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Photoxidation of cholesterol and lipids of turkey meat during storage under commercial retail conditions

Emanuele Boselli [a,*], Maria Fiorenza Caboni [b], Maria Teresa Rodriguez-Estrada [b], Tullia Gallina Toschi [b], Mara Daniel [b], Giovanni Lercker [b]

[a] *Dipartimento di Scienze degli Alimenti, Università Politecnica delle Marche, Via Brecce Bianche, I-60131 Ancona, Italy*
[b] *Dipartimento di Scienze degli Alimenti, Università di Bologna, Viale G. Fanin, 40, I-40127 Bologna, Italy*

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Abstract

Photoxidation of cholesterol and lipids of raw turkey patties packed in vessels with transparent shrink film was studied during storage at 4 °C under commercial retail conditions. Two different storage periods were applied: a 3-day storage and a 11-day storage. When meat was stored in the dark at 4 °C, the maximum peroxide number was reached after 5 days and the maximum concentration of cholesterol oxidation products was attained only after 7 days. Turkey meat exposed to the white fluorescent light (under a daylight lamp) showed a maximum COPs concentration and peroxide value after just 1 day of storage (12 h effective light exposure). A lamp with low emission in the blue band (warm-tone lamp) was useful for lowering peroxidation and cholesterol oxidation, thus being a suitable solution for the exhibition of meat products in supermarkets or meat processing industries.

Keywords: Turkey meat; Photoxidation; Cholesterol oxidation; Lipid oxidation; Gas chromatography-mass spectrometry

1. Introduction

The consumer's preference for meat and meat products is influenced by several factors, such as quality-freshness, colour, price, aroma, food habits and, particularly, safety (Saba & Di Natale, 1999; Verbecke, 2001; Verbecke & Viaene, 1999). In the past two years, the consumption of poultry and rabbit meats has undergone a significant increase in Europe, mainly due to the bovine spongiform encephalopaty (BSE) crisis (FAO/GIEWS, 2001; Morabia, Bernstein, Héritier, & Beer-Borst, 1999), which has led to a marked reduction of beef consumption (Cade, Calvert, & Barrett, 1998). This trend has also been influenced by the release of new types of packaging for meat products and the diffusion of prepacked or precooked ready-to-eat food based on chicken or turkey meat (Pszczola, 2002), which reduce the preparation time.

Lipid oxidation is one of the most important factors limiting the shelf life and commercial stability of meat and meat products. Meat oxidation is related to the content of natural antioxidants and the polyunsaturation degree of fatty acids (Morrissey, Sheehy, Galvin, Kerry, & Buckley, 1998; Nam, Du, Jo, & Ahn, 2001). Turkey meat has a low content of α-tocopherol as compared with chicken (Marusich et al., 1975; Sklan, Bartov, & Hurwitz, 1982; Wen et al., 1997) and more than 50% of its fatty acids are unsaturated (Carnovale & Marletta, 2000), which makes turkey meat particularly prone to fatty acid and cholesterol oxidations (Li, Ohshima, Shozen, Ushio, & Koizumi, 1994; Rodriguez-Estrada, Tocco, Savioli, & Lercker, 2003). Cholesterol can give rise to

* Corresponding author. Tel.: +39 071 2204923; fax: +39 071 2204980.
E-mail address: eboselli@univpm.it (E. Boselli).

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Nomenclature

COPs	cholesterol oxidation products, oxycholesterols:
7α-HC	cholest-5-en-3β,7α-diol
7β-HC	cholest-5-en-3β,7β-diol
β-CE	5,6β-epoxy-5β-cholestan-3β-ol
α-CE	5,6α-epoxy-5α-cholestan-3β-ol
Triol	5α-cholestan-3β,5,6β-triol
7-KC	3β-hydroxycholest-5-en-7-one
19-HC	19-hydroxy-cholesterol (IS used for the determination of COPs)
Dihydrocholesterol	(IS used for the determination of cholesterol)

more than 60 cholesterol oxidation products (COPs) (Smith, 1987), which are likely to be involved in lipid metabolism, various chronic and degenerative diseases (such as cancer, aging and human atherosclerosis) and disturbance of cell functionality (Garcia-Cruset, Carpenter, Codony, & Guardiola, 2002; Osada, 2002; Schroepfer, 2000).

The aim of the current work was to evaluate cholesterol and lipid oxidations of turkey breast slices, during storage under artificial light in a commercial retail bench refrigerator. The concentration of COPs and the peroxide number (PV) were studied according to the exposure time to artificial light, the lamp emission spectrum, the cholesterol and fat content of meat and the initial oxidation status of meat lipids. Two different storage intervals at 4 °C were applied: an 11-day storage (experiment A) and a 3-day storage (experiment B).

2. Materials and methods

2.1. Sampling

Two samplings (experiment A and experiment B) were performed on fresh turkey meat as described below. For each point, three meat samples were obtained from three different animals. Thus, the average values and standard deviations reported in Section 3 were calculated on the basis of the three samples.

