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# Animal fat and vitamin E in rabbit diets: Total tract apparent digestibility, growth performance, carcass and meat quality traits

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**Abstract:** The present study tested the effect of a dietary inclusion with vitamin E and pork lard on the apparent digestibility of the nutrients, the growth performance, the carcass traits, the physical meat quality, and the α-tocopherol content. A total of 60 hybrid rabbits were reared in individual cages from weaning (35 days of age) until slaughter (78 days of age). A control diet with no supplements, one diet supplemented with 2% pork lard, and two diets that used the aforementioned diets supplemented with an additional 200 mg/kg α-tocopheryl acetate were designed. The diets were isoprotein and isoenergy. The fat inclusion increased the crude protein ($P < 0.05$) and ether extract ($P < 0.001$) total tract apparent digestibility, and the same was observed for the vitamin E inclusion ($P < 0.001$ for both variables). This improved the dietary digestible protein content ($P < 0.05$), which increased the digestible protein to digestible energy ratio ($P < 0.001$). The fat × vitamin E interaction was observed for the total tract apparent digestibility of the ether extract ($P < 0.001$), the neutral detergent fibre ($P < 0.05$) and the acid detergent fibre ($P < 0.01$). The growth traits were unaffected, with the exception of the feed conversion ratio that improved with the vitamin E addition ($P < 0.05$). Similarly, the carcass traits remained unaffected, with the exception of the perirenal and total fat incidence that increased with the fat supplement ($P < 0.05$), and the scapular fat that was reduced with the vitamin E inclusion ($P < 0.05$). The meat L* (lightness), a* (redness), b* (yellowness) colour values and ultimate pH were unaffected by the experimental treatments, even though a fat × vitamin E interaction was observed for the a* and chroma values of the *Longissimus thoracis et lumborum* muscle ($P < 0.05$). Both the fat ($P < 0.05$) and vitamin E ($P < 0.001$) dietary inclusion increased the meat α-tocopherol content. Based on the results, it was concluded that the 2% dietary inclusion of animal fat did not provide more benefits for the considered parameters than the sole α-tocopheryl acetate incorporation, but contributed to the increase in the vitamin E content in the meats.

**Keywords:** antioxidant; dietary strategy; monogastric; nutrition; nutritive value; supplement

The rabbit could be considered an ideal meat from a nutritional point of view, thanks to its unique nutritional properties (Dalle Zotte 2002): besides the high biological value of its protein content, it is a good source of minerals, mainly potassium, phosphorus and selenium. It is also low in sodium and cholesterol, and rich in B vitamins. Specifically, rabbit meat is considered one of the richest sources of vitamin $B_{12}$ among meat species (Dalle Zotte and Szendro 2011). Furthermore, the meat lipids have a favourable fatty

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acid (FA) profile in which the unsaturated FAs account for about 60% of the total fatty acids (Cardinali et al. 2015). A possible drawback of the degree of the lipid unsaturation is the proneness to peroxidation, which can negatively affect the stability of the feeds during the processing and storage and, in turn, also the meat quality. In fact, lipid oxidation is known to negatively impact the sensory characteristics of the meat, reduce its nutritional value and generate compounds that are detrimental to human health (Albonetti et al. 2017). To this regard, vitamin E is a widely appreciated antioxidant which is commonly included in rabbit diets to prevent oxidative deterioration. As high temperatures only have a limited deterioration effect on vitamin E, it maintains its efficacy even after the pelleting process. Furthermore, vitamin E is a fat-soluble vitamin and, therefore, by eating a feed containing an extra quota of it, the rabbit can effectively incorporate it into its meat lipids. This ultimately improves the meat functionality by protecting it from oxidative stress and making it a better source of vitamin E for consumers (Ebeid et al. 2013; Cardinali et al. 2015). The fat addition in rabbit diets, which is used to improve the feed efficiency, ultimately allowing one to achieve desirable carcass characteristics, has been shown to partly increase the body fat content (Fernandez and Fraga 1996; Maertens 1998). This feeding strategy can, therefore, be exploited to provide further enrichment of the rabbit meat with vitamin E. Furthermore, if animal fat is used, it would not compromise the oxidative stability of the feed due to the high saturated FA proportion, ultimately making the addition of vitamin E available for the rabbit. Based on the above-mentioned considerations, the present research work studied the effect of animal fat and vitamin E inclusion in rabbit diets during the fattening phase, on the total tract apparent digestibility (TTAD) of the nutrients, the nutritive value of the diets, the growth performance, the carcass traits, the meat physical quality and the α-tocopherol content.

