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Effect of the housing system (free-range vs. open air cages) on growth performance, carcass and meat quality and antioxidant capacity of rabbits

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Abstract

Growth performances and meat quality of free-range or cage raised rabbits were compared in 36 male animals. Rabbits were raised in free-range areas (2000 cm^2/head) or in open-air cages (800 cm^2/head) from weaning to 99 days old. Daily weight gain and final live weight were higher ($P < 0.05$) for the rabbits raised in cages which presented a more favourable feed conversion ratio ($P < 0.05$) than in the free-range group. The average feed intake, liver and empty gastro-intestinal tract weights were higher ($P < 0.05$) in the free-range group, while the interscapular fat percentage was higher ($P < 0.05$) in the caged rabbits. Loins of free-range rabbits had higher amount of PUFA n-6 in neutral lipids ($P < 0.05$) whereas their polar lipids were richer in PUFA n-6 and n-3 than in those of the cage group. Muscular fat of free-raised rabbits was found to be less susceptible to be oxidized, having a higher antioxidant capacity than the caged group.

Keywords: Rabbits; Free-range; Open air cages ; Meat quality; Antioxidant capacity

Introduction

In the recent years, intensive rabbit production in Italy has been going through a profound crisis. Despite the fact that data available on the FAO website (FAOSTAT, 2018) report increased meat production in Italy in 2014 (268,980 t), the consumption of rabbit meat, estimated to be 4.5 kg per-capita in the year 2000 was recently estimated as 1.0 kg per-capita in 2016, with a total rabbit meat production of 32,000 t (UNAITALIA, 2017).

The decline in the intensive production of rabbit meat and the increased demand on the part of consumers for more welfare friendly systems in rabbit farming, has focused the attention of the producers on semi-intensive or extensive systems, able to satisfy the demands of the consumers in terms of animal welfare and high quality of the meat. Several studies have examined alternative housing systems for growing rabbits and their impact on meat production and quality (D'Agata et

al., 2009; Jekkel, Milisits, & Nagy, 2010; Pla, 2008). Dal, Castellini, and Mugnai (2002) compared the characteristics of rabbits reared in pens or in cages and slaughtered at the same age, and they found that pen - reared rabbits showed lower growth rate, pH, redness and maturity of meat than those reared in cages. Mattioli et al. (2016) showed that the fattening of rabbits reared in mobile arks could be a possible alternative system that can improve the meat quality. It is known that organic and free-range production systems make the meat more acceptable and attractive to consumers (De Boer, Boersema, & Aiking, 2008) because of the appealing idea of raising rabbits under "natural" conditions with more available space in which to express their natural behaviour. However, when rabbits are kept on the ground, they may come into contact with faeces, and this may bring about health problems, such as enteric diseases and coccidiosis, and thereby reduce growth performance (Pinheiro, Outor-Monteiro, Silva, Silva, & Mourão, 2011). In addition, if pasture is available in the raising area, it is difficult to control the feed intake and, furthermore, growth performance could be further penalized due to a higher intake of fibrous feed. For this reason, studies on extensive housing systems have often led to poor conclusions due to the numerous variables involved (stocking density, group size, type of pen, etc.).

This study aimed to investigate the effect of a free-range system in comparison with the cage system on growth performance, carcass traits and meat quality of growing rabbits. The two raising systems differ in stocking density in order to evaluate the effect of greater movement on rabbit performance. To reduce the number of the other variables affecting meat quality, free-range rabbits were housed in an area without pasture and the size of each group, caged or free-range rabbits, was the same.

Materials and methods

All the animals were treated according to the principles stated by the EC Directive 2010/63/UE, regarding the protection of animals used for experimental and other scientific purposes. The trial was carried out in a private farm located in the province of Caserta (Italy), certificated for organic production, during the period September – December 2016. A total of 36, thirty-seven-day old, male California × New Zealand White rabbits (average weight 1079.1 g ± 181.7) were equally divided into 2 groups; one group was housed in open-air cages and the other free-range on the ground. In both the groups, the rabbits were divided into 6 replicates (3 rabbits/replicate, 18 rabbits per group). The cages (in galvanized metal, 60 × 40 × 60 cm high, homemade by the farmer) were placed outside, according to an open-air system, near the free - range area, and under a plastic canopy to protect animals from the bad weather. The rabbits had around 800 cm^2/head (for each group, 6 cages of 2400 cm^2). In the free-range system, the available space was 2000 cm^2/head, so that each area available for replicate (3 rabbits) was 6000 cm^2. Each free-range area was enclosed by a 2 m high metal fence protected by a shaded net to deny access to predators. Three "feeding points", containing troughs and nipples for the distribution of fresh water, were organized in each area under a plastic canopy. In the free- range area there were shelters and trees but no grass, so no additional feeds were available to the free-range animals.

