PAPER

EFFECT OF DIFFERENT ILLUMINATION SOURCES ON COLOUR AND OXIDATIVE STABILITY OF SEASONED COPPA DI PARMA PGI

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ABSTRACT

The influence of different lighting durations, lamps and modified atmosphere packaging (MAP) on the colour and oxidative stability of lipids was studied in Coppa di Parma PGI. The samples were stored (4°C) in darkness or lighted by UV-free lamps. In trials 1 and 2, the samples were lighted 24 and 12 h/day, respectively, and were packaged in air. In trial 3, samples were packaged in MA (70% N_2/30% CO_2) and lighted 12 h/day. In air, illumination reduced oxidative stability, redness, colour saturation and increased the Hue angle. In MAP, the lighting conditions did not affect colour and oxidative stability. During storage the lipid oxidation increased. Overall, light negatively affected the studied parameters.

Keywords: colour, cured salami, lighting conditions, lipid stability, modified atmosphere packaging

1. INTRODUCTION

The colour of meat plays a pivotal role in determining the decision of the consumer to buy a particular product. Indeed, it is perceived as relating to the freshness, integrity and quality of the food. Thus, maintaining an attractive colour during storage is a key of success in the selling of meat. Discolouration in retail-fresh