## MATERIAL AND METHODS

### Animals and diets

All the rabbits were handled according to the principles stated by the European Commission Directive 86/609/EC with regard to the protection of animals used for experimental and other scientific purposes. For the present experiment, the approval of the Ethical Committee was not requested.

A total of 60 rabbits of both sexes from a hybrid line (PS 59: Grimaud Frères, France) were reared in individual cages (28 cm wide × 41 cm long × 28 cm high) from weaning (35 days of age) to the day of slaughter (78 days of age). The rabbits were reared at the experimental rabbit unit of Padova University (Italy) under controlled environmental conditions (15–18 °C and 16 h lighting period). The experiment was divided into two feeding phases: the post-weaning phase (35–48 days of age) during which all the animals received the same commercial weaning diet *ad libitum*, and the fattening phase (49–78 days of age) during which the animals were divided into four experimental groups (15 animals per group). Each group received one of the four isonitrogenous and isoenergy experimental diets *ad libitum*, which contained two different levels of animal fat (pork lard) and two levels of vitamin E (α-tocopheryl acetate). Specifically, the first diet contained no fat and no vitamin E supplements (F0-E0). The second diet was formulated to include 2% fat (F2-E0). The other two diets used the aforementioned diets supplemented with an additional 200 mg/kg of α-tocopheryl acetate (F0-E200 and F2-E200, respectively). The feed ingredients of the F0-E0 and F2-E0 diets are depicted in Table 1, whereas the chemical composition of all the experimental diets is shown in Table 2.

### Growth performance, carcass traits and meat physical quality

The individual feed intake and live weight were recorded twice per week and they were used to calculate the daily weight gain and feed conversion ratio (FCR). At 78 days of age, the rabbits were weighed at the experimental rabbit unit to the obtain slaughter weight, then slaughtered at a commercial slaughterhouse following the standard commercial procedure: after electrical stunning (90 V for 2 s), the jugular veins and the carotid arteries were excised and the carcasses were bled. The carcasses were then dissected according to the recommendations of the World Rabbit Science Association (Blasco and Ouhayoun 1996). The full gastrointestinal tract, skin and paws were then removed. The carcasses were chilled for 24 hours and weighed to obtain the chilled carcass weights. The slaughter yield and drip

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Table 1. Formulation (g/kg) of the experimental diets

| | Experimental diets | |
|---|---|---|
| | F0-E0 | F2-E0 |
| Alfalfa hay 17% CP | 300 | 300 |
| Barley | 240 | 200 |
| Wheat bran | 260 | 260 |
| Sugar beet pulp | 75.0 | 75.0 |
| Soybean meal 44% CP | 45.0 | 45.0 |
| Sunflower meal 30% CP | 45.0 | 65.0 |
| Pork lard | 0.00 | 20.0 |
| Cane molasses | 23.0 | 23.0 |
| Dicalcium phosphate | 3.5 | 3.5 |
| Salt | 3.5 | 3.5 |
| Vitamin-mineral premix | 3.0 | 3.0 |
| DL-methionine | 1.0 | 1.0 |
| Coccidiostat | 1.0 | 1.0 |

CP = crude protein; F0-E0 = no fat, no vitamin E; F2-E0 = 2% fat, no vitamin E

loss were calculated as a percentage of the slaughter weight. The reference carcass (RC) weight was obtained by removing the head and organs (liver, kidneys, organs of the chest and neck) from the chilled carcass. All the dissectible fat (perirenal fat, scapular fat and other dissectible fat) was removed from the RC and expressed as a percentage of the RC. The hind legs were deboned to compute the hind leg meat to bone ratio.