Both the groups fed on the same diet consisting of an alfalfa hay and a cereal mix (1/3 germinated barley, 1/3 oat, 1/3 wheat bran). The alfalfa and cereal mix were administered in separate troughs. Samples of the feeds were collected weekly and the chemical-nutritional characteristics were analysed according to AOAC (2004) Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest, Robertson, and Lewis (1991). Diets were formulated to meet rabbit requirements according to the National Research Council

(NRC, 1977) guidelines. The average chemical-nutritional characteristics of the administered feeds and their fatty acid profile are reported in the Tables 1 and 2, respectively. The amount of digestible energy of the feeds was estimated according to the equation of Wiseman, Villamide, Carabaño, and Carabaño (1992).

Throughout the experiment, the mortality rate in the groups was recorded daily. Individual live weight and feed intake per cage were recorded weekly to calculate body weight (BW) gain, average daily feed intake (ADFI) and the feed conversion ratio (FCR). The feed intake of each diet component (alfalfa hay and cereal mix) was calculated from the difference between the pre-weighed amount of feed and the remaining or scattered feed at the end of the week. Samples of the remaining and scattered feed were collected and evaluated to estimate the different proportion of the three cereals. One month after the beginning of the trial and at the end of the trial, samples of faeces were collected and sent to a private laboratory for the detection of enteric coccidia infection using the McMaster Egg Count technique, according to Vereecken et al. (2012).

At 99 days of age, two rabbits per replicate (12 per group) were slaughtered in a specialized slaughterhouse and the carcass traits were evaluated following the World Rabbit Science Association recommendations, as described by Blasco and Ouhayoun (1996). The slaughtered rabbits were bled, and then the full gastrointestinal tract, skin, distal part of legs and tail, kidneys, genitals and urinary bladder were removed. The carcasses were weighed and then chilled to 4 °C for 24 h in a ventilated room. After 24 h chilling, the carcasses were weighed again to obtain the chilled carcass (CC) weight, then head, liver, heart, the lungs+oesophagus+trachea+thymus gland package, and kidneys freed of perirenal fat, were removed to obtain the reference carcass (RC). From the RC, hind legs (HL) and *Longissimus thoracis et lumborum* (LTL) muscle were separated. With a portable instrument (Model HI 9025; Hanna Instruments, Woonsocket, RI, USA), equipped with an electrode (FC 230C; Hanna Instruments), the value of pH 1 h after slaughtering was measured in the *Biceps femoris* (BF) muscle. The left HL was utilized to evaluate the percentage of meat, bone and fat. The meat was manually separated from bone and fat, and the meat to bone ratio was calculated. Moisture, protein, and ash content of the meat were determined by using 950.46, 976.05, and 920.153 AOAC (2012) methods, respectively.

The LTL muscle of each carcass was separated, stored at −80 °C, and sent to the Department of Agri-Food Production and Environmental Sciences of the University of Florence (Italy) for further analyses.

The total lipids content of the samples was determined according to Folch, Lees, and Sloane Stanley (1957). Lipids fraction (neutral, NL, and polar ones, PL) separation was obtained with the method described by Juaneda and Rocquelin (1985). Lipids extract was diluted with chloroform to obtain 30 mg of lipids in 500 µL of solvent. This dilution was then injected in a Sep-Pack Silica column (Waters, Milford, MA, USA) and subjected to three subsequent washes: 20 mL of chloroform, 5 mL of chloroform:methanol (49:1, *v*/v), and 30 mL of methanol. Neutral lipids were eluted after the first step, whereas polar lipids were obtained after the third one. Solvent was then evaporated, and lipids fractions were firstly gravimetrically quantified and then analysed for their fatty acids (FAs) composition. FAs in the lipids extract fractions were trans-esterified to methyl esters (FAME) by base-catalysed transesterification (Christie, 1982) and their fatty acid profile was determined by gas chromatography using a Varian GC gas chromatograph (Varian Inc., Palo Alto, CA, USA), set as described in Secci et al. (2018). FAs were identified and then quantified by calibration curves by using tricosanoic acid (C23:0; 0.4 mg/mL) (Supelco, Bellefonte, PA, USA) as internal standard. The cholesterol in LTL meat samples was determined by gas chromatography analysis, according to Secci et al. (2018).

