

Fresh meat quality of pigs fed diets with different fatty acid profiles and supplemented with red wine solids

Pier Giorgio PEIRETTI¹, Francesco GAI¹, Alberto BRUGIAPAGLIA², Pier Paolo MUSSA³, Giorgia MEINERI^{3*}

Abstract

Three groups of pigs were fed three different diets, namely a diet rich in saturated fatty acids (palm oil-based, PO), a polyunsaturated fatty acid (PUFA)-rich diet (corn oil-based, CO), and a PUFA-rich diet (corn oil-based) supplemented with red wine solids (RWS), which was added to the diet (CO+RWS) in order to assess the protective effect on the oxidative status of the pork meat. The addition of corn oil favourably modulates the FAs profile of the backfat, and to a lesser extent of the intramuscular fat of *semimembranosus* muscle, without causing adverse effects on the meat quality or on its oxidative stability. Moreover, these parameters were not affected by the addition of the RWS in the CO+RWS diet.

Keywords: pig; meat quality; red wine solids; fatty acids.

Practical Application: The red wine solids supplementation in feed should provide a good protection of the meat from oxidation.

1 Introduction

In recent years, awareness of the importance of diet in human health has increased. During the last two decades, nutritionists have clearly identified selected foods that play an important role in maintaining the physical and mental health status of consumers. Beyond meeting nutritional needs, it is generally recognized that dietary factors are considered to modulate the detrimental development of certain chronic diseases (Anjum et al., 2013).

Regarding the lipid component of the diet, specific advice (Gibney, 1993) is to reduce the intake of saturated fatty acids (SFAs) and to increase the intake of polyunsaturated fatty acids (PUFAs). Numerous epidemiological and clinical studies have documented the nutritional benefits of PUFAs to prevent the incidence of cardiovascular diseases (Wijendran & Hayes, 2004) and cancer pathogenesis (Larsson et al., 2004). In addition, the increased intake of PUFAs decreases serum cholesterol, which has a beneficial effect on blood pressure, skin diseases, diabetes, thrombosis, atherosclerosis, and hyperlipidemia (Yashodhara et al., 2009).

Diets rich in PUFAs have been shown to reduce plasma levels of low density lipoproteins (LDL), without decreasing high density lipoproteins (HDL), leading to a simultaneous decline of oxidized LDL (Noori et al., 2009; Stein et al., 2008).

In addition, the dietary introduction of PUFAs is very important during neonatal and aging periods (Noble & Cocchi, 1989; Innis, 1991; Péntzes et al., 1993). As a result, there are increasing moves to enhance the levels of these fatty acids (FAs) in major human dietary components. Although it is the balance of FAs in the total diet that is physiologically important, attempts have been made to change many individual foods in line with the new

dietary guidelines, to make them more attractive to consumers (Wood & Enser, 1997). The FAs profile of the diet has been extensively examined in monogastric animal research, in view of the possibility of adjusting the FAs composition of animal meat and fat to produce healthier foods for human consumption (Averette Gatlin et al., 2003; Rentfrow et al., 2003).

As a large proportion of the saturated fat intake in Western society arises from animal fat, a greater degree of unsaturation of the pork meat lipid fraction is therefore expected to have a general positive impact on human health (Cardenia et al., 2011). The pork meat market has, in the past few years, been subjected to several changes influenced by consumer demands, which have addressed the production towards leaner and healthier meat. Special strategies have been undertaken to modify the lipid fraction of pork meat, which is known to greatly affect its overall quality. Lipid composition of pork meat varies depending on the muscle type and fibre, and it is influenced by many factors, such as animal genotype and feeding (Wood et al., 2004). Recently, swine feed has been formulated with a higher content of natural sources of PUFAs, such as n-3 series or conjugated linoleic acid (CLA), due to human health concerns (Boselli et al., 2008).

Several researchers have studied the effect of diets supplemented with a high PUFAs content on fresh pork meat lipids. Diets enriched with vegetable oils (such as sunflower oil, soybean oil or corn oil) that contain an elevated PUFAs percentage should result in healthier products for consumers (Mitchothai et al., 2007). Therefore, interests have been focused on supplementing diets with PUFAs to increase the tissue deposition of PUFAs and to improve the health status of meat consumers.

