of the diet for pigs with a mixture of linseed oil and fish oil makes it possible to obtain good quality pork with health-promoting properties, since meat and fat from pigs fed linseed and fish oil had PUFA/SFA and n-6/n-3 values in agreement with WHO recommendations. Studies on the effect of fat supplements such as palm oil, linseed oil, rapeseed oil, and sunflower oil on pork quality showed a significantly higher MUFA level in the *m. longissimus dorsi* of pigs receiving dietary palm oil when compared to the linseed oil-fed pigs ($P<0.05$) [Pieszka *et al*. 2007].

In pigs, the dietary treatments based on plant feedstuffs (linseed oil with or without a supplement like selenium, vitamin E and C and soybean oil), animal fat (tallow) and fish oil had no significant effects on meat quality, but the FA composition of the loin and the backfat resembled the FA profiles of the diets [Morel *et al*. 2013]. As expected, pigs fed diets without linseed oil or soybean had the lowest levels of linoleic acid and α-linolenic acids in the backfat [Morel *et al*. 2013]. In turn, Mas *et al.* [2011] observed in a study where York-crossed pigs were fed a high oleic acid (HO) diet between 30 and 120 kg of body weight, a modified FA composition of subcutaneous fat with minor changes in intramuscular FA composition. Feeding the HO diet did not alter meat quality traits, and major primal cuts from animals fed both diets were suitable as the base for dry cured products. Subcutaneous fat from pigs fed the HO diet had a higher MUFA level, while the levels of PUFAs decreased without adversely affecting carcass quality and producing suitable hams for processing by the meat industry. In an earlier study conducted by Mas *et al*. [2010] with the same diets but on pigs of a different genotype − high-lean (Landrace×Large White)× Pietrain), resulted in a significant increase of the C18:1 and MUFA levels in intramuscular fat from animals fed HO diet as compared to pigs from the control group.

The use of antioxidants in pig diet

As mentioned earlier, enrichment of pork meat with n-3 PUFAs may resulted in a deterioration of the quality of pork and increase of its susceptibility to oxidation. Supplementation of pig feed with linseed oil leads to an acceleration of the oxidation processes in meat samples obtained from fresh loin [Godziszewska *et al*. 2017]. Pork, in particular, oxidises more rapidly than either beef or lamb, because of its relatively high content of unsaturated fatty acids [Botsoglou *et al*. 2012]. Thus, the use of antioxidants, such as vitamins A, C, E and selenium, in the animal diets leads to a decrease in the susceptibility of pork to oxidation [Godziszewska *et al*. 2017, Polawska *et al.* 2016]. For example diet supplementation with vitamin E, that function either through free radical scavengers or by diminishing the formation of initiating lipid radicals, must be considered when formulating PUFA-enriched pig diets [Botsoglou and Botsoglou 2010]. Moreover, the use of dietary antioxidants in pig diets showed positive effects on colour, nutritive value [Faustman *et al*. 2010] and meat flavour of pork [Cardenia *et al*. 2011]. Furthermore, a meta-analysis showed a positive effect of dietary vitamin E supplementation on pork colour [Trefan *et al*. 2010]. The oxidative and colour stability of pork depends mostly on the balance of anti-oxidant and oxidant substances [Serpen *et al*. 2012]. In a study on pigs fed linseed the authors reported that 200 mg/kg feed of dietary vitamin E is sufficient to protect muscles from lipid oxidation, increasing α-tocopherol tissue levels [Botsoglou *et al*. 2012, Sales and Koukolová 2011]. Antioxidant supplementation in pig feed has a positive impact on the characteristics of raw pork. Vitamin E and selenium supplementation in pig diets decreased the level of volatile aldehydes in the *Longissimus dorsi* muscle [Wojasik-Kalinowska *et. al.* 2016]. However, the authors suggest that further studies should be conducted in order to investigate the mechanism of volatile compound formation, both in raw meat and meat after heat treatment, when the pig diet is supplemented with bioactive components. The effects of different concentrations of dietary oregano essential oil supplementation (from 0.25 to 1 ml/kg of fed diet) on finishing pig meat characteristics were investigated in a study conducted by Simitzis *et al*. [2009]. The mentioned authors concluded that meat quality attributes were unchanged, indicating that the dietary administration of different levels of oregano essential oil did not exert any effect on pig meat parameters. Moreover, the lipid oxidation levels suggested a lack of antioxidant effect for the oregano essential oil. In turn, the combination of oregano essential oil and sweet chestnut wood extract may be useful to increase the pig antioxidant status, since no marked effects were observed on pig performance and raw meat quality traits [Ranucci *et al*. 2015]. However, the mix was responsible for a higher palatability for consumers and for a darker and redder colour of the cooked meat. Interesting data was delivered by Choi *et al*. [2013] who demonstrated that the oxidative stability of sunflower seed oil, which delays the loss of nutritional value and the development of unpleasant flavors, depends on the proportion of oleic acid and the amounts of antioxidants, mainly α-tocopherol. This suggests that the advantage of sunflower seed oil lies in its higher oxidative stability than oils low in oleic acid, what is desirable for refining and storage [Cardenia *et al*. 2011]. In turn, olive oil provides meat products with high levels of oleic acid and monounsaturated fatty acids (MUFA), natural antioxidants such as tocopherols and reduces cholesterol levels without affecting considerably the sensory characteristics of the products [Rodriguez-Carpena *et al*. 2012].

According to Botsoglou *et al*. [2012], extracts from olive leaves can constitute a source of alternative natural antioxidants with the potential antioxidant activity, as they are rich in phenolic constituents which delay lipid oxidation by reducing the production of primary and secondary products like MDA. Moreover, this could improve odor and taste scores of the n-3 enriched pork products [Botsoglou *et al*. 2014].

Summary

On the basis of the reviewed literature, one may conclude that the positive effect of supplementing pig diets with oil plants like linseed, rapeseed or olives, has been demonstrated, especially on the nutritional value of raw pork meat and pork products. Among oil plants the linseed in pig diet seems to be especially good source of n-3 PUFA, due to its economic and technical sustainability as well as ALA content (50% of fatty acids). However, enrichment of pork meat with n-3 PUFAs increased its susceptibility to oxidation and led to a deterioration of the quality of pork, especially in relation to the sensory characteristics of meat. The overall flavor of the combined meat/ backfat sample seems to be negatively affected by linseed oil supplementation. Thus, pig diets should also be supplemented with antioxidants such as vitamin E, C or Se, or natural ones like olive leaves extracts, rich also in phenolic constituents. Vitamins are a inhibitor of lipid oxidation acting through free radicals-scavenging mechanism. Furthermore, recent studies revealed also that supplementation of pig fodder with vitamins increases deposition of tocopherols and antioxidative elements in the pork meat.

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