2.2. Experiment A (11-day storage)

Three male turkeys of race Big 6 (147-day old and 18.1 kg on average) were slaughtered in winter. After a 6-day holding period, the breasts were cut along their major axis with an automated cutter. Fourteen slices with constant weight (100–130 g) and thickness (0.8–1 cm) were obtained from each turkey breast, as shown in Fig. 1(A). Since three animals were sampled, a total of 42 slices were collected. In order to minimise the variability of the experimental conditions, sample cutting and preparation were performed in a single afternoon in the meat industry, under controlled environmental temperature (15 °C). Each slice was packed in a polyethylene vessel, which was wrapped with a transparent shrink film (14 μm thickness) with 10445 ml/m^2/24 h of oxygen permeability. The packed slices from each animal were subjected to the following storage conditions:

(a) One vessel was immediately frozen (−18 °C), which represented the control.
(b) Five vessels were stored at 4 °C in the dark (wrapped with tinfoil) for 1, 5, 7, 9 and 11 days, respectively.
(c) Five vessels were stored at 4 °C under a daylight lamp for 1, 5, 7, 9 and 11 days, respectively.
(d) The remaining three vessels were stored at 4 °C under a warm-tone lamp for 5, 9 and 11 days, respectively.

The daylight lamp had a temperature and power of 6000 °K and 36 W (Osram, Milan, Italy), respectively. The warm-tone lamp emanated red light with low emission in the blue radiation (3000 °K, 36 W) (Osram, Milan, Italy). The lamps were located 1.5 m above the samples, as in the retail shop. One-day exposure corresponded to 12 h of effective exposure and 12 h of darkness, as usually happens in Italian supermarkets. When the programmed storage time was reached, the samples were immediately frozen and kept at −18 °C until analysis. The analyses were performed immediately after the 11-day storage sample had been collected.

2.3. Experiment B (3-day storage time)

Three male turkeys of race Big 6 (137-day old and 18.2 kg on average) were slaughtered in spring. The breasts were cut along their major axis 2 days after slaughter with an automated cutter. Seven slices with constant weight (100–130 g) and thickness (0.8–1 cm) were obtained from each turkey breast, as shown in Fig. 1(B). Since three animals were sampled, a total of 21 slices were collected. Each slice was packed using the same procedure as the previous sampling design. The packed slices of each animal were subjected to the following storage conditions:

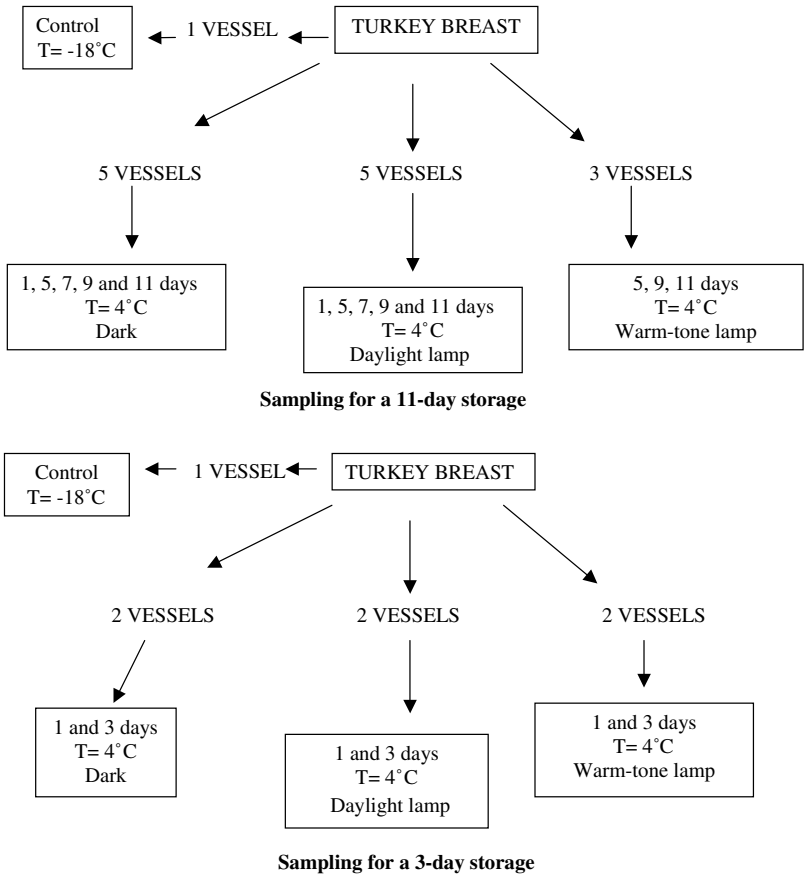

Fig. 1. (A) Sampling design for experiment A (11-day storage at 4 °C). Breast samples were obtained from three different animals. (B) Sampling design for experiment B (3-day storage at 4 °C). Breast samples were obtained from three different animals.

(a) One vessel was used as the control and was immediately frozen.
(b) Two vessels were stored at 4 °C in the dark (wrapped with tinfoil) for 1 and 3 days, respectively.
(c) Two vessels were stored at 4 °C under the daylight lamp for 1 and 3 days, respectively.
(d) The remaining two vessels were stored at 4 °C under the warm-tone lamp for 1 and 3 days, respectively.

2.4. Reagents

Analytical grade solvents and reagents were utilised. The standards supplied by Sigma Chemical Co. (St. Louis, MO, USA) are listed as follows: 19-hydroxycholesterol (19-HC), cholesterol, dihydrocholesterol, 3β-hydroxycholest-5-en-7-one (7-KC), 5,6α-epoxy-5α-cholestan-3β-ol (α-CE), 5,6β-epoxy-5β-cholestan-3β-ol (β-CE), cholesta-3,5-dien-7-one (3,5-dien-7-one) and 5α-cholestan-3β,5,6β-triol (triol). The standards cholest-5-en-3β,7α-diol (7α-HC) and cholest-5-en-3β,7β-diol (7β-HC) were purchased from Steraloids (Wilton, NH, USA).