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¹Institute of Science of Food Production, Consiglio Nazionale delle Ricerche, Grugliasco, Italy

²Department of Agriculture, Forestry, and Food Sciences, Università di Torino, Grugliasco, Italy

³Department of Veterinary Sciences, Università di Torino, Grugliasco, Italy

*Corresponding author: giorgia.meineri@unito.it

Unfortunately, despite numerous scientific papers that describe the beneficial effects of PUFAs in the body, an increasing number of studies have clearly demonstrated the harmful effects of polyunsaturated fat in the diet on the oxidative status of animals (Ferguson & Harris, 1999; Knudsen et al., 1993). In fact, PUFAs are the most vulnerable to the attack of free radicals, which induce lipid peroxidation. A diet containing linseed oil (rich in PUFAs), induced oxidative stress by significantly increasing not only the plasma malondialdehyde (MDA) concentration and urinary MDA excretion, but also by increasing the rate of leukocyte DNA damage in pigs (Rezar et al., 2003). Several human studies have also shown enhanced production of nitric oxide after dietary PUFAs supplementation. In fact, significant evidence of oxidative stress *in vivo*, caused by a high content of linoleic acid (LA, C18:2 n-6) in the diet, was observed in healthy subjects, despite their intake and plasma levels of antioxidants being within recommendations (Turpeinen et al., 1998).

In the case of animals, such as pigs, reared for the production of meat for human consumption, a greater degree of FAs unsaturation increases the susceptibility of fresh meat towards oxidation (Boselli et al., 2008). Lipid oxidation in meat products is mainly initiated in the highly unsaturated phospholipid fraction of cell membranes, which contain other unsaturated liposoluble molecules, such as cholesterol, which are also prone to oxidation (Boselli et al., 2005).

Furthermore, in fresh meat, PUFAs diet supplementation resulted in an undesirable flavour, an undesirable meat colour and nutrient loss due to peroxidation of these FAs (Byrne et al., 2001). Lipid oxidation is therefore the limiting factor for PUFAs to serve as nutritionally beneficial lipids in functional foods (Chaiyasit et al., 2007). However, the oxidative stability of muscle tissue also depends on the anti/pro-oxidant balance (Decker & Xu, 1998), so dietary supplementation with antioxidants might increase the oxidative stability of pork lipids (Boselli et al., 2008; Eder et al., 2005; Guo et al., 2006).

To counteract the oxidative processes in PUFAs-enriched meat, adequate protection must be implemented to ensure stable quality of fresh meat and a longer shelf-life of the meat. However, problems were found to arise when synthetic free radical scavengers, such as butylated hydroxyanisole, butylated hydroxytoluene, propyl gallate, and tertiary butylhydroquinone were involved, due to their potential deleterious effects on human health (Decker & Mei, 1996). Thus, researchers have focused special attention on natural antioxidants that may be included in animal diets, as alternatives to minimize the use of synthetic food additives.

The scientific literature offers a wide range of examples of food and feed including antioxidant supplements, which resulted in a reduction of lipid peroxidation (O'Neill et al., 1999; Grau et al., 2001; Sáyago-Ayerdi et al., 2009). Recent studies have shown, for example, that the juice of red grapes contains antioxidant substances, which are considered as being effective in preventing chronic-degenerative diseases in humans and animals (Geleijnse et al., 2002; Lamont et al., 2012; Williamson & Holst, 2008). Specific investigations carried out into red grapes and their

juice have demonstrated that the antioxidant and anti-radical activity could be directly correlated with the complex matrix of polyphenols within the red grapes (Brenna & Pagliarini, 2001; De Beer et al., 2003; Auger et al., 2004).

The high resistance against lipid oxidation of meat from animal fed red grape by products have been shown in poultry (Brenes et al., 2008; Smet et al., 2008), in rabbits (Choi et al., 2010), and in ruminants (Luciano et al., 2011; Rivas-Cañedo et al., 2013).

Furthermore, scientific research has correlated polyphenols, contained in plants used in the human diet, with a lower incidence of cardiovascular disease and inhibition of some types of cancer (Donaldson, 2004).

In this work, we intend to evaluate the possible effect of a red wine solids (RWS) obtained by freeze-drying organic red wine, which is alcohol-free and possesses a high content of phenolic compounds (Liofenol™). These antioxidants are not only beneficial due to their intrinsic properties, but can also safeguard PUFAs from possible peroxidation. The RWS chemical composition in terms of total polyphenols, anthocyanins, total flavonoids, proanthocyanidins and flavans, and its antioxidant power has been reported in a previous work by Peiretti et al. (2013). The RWS supplementation of the corn oil diet should provide a good protection of the meat from oxidation.

The aim of our study was to compare the effect on FAs profiles and the quality of fresh meat of three groups of pigs fed different diets, containing palm oil (rich in SFA), corn oil (rich in PUFAs) and corn oil supplemented with RWS, respectively. Assuming that the substitution of palm oil with corn oil in the diet could result in an increase of peroxidation products in fresh pork.

2 Materials and methods

2.1 Animals and diets

The study was carried out at the experimental piggery of the Department of Veterinary Sciences in Grugliasco (NW Italy). A total of 18 pigs belonging to the same genotype, aged 3 months, with a mean weight of 74 kg, were randomly assigned to three different groups of six (three male and three female pigs each) with equal initial weight variability. Each group of animals was placed in a box of 2.3 x 3 m, under standard conditions at a temperature of 20±2 °C, in an environment with artificial light and forced ventilation.