Table 2. Chemical composition (g/kg as fed) and energy content (MJ/kg as fed) of the experimental diets

| | Experimental diets | | | |
|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 |
| Dry matter (DM) | 899 | 899 | 899 | 902 |
| Crude protein (CP) | 147 | 151 | 153 | 155 |
| Ether extract (EE) | 26.1 | 25.2 | 43.2 | 45.1 |
| Crude fibre (CF) | 138 | 139 | 142 | 136 |
| Ash | 71.0 | 71.9 | 71.9 | 72.2 |
| Neutral-detergent fibre (NDF) | 342 | 343 | 344 | 338 |
| Acid-detergent fibre (ADF) | 160 | 173 | 168 | 169 |
| Acid-detergent lignin (ADL) | 29.7 | 36.8 | 38.7 | 37.0 |
| α-tocopheryl acetate (mg/kg as fed) | 55.7 | 200 | 66.5 | 198 |
| Gross energy (GE) | 16.31 | 16.33 | 16.67 | 16.87 |

F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate

The ultimate pH ($pH_u$) was measured (FG2-Five GoTM; Mettler Toledo, Greifensee, Switzerland) on the *Longissimus thoracis et lumborum* (LTL; at 5$^{th}$ lumbar vertebra level) and *Biceps femoris* muscles of each animal. On the same muscles and positions, the L* (lightness), a* (redness), b* (yellowness) colour values (CIELAB Colour System, 1976) were measured by using a portable colorimeter (RM200QC; X-Rite Co., Neu-Isenburg, Germany). Subsequently, the chroma (C*) value was calculated by using the following equation: $C^* = (a^{*2} + b^{*2})^{1/2}$. Both the $pH_u$ and colour values were measured in duplicate.

## Digestibility trial

An *in vivo* digestibility trial was carried out on $n = 40$ ($n = 10$/dietary treatment) 56-day old rabbits of the Grimaud Frères hybrid line, according to the European standardised method described by Perez et al. (1995). The rabbits were equally distributed by sex and live weight in the four dietary groups and individually housed in digestibility cages. The faeces were collected over a 4-day period. At the beginning of the digestibility trial, the experimental diets were sampled for the subsequent chemical determinations. At each collection step, the faeces were stored at –18 °C until further analysis. Two rabbits from the F0-E0 group and one rabbit from the F2-E200 group were excluded from the digestibility trial due to water and feed waste reasons.

## Chemical analyses of diets and faeces

The chemical analyses were performed in duplicate on the feed and faeces collected during the digestibility trial. The analyses were performed according to the Association of Official Analytical Chemists (AOAC 2000) to determine the dry matter (method No. 934.01), crude protein (method No. 2001.11), crude fibre (method No. 978.10), and ash (method No. 967.05) contents. The ether extract was determined after acid hydrolysis (EC 1998). The fibre fractions were determined according to the method by Goering and Van Soest (1970), modified by Robertson et al. (1981). The gross energy was determined with an adiabatic bomb calorimeter (ISO 9831 Determination of gross calorific value – Bomb calorimetric method). On $n = 3$

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rabbits/treatment, the α-tocopherol content of the LTL muscle was analysed by the company Istituto delle Vitamine SpA (DSM group), Milano, Italy.

### Statistical analysis

The data from the present experiment were analysed by a two-way ANOVA (analysis of variance) with vitamin E and fat as the fixed effects, following the PROC GLM of the SAS v9.1.3 statistical analysis software for Windows (SAS Institute 2008). The statistical analysis also considered the vitamin E × fat interaction. The least-square means were obtained using the Bonferroni test, and the significance was calculated at a 5% confidence level.

## RESULTS

### Total tract apparent digestibility and nutritive value of diets

The results of the TTAD of the nutrients and the nutritive value of the diets for the fattening rabbits are presented in Table 3. The feed intake, dry matter and energy TTAD were not affected by the dietary treatment and, therefore, exhibited similar values. The addition of animal fat to the rabbit diets improved the crude protein (CP) ($P < 0.05$) and ether extract (EE) ($P < 0.001$) TTAD, whereas it decreased that of N-free extracts ($P < 0.001$). Consequently, the digestible protein (DP) as well as the DP to digestible energy (DE) ratios were higher in the F2 diets compared to the F0 groups ($P < 0.001$ and $P < 0.05$ for DP and DP/DE, respectively).