Lipids oxidation was evaluated in terms of primary (conjugated dienes, CD) and secondary (2-thiobarbituric acid reactive substances, TBARS) oxidation products. CD content in the lipid extract was measured by the colorimetric method proposed by Sirinvasan, Xiong, and Decker (1996) and for CD quantification the molar extinction coefficient of 29,000 mL/mmol cm was utilized. The results are expressed as mmol hydroperoxides/kg loin. TBARS were measured using the colorimetric method described by Vyncke (1970) at the extinction coefficient of 532 nm. A calibration curve prepared with TEP (1,1,3,3-tetra- ethoxypropane) in 5% (*w*/*v*) TCA (0.2 to 3.1 µmol/L) was necessary for TBARS quantification (expressed as mg malondialdehyde equivalents, MDA-eq, per kg loin).
Samples of LTL (3 g) were extracted with 10 mL of ethanol to analyse, on the ethanol-extracted samples, the antioxidant capacity according to Mancini et al. (2015). ABTS-reducing activity assay (ABTS, 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid)), DPPH-scavenging activity (DPPH, 2,2-diphenyl-1-picrylhydrazyl) and FRAP assay (ferric-reducing ability) were analysed.

Statistical analysis

The data were processed by a one-way ANOVA, using the PROC GLM of SAS (2000) according to the following model:

$Yij = m + HSi + eij$

where Y is the single observation, m the general mean, HS the effect of the housing system (i = in cage or free range), e the error. Comparison between means was performed by Tukey's test (SAS, 2000) at $P < 0.05$. The replicate (cage or single free-range area) was considered as the experimental unit.

Results

The average temperature and humidity during the trial ranged from 20.7 °C and 68.5%, respectively in September to 9.1 °C and 86.3% in December (data from https://it.climate-data.org/location/1167/). No mortality or morbidity were recorded during the trial, and the analysis of the faeces in order to detect parasites showed very low amount of oocystis (< 10 of *Eimeria magna* and *Eimeria media*).
Table 3 shows the growth performance of the rabbits during the trial. The live weight at 99 days of age and the daily weight gain during the trial (37–99 days) were higher ($P < .05$) for the rabbits raised in cages while the total average feed intake was higher ($P < 0.05$) in the free-range group. The feed conversion ratio showed a more favourable value ($P < 0.05$) in the caged rabbits.
Table 4 shows the carcass traits of the rabbits slaughtered at 99 days of age. Liver and empty gastro-intestinal tract incidences were higher ($P < 0.05$) in the rabbits raised in the free-range system, whereas the interscapular fat percentage was higher ($P < 0.05$) in the caged rabbits.
Table 5 reports the weight of the left hind leg, the incidences of the meat, bone and fat as well as the meat to bone ratio. The weight of bone, expressed as percentage of the hind leg weight, was higher ($P < 0.05$) in the free-range rabbits and thus the meat to bone ratio was higher ($P < 0.05$) in the caged rabbits.
The raising system had no significant effects on the chemical composition and cholesterol content of the rabbit loin meat, as shown in Table 6.
The Table 7 reports the content of neutral lipids and their fatty acid profile in the LTL muscle of the rabbits, according to the raising system. Raising system and space availability had only a minor influence on FA.
Several saturated fatty acids (C15:0, C15:0 iso and anteiso, C16:0 and C16:0 anteiso) had higher concentrations in caged rabbits and the same happened for C16:1 n-7 and C18:3 n-6, while C18:2

n-6 and C20:0 contents were higher in the neutral lipids of the rabbits raised in the free-range system. However, considering the FA classes (SFA, MUFA and PUFA), a difference was found only for the sum of PUFA n-6 which resulted higher ($P < 0.05$) in the free-range group.

Table 8 shows the content of polar lipids and their fatty acid profile in the loin of the rabbits according to the raising system. As regards FA content, only a few differences between the groups were observed. The fatty acids C15:0, C17:0, C17:0 anteiso and C18:1 n-9 were higher ($P < 0.05$) in the caged rabbits, while C22:5 n-3 fatty acid was higher in free range rabbit loin. As regards the fatty acid groups, MUFA resulted higher in the caged rabbits, while PUFA n-6 and PUFA n-3 was found to be higher ($P < 0.05$) in the free-range rabbits.

Table 9 shows that there were no significant differences between the groups regarding the primary and secondary products of the oxidation, expressed by conjugated dienes (CD) and TBARS, respectively. In addition, the antioxidant capacity of the loin of the rabbits raised in the free-range system, measured by ABTS, was higher ($P < 0.01$) than in the other group. However, when the relation between CD and lipid content in meat is analysed (Fig. 1), two different oxidation patterns are clearly shown in relation to the content of 1 kg of loin meat. Cage raised rabbits had an exponential increase in CD value when their fat content in loin increased whilst, on the other hand, CD remained unchanged increasing fat content in loin of the free-range rabbits.