Three different diets were formulated (Table 1): a palm oil-based diet (PO), a corn oil-based diet (CO) and finally a corn oil-based diet supplemented with RWS (CO+RWS). Each mixed feed was stored in silos sheltered from light to avoid auto-oxidation of the lipid components, and the feed was offered *ad libitum* for the duration of the experiment (8 weeks).

Diet samples were analysed in duplicate for dry matter (DM; cod. 930.13), ash by ignition to 550 °C, crude protein (CP; cod. 954.01) and ether extract (EE; cod. 945.16) according to the methods of the Association of Official Analytical Chemists (Association of Official Analytical Chemists, 1990). The gross energy (GE) was determined using an adiabatic bomb calorimeter (IKA C7000, Staufen, Germany).

Table 1. Ingredients and chemical composition of the experimental diets (from Peiretti et al., 2013).

	PO	CO	CO+RWS
<i>Ingredients (g/kg as-fed basis)</i>			
Barley	800	800	800
Soybean meal	90	90	86.4
Wheat bran	60	60	60
Palm oil	30	-	-
Corn oil	-	30	30
Red wine solids (RWS)	-	-	3.6
Vitamin mineral premix ⁽¹⁾	17	17	17
Lysine	3	3	3
<i>Chemical composition (g/kg as-fed basis)</i>			
Dry matter	891	911	890
Crude protein	141	140	143
Ether extract	42	46	47
Ash	48	46	50
Gross energy, MJ/kg DM	18.9	18.3	18.6

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil supplemented with red wine solids (RWS). ⁽¹⁾Composition of the vitamin-mineral premix (per kg of diet): vit. A 312,000 IU; vit. D3 48,800 IU; α -tocopheryl acetate 68 mg; vit. B1 39 mg; vit. B2 125 mg; vit. B6 39 mg; vit. B12 0.75 mg; vit. PP 623 mg; biotin, 0.75 mg; choline chloride, 12,500 mg; folic acid, 40 mg; D-pantothenic acid 500 mg; sodium menadione bisulphate, 25 mg; lysine, 18,300 mg; Zn, 275 mg; Fe, 275 mg; Cu, 25 mg; Mn, 17 mg; J, 800 μ g; Se, 300 μ g.

2.2 Slaughter procedures and sample collection

At the end of the experiment, animals (mean live weight 117 kg) were slaughtered in a commercial pig slaughterhouse according to industry-accepted procedures. The *semimembranosus* muscle (SM) and backfat (BF) were immediately removed from the left half-carcasses. SM muscle was divided into two parts. The fore part was used to measure water content, pH, colour, shear force, drip and cooking losses. The hind part of the SM muscle was vacuum-packed, frozen at -20°C and then freeze dried (5Pascal, Trezzano sul Naviglio, Italy). Proximate composition, FAs profile and thiobarbituric-acid reactive substances (TBARS) values were determined on freeze-dried samples. BF samples were immediately vacuum-packed, frozen and stored at -20°C for a week until gas chromatographic analysis.

2.3 Fatty acid determination

To determine FA composition, lipid extraction was performed on the diets, SM and BF samples, according to Peiretti & Meineri (2008). The FAs content in the experimental diets was the mean of two replicates, and the FAs were analysed as methyl esters. Analysis was carried out by gas chromatography, using a Dani GC 1000 DPC (Dani Instruments S.P.A., Cologno Monzese, Italy), equipped with a fused silica capillary column - Supelcowax-10 (60 m \times 0.32 mm (i.d.), 0.25 μ m). The programmed temperature vaporizing (PTV) injection and flame ionization detector (FID) ports were set at 245°C and 270°C , respectively. The oven temperature programme was set at 50°C for the first minute, increased at a rate of $5^{\circ}\text{C}/\text{min}$ to 230°C , where it remained for 24 min; the carrier gas was hydrogen. A volume of 1 μ l was injected using a Dani ALS 1000 auto sampler with a 1:50 split ratio. The peak area was measured using a Dani Data Station DDS

1000, and each peak was identified and quantified according to pure methyl ester standards (Restek Corporation, Bellefonte, PA, USA). The atherogenic (AI) and thrombogenic (TI) indexes of the fat (Equations 1 and 2) were calculated according to Ulbricht & Southgate (1991) as follows:

$$\text{AI} = (\text{C12:0} + 4 \times \text{C14:0} + \text{C16:0}) / [\Sigma\text{MUFA} + \Sigma(\text{n}-6) + \Sigma(\text{n}-3)] \quad (1)$$

$$\text{TI} = (\text{C14:0} + \text{C16:0} + \text{C18:0}) / \left[\frac{0.5 \times \Sigma\text{MUFA} + 0.5 \times \Sigma(\text{n}-6) + 3 \times \Sigma(\text{n}-3) + \Sigma(\text{n}-3)}{\Sigma(\text{n}-6)} \right] \quad (2)$$

where MUFA is monounsaturated fatty acid. These indexes can indicate whether a food is suitable for the prevention of human cardiovascular diseases.