2.5. Lipid extraction

The turkey breast lipids were extracted according to a modified version of the method described by Folch, Lees, and Sloane-Stanley (1957). The extraction procedure was the same as that recently reported by Boselli, Velazco, Caboni, and Lercker (2001), except that the solvent volumes were 2.5 times larger. The frozen samples were minced and 60 g was homogenised with 500 ml of a chloroform:methanol solution (1:1, v/v) in a glass bottle with screw-cap. The bottle was kept at 60 °C for 20 min before adding 250 ml chloroform. After 3 min of homogenisation, the content of the bottle was filtered through filter paper. The filtrate was mixed thoroughly with a 1 M KCl solution and left overnight at 4 °C in order to obtain phase separation. The lower phase was collected and dried with a rotary evaporator. The fat content was determined gravimetrically.

2.6. Determination of total cholesterol and cholesterol oxidation products (COPs)

A 250 mg lipid subfraction of the Folch extract was treated with known amounts of the internal standard

solutions (12.5 μg of 19-hydroxycholesterol and 5 mg dihydrocholesterol, for the determination of COPs and total cholesterol, respectively). Subsequently, the sample was dried under nitrogen and treated with 10 ml of 1 N KOH solution in methanol, in order to perform a saponification at room temperature for 18 h (Sander, Addis, Park, & Smith, 1989). For the extraction of the unsaponifiable matter, 10 ml of water and 10 ml of diethyl ether were added to the samples, which were then shaken and the diethyl ether fraction was then separated; the extraction with 10 ml of diethyl ether was repeated twice. The three portions of diethyl ether were pooled, treated with 5 ml of a 0.5 N KOH solution and extracted. The resulting ethereal extract was washed twice with 5 ml of water. The ether solution was finally evaporated in a rotary evaporator, after elimination of excess water by addition of anhydrous sodium sulfate. One tenth of the unsaponifiable matter was used for the determination of total cholesterol, whereas the remaining part was utilised for COPs analysis.

The determination of total cholesterol (sum of free and esterified) was achieved by means of capillary gas chromatography after silylation (Sweeley, Bentley, Makita, & Wells, 1963). The gas chromatograph (HRGC Mega2 Series, Fisons, Rodano, Italy) was equipped with a split–splitless injector and a flame ionisation detector. A fused-silica capillary column (30 m × 0.32 mm i.d., 0.25-μm film thickness) coated with 100% dimethyl-polysiloxane (DB-1, J&W Scientific, Folsom, CA, USA) was used. The oven temperature was programmed from 250 to 325 °C at 3 °C/min; the injector and detector temperatures were both set at 325 °C. Helium was used as carrier gas at a flow of 2 ml/min; the split ratio was 1:15.

The COPs purification was performed by NH_2 solid-phase extraction (SPE) of nine tenths of the unsaponifiable matter, according to Rose-Sallin, Hugget, Bosset, Tabacchi, and Fay (1995); after silylation, the derivatised COPs were injected for gas chromatography under the same conditions as reported for the determination of total cholesterol. The identification of COPs was confirmed by comparison with the retention time and mass spectra of the COPs standards (Boselli et al., 2001).

2.7. Determination of peroxide value (PV)

The peroxide value was determined in 50 mg of lipid extract as suggested by Takagi, Mitsuno, and Masumura (1978). The peroxides present in the meat lipids oxidised iodide to iodine and, after 5 min, the excess of iodide ion was immediately converted to cadmium complex under a nitrogen atmosphere. The iodine was measured at 358 nm with a double beam UV/visible spectrophotometer Jasco model UVIDEC-430 (Tokyo, Japan) and PV was calculated from the absorbance. For the quantitative determination of PV, a calibration curve was prepared by adding solutions of potassium dichromate at different concentrations to the KI solution; the same procedure was used for the measurement of the released iodine absorbance (358 nm), which was plotted against the active oxygen content.

2.8. Statistical analysis

One-way analysis of variance (ANOVA) was applied to the data. The means of the different storage conditions were compared using the Tukey–Kramer multiple comparisons test ($p < 0.05$).

3. Results and discussion

3.1. Experiment A (11-day storage)

The fat contents of the three slices (three different animals) were 3.0 ± 0.6, 3.8 ± 0.7 and 4.3 ± 0.9 mg/100 mg of meat (mean ± SD). The total cholesterol content of the samples ranged from 1.3 to 2.5 mg/100 mg fat. It must be noted that a large variation in the cholesterol content was registered, even within the same breast, due to the heterogeneous structure of the muscle body.

The COPs initial level was 50.4 ± 2.3 mg/kg (on lipid basis). Park and Addis (1987) reported an initial content of COPs in turkey meat equal to zero, whereas Nam et al. (2001) detected about 33–39 mg of COPs/kg lipids; it must be noted that the latter only refers to free COPs, while the data of this study embrace both free and esterified COPs. The extent of initial cholesterol oxidation found here could be due to the long holding period to which the meat was subjected (6 days). A similar effect of the holding period on the oxidative quality of beef meat has previously been reported by Rodriguez-Estrada, Penazzi, Caboni, Bertacco, and Lercker (1997). The COPs determined in all the samples subjected to prolonged oxidation were 7α-HC (at a concentration ranging from 9.9 to 76.6 mg/kg fat), 7β-HC (10.4–91.1 mg/kg), β-CE (7.3–67.4 mg/kg), α-CE (traces – 15.5 mg/kg), triol (traces – 8.0 mg/kg) and 7-KC (15.6–110 mg/kg), and are shown in the gas chromatographic trace of Fig. 2. The most abundant COP, in almost all cases was 7-KC, which corresponded to about one third of COPs.