Discussion

In this trial, the groups housed in the open-air cages or in the ground free-range system were of the same size and genetic type, and feed availability was also the same although, of course, as regards the freerange system, there was a reduced stocking density that allowed the rabbits to move more freely. Castellini, Berri, Le Bihan-Duval, and Martino (2008) observed that the increasing of available space and the availability of nutrient sources from vegetation in an out-door system might contribute to modifying the quality of the final product. In the present trial, rabbits had no access to other sources of feed than that daily administered, thus all the changes observed are attributable to the different housing systems and stocking densities.

As regards growth performance, the hay to cereal mix ratio did not differ to any greater extent (1.36 vs. 1.39 for caged and free-range rabbits, respectively) and also the proportion of the three cereals used in the scattered and refused mix was similar to that used in the mix formulation, thus no specific feed preference was observed among those offered. However, the results obtained concerning daily weight gain and the feed intake of free-range rabbits differed from other studies which showed a reduction in the feed intake of rabbits raised in an outdoor range system compared to the cages (Pinheiro et al., 2011). However, other nutrients (spontaneous herbs) were available for rabbits in the previous mentioned studies, and their intake and chemical composition were not evaluated. In the present study, since no other feed sources than those administered were available for rabbits, the higher feed intake recorded for free-range rabbits could be ascribed to the increase in the energy requirements of rabbits due to the greater availability for them to move around in, which lead to increased activity (Maertens & Van Herck, 2000). In addition, the higher feed intake of the rabbits raised in the free-range system could be responsible for the higher incidence of their empty gastro-intestinal tract. More difficult to explain is the increase in liver percentage in the free-range rabbits. The liver plays an important role in energy and nutrient metabolism in animal species and several studies have shown that its weight can change according to the amount and type of carbohydrates (van Bennekum, Nguyen, Schulthess, Hauser, & Phillips, 2005) and fat (Buettner et al., 2006) of the feed. Papadomichelakis, Zoidis, and Kostas (2012) correlated the liver weight to the amount of SFA, MUFA and PUFA in the rabbit diet showing a

positive correlation with SFA and MUFA and a negative correlation with PUFA content. In addition, parasitic problem can be excluded as the search for parasites in rabbit faeces showed a very low amount of oocystis. Among the carcass traits, only the interscapular dissectible fat content showed difference due to the rearing system and stocking density, with the rabbits from the free-range system (i.e. those with available space) having lower (−50%) value than that observed in the caged rabbits. Pinheiro et al. (2011) found a lower percentage of dissectible fat in the carcasses of the rabbits raised in an open-air system (around 1/3) than in raised in cages. Additionally, Dal Bosco, Castellini, and Bernardini (2000) observed a lower lipid content in the carcasses of rabbits reared in open-air or indoor pens than in carcasses from caged rabbits which can be explained by the higher energy expenditure involved in moving around as regards the first of the two groups. The lower meat to bone ratio observed in this study for free-range rabbits is in line with other findings on this topic (Dal Bosco et al., 2000; Pinheiro et al., 2011), but in the present trial the higher weight of the bone in the free-range group was the main reason for a decrease of the meat to bone ratio. The disparities in the fatty acid profiles of neutral and polar lipids of the rabbits' loins could be attributed both to the higher feed intake and higher muscular activity of the rabbits raised under the free-range system. It is well known that dietary lipid sources have a direct effect on the fatty acid composition of monogastric meats and the supply of unsaturated fatty acids to tissues may be increased simply by increasing their proportion in the diet administered (Woods & Fearon, 2009). In our trial, the higher feed intake of rabbits raised in the free-range system might have affected the amount of fatty acids intake as shown previously. Thus, this justifies the higher amount of PUFA in the polar fraction of the lipids.

Previous studies on the effects of raising systems on muscle fatty acid composition in rabbits have shown significant differences in both total lipid content and fatty acid profile (D'Agata et al., 2009; Dal et al., 2002). More specifically, rabbits with a large space at their disposal (e.g. outdoor rearing system in D'Agata et al., 2009) showed higher total lipid, and MUFA fraction contents, whereas PUFA fraction was significantly reduced in comparison with the value found in the muscle of rabbits raised in a similar area (indoor system). The differences observed have been attributed by the authors to the higher amount of intramuscular fat and hence to the lower percentage of phospholipids, which are rich in PUFA. Interestingly, present results demonstrate that rabbits raised in a free-range or an open-air cage system had the same amount of intramuscular fat and phospholipids, and that the loins of the free-range rabbits were richer in PUFA fractions compared to those of the other group. In addition, based on our knowledge, there are few studies available in the literature on the effect of physical exercise on the fatty acid profile of rabbit muscle. Our findings disagree with the study by Szabò, Romvàri, Fébel, Bogner, and Szendrő (2002) who observed that the level of stearic (C18:0) and arachidonic (C20:4 n-6) acids significantly decreased in the *Vastus lateralis* muscle of rabbits after exercising. In humans, the fatty acid profile of skeletal muscle lipids in a group of sedentary men (Thomas, Londeree, Gerhardt, & Gehrke, 1977) showed a higher proportion of palmitic acid (C16:0) in comparison with a group of long-distance runners. This is in accordance with our results which showed a lower amount of C16:0 and C16:0anteiso in the neutral fraction of the loin muscle of free-range rabbits.