2.4 pH measurement

pH assessment in the SM muscle was performed at 45 min and 24 h after slaughter, using a Crison portable pH-meter equipped with a spear tip electrode and an automatic temperature compensator probe (Crison Instruments, S.A., Alella, Spain).

2.5 Colour measurement

At 24 hours after slaughter, colour was evaluated by the CIELAB colour system. Lightness (L^*), redness (a^*) and yellowness (b^*) colour indexes were obtained in duplicate after 1 h of blooming at 4°C with a Minolta CR331C Colorimeter (Minolta Camera Co., Japan) calibrated on D65 illuminant. Hue angle, which describes the fundamental colour of a substance, and Chroma, which describes the vividness of a colour, were calculated as $\tan^{-1}(b^*/a^*)$ and $(a^{*2} + b^{*2})^{0.5}$, respectively (Commission International de l'Eclairage, 1976).

2.6 Drip loss measurements

Drip losses were evaluated in 70 to 170 g samples. The samples were weighed, placed in a plastic container with a double bottom (Lundström & Malmfors, 1985), refrigerated at $2-4^{\circ}\text{C}$ for 24 h, and re-weighed. Drip losses were given as a percentage of the difference between the initial and the final sample weight.

2.7 Cooking loss measurements

To determine cooking losses, raw samples were individually weighed, vacuum packaged in a plastic bag and cooked in a water bath at 70°C for 35 min. Samples were then removed from the water bath, cooled under tap water, blotted and reweighed. Cooking losses were determined by calculating the weight difference in samples before and after cooking, expressed as a percentage of initial weight.

2.8 Shear force measurement

After the cooking loss measurements, the same samples were utilised in order to determine shear force. For each sample, 8 to 10 blocks of 1 cm^2 cross-section area, cut parallel to the muscle fibre direction, were obtained. Shear force was employed

to assess the texture characteristics of meat using an Instron 5543 universal testing machine (Instron Corporation, USA). Samples were sheared perpendicular to the fibre at 200 mm/min crosshead speed.

2.9 Proximate analyses

Proximate analyses were carried out according to the methods of the Association of Official Analytical Chemists (Association of Official Analytical Chemists, 1990). Raw muscle samples were weighed, dried at 125 °C for 5 h and reweighed to determine the water content. Freeze dried samples were analysed to determine ash by ignition at 550 °C and ether extract (EE) using the Soxhlet method. Nitrogen was determined by the Kjeldahl method using a Buchi System apparatus (Buchi Labor Technik, Flawil, Switzerland). The crude protein was then calculated by multiplying N × 6.25.

2.10 TBARS assay

Lipid oxidation was determined on the freeze dried muscle. The TBARS assay was modified from that of Witte et al. (1970), and was performed for each meat sample in triplicate; 3 g of freeze-dried meat was homogenised for 30 sec at high speed with 20 mL of 10% trichloroacetic acid using a Polytron tissue homogenizer (Type PT 10-35; Kinematica GmbH, Luzern, Switzerland). The supernatant was filtered through Whatman #1 filter paper. A volume of 1 mL of filtrate was combined with 1 mL of a 0.02 M aqueous 2-thiobarbituric acid solution (TBA), heated in a boiling water bath for 20 min, together with a blank containing 1 mL of a TCA/water mix (1/1) and 1 mL of a TBA reagent, and subsequently cooled under running tap water. Samples were analysed in duplicate, and the results were expressed as mg of MDA per kilogram of freeze dried meat, using a standard curve that covered a concentration range of 1 to 10 mM 1,1,3,3-tetramethoxypropane (Sigma-Aldrich, Steinheim, Germany). The absorbance was measured at 532 nm with a Helios spectrophotometer (Unicam Limited, Cambridge, UK) against a blank that contained all the reagents, but no meat.

2.11 Statistical analysis

Statistical analyses were performed using the SPSS software package (version 11.5.1 for Windows, SPSS Inc., USA). Analysis of variance was used to evaluate the effect of diet on the FAs profiles of the SM and BF and meat quality traits. Differences were tested using Duncan's New Multiple Range Test. Results were considered as being statistically significant with P values of <0.05.