The addition of 200 mg/kg α-tocopheryl acetate to the diets had a positive effect on the CP ($P < 0.001$) and EE ($P < 0.001$) TTAD, while the other nutrients remained unaffected. This resulted in a higher DP content in the E diets compared to the other diets ($P < 0.001$), which also increased the DP to DE ratio ($P < 0.001$). A fat × vitamin E interaction was observed for the EE digestibility ($P < 0.001$): the highest value was observed for the F2-E200 group with an average of 82.7%, and the lowest output was provided by the F0-E0 group (53.3%). The groups F0-E200 and F2-E0, which did not differ from each other (72.6 and 71.2% for F0-E200 and F2-E0, re-

Table 3. Effect of the animal fat and vitamin E on the total tract apparent digestibility (TTAD) and nutritive value of the diets

| | Experimental diets | | | | Significance | | | RSD |
|---|---|---|---|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 | fat (F) | vitamin E (E) | F × E | |
| Rabbits (*n*) | 8 | 10 | 10 | 9 | | | | |
| Feed intake (g) | 730 | 681 | 692 | 676 | ns | ns | ns | 69 |
| TTAD | | | | | | | | |
| Dry matter (DM) | 63.29 | 64.09 | 63.09 | 63.09 | ns | ns | ns | 2.21 |
| Crude protein | 71.2 | 73.7 | 73.1 | 74.7 | < 0.05 | < 0.001 | ns | 1.7 |
| Ether extract | 53.3$^{A}$ | 72.6$^{B}$ | 71.2$^{B}$ | 82.7$^{C}$ | < 0.001 | < 0.001 | < 0.001 | 2.2 |
| N-free extracts | 75.3 | 75.0 | 73.4 | 73.2 | < 0.001 | ns | ns | 1.5 |
| NDF | 31.3$^{a}$ | 33.8$^{b}$ | 32.3$^{ab}$ | 28.9$^{a}$ | ns | ns | < 0.05 | 4.1 |
| ADF | 14.6$^{A}$ | 22.4$^{B}$ | 17.4$^{B}$ | 14.0$^{A}$ | ns | ns | < 0.01 | 5.1 |
| Gross energy | 63.7 | 64.3 | 63.7 | 64.0 | ns | ns | ns | 2.2 |
| Nutritive value | | | | | | | | |
| Digestible protein (DP) (g/kg DM) | 117 | 121 | 120 | 123 | < 0.05 | < 0.001 | ns | 3.0 |
| Digestible energy (DE) (MJ/kg DM) | 11.56 | 11.65 | 11.55 | 11.61 | ns | ns | ns | 0.40 |
| DP to DE ratio (g/MJ) | 10.11 | 10.37 | 10.38 | 10.56 | < 0.001 | < 0.001 | ns | 0.12 |

ADF = acid detergent fibre; F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate; NDF = neutral detergent fibre; RSD = residual standard deviation

$^{A,B}$The means in the same row with different superscript letters differ for $P < 0.01$ and $P < 0.001$; $^{a,b}$the means in the same row with different superscript letters differ for $P < 0.05$

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spectively), had a higher EE TTAD compared to the F0-E0 rabbits, but lower than the F2-E200 rabbits. A significant interaction was also observed for the TTAD of the NDF (neutral detergent fibre) ($P < 0.05$) and ADF (acid detergent fibre) ($P < 0.01$): the NDF fraction was better digested by the F0-E200 rabbits (33.8%) compared to the F0-E0 (31.3%) and F2-E200 (28.9%) rabbits, while the F2-E0 rabbits showed an intermediate result (32.3%). A similar outcome was observed for the TTAD of the ADF fraction.

## Growth performance, carcass traits and meat quality

The growth performance of the fattening rabbits fed the experimental diets is displayed in Table 4. Overall, the live weight, feed intake and daily weight gain were not affected by the experimental diets. The dietary inclusion of vitamin E significantly improved the FCR of the rabbits ($P < 0.05$), and the treatment was also effective when the previous period devoid of supplement was considered.

Observing the results presented in Table 5, it emerged that neither the animal fat nor the vitamin E inclusion affected the slaughter data and carcass traits. In addition, no interaction was exhibited. Opposed to what was observed for carcass traits, the considered experimental treatments affected the incidence of the fat depots on the RC. The dietary inclusion of animal fat increased the perirenal fat of the RC ($P < 0.001$), which was also responsible for the highest total dissectible fat percentage observed for the F2-E0 and F2-E200 groups ($P < 0.05$). Conversely, vitamin E augmented the scapular fat incidence on the RC ($P < 0.05$), which, however, did not influence the total dissectible fat percentage. The meat to bone ratio was not influenced by the tested dietary treatments. For the muscles $pH_u$ and the L*a*b* colour values, a significant interaction was detected ($P < 0.05$) only for the a* and C* of the LTL muscle (Table 6). The addition of either animal fat or vitamin E increased the a* and C* values, but their combination (F2-E200) showed values similar to the F0-E0 diet. The α-tocopherol content of the LTL muscle (Table 7) was significantly increased by both the fat ($P < 0.05$) and vitamin E ($P < 0.001$).