Lipid oxidative status of loin meat was found to be slightly affected by the different housed systems. Indeed, the CD pattern shown in Fig. 1 underlines that fat contained in muscle of rabbits grown in a cage system were more susceptible to being oxidized than that of the free - range ones, despite the lower PUFA content in muscle from rabbits raised in cage system. In addition, the lower antioxidant capacity found in muscle from rabbits raised in cages compared to those free-range housed might have protected the muscle from lipid oxidation. However, these results should be

treated with caution due to the limited sample size. None the less, it is widely suggested that the lipid oxidative status of meat can be affected from a variety of factors, both *infra-vitam* and *post-mortem* (Samples, 2013). However, the possible effects on lipid oxidation of housing conditions of rabbits have barely been investigated. Dal et al. (2002) showed that housing conditions had a significant effect on the LTL muscle's oxidative status of rabbits raised in cages, straw bedded pens and wire netted pens. The lowest level of reactive oxygen molecular substances (ROMs, 26 mg hydrogen peroxide/100 mL) and antioxidant capacity (387 mmol HClO/mL) were observed in the blood serum of cage-reared animals and the highest (33 mg hydrogen peroxide/100 mL and 506 mmol HClO/mL, respectively) in those held on straw litter (Dal et al., 2002). The intensification of physical activity increased the oxidative capacity of the organism producing a high amount of free radicals (ROMs) according to Gondret, Hernandez, Rémignon, and Combes (2009) but also induced the animals to develop an adaptive response in order to control the greater amount of free radicals produced. In addition, Dal et al. (2002) highlighted that a more stressful environment (straw bed) caused an increase in TBARS content in the LTL muscle compared with the wire net raising system, probably as a consequence of the highest ROMs content in plasma.

Conclusions

The housing of the rabbits in a free-range system without access to grass and with a higher space availability negatively influenced, compared to an open-air caging system, the growth performance of the animals and slightly influenced the carcass traits and the chemical characteristics of the meat. However, the effect of a larger space was evident on the antioxidant capacity of the loin meat; being higher in the free-range rabbits, and this action against lipid peroxidation could have an important role in meat preservation after the slaughtering.

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Table 1. Chemical composition and digestible energy (DE) content of the feeds administered to the rabbits along the trial.

	Alfalfa hay	Cereal mix
Dry matter, g/kg	894	763
Ash, g/kg DM	104	53.7
Crude protein, g/kg DM	150	150
Ether extract, g/kg DM	16.7	46.8
Crude fiber, g/kg DM	302	124
NDF, g/kg DM	464	271
ADF, g/kg DM	306	110
ADL, g/kg DM	48.9	32.7
DE, MJ/kg	6.30	12.4

DM: dry matter; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; DE: calculated as: DE=12.912 – (0.0236×CF)+(0.010×CP)+(0.020×EE), R2=0.92

411 Table 2. Total fatty acids methyl-esters (g FAME/100 g of feed) and fatty acid profile (% of total FAME) of
412 the feed administered to the rabbits along the trial.

	Alfalfa hay	Cereal mix
Total FAME	1.02	2.05
C12:0	0.39	0.02
C13:0	0.02	–
C14:0 iso	0.18	–
C14:0	1.33	0.22
C14:1 n-5	0.14	–
C15:0 iso	0.80	–
C15:0 anteiso	0.04	0.01
C15:0	0.64	0.07
C16:0 anteiso	0.08	–
C16:0	28.8	16.5
C16:1 n-11	2.20	–
C16:1 n-9	0.09	0.05
C16:1 n-7	0.24	0.18
C17:0 anteiso	–	0.01
C16:2 n-4	–	0.01
C17:0	0.58	0.11
C16:3 n-4	1.21	0.24
C17:1	0.04	0.01
C16:4 n-1	–	0.02
C18:0	4.29	1.76
C18:1 n-9	2.93	29.3
C18:1 n-7	0.42	0.82
C18:2 n-6	16.6	44.0
C18:3 n-6	0.03	0.04
C18:3 n-3	29.1	3.13
C20:0	1.44	0.22
C20:1 n-11	0.06	0.04
C20:1 n-9	0.46	0.92
C20:1 n-7	–	0.02
C20:2 n-6	0.61	0.11
C20:3 n-6	0.05	–
C21:0	0.17	0.02
C20:4 n-6	0.23	0.04
C20:3 n-3	0.07	0.01
C20:4 n-3	0.03	0.01
C20:5 n-3	–	0.003
C22:0	1.97	0.17
C22:1 n-11	0.56	0.27
C22:1 n-9	0.77	1.36
C22:1 n-7	–	0.01
C22:2 n-6	–	0.01
C21:5 n-3	0.12	–
C22:4 n-6	0.10	0.02
C24:0	2.30	0.22
C22:6 n-3	0.83	0.14
C24:1 n-9	0.19	–