3 Results and discussion

3.1 Composition and fatty acid profile of the diets

Table 1 shows the ingredients and chemical composition of experimental diets (data previously reported by Peiretti et al., 2013). The three diets administered were isocaloric and isonitrogenous and differed in the lipid source: PO or CO and in the presence of the phytocomplex RWS in the CO+RWS diet. Previous studies

carried out by our group (Peiretti et al., 2013) indicated that there were no statistically significant differences in final live weight, weight gain, and feed conversion rate between the three groups of pigs.

Table 2 illustrates the total lipids (g/Kg diet) and FAs contents (g/100g of total FAs) of the experimental diets. The total lipid content is very similar between the three diets. Regarding the FAs, we can observe that myristic acid (C14:0) is only present, albeit at low quantities, in the PO diet; palmitic acid (PA, C16:0) and stearic acid (C18:0) are present in the PO diet in amounts approximately double compared to the CO and CO+RWS diets: LA is instead present at much higher levels in diets containing CO. Other minor FAs have approximately similar values in all three diets.

3.2 Fatty acid profile of the meat and backfat

Table 3 shows the total lipid contents and the FAs composition in the SM muscle of pigs fed the three experimental diets. There are no statistically significant differences regarding the total lipid content and FAs profile between the groups, with the exception of PA and the atherogenic index, which are statistically higher in the PO group than the CO and CO+RWS groups. Therefore addition of RWS in the CO+RWS group did not affect the intramuscular lipid composition when compared to the CO group.

Table 4 reports the total lipid contents and the FAs composition in the BF of pigs fed the experimental diets. The PO group resulted in a statistically significant greater percentage of oleic acid (C18:1 n-9) in adipose tissue compared to the CO and CO+RWS groups; while the CO and CO+RWS groups have a significantly higher content of LA than the PO group. As for all the essential FAs, LA cannot be synthesized by the body, and thus LA dietary levels have a great influence on tissue concentration of this FA (Wood & Enser, 1997). LA is found mainly in soybean and corn oils; in fact, in our study, pigs fed diets containing CO have higher levels of LA than those fed the PO diet.

The total amount of MUFAs shows a significant difference in the PO group (higher values) with respect to the other two groups (lower values); the total amount of PUFAs shows a statistically significant difference between the CO and CO+RWS

Table 2. Fatty acid contents (g/100g of total FAs) of the experimental diets.

	PO	CO	CO+RWS
Lipid (g/kg)	32.9	33.3	31.2
C14:0	0.3	0.0	0.0
C16:0	30.3	15.8	15.0
C18:0	4.2	2.2	2.1
C18:1n-9	28.7	25.3	24.4
C18:1n-7	0.8	0.8	0.8
C18:2n-6	32.2	52.1	54.0
C18:3n-3	2.7	2.8	2.8
C20:0	0.4	0.4	0.4
C20:1n-9	0.4	0.5	0.4

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil supplemented with red wine solids (RWS).

Table 3. Fatty acid composition (g/100g of total FAs; means \pm S.E.) in the *semimembranosus* muscle of pigs (n=6 per group) fed the experimental diets.

	PO	CO	CO+RWS
Lipid (g/kg)	5.08 \pm 0.61	5.66 \pm 1.10	5.68 \pm 0.86
C14:0	1.07 \pm 0.05	0.97 \pm 0.06	0.98 \pm 0.03
C16:0	23.37 ^a \pm 0.21	22.45 ^b \pm 0.29	22.65 ^b \pm 0.14
C16:1	2.85 \pm 0.29	2.65 \pm 0.14	2.55 \pm 0.18
C17:0	0.35 \pm 0.05	0.23 \pm 0.02	0.28 \pm 0.03
C18:0	10.93 \pm 0.58	10.53 \pm 0.19	11.23 \pm 0.43
C18:1n-9	44.58 \pm 1.02	42.93 \pm 1.37	42.73 \pm 0.67
C18:1n-7	4.33 \pm 0.34	4.22 \pm 0.10	4.03 \pm 0.21
C18:2n-6	9.65 \pm 1.15	12.62 \pm 1.13	12.35 \pm 0.78
C18:3n-3	0.40 \pm 0.06	0.37 \pm 0.03	0.42 \pm 0.05
C20:0	0.93 \pm 0.05	0.80 \pm 0.05	0.88 \pm 0.03
C20:1n-9	0.45 \pm 0.04	0.53 \pm 0.04	0.53 \pm 0.03
C20:4n-6	1.12 \pm 0.15	1.72 \pm 0.54	1.38 \pm 0.14
SFA ⁽¹⁾	36.63 \pm 0.55	34.95 \pm 0.42	36.02 \pm 0.40
MUFA ⁽²⁾	52.18 \pm 1.53	50.33 \pm 1.58	49.82 \pm 1.01
PUFA ⁽³⁾	11.18 \pm 1.21	14.72 \pm 1.61	14.15 \pm 0.79
PUFA n-3 ⁽⁴⁾	0.40 \pm 0.06	0.37 \pm 0.03	0.42 \pm 0.05
PUFA n-6 ⁽⁵⁾	10.75 \pm 1.15	14.32 \pm 1.60	13.77 \pm 0.75
n-6/n-3 ⁽⁶⁾	27.97 \pm 2.10	39.46 \pm 5.32	35.32 \pm 1.68
Atherogenic Index	0.45a \pm 0.01	0.42b \pm 0.01	0.43b \pm 0.01
Thrombogenic Index	1.08 \pm 0.02	1.01 \pm 0.02	1.05 \pm 0.02