Table 1 shows the average value of total COPs in the samples kept in the dark, under the warm-tone and the daylight lamps during storage, and it lists the groups which are significantly different according to the ANOVA.

3.2. Non-photoxidised turkey meat

The results listed in Table 1 show that turkey meat undergoes important modifications during the conser-

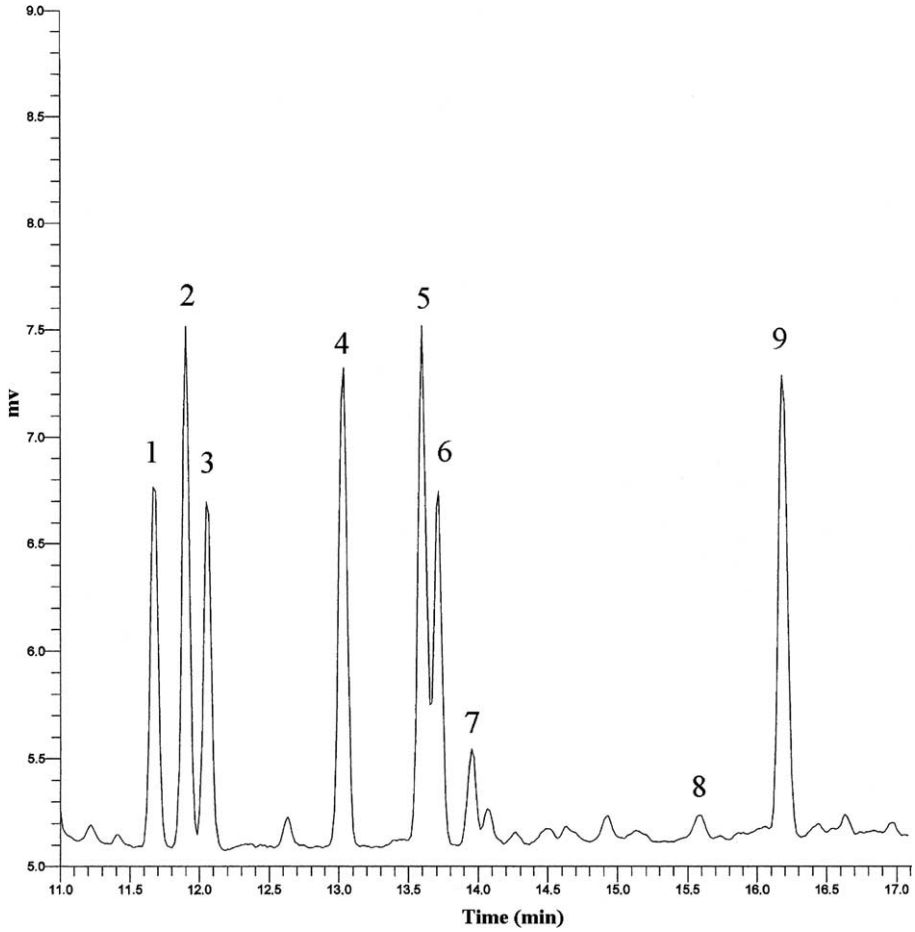

Fig. 2. Gas chromatographic trace of COPs found in turkey meat kept in the dark for 5 days. Peaks: 1, 7α-HC; 2, cholesterol; 3, dihydrocholesterol (IS); 4, 19-HC (IS); 5, 7β-HC; 6, β-CE; 7, α-CE; 8, triol; 9, 7-KC.

vation, even if the temperature is low (4 °C) and the samples are protected from direct light exposure. The long storage conditions here tested were chosen in order to determine the maximum COPs concentration that could be reached; in fact, the highest amount was attained between the fifth and seventh day of storage. On average, the formation rate of COPs was higher than the degradation rate until the seventh day; successively, they were converted into other degradation products and/or combined with other components, making them undetectable under the analytical conditions here used.

Unlike the COPs content, the maximum peroxide value (PV) was reached between the first and the fifth day of storage (Table 1). This could be explained by the fact that peroxides are the primary products of lipid oxidation and their formation anticipates that of other oxygenated compounds, which are considered to be secondary oxidation products. Due to their bell-shaped behaviour, a low value of PV or COPs could be associated with a low oxidation (short storage) or a high oxidation state of the sample (long storage).

3.3. Experiment A: Turkey meat irradiated during 11 days with high and low emission lamps in the blue spectrum

The photoxidised samples showed significant differences with respect to those protected from light (Table 1). When turkey meat was irradiated with a daylight-type fluorescent lamp with a high emission in the blue component of the visible spectrum, the rate of oxidation was higher. The peak concentration of oxycholesterols was reached just after 1 day of light exposure. Moreover, the COPs formation was remarkable: the average concentration of total COPs was 283 mg/kg fat after 1 day of light exposure, whereas it reached only 104 mg/kg fat during storage in darkness. After the first day, oxycholesterols were degraded but the final concentration after 11 days was still 50% higher than the samples kept in darkness. All COPs showed this trend except the triol, whose concentration displayed a constant increase during the 11-day storage under the daylight lamp, reaching 5.3 mg/kg fat. Since triol is formed from the opening of the oxygen ring of the epoxy derivatives of

Table 1
Effect of different light exposure conditions on the COPs (mg/kg fat) and PV (meq O_2/kg fat), determined in the lipid extract of raw turkey meat stored at 4 °C for 11 days (experiment A)

