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Dietary citrus pulp reduces lipid oxidation in lamb meat

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ABSTRACT

This study investigated the effect of replacing cereal concentrates with high levels of dried citrus pulp in the diet on lamb meat oxidative stability. Over 56 days, lambs were fed a barley-based concentrate (Control) or concentrates in which 24% and 35% dried citrus pulp were included to partially replace barley (Citrus 24% and Citrus 35%, respectively). Meat was aged under vacuum for 4 days and subsequently stored aerobically at 4 °C. The Control diet increased the redness, yellowness and saturation of meat after blooming ($P < 0.01$). Regardless of the level of supplementation, dietary dried citrus pulp strongly reduced meat lipid oxidation over 6 days of aerobic storage ($P < 0.001$), while colour parameters did not change noticeably over storage and their variation rate was not affected by the diet. In conclusion, replacing cereals with dried citrus pulp in concentrate-based diets might represent a feasible strategy to naturally improve meat oxidative stability and to promote the exploitation of this by-product.

1. Introduction

Meat quality is increasingly important in animal production in order to meet consumer demands, with colour and flavour being among the most relevant attributes (Liu, Lanari, & Schaefer, 1995). Besides microbial spoilage, the oxidation of meat lipids and myoglobin over storage duration and display at retail causes the development of off-flavours and the deterioration of the appealing colour (Gray, Gomaa, & Buckley, 1996). Meat storage stability can be extended with opportune packaging systems (McMillin, 2008), by the exogenous addition of antioxidants (Zhang, Xiao, Samaraweera, Lee, & Ahn, 2010) or by adopting feeding systems able to improve the antioxidant status of muscle (Descalzo & Sancho, 2008). In particular, the latter strategies could contribute to the promotion of low-input production systems based on the use of local forages and agro-industrial by-products naturally rich in bioactive molecules which could find valuable applications in ruminant feeding and could positively affect product quality (Vasta & Luciano, 2011).

The interest in the use of agro-industrial by-products as alternative feeding resources for ruminants is justified by the fluctuating prices and supply dynamics of conventional feeds, which lead farmers to adapt their production system accordingly. Therefore, the use of local alternative feedstuffs can offer economical advantages by reducing feeding costs and by mitigating adverse socio-environmental impacts that would otherwise arise from the disposal of several by-products (Vasta, Nudda, Cannas, Lanza, & Priolo, 2008). Citrus fruits, comprising mainly of oranges, lemons, grapefruits and mandarins, are widespread in the Mediterranean area. Citrus fruits can be processed to obtain juices and a substantial amount of by-products originates. Among these, the dried citrus pulp is widely used for ruminant feeding and, for its favourable nutrient composition, it can replace high proportions of cereal concentrates in the diet with no detrimental effects on animal productivity (for a review, see Bampidis & Robinson, 2006). However, very little information has been so far provided on the effects of dietary dried citrus pulp on meat quality in general, and to the best our knowledge, no studies investigated the effects of feeding ruminants with dried citrus pulp on meat storage stability. Citrus fruits contain high levels of bioactive compounds, including polyphenols, terpenes, carotenoids and ascorbic acid, which exhibit antioxidant properties (Abeysinghe et al., 2007; Tripoli, La Guardia, Giammanco, Di Majo, & Giammanco, 2007). Depending on the production and preservation procedures, citrus pulp can contain remarkable amounts of these compounds (Balasundram, Sundram, & Samman, 2006).

The specific objective of the present research was to assess the effect of replacing cereal concentrates with high levels of dried citrus pulp in diets for growing lambs on meat lipid and colour stability.

2. Materials and methods

2.1. Animals and diets

Twenty-nine Comisana male lambs, born in late November 2011, were weaned at 60 days of age. From 60 to 90 days of age, lambs were fed with a concentrate-based diet comprising, on a fresh weight basis, of 25% wheat, 25% wheat bran, 25% barley and 25% faba bean. At 90

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days of age, the lambs were weighed (mean ± SD initial weight: 19.76 ± 3.84 kg) and were housed indoors in individual pens. The animals were randomly divided into three homogeneous groups and were assigned to one of the following dietary treatments: one group of 9 lambs (Control) was fed commercial concentrates including 60% of barley. One group of 10 lambs (Citrus 24%) received a mixture of the same ingredients in which the proportion of barley was reduced to 35%, while 24% dried citrus pulp was included. Another group of 10 lambs (Citrus 35%) received a diet in which the proportion of barley was further reduced to 23% and that of citrus pulp was increased up to 35%. No vitamin premix was included into the concentrates. The composition of the experimental diets is shown in Table 1. All the ingredients composing the experimental concentrates were finely ground to pass a 5-mm screen in order to achieve the same particle size of all the ingredients. For 10 days before the beginning of the experimental feeding period, lambs in the three groups were adapted to the experimental diets by gradually replacing the starter concentrates with the experimental concentrates. During 56 days of experimental feeding period, the diets were offered each morning at 0900 h and the feeders were removed at 1800 h, while water was always available. The amounts of feed offered and refused were recorded every day in order to measure the daily voluntary feed intake. Samples of the feeds offered were collected 4 times during the trial, vacuum packaged and stored at −30 °C for analyses. The animals were weighed weekly before the administration of the feeds. One animal from the Control group, one from the Citrus 24% group and one from the Citrus 35% group performed very poorly during the experimental period for reasons unrelated to the dietary treatments and were eliminated from the trial. Therefore, the number of lambs retained in each treatment for the subsequent determinations was 8 (Control group), 9 (Citrus 24% group) and 9 (Citrus 35% group).