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil supplemented with red wine solids (RWS). ^{a,b}Means in the same row with unlike superscripts differ (P<0.05). ⁽¹⁾SFA: Saturated Fatty Acid. ⁽²⁾MUFA: Monounsaturated Fatty Acid. ⁽³⁾PUFA: Polyunsaturated Fatty Acid. ⁽⁴⁾PUFA n-3: Polyunsaturated Fatty Acid series n-3. ⁽⁵⁾PUFA n-6: Polyunsaturated Fatty Acid series n-6. ⁽⁶⁾n-6/n-3: PUFA n-6/ PUFA n-3 ratio.

groups (higher values) compared to the PO group (lower value). Within the family of PUFAs, PUFA n-3 levels are not significantly different between the three groups, while PUFA n-6 levels are significantly lower in the PO group with respect to the CO and CO+RWS groups.

By analyzing the PUFA n-6/n-3 ratio, there is a statistically significant difference between all three groups in the study: the PO group has the lowest value, the CO group has an intermediate value, and the CO+RWS group presents the highest value. Bertol et al. (2013) have observed that in different body fat depots, there are changes in the PUFA n-6/n-3 ratio according to the different dietary oil supplementation.

The adipose tissue of pigs shows major differences in FAs composition between the various groups, compared to the muscles tissue (Leskanich et al., 1997; Rey et al., 2006). In monogastric animals, the FAs content in the muscular and adipose tissues reflects the FAs profile of the diet, as part of the ingested FAs is deposited directly into these tissues. This effect has been reported in several studies assessing different fat sources for finishing pigs (Apple et al., 2009; Benz et al., 2011; Enser et al., 2000; Juárez et al., 2010; Lauridsen et al., 1999; Olivares et al., 2009; Teye et al., 2006). Several studies have shown that the fat deposition in the tissues may be influenced by the degree of fat saturation of the diet (Averette Gatlin et al., 2003; Olivares et al., 2009).

Table 4. Fatty acid composition (g/100g of total FAs; means \pm S.E.) in the backfat of pigs (n=6 per group) fed the experimental diets.

	PO	CO	CO+RWS
Lipid (g/kg)	65.40 \pm 3.90	68.64 \pm 1.17	67.42 \pm 0.93
C14:0	0.90 \pm 0.05	0.87 \pm 0.02	0.85 \pm 0.04
C16:0	21.90 ^a \pm 0.49	20.27 ^b \pm 0.29	21.04 ^{ab} \pm 0.41
C16:1	1.67 \pm 0.18	1.48 \pm 0.06	1.31 \pm 0.10
C17:0	0.63 ^a \pm 0.04	0.48 ^b \pm 0.05	0.49 ^b \pm 0.03
C18:0	11.62 \pm 0.81	11.02 \pm 0.40	12.69 \pm 0.45
C18:1n-9	42.72 ^a \pm 0.30	39.40 ^b \pm 0.29	38.37 ^b \pm 0.80
C18:1n-7	2.65 ^a \pm 0.16	2.37 ^{ab} \pm 0.06	2.17 ^b \pm 0.07
C18:2n-6	15.22 ^b \pm 0.76	21.22 ^a \pm 0.44	20.22 ^a \pm 1.23
C18:3n-3	0.77 \pm 0.03	0.87 \pm 0.02	0.78 \pm 0.05
C20:0	0.90 ^a \pm 0.04	0.68 ^b \pm 0.02	0.80 ^{ab} \pm 0.05
C20:1n-9	0.73 ^b \pm 0.04	0.92 ^a \pm 0.03	0.92 ^a \pm 0.04
C20:4n-6	0.32 \pm 0.03	0.37 \pm 0.02	0.36 \pm 0.06
SFA ⁽¹⁾	35.93 \pm 0.98	33.35 \pm 0.63	35.85 \pm 0.74
MUFA ⁽²⁾	47.78 ^a \pm 0.56	44.17 ^b \pm 0.37	42.80 ^b \pm 0.84
PUFA ⁽³⁾	16.25 ^b \pm 0.81	22.48 ^a \pm 0.48	21.37 ^a \pm 1.33
PUFA n-3 ⁽⁴⁾	0.77 \pm 0.03	0.87 \pm 0.02	0.78 \pm 0.05
PUFA n-6 ⁽⁵⁾	15.50 ^b \pm 0.78	21.60 ^a \pm 0.45	20.57 ^a \pm 1.28
n-6/n-3 ⁽⁶⁾	20.35 ^a \pm 0.22	24.62 ^b \pm 0.58	26.42 ^a \pm 0.32
Atherogenic Index	0.42 \pm 0.01	0.38 \pm 0.01	0.41 \pm 0.01
Thrombogenic Index	1.02 \pm 0.05	0.91 \pm 0.03	1.02 \pm 0.04