	Dark						Warm-tone lamp			Daylight lamp				
	Day 0	Day 1	Day 5	Day 7	Day 9	Day 11	Day 5	Day 9	Day 11	Day 1	Day 5	Day 7	Day 9	Day 11
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
7α-HC	$10.5^{a} \pm 0.4$	$20.3^{a} \pm 0.1$	$27.8^{a} \pm 7.9$	34.6 ± 9.5	34.2 ± 5.2	$21.1^{a} \pm 1.9$	$26.8^{a} \pm 6.2$	$27.5^{a} \pm 10.5$	$21.6^{a} \pm 6.1$	$57.3^{b} \pm 12.6$	35.0 ± 9.0	34.9 ± 12.7	$38.3^{b} \pm 17.7$	30.6 ± 8.9
7β-HC	11.2 ± 0.7	27.3 ± 3.9	40.0 ± 14.7	60.1 ± 18.0	47.7 ± 0.8	32.4 ± 7.2	44.4 ± 16.8	43.7 ± 21.4	33.7 ± 16.2	71.2 ± 18.7	54.3 ± 21.7	51.9 ± 22.4	64.9 ± 43.0	52.2 ± 21.1
β-CE	$9.1^{a} \pm 1.6$	19.4 ± 4.0	22.8 ± 12.5	28.3 ± 8.8	23.2 ± 3.8	$17.7^{a} \pm 0.2$	24.9 ± 5.7	23.2 ± 8.4	19.6 ± 7.3	$53.4^{b} \pm 15.7$	28.7 ± 9.5	29.8 ± 9.4	32.9 ± 16.4	23.3 ± 6.0
α-CE	$1.9^{a} \pm 1.4$	$4.7^{a} \pm 2.3$	$6.0^{a} \pm 3.9$	6.7 ± 2.2	$6.1^{a} \pm 0.6$	$5.0^{a} \pm 1.3$	$5.8^{a} \pm 1.7$	6.7 ± 2.1	$5.7^{a} \pm 0.9$	$14.2^{b} \pm 4.1$	7.2 ± 2.4	$11.3^{b} \pm 5.8$	$10.2^{b} \pm 2.2$	6.3 ± 2.2
Triol	1.2 ± 1.6	2.4 ± 0.1	4.3 ± 1.8	4.9 ± 2.9	3.9 ± 1.1	3.3 ± 0.5	2.6 ± 2.3	3.4 ± 2.9	4.7 ± 1.3	1.9 ± 1.7	1.6 ± 0.9	4.1 ± 1.3	4.2 ± 3.8	5.3 ± 0.8
7-KC	$16.5^{a} \pm 1.2$	$30.2^{a} \pm 3.2$	40.1 ± 14.5	48.8 ± 18.1	48.0 ± 6.8	$29.6^{a} \pm 2.8$	$37.3^{a} \pm 7.8$	$37.1^{a} \pm 16.0$	$29.6^{a} \pm 10.5$	$84.7^{b} \pm 20.9$	51.5 ± 16.3	49.9 ± 19.7	54.6 ± 29.8	41.2 ± 17.0
Sum of COPs	$50.4^{a} \pm 2.3$	$104.3^{a} \pm 5.8$	140.9 ± 52.9	183.4 ± 56.8	163.0 ± 15.1	$109.1^{a} \pm 10.3$	141.9 ± 35.3	141.6 ± 54.5	$114.9^{a} \pm 42.3$	$282.8^{b} \pm 66.7$	178.3 ± 56.2	182.0 ± 59.8	205.1 ± 112.2	158.8 ± 52.8
PV	16.6 ± 0.4	21.6 ± 8.6	$25.4^{a} \pm 7.7$	18.0 ± 2.8	19.8 ± 0.8	$10.1^{b} \pm 0.4$	13.2 ± 3.3	17.9 ± 4.9	12.5 ± 0.5	$24.9^{a} \pm 6.2$	23.1 ± 5.5	13.8 ± 3.7	16.3 ± 5.4	12.2 ± 2.3

The average value of slices obtained from three breasts ± SD is reported. Means in the same row followed by different letters are significantly different according to Tukey's test ($p < 0.05$).

cholesterol, its formation is slower than that of other COPs.

During storage under the daylight lamp, the formation of peroxides was also faster than in meat stored in the darkness; the PV reached its maximum concentration after 1 day of light exposure, as listed in Table 1. These data agree with the results reported by Whang and Peng (1988), who also noted that ground turkey breast meat exposed to light (with a fluorescent tube, cool white) exhibited higher PV than samples kept in the dark. It is noteworthy that, in the present study, the oxidative behaviours of the whole lipid fraction and COPs are similar. However, unlike COPs, the concentration of peroxides produced during the irradiation did not differ significantly from the samples kept in the dark.

The effect of light irradiation with a red fluorescent lamp (a warm-tone lamp with low emission in the blue band) on the oxycholesterol formation is also listed in Table 1. The COPs concentration in samples irradiated with the red lamp was comparable to that of meat kept in darkness with a similar storage time, thus being much lower than that of irradiated samples with the daylight lamp. The same consideration is true for the PV; in fact, the peroxide concentrations of meat kept in the dark and those of the samples exposed to the warm-tone light were not significantly different. Nam et al. (2001) found that packaging and storage conditions are more determinants of cholesterol and lipid oxidation of raw turkey than is irradiation.