Table 4. Effect of the animal fat and vitamin E on the growth performance

| | Diets | | | | Significance | | | RSD |
|---|---|---|---|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 | fat (F) | vitamin E (E) | F × E | |
| Rabbits (*n*) | 15 | 15 | 15 | 15 | | | | |
| Live weight (g) | | | | | | | | |
| Day 35 | 946 | 945 | 945 | 944 | ns | ns | ns | 73 |
| Day 49 | 1745 | 1728 | 1744 | 1749 | ns | ns | ns | 125 |
| Day 78 | 2956 | 3021 | 3045 | 3054 | ns | ns | ns | 218 |
| Feed intake (g/day) | | | | | | | | |
| Day 35–48 | 141 | 131 | 135 | 134 | ns | ns | ns | 20 |
| Day 49–78 | 169 | 167 | 171 | 167 | ns | ns | ns | 17 |
| Day 35–78 | 160 | 155 | 160 | 156 | ns | ns | ns | 16 |
| Daily weight gain (g/day) | | | | | | | | |
| Day 35–48 | 57.0 | 56.0 | 57.1 | 57.5 | ns | ns | ns | 6.5 |
| Day 49–78 | 41.7 | 44.6 | 44.9 | 45.0 | ns | ns | ns | 5.7 |
| Day 35–78 | 46.7 | 48.3 | 48.9 | 49.1 | ns | ns | ns | 4.9 |
| Feed conversion ratio | | | | | | | | |
| Day 35–48 | 2.48 | 2.35 | 2.38 | 2.33 | ns | ns | ns | 0.26 |
| Day 49–78 | 4.08 | 3.78 | 3.84 | 3.73 | ns | < 0.05 | ns | 0.34 |
| Day 35–78 | 3.43 | 3.23 | 3.27 | 3.19 | ns | < 0.05 | ns | 0.22 |

F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate; RSD = residual standard deviation

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Table 5. Effect of the animal fat and vitamin E on the slaughter data and main carcass traits

| | Diets | | | | Significance | | | RSD |
|---|---|---|---|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 | fat (F) | vitamin E (E) | F × E | |
| Rabbits (*n*) | 15 | 15 | 15 | 15 | | | | |
| Weight (g) | | | | | | | | |
| Slaughter weight (SW) | 2 956 | 3 021 | 3 046 | 3 054 | ns | ns | ns | 218 |
| Chilled carcass (CC) | 1 696 | 1 764 | 1 772 | 1 764 | ns | ns | ns | 136 |
| Reference carcass (RC) | 1 385 | 1 427 | 1 453 | 1 453 | ns | ns | ns | 119 |
| % SW | | | | | | | | |
| Full gastrointestinal tract | 18.3 | 18.7 | 18.2 | 18.6 | ns | ns | ns | 1.6 |
| Skin and paws | 17.4 | 17.2 | 17.2 | 17.3 | ns | ns | ns | 1.0 |
| Slaughter yield | 57.4 | 57.8 | 58.2 | 57.8 | ns | ns | ns | 1.7 |
| Drip loss | 2.26 | 2.22 | 2.05 | 2.19 | ns | ns | ns | 0.39 |
| % CC | | | | | | | | |
| Liver | 6.84 | 6.67 | 6.86 | 6.96 | ns | ns | ns | 1.07 |
| RC | 81.6 | 81.7 | 82.0 | 82.3 | ns | ns | ns | 1.6 |
| % RC | | | | | | | | |
| Perirenal fat | 3.21 | 2.64 | 3.72 | 3.61 | < 0.001 | ns | ns | 0.80 |
| Scapular fat | 1.25 | 0.94 | 1.15 | 1.13 | ns | < 0.05 | ns | 0.30 |
| Other dissectible fat | 1.97 | 1.87 | 1.88 | 2.28 | ns | ns | ns | 1.18 |
| Total dissectible fat | 6.44 | 5.44 | 6.77 | 7.02 | < 0.05 | ns | ns | 1.78 |
| Meat to bone ratio | 2.35 | 2.47 | 2.65 | 2.46 | ns | ns | ns | 0.43 |