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil supplemented with red wine solids (RWS). ^{a,c}Means in the same row with unlike superscripts differ (P<0.05). ⁽¹⁾SFA: Saturated Fatty Acid. ⁽²⁾MUFA: Monounsaturated Fatty Acid. ⁽³⁾PUFA: Polyunsaturated Fatty Acid. ⁽⁴⁾PUFA n-3: Polyunsaturated Fatty Acid series n-3. ⁽⁵⁾PUFA n-6: Polyunsaturated Fatty Acid series n-6. ⁽⁶⁾n-6/n-3: PUFA n-6/ PUFA n-3 ratio.

3.3 Meat quality traits

The SM muscle quality traits of pigs fed experimental diets are shown in Table 5. All parameters considered were not statistically different between the groups. In our study, we were aiming to determine whether the change in the FAs profile of the diets could have an influence on the quality characteristics of the meat. The substitution of SFAs with PUFAs in pig meat may have important implications for the quality of the meat, affecting the organoleptic characteristics, pH, colour, and production of volatile compounds during the cooking of the meat (Apple et al., 2007; Wiseman et al., 2000). Some studies have reported that feeding highly unsaturated oil to pigs could negatively impact carcass fat for further processing due to the reduction of the fat melting point (Averette Gatlin et al., 2003; Rentfrow et al., 2003). Moreover, the flavour and odour of fresh pig meat may be negatively affected due to a high PUFAs content, as the meat is more susceptible to oxidation (Daza et al., 2005); on the other hand, a higher content of saturated fat can favour fat quality for processing due to its higher melting point and better oxidative stability (Bertol et al., 2013).

With regard to pH, the different fat sources in the diet did not affect the meat pH values, and these results are in agreement with those obtained from previous studies (Bertol et al., 2013).

In relation to drip loss, the results obtained in our work are similar to those reported by Fraga et al. (2008). Schäfer et al. (2002)

Table 5. *Semimembranosus* muscle traits (means \pm S.E.) of pigs (n=6 per group) fed experimental diets.

	PO	CO	CO+RWS
pH _{45min}	6.50 \pm 0.06	6.42 \pm 0.07	6.41 \pm 0.06
pH _{24h}	5.49 \pm 0.04	5.54 \pm 0.05	5.57 \pm 0.04
Lightness (L*)	48.70 \pm 1.15	48.50 \pm 0.68	49.26 \pm 0.45
Redness (a*)	20.50 \pm 0.67	20.19 \pm 0.27	19.47 \pm 0.27
Yellowness (b*)	6.06 \pm 0.50	4.74 \pm 0.26	5.17 \pm 0.54
Chroma (C*)	21.45 \pm 0.62	20.77 \pm 0.28	20.82 \pm 0.27
Hue angle (H*)	16.59 \pm 1.57	13.22 \pm 0.68	14.79 \pm 1.53
Drip losses, %	7.00 \pm 0.45	6.77 \pm 0.35	6.72 \pm 0.29
Cooking losses, %	22.97 \pm 1.59	24.87 \pm 0.37	25.68 \pm 1.27
Shear force, N	50.75 \pm 2.01	53.70 \pm 2.40	42.43 \pm 1.42

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil and supplemented with red wine solids (RWS).

reported drip losses in the range of 2.2 to 12.6%. A higher level of drip losses is an indicator of a reduced quality of the meat, as meat that releases an excessive amount of liquid is less appreciated by consumers.

In this study, meat colour parameters were not significantly affected by diets. Several studies have shown that the colour parameters of pig meat were affected by the pigments present in the diet or by the oil supplementation. In the study by Joo et al. (2002), an alteration in the yellowness was determined by a modification of the FA composition of the muscle. In pork meat, Fraga et al. (2008) showed a decrease in redness and yellowness due to the addition of rice hulls to the diets, probably because of a decrease in food pigments resulting from the lower level of corn in the ration.

Cooking loss values observed in our study were slightly lower than the 32.3% reported by Hodgson et al. (1991), the 30.8% reported by Pires et al. (2002), and the 27.8% reported by Bridi et al. (2006). This is advantageous for the consumer as the meat was able to retain liquids during the cooking, and also tended not to withdraw.