The different degrees of oxidation induced by the two types of lamps can be attributed in part to their energy of radiation, which is higher in the daylight lamp than in the red fluorescent one, because it has a greater amount of blue light in it. The energy of radiation is expressed as °K and it is inversely proportional to the wavelength (Francis & Clydesdale, 1975); in fact, the temperature and wavelength of the daylight are 6000 °K and 480 nm, respectively, whereas the warm-tone lamp has a temperature equal to 3000 °K and a wavelength of 680 nm. Another important aspect is the presence of the meat pigments (haemoglobin and myoglobin), which act as photosensitisers and show absorption maxima at different wavelengths (intense absorption band in the blue region of the spectrum, i.e., 410–430 nm-Soret band) (Giddings, 1977; Livingston & Brown, 1981), depending on the oxidation status of iron, the occurrence of covalent and ionic complexes with molecular oxygen and water, respectively (Francis, 1985). The colour cycle in fresh meats is reversible and dynamic; the three pigments, myoglobin (purplish red colour), oxymyoglobin (bright red colour) and metmyoglobin (brown colour), are constantly interconverted (Francis, 1985). For covalent complexes, the absorption maximum of myoglobin ranges from 535 to 545 nm, whereas that of metmyoglobin goes from 575 to 588

nm. These absorption maxima shift when myoglobin (555 nm in the green portion of the spectrum) and metmyoglobin (505 nm in the blue end of the spectrum and a smaller peak at 627 nm in the red) form ionic complexes with water (Francis, 1985). It is noteworthy that the spectrum of oxymyoglobin is typical of all coordinated covalent complexes of haem pigments, having two absorption maxima, at about 550 and 590 nm. Considering all these facts, it can be stated that meat pigments tend to absorb more in the blue and green parts of the light spectrum, rather than in the red one. These photoenergised pigments interact with ground state triplet oxygen, producing singlet oxygen, which is considered to be the active agent in lipid, protein and DNA photoxidation (Varman & Sutherland, 1995). Therefore, it can be deduced that the higher oxidation degree of meat exposed to the daylight lamp is a consequence of the absorption characteristics of the meat pigments, as well as the amount of blue light and energy of radiation of this type of lamp.

3.4. Experiment B (3-day storage)

The results obtained with the extreme time conditions of experiment A led to the conclusion that it was possible to detect differences in the extents of fatty acids and cholesterol oxidations in turkey meat, after a few days of light exposure in a bench refrigerator. Since, under common retail conditions, meat is usually stored for 1–3 days before it is purchased by the consumer, a second experiment (experiment B) was designed, so as to evaluate the effects of a shorter storage time and different light exposure conditions on the turkey meat.

In this experiment, a new batch of turkey breast meat was used; the fat contents of the slices were 1.3 ± 0.2, 1.6 ± 0.4 and 1.4 ± 0.2 mg/100 mg of meat. This meat batch was particularly lean, having 50% less lipids than the one used in experiment A; these differences can be ascribed to different feedings and slaughtering seasons. The total cholesterol content of the samples varied from 2.5 to 4.2 mg/100 mg fat, which was 70–100% higher than that of meat used in the first set of experiments; since cholesterol is present in cell membranes, its relative percentage, expressed on a lipid basis, rises when the amount of depot fat decreases.

Table 2 shows the average value of total COPs and peroxide value, as well as the significant differences among groups, according to the ANOVA analysis. The lipid fraction of the control had a low oxycholesterol content (23.7 ± 7.5 mg/kg fat) and peroxide number (11.2 ± 5.9 meq/kg fat) with respect to the control meat analysed in the first stage of this study. The concentration ranges of the different COPs (expressed as mg/kg fat) were 3–16.4, 3–20.6, 5.1–19.1, traces – 6.8, traces – 3.0 and 15.9–87.6 for 7α-HC, 7β-HC, β-CE, α-CE, triol and 7-KC, respectively. As in the previous case study, 7-KC was the most abundant oxysterol (one third of the total oxycholesterols, on average). The initial COPs content was about 50% of the control used in experiment A, which was probably due to the shorter holding period (2 days).

3.5. Experiment B: Non-photoxidised turkey meat

Although the samples used in this experiment had different initial fat and cholesterol compositions and showed a higher quality in terms of oxidative status, the data obtained were not in contrast with those found after 11 days of storage (experiment A). In fact, these samples also exhibited important modifications during storage at 4 °C. On average, the formation rate of COPs was higher than their degradation rate during the first 3

Table 2
Effect of different light exposure conditions on the COPs (mg/kg fat) and PV (meq O_2/kg fat) determined in the lipid extract of raw turkey meat stored at 4 °C for 3 days (experiment B)

	Dark			Warm-tone lamp		Daylight lamp	
	Day 0	Day 1	Day 3	Day 1	Day 3	Day 1	Day 3
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
7α-HC	3.6 ± 0.7	5.4 ± 1.0	10.1 ± 5.6	7.4 ± 1.2	5.8 ± 1.3	9.9 ± 2.1	7.5 ± 1.6
7β-HC	4.8 ± 1.6	6.6 ± 1.2	13.2 ± 6.7	8.1 ± 1.7	9.2 ± 3.4	10.0 ± 1.0	11.8 ± 2.0
β-CE	7.0^{a} ± 1.7	10.0 ± 1.7	14.7^{b} ± 4.8	13.8 ± 0.9	9.4 ± 1.9	16.2^{b} ± 2.6	12.3 ± 2.2
α-CE	1.6^{a} ± 1.2	2.8^{a} ± 0.5	4.5^{b} ± 1.5	4.1 ± 0.9	3.1 ± 0.9	5.8^{b} ± 0.9	3.6 ± 0.5
Triol	1.5^{a} ± 0.8	1.7^{a} ± 1.2	1.3^{a} ± 0.5	2.7 ± 0.8	1.2^{a} ± 0.2	4.9^{b} ± 1.3	2.3^{a} ± 0.8
7-KC	5.1^{a} ± 1.9	12.3 ± 3.8	16.4 ± 8.2	19.4^{b} ± 1.6	9.4 ± 1.1	19.5^{b} ± 5.0	11.9 ± 3.6
Sum of COPs	23.7^{a} ± 7.4	38.7 ± 7.7	60.2^{b} ± 26.4	55.6 ± 6.3	38.1 ± 7.0	66.2^{b} ± 10.1	49.5 ± 9.7
PV	11.2^{a} ± 5.9	18.3 ± 1.7	23.9 ± 8.1	10.6^{a} ± 3.1	24.2 ± 6.5	32.1^{b} ± 7.5	20.2 ± 4.1