F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate; RSD = residual standard deviation

Table 6. Effect of the animal fat and vitamin E on the ultimate pH ($pH_u$) and L*a*b* colour values of the *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles measured 24 h *post mortem*

| | Diets | | | | Significance | | | RSD |
|---|---|---|---|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 | fat (F) | vitamin E (E) | F × E | |
| Rabbits (*n*) | 15 | 15 | 15 | 15 | | | | |
| LTL muscle | | | | | | | | |
| $pH_u$ | 5.49 | 5.48 | 5.50 | 5.48 | ns | ns | ns | 0.13 |
| L* value | 58.1 | 57.1 | 58.3 | 58.4 | ns | ns | ns | 2.5 |
| a* value | 3.97$^a$ | 4.56$^b$ | 4.62$^b$ | 3.96$^a$ | ns | ns | < 0.05 | 1.10 |
| b* value | −0.27 | 0.64 | 0.41 | 0.69 | ns | ns | ns | 1.40 |
| C* value | 4.23$^a$ | 4.82$^b$ | 4.87$^b$ | 4.09$^a$ | ns | ns | < 0.05 | 1.16 |
| BF muscle | | | | | | | | |
| $pH_u$ | 5.66 | 5.62 | 5.68 | 5.63 | ns | ns | ns | 0.16 |
| L* value | 56.3 | 56.7 | 56.6 | 56.2 | ns | ns | ns | 2.4 |
| a* value | 4.16 | 4.37 | 4.47 | 4.44 | ns | ns | ns | 0.97 |
| b* value | 2.79 | 2.67 | 2.59 | 3.22 | ns | ns | ns | 1.32 |
| C* value | 5.09 | 5.26 | 5.25 | 5.52 | ns | ns | ns | 1.32 |

a* = redness; b* = yellowness; C* = chroma, $(a^{*2} + b^{*2})^{1/2}$; F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate; L* = lightness; RSD = residual standard deviation

$^{a,b}$The means in the same row with different superscript letters differ for $P < 0.05$

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Table 7. Effect of the animal fat and vitamin E on the α-tocopherol content (mg/kg) of the *Longissimus thoracis et lumborum* muscle

| | Diets | | | | Significance | | | RSD |
|---|---|---|---|---|---|---|---|---|
| | F0-E0 | F0-E200 | F2-E0 | F2-E200 | fat (F) | vitamin E (E) | F × E | |
| Rabbits (*n*) | 3 | 3 | 3 | 3 | | | | |
| α-tocopherol | 1.56 | 4.42 | 2.14 | 5.21 | < 0.05 | < 0.001 | ns | 0.37 |

F0-E0 = no fat, no vitamin E; F0-E200 = no fat, 200 mg/kg of α-tocopheryl acetate; F2-E0 = 2% fat, no vitamin E; F2-E200 = 2% fat, 200 mg/kg of α-tocopheryl acetate; RSD = residual standard deviation

## DISCUSSION

In the present study, the results of the TTAD of the nutrients was in accordance with the values that are normally observed in literature for this species at the same considered age (Fernandez et al. 1994). It is well understood that supplementing rabbit diets with fat can increase the digestibility of the fats themselves and of other feed nutritional components (Santoma et al. 1987). However, excessive levels of dietary fat (> 60 g/kg) can negatively interact with the caecal microflora ultimately worsening the digestive efficiency (Casado et al. 2010). Added-fat diets tend to directly increase the EE digestibility thanks to the remarkable digestibility of pure fats, which is what was observed in the present study. When a feed, characterised by a high dietary energy value, is provided to rabbits, they tend to reduce the feed intake as a result of the chemostatic regulation of the appetite. The resulting slower digesta transit would enhance the overall digestive efficiency (Falcao-e-Cunha et al. 2004). However, this was not the case in the present study, as the feed intake was similar for all the treatment groups. Therefore, the increased CP TTAD, resulting from the addition of 2% pork lard, could be ascribed to one of or the combination of the following factors: the slightly higher protein content of the fat-supplemented diets (average value of F2-E0 and F2-E200: 154 g/kg as fed) compared to the other diets (average value of F0-E0 and F0-E200: 149 g/kg as fed), or the slightly different protein sources of the two groups of the diets (Villamide et al. 2010). In fact, the fat-supplemented diets had 2% more sunflower meal and 4% less barley compared to those that were not supplemented with the animal fat. Furthermore, the improved EE digestibility also led to the observed higher carcass fatness (perirenal and total dissectible fat incidences on the RC). The results of the present research were partly coherent with existing literature: Fernandez et al. (1994) reported similar effects on the EE digestibility due to an animal fat inclusion (3% beef tallow). The above-cited study also reported an increase in the energy digestibility, which was, however, attributable to the increased energy content of the diet rather than the addition of the beef tallow. Furthermore, in the latter study, no effect on the CP digestibility was detected.