SFA	42.8	19.3
MUFA	8.26	33.0
PUFA n-6	17.6	44.2
PUFA n-3	30.1	3.29
PUFA n-4	1.21	0.24
PUFA n-1	–	0.02

413 SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: poly-
414

Table 3. Growth performance of the rabbits along the trial according to the housing system (mean ± standard error).

	Cage	Free-range	*P*-value
Live weight 37 d, kg	1.12 ± 0.10	1.11 ± 0.09	0.652
Live weight 99 d, kg	2.60 ± 0.12	2.41 ± 0.11	0.028
DWG, g/d	23.7 ± 0.85	20.9 ± 0.77	0.035
AFI hay, g DM/d/head	73.2 ± 1.65	76.6 ± 1.86	0.456
AFI cereal mix, g DM/d/head	53.8 ± 1.12	54.9 ± 1.07	0.370
Total FI, g DM/d/head	127 ± 1.33	132 ± 1.45	0.048
FCR	5.36 ± 0.21	6.30 ± 0.24	0.022

DWG: daily weight gain; AFI: average feed intake; FCR: feed conversion ratio; DM: dry matter.

419 Table 4. Carcass traits of the rabbits at the end of the trial (99 d of age) according to the housing system
420 (mean ± standard error).

	Cage	Free-range	P-value
Slaughter weight (SW), kg	2.59 ± 0.11	2.41 ± 0.11	0.032
Full GIT, %SW	22.8 ± 0.52	24.7 ± 0.58	0.174
Empty GIT, %SW	9.26 ± 0.12	10.7 ± 0.11	0.042
Skin, %SW	16.7 ± 0.33	17.1 ± 0.28	0.659
Chilled carcass (CC), kg	1.41 ± 0.12	1.35 ± 0.10	0.632
Reference carcass (RC), kg	1.13 ± 0.09	1.05 ± 0.08	0.412
Slaughter yield, %SW	55.0 ± 1.23	56.0 ± 1.20	0.687
Heart, % CC	1.76 ± 0.12	1.98 ± 0.10	0.487
Liver, % CC	4.66 ± 0.19	5.76 ± 0.21	0.045
Spleen, % CC	0.18 ± 0.01	0.19 ± 0.01	0.548
Carcass length, cm	39.7 ± 1.35	39.7 ± 1.33	0.913
Carcass circumference, cm	15.4 ± 0.89	16.7 ± 0.91	0.632
Kidneys, % CC	1.16 ± 0.02	1.42 ± 0.03	0.246
RC yield, %CC	80.1 ± 3.11	77.8 ± 2.29	0.235
Perirenal fat, % RC	0.71 ± 0.01	0.54 ± 0.01	0.098
Inguinal fat, % RC	0.12 ± 0.001	0.10 ± 0.001	0.354
Interscapular fat, % RC	0.65 ± 0.02	0.32 ± 0.01	0.034

421 GIT: gastro-intestinal tract.

Table 5. Composition of the left hind leg (HL) of the rabbits according to the housing system (mean ± standard error).

	Cage	Free-range	P-value
Hind leg weight, g	175 ± 6.29	161 ± 6.11	0.406
Hind leg, % RC	15.5 ± 0.33	15.3 ± 0.38	0.742
Meat, % HL	84.1 ± 1.12	81.5 ± 0.90	0.541
Dissectible fat, % HL	0.43 ± 0.01	0.35 ± 0.01	0.230
Bones, % HL	13.0 ± 0.85	16.6 ± 0.88	0.035
Meat to bone ratio	6.57 ± 0.62	4.89 ± 0.39	0.049

RC: reference carcass.