The average value of slices obtained from three breasts ± SD is reported. Means in the same row followed by different letters are significantly different according to the Tukey's test ($p < 0.05$).

days of storage in darkness (Table 2). The total COPs content reached on the third day (49.5 μg/g fat) was more than twice the control content (23.7 μg/g fat).

3.6. Experiment B: Turkey meat irradiated with high and low emission lamps in the blue spectrum for 3 days

Cholesterol oxidation was faster when slices were exposed to the daylight lamp (Table 2), as already observed in experiment A. Moreover, after a 1-day exposure under the retail commercial conditions (12 h effective light exposure), the COPs content of meat was 66.2 mg/kg fat, thus being 10% higher than the maximum level found in the meat kept in darkness. The red lamp provided a good protection against cholesterol oxidation; in fact, the total oxycholesterol content in meat exposed to this type of light was always 15–20% less than that of the meat irradiated with the daylight lamp for the same time. This trend was observed for all COPs here analysed, except for the triol, whose level did not significantly increase in the meat irradiated with red light (2.69 ± 0.8 mg/kg after 1 day) or kept in darkness after 3-day storage (1.32 ± 0.5 mg/kg).

After reaching a maximum, COPs were degraded to products that could not be evaluated with the current analytical method, as observed for the 11-day storage. Therefore, COPs can be considered intermediate products during meat photoxidation, leading to still unidentified degradation products. Meat samples with a small COPs content can be either fresh products, or highly oxidised ones, as reported in the previous experiment.

The modifications observed in the PV are similar to those of COPs (Table 2). After a 1-day exposure to the daylight lamp, peroxides reached their maximum concentration (32.1 meq O_2/kg fat) and they were successively degraded to secondary products. The exposure to red light had two positive effects; in fact, it reduced the velocity of formation and the amount of peroxides with respect to the daylight lamp. The maximum peroxide value was 24.2 meq O_2/kg fat, after a 3-day treatment with the warm-tone lamp.

4. Conclusions

Photoxidation of raw turkey meat under different storage conditions was studied. Raw turkey breast meats with different initial oxidative status, fat and cholesterol contents were analysed in two different sets of experiments, showing that meat stored in the dark at 4 °C reached its maximum peroxide content after 5 days, whereas the maximum COPs concentration was attained only after a 7-day storage. However, COPs are only intermediate products of degradation of cholesterol and the nature of the final products should still be investigated. On the other hand, when meat was exposed to white fluorescent light, the maximum COPs concentration and peroxide value were higher and they were reached after just 1 day (12 h effective light exposure). A lamp with low emission in the blue band proved to be useful for lowering peroxidation and cholesterol oxidation of turkey breast meat and it can be a suitable solution for the exhibition of meat products in supermarkets or meat processing factories. This positive effect of the warm-tone lamp on meat oxidation could be further enhanced if combined with a suitable packaging material, that transmits wavelengths between 490 and 589 nm (Bekbölet, 1990), as well as with vacuum packaging (Du, Nam, & Ahn, 2001).

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References

Bekbölet, M. (1990). Light effects on food. *Journal of Food Protection, 53*, 430–440.

Boselli, E., Velazco, V., Caboni, M. F., & Lercker, G. (2001). Pressurized liquid extraction of lipids for the determination of oxysterols in egg-containing food. *Journal of Chromatography A, 917*, 239–244.

Cade, J., Calvert, C., & Barrett, J. (1998). How could the BSE crisis affect nutrient intake? Comparison of beef and non-beef eating meat eaters from the UK women's cohort study. *European Journal of Clinical Nutrition, 52*, 151–152.

Carnovale, E., & Marletta, L. (2000). *Tabelle di Composizione degli Alimenti, Aggiornamento. Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione*. Milano: EDRA.

Du, M., Nam, K. C., & Ahn, D. U. (2001). Cholesterol and lipid oxidation products in cooked meat as affected by raw-meat packaging and irradiation and by cooked-meat packaging and storage time. *Journal of Food Science, 66*, 1396–1401.

FAO/GIEWS. (2001). Food Outlook No. 3, June, p. 12.

Folch, J., Lees, M., & Sloane-Stanley, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry, 226*, 497–509.

Francis, F. J. (1985). Pigments and other colorants. In O. Fennema (Ed.), *Food Chemistry* (2nd ed., pp. 545–584). New York: Marcel Dekker.

Francis, F. J., & Clydesdale, F. M. (1975). *Food colorimetry: Theory and applications*. Westport: AVI Publishing Co..

Garcia-Cruset, S., Carpenter, K. L., Codony, R., & Guardiola, F. (2002). Cholesterol oxidation products and atherosclerosis. In F. Guardiola, P. C. Dutta, R. Codony, & G. Savage (Eds.), *Cholesterol and phytosterol oxidation products: Analysis, occurrence, and biological effects* (pp. 241–277). Champaign: AOCS Press.