2.2. Slaughter procedures and muscle sampling

The animals were slaughtered at 158 days of age at a commercial abattoir. Lambs had access to the experimental feeds until approximately 15 min before slaughtering. Animals were stunned by captive bolt and exsanguinated. The carcasses were weighed, halved and kept refrigerated at 4 °C. After 24 h of refrigerated storage, the *longissimus thoracis et lumborum* muscle (LTL) was excised from the right half of each carcass, and the pH was measured using a pH-meter Orion 9106. Subsequently, the whole LTL was vacuum packed and stored at 4 °C in the dark during a 4-day ageing period. After ageing in vacuum packaging conditions, 3 slices (2 cm thick) were prepared from each LTL using a knife. The slices were placed in polystyrene trays, covered with air-permeable PVC film and stored in the dark at 4 °C. Lipid and colour stability were measured after 2 h of blooming (day 0) and after 3 and 6 days of refrigerated storage in atmospheric conditions, using one slice of LM for each day of storage.

Table 1
Ingredients and chemical composition of the experimental concentrate feeds.

	Control	Citrus 24%	Citrus 35%
Ingredients (g/100 g as fed)			
Barley	60	35	23
Dried citrus pulp	0	24	35
Dehydrated alfalfa	20	19	20
Soybean meal	9	12	13
Wheat bran	11	10	9
Chemical composition			
Dry matter (DM) [1]	88.9	89.4	90.6
Crude protein (CP) [2]	18.0	18.5	17.8
Neutral detergent fibre (NDF) [2]	34.6	31.8	33.1
Acid detergent fibre (ADF) [2]	13.7	16.0	18.0
Crude fat (CF) [2]	2.2	1.6	2.2
Total phenolic compounds [3]	4.0	6.7	7.9

[1] Expressed as g/100 g of fresh weight.
[2] Expressed as g/100 g of DM.
[3] Expressed as g of tannic acid equivalents/kg of DM.

2.3. Laboratory analyses

2.3.1. Analyses of feed samples

Feed samples collected during the trial were pooled and analysed for neutral detergent and acid detergent fibre fractions (NDF and ADF, respectively) according to Van Soest, Robertson, and Lewis (1991). According to AOAC (1995), feedstuffs were also analysed for crude protein (CP; method 984.13) and crude fat (CF; method 935.38) extracted with petroleum ether. As described by Makkar, Blümmel, Borowy, and Becker (1993), total phenolic compounds were extracted from the feeds using aqueous acetone (70% v/v), analysed by means of the Folin-Ciocalteau reagent and expressed as tannic acid equivalents.

2.3.2. Colour stability and myoglobin oxidation measurements

A Minolta CM-2022 spectrophotometer (*d*/8° geometry; Minolta Co., Ltd. Osaka, Japan) was used for measuring meat colour descriptors in the CIE L*a*b* space. The following parameters were measured: lightness (L^*), redness (a^*), yellowness (b^*), chroma (C^*) and hue angle (H^*).

The reflectance spectra from 400 to 700 nm wavelength were also recorded for calculation of metmyoglobin (MMb) formation as described by Krzywicki (1979).

All measurements were taken in duplicate directly on the meat surface and the mean values were computed. The spectrophotometer were set for using the illuminant A and 10° standard observer.

2.3.3. Lipid oxidation measurement

Lipid oxidation was assessed by measuring 2-thiobarbituric acid reactive substances (TBARS) according to the method described by Siu and Draper (1978). Meat samples (2.5 g) were homogenised with 12.5 ml of distilled water using a Heidolph Diax 900 tissue homogenizer (Heidolph Elektro GmbH & Co. KG, Kelheim, Germany) operating at 9500 rpm. During the homogenisation, samples were put in a water/ice bath. Subsequently, 12.5 ml of 10% (w/v) trichloroacetic acid was added to precipitate proteins and then the samples were vortexed. Using a Whatman No. 1 filter paper, the homogenates were filtered and 4 ml of filtrate were added to 1 ml of 0.06 M aqueous thiobarbituric acid into Pyrex glass tubes. The tubes were incubated in a water bath at 80 °C for 90 min, and the absorbance of each sample was read at 532 nm using a Shimadzu UV–vis spectrophotometer (UV-1601; Shimadzu Corporation, Milan, Italy). The assay was calibrated with a solution of known concentration of TEP (1,1,3,3,-tetraethoxypropane) in distilled water. Results were expressed such as mg of malonaldehyde (MDA)/kg of meat.

2.4. Statistical analysis

A one-way ANOVA was used to test the effect of the dietary treatment (Control, Citrus 24% and Citrus 35%) on meat pH and colour descriptors measured after blooming.

Data of meat colour stability descriptors (a*, H* and MMb%) and lipid oxidation (TBARS values) were analysed using a mixed model. The model included the fixed effect of the dietary treatment (Diet; Control, Citrus 24% and Citrus 35%) of the time of storage (Days; 0, 3, and 6) and their interaction (Diet × Time), while the individual animal was considered as a random effect in the model.

Multiple comparisons of the means were performed using the Tukey's adjustment. Analyses were performed using the statistical software Minitab version 16 (Minitab Inc., State College, PA).