426 Table 6. Proximate analysis (g/100 g) and cholesterol content (mg/100 g) of the rabbit
427 *Longissimus thoracis et lumborum* meat (mean ± standard error).
428

	Cage	Free-range	P-value
Moisture	77.0 ± 0.71	76.9 ± 0.72	0.952
Protein	20.6 ± 0.13	20.9 ± 0.10	0.836
Ash	1.29 ± 0.01	1.29 ± 0.01	0.965
Total lipids	1.08 ± 0.11	0.92 ± 0.09	0.321
Neutral lipids	0.34 ± 0.06	0.51 ± 0.08	0.128
Polar lipids	0.57 ± 0.03	0.61 ± 0.04	0.429
Cholesterol	54.1 ± 1.52	58.6 ± 1.83	0.090

429

Table 7. Fatty acid profile of neutral lipids (g/100 g neutral FAME) of the rabbit *Longissimus thoracis et lumborum* meat according to the housing system (mean ± standard error).

	Cage	Free-range	P-value
C12:0	0.19 ± 0.03	0.17 ± 0.04	0.717
C13:0	0.04 ± 0.01	0.04 ± 0.01	0.879
C14:0	3.11 ± 0.16	2.57 ± 0.19	0.071
C14:1 n-5	0.15 ± 0.03	0.06 ± 0.04	0.085
C15:0 iso	0.08 ± 0.01	0.06 ± 0.01	0.009
C15:0 anteiso	0.13 ± 0.01	0.10 ± 0.01	0.013
C15:0	0.66 ± 0.20	0.58 ± 0.25	0.037
C16:0 anteiso	0.22 ± 0.01	0.17 ± 0.02	0.048
C16:0	31.2 ± 0.60	29.0 ± 0.74	0.046
C16:1 n-9	0.38 ± 0.04	0.38 ± 0.04	0.998
C16:1 n-7	3.49 ± 0.04	1.89 ± 0.05	0.032
C17:0 anteiso	0.13 ± 0.01	0.11 ± 0.01	0.059
C17:0	1.09 ± 0.03	1.05 ± 0.04	0.444
C16:3 n-4	0.55 ± 0.10	0.24 ± 0.12	0.086
C17:1	0.04 ± 0.01	0.03 ± 0.01	0.383
C18:0	5.90 ± 0.29	6.73 ± 0.36	0.111
C18:1 n-9	23.5 ± 0.55	24.3 ± 0.68	0.384
C18:1 n-7	0.86 ± 0.15	1.00 ± 0.18	0.551
C18:2 n-6	21.5 ± 0.52	24.3 ± 0.64	0.009
C18:3 n-6	0.15 ± 0.01	0.10 ± 0.02	0.044
C18:3 n-4	0.07 ± 0.01	0.07 ± 0.02	0.857
C18:3 n-3	3.30 ± 0.31	3.64 ± 0.38	0.504
C20:0	0.13 ± 0.01	0.17 ± 0.01	0.008
C20:1 n-11	0.12 ± 0.05	0.02 ± 0.06	0.240
C20:1 n-9	0.20 ± 0.07	0.47 ± 0.09	0.059
C20:2 n-6	0.14 ± 0.01	0.17 ± 0.01	0.110
C20:3 n-6	0.18 ± 0.02	0.16 ± 0.03	0.658
C20:4 n-6	1.19 ± 0.17	1.06 ± 0.21	0.646
C20:3 n-3	0.04 ± 0.01	0.05 ± 0.01	0.362
C20:4 n-3	0.02 ± 0.01	0.01 ± 0.01	0.775
C20:5 n-3	0.07 ± 0.01	0.07 ± 0.01	0.798
C22:0	0.06 ± 0.01	0.08 ± 0.01	0.270
C22:1 n-9	0.05 ± 0.01	0.07 ± 0.01	0.105
C22:4 n-6	0.42 ± 0.06	0.41 ± 0.08	0.884
C22:5 n-6	0.14 ± 0.02	0.11 ± 0.02	0.365
C22:5 n-3	0.32 ± 0.05	0.36 ± 0.06	0.600
C24:0	0.06 ± 0.01	0.08 ± 0.02	0.490
C22:6 n-3	0.10 ± 0.02	0.11 ± 0.02	0.648
SFA	43.0 ± 0.71	40.9 ± 0.87	0.092
MUFA	28.8 ± 0.67	28.3 ± 0.83	0.608
PUFA n-6	23.7 ± 0.67	26.3 ± 0.82	0.038
PUFA n-3	3.85 ± 0.31	4.24 ± 0.38	0.441
PUFA n-4	0.62 ± 0.10	0.31 ± 0.13	0.095

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: poly- unsaturated fatty acids.

435 Table 8. Fatty acid profile of polar lipids (g/100 g polar FAME) of the *Longissimus thoracis et lumborum*
436 meat of the rabbits according to the housing system (mean ± standard error).