Giddings, G. C. (1977). The basis of color in muscle foods. *CRC Critical Reviews in Food Science and Nutrition, 9*, 81–114.

Li, N., Ohshima, T., Shozen, K. I., Ushio, H., & Koizumi, C. (1994). Effects of the degree of unsaturation of coexisting triacylglycerols on cholesterol oxidation. *Journal of the American Oil Chemists Society, 71*, 623–627.

Livingston, D. G., & Brown, W. D. (1981). The chemistry of myoglobin and its reactions. *Food Technology, 35*, 244–252.

Marusich, W. L., De Ritter, E., Ogrinz, E. F., Keating, J., Mitrovic, M., & Bunnell, R. H. (1975). Effect of supplemental vitamin E in control of rancidity of poultry meat. *Poultry Science, 54*, 831–844.

Morabia, A., Bernstein, M. S., Héritier, S., & Beer-Borst, S. (1999). A Swiss population-based assessment of dietary habits before and after the March 1996 'mad cow disease' crisis. *European Journal of Clinical Nutrition, 53*, 158–163.

Morrissey, P. A., Sheehy, P. J. A., Galvin, K., Kerry, J. P., & Buckley, D. J. (1998). Lipid stability in meat and meat products. *Meat Science, 49*, S73–S86.

Nam, K. C., Du, M., Jo, C., & Ahn, D. U. (2001). Cholesterol oxidation products in irradiated raw meat with different packaging and storage time. *Meat Science, 58*, 431–435.

Osada, K. (2002). Cholesterol oxidation products: Other biological effects. In F. Guardiola, P. C. Dutta, R. Codony, & G. Savage (Eds.), *Cholesterol and phytosterol oxidation products: Analysis, occurrence, and biological effects* (pp. 278–318). Champaign: AOCS Press.

Park, S. W., & Addis, P. B. (1987). Cholesterol oxidation products in some muscle foods. *Journal of Food Science, 52*, 1500–1505.

Pszczola, D. E. (2002). Beefing up innovations for meat and poultry ingredients. *Food Technology, 56*, 54–66.

Rodriguez-Estrada, M. T., Penazzi, G., Caboni, M. F., Bertacco, G., & Lercker, G. (1997). Effect of different cooking methods on some lipid and protein components of hamburgers. *Meat Science, 45*, 365–375.

Rodriguez-Estrada, M. T., Tocco, N., Savioli, S., & Lercker, G. (2003). Effects of light, cooking, and storage on lipid oxidation of ground turkey meat. In *Proceedings of the 25th World Congress and Exhibition of the ISF Bordeaux, 12–15 october* (pp. 10). Champaign: AOCS Press.

Rose-Sallin, C., Hugget, A. C., Bosset, J. O., Tabacchi, R., & Fay, L. B. (1995). Quantification of cholesterol oxidation products in milk powders using [$^2H_7$] cholesterol to monitor cholesterol autoxidation artefacts. *Journal of Agricultural and Food Chemistry, 43*, 935–941.

Saba, A., & Di Natale, R. (1999). A study on the mediating role of intention in the impact of habit and attitude on meat consumption. *Food Quality and Preference, 10*, 69–77.

Sander, B. D., Addis, P. B., Park, S. W., & Smith, D. E. (1989). Quantification of cholesterol oxidation products in a variety of foods. *Journal of Food Protection, 52*, 109–114.

Schroepfer, G. J. Jr., (2000). Oxysterols: Modulation of cholesterol metabolism and other processes. *Physiology Reviews, 80*, 361–554.

Sklan, D., Bartov, I., & Hurwitz, S. (1982). Tocopherol absorption and metabolism in the chick and turkey. *Journal of Nutrition, 122*, 1394–1400.

Smith, L. L. (1987). Cholesterol Autoxidation 1981–1986. *Chemistry and Physics of Lipids, 44*, 87–125.

Sweeley, C. C., Bentley, R., Makita, M., & Wells, W. W. (1963). Gas–liquid chromatography of trimethylsilyl derivatives of sugars and related substances. *Journal of the American Oil Chemists' Society, 85*, 2497–2507.

Takagi, T., Mitsuno, Y., & Masumura, M. (1978). Determination of peroxide value by the colorimetric iodine method with protection of iodide as cadmium complex. *Lipids, 13*, 147–151.

Varman, A. H., & Sutherland, J. P. (1995). *Meat and meat products. Technology, chemistry and microbiology*. London: Chapman & Hall (pp. 97).

Verbecke, W. (2001). Beliefs, attitude and behavior towards fresh meat revisited after the Belgian dioxin crisis. *Food Quality and Preference, 12*, 489–498.

Verbecke, W., & Viaene, J. (1999). Beliefs, attitude and behavior towards fresh meat consumption in Belgium: Empirical evidence from a consumer survey. *Food Quality and Preference, 10*, 437–445.

Wen, J., McCarthy, S. N., Higgins, F. M., Morrisey, P. A., Buckley, D. J., & Sheehy, P. J. A. (1997). Effect of dietary α-tocopheryl acetate on the uptake and distribution of α-tocopherol in turkey tissues and lipid stability. *Irish Journal of Agricultural and Food Research, 36*, 65–74.

Whang, K., & Peng, I. C. (1988). Photosensitized lipid peroxidation in ground pork and turkey. *Journal of Food Science, 53*, 1596–1598, 1614.