Despite the fact that dietary fat can exert an inhibitory effect on the caecal and colon microbial activity (Martins et al. 2018), thus, negatively affecting the fibre fractions digestibility, this was only partly observed in the present experiment as the F2-E200 and F0-E0 rabbits showed the lowest NDF and ADF digestibility, whereas the F0-E200 and F2-E0 rabbits showed the highest ones. Providing dietary animal fat to the rabbits also increased the α-tocopherol content of the LTL muscle, which is linked with the metabolic pathway of vitamin E; in fact, α-tocopherol is mostly hydrolysed in the intestinal lumen where it is absorbed along with the dietary fat (Belles et al. 2019).

Alpha-tocopheryl acetate is typically added to animal feeds to prevent the oxidative phenomena, and to provide the animal with an effective antioxidant that can be easily incorporated into cell membranes, where it inhibits lipid peroxidation through a chain-breaking activity (Belles et al. 2019). It is well established that the amount of dietary α-tocopheryl acetate is positively correlated with that found in the meat (Castellini 2000), which was also observed in the present experiment. Due to its activity, α-tocopherol protects the integrity of the small intestine mucosa, thereby increasing the digestive and absorptive capacity of the digestive tract (Carabano et al. 2010). This effect was likely responsible for the increased CP and EE TTAD and the subsequent increased DP content. As a result of the increase in DP content due to both fat and vitamin E inclusions, the DP to DE ratio was also increased, thus reaching the recom-

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mended range for growing rabbits of 10.5–11.0 g/MJ (Xiccato and Trocino 2010). The positive effect of vitamin E on the rabbit's digestive absorption was reflected on the FCR, being the lowest in the E groups, the latter being coherent with the results from Selim et al. (2008). However, the extra dietary vitamin E did not always provide the same improvements in the rabbit's performance, which is attributable to heterogeneous inclusion durations and experimental conditions (Selim et al. 2008; Cardinali et al. 2015). The fat × vitamin E interaction on the EE TTAD, with the highest EE TTAD observed for the F2-E200 diet compared to the other three diets, was attributable to the above-mentioned positive effect of vitamin E on the absorptive capacity of the digestive tract, combined with the pronounced digestibility of the pure dietary fats. The latter could also explain the results observed for the fibre fractions (NDF and ADF) of the TTAD, which is in line with previous research (Fernandez et al. 1994).

Vitamin E is known to better protect red meat from discolouration during storage, which is attributable to its remarkable antioxidant activity on meat lipids (Belles et al. 2019). Diversely, it has a negligible direct effect on the colour of fresh white meat (Mercier et al. 1998), as observed in the present study. The decrease in the LTL a* value of the F2-E200 group was unexpected, as vitamin E should protect the meat from a colour change, as observed for the F0-E200 meat samples. Thus, this finding needs to be further investigated to understand the reason behind this pattern.

## CONCLUSIONS

The present research highlighted that the inclusion of 2% pork lard in the diet for the fattening rabbits did not provide further benefits to their growth performance, carcass traits and physical meat quality, despite a slight positive effect on the ether extract and protein digestibility. Furthermore, no synergistic effect between the pork lard and the α-tocopheryl acetate dietary inclusion was observed. This highlights that the sole supplement α-tocopheryl acetate is sufficient to increase the total tract apparent digestibility of the nutrients, improve the rabbit growth efficiency and enhance its content in the meat, thus protecting the fresh meat from oxidative stress.

## Conflict of interest

The authors declare no conflict of interest.

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