Shear force (SF) values obtained in our study ranged from 42.2 to 50.8 Newton, which were lower than those demonstrated by Morel et al. (2013). These authors reported, in the SM of pigs fed diets containing a blend of soybean and linseed oil, SF values ranging from 59.2 to 62.2 Newton. A high SF value is considered to be an index of poor meat quality, because, the greater the value, the lower the tenderness of the meat will be.

Data from Table 6 shows that there were no significant differences between groups regarding their chemical composition and oxidative status of SM muscle.

Chemical composition data are in agreement with the food composition tables for pork meat reported by the Italian Food Research Institute database (Marletta & Carnovale, 2000).

In relation to the oxidative status of the muscle, TBARS ranged from 0.24 to 0.27 mg MDA/ kg meat. The mean TBARS values obtained were low across all the groups, which is certainly positive and protects the health of the consumer. Our study is in accordance with Miller et al. (1993), who reported that the meat

Table 6. Chemical composition (% of freeze dried meat) and oxidative status (TBARS, mg malondialdehyde/kg freeze dried meat) (means \pm S.E.) of the *semimembranosus* muscle of pigs (n=6 per group) fed experimental diets.

	PO	CO	CO+RWS
Water	72.65 \pm 0.31	72.92 \pm 0.38	73.27 \pm 0.54
Ash	4.47 \pm 0.10	4.45 \pm 0.10	4.34 \pm 0.13
Ether extract	9.01 \pm 1.29	9.23 \pm 1.83	10.81 \pm 1.18
Crude protein	86.47 \pm 0.27	86.45 \pm 0.19	84.93 \pm 0.17
TBARS	0.24 \pm 0.02	0.27 \pm 0.03	0.24 \pm 0.04

PO= diet with palm oil; CO= diet with corn oil; CO+RWS= diet with corn oil supplemented with red wine solids (RWS); TBARS = thiobarbituric-acid reactive substances.

of pigs fed 10% of animal fat, safflower oil, or sunflower oil did not differ in terms of the resulting TBARS values. Other authors, in previous tests performed on fresh pork found TBARS values equal to 0.50 mg MDA/kg (Watanabe et al., 2010; Joo et al., 2002). In our work, the CO diet, even in the absence of RWS, did not produce a meat susceptible to premature oxidation. This could be explained to the fact that in our study, we used CO, which contains a moderate amounts of vitamin E. In fact it is known that the animal diets containing high levels of vitamin E or other antioxidants can reduce the lipid oxidation of the meat (Corino et al., 2008; Jensen et al., 1997). Indeed, the dietary vitamin E clearly improved the oxidative stability of n-3 enriched lamb meat, as reported by Muñio et al. (2014).

Conversely, in the study by Rezar et al. (2003), the use of linseed oil introduced in the diets of pigs increased the meat oxidative stress, but in this case the oil contained very low amounts of vitamin E. The oxidative stress in the groups of pigs fed linseed oil was additionally increased by the fact that the delivery of antioxidant supplements has not been increased. Diets containing high levels of PUFAs, such as of linseed oil, needed an antioxidant protection that could be achieved through the use of natural antioxidants. In fact, Zhang et al. (2015), have provided evidence that liquorice extract (LE), containing 16.4% total flavonoids, could be used as an attractive natural source of antioxidant additive in meat. The authors, evaluating the antioxidant ability of LE fed to sheep at different levels, demonstrated that dietary LE inclusion of 3000 to 4000 mg/kg feed increased total flavonoid, vitamin E and glutathione contents in meat. Moreover, LE improved free radical scavenging ability of meat, decreased malondialdehyde content and protected the meat against oxidation.

The possibility of using red wine solids as natural antioxidant in animals feeding was also investigated by Muñio et al. (2014). The authors found that red wine extract in the lamb diet lowered the n-6/n-3 ratio of meat and did not improve lipid or protein stability, or sensory attributes of meat during the storage period. According to the authors, the lack of an effect of red wine extract on oxidative stability of lamb meat could arise from the use of a low dose (900 mg/kg feed), or due to a high level of n-3 fatty acids in the meat.

4 Conclusions

The addition of corn oil, which is a good dietary source of lipids for pigs, as rich in PUFAs, favourably modulates the FAs profile of the BF, and to a lesser extent of the SM muscle, without causing adverse effects on fresh meat quality. The addition of antioxidants (RWS) to the CO+RWS diet compared to CO diet did not improve the muscle oxidative stability and did not affect the fresh meat quality. Further researches are needed to determine the optimum level of inclusion of polyphenols in pig diets rich on n-3 PUFAs with the aim to evaluate the storage of the meat subjected to different processing conditions and different time of storage.

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