	Cage	Free-range	P-value
C12:0	0.016 ± 0.003	0.007 ± 0.004	0.117
C13:0	0.004 ± 0.001	0.002 ± 0.001	0.332
C14:0	0.158 ± 0.005	0.158 ± 0.006	0.949
C14:1 n-5	0.076 ± 0.003	0.077 ± 0.003	0.877
C15:0 iso	0.010 ± 0.001	0.010 ± 0.001	0.169
C15:0 anteiso	0.088 ± 0.004	0.074 ± 0.005	0.054
C15:0	0.36 ± 0.02	0.30 ± 0.02	0.039
C16:0 anteiso	0.06 ± 0.01	0.06 ± 0.01	0.697
C16:0	20.6 ± 0.24	20.2 ± 0.29	0.307
C16:1 n-9	0.29 ± 0.02	0.27 ± 0.03	0.649
C16:1 n-7	0.36 ± 0.04	0.22 ± 0.05	0.068
C17:0 anteiso	0.60 ± 0.02	0.52 ± 0.02	0.023
C17:0	0.95 ± 0.02	0.85 ± 0.03	0.017
C16:3 n-4	0.11 ± 0.01	0.10 ± 0.01	0.512
C17:1	0.009 ± 0.001	0.011 ± 0.002	0.585
C18:0	8.42 ± 0.24	8.96 ± 0.29	0.186
C18:1 n-9	16.3 ± 0.49	14.0 ± 0.61	0.019
C18:1 n-7	1.44 ± 0.04	1.44 ± 0.05	0.955
C18:2 n-6	21.0 ± 1.19	22.1 ± 1.46	0.580
C18:3 n-6	0.12 ± 0.01	0.09 ± 0.01	0.135
C18:3 n-4	0.035 ± 0.002	0.028 ± 0.003	0.141
C18:3 n-3	0.47 ± 0.08	0.47 ± 0.10	0.999
C20:0	0.04 ± 0.007	0.04 ± 0.008	0.802
C20:1 n-11	0.01 ± 0.001	0.01 ± 0.001	0.558
C20:1 n-9	0.11 ± 0.008	0.12 ± 0.10	0.265
C20:2 n-6	0.24 ± 0.01	0.29 ± 0.02	0.059
C20:3 n-6	1.50 ± 0.03	1.48 ± 0.04	0.624
C20:4 n-6	16.6 ± 1.37	17.7 ± 1.68	0.653
C20:3 n-3	0.05 ± 0.01	0.07 ± 0.01	0.137
C20:4 n-3	0.03 ± 0.01	0.03 ± 0.01	0.865
C20:5 n-3	0.69 ± 0.06	0.73 ± 0.07	0.350
C22:0	0.04 ± 0.01	0.03 ± 0.01	0.663
C22:1 n-9	0.02 ± 0.001	0.02 ± 0.002	0.328
C22:4 n-6	3.84 ± 0.16	3.73 ± 0.20	0.686
C22:5 n-6	1.90 ± 0.10	1.82 ± 0.12	0.625
C22:5 n-3	2.74 ± 0.11	3.32 ± 0.12	0.009
C24:0	0.04 ± 0.01	0.03 ± 0.01	0.576
C22:6 n-3	0.64 ± 0.05	0.66 ± 0.07	0.840
SFA	31.4 ± 0.33	31.2 ± 0.40	0.767
MUFA	18.7 ± 0.55	16.2 ± 0.68	0.024
PUFA n-6	45.3 ± 0.47	47.2 ± 0.58	0.034
PUFA n-3	4.56 ± 0.17	5.27 ± 0.21	0.030
PUFA n-4	0.14 ± 0.01	0.13 ± 0.01	0.289

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

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Table 9. Primary (conjugated dienes, mmol Hp/kg loin) and secondary (TBARS, mg malondialdehyde equivalents, MDA-eq/kg loin) oxidation products; antioxidant capacity measured as ABTS (2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid), mmol Trolox/kg), DPPH (2,2-diphenyl-1-picrylhydrazyl, mmol Trolox/kg) and FRAP (ferric-reducing ability, mmol Fe^{2+}/kg) in the *Longissimus thoracis et lumborum* meat of the rabbits according to the housing system (mean ± standard error).

	Cage	Free-range	P-value
Conjugated dienes	0.36 ± 0.08	0.26 ± 0.09	0.442
TBARS	0.45 ± 0.04	0.44 ± 0.05	0.939
ABTS	0.63 ± 0.02	0.76 ± 0.02	0.003
DPPH	0.023 ± 0.005	0.032 ± 0.008	0.387
FRAP	0.098 ± 0.003	0.102 ± 0.004	0.522

Figure 1. Conjugated dienes in relation to total lipids contained in LTL from rabbit raised in cage (black rhombus) and free-range systems (grey square). LTL: *Longissimus thoracis et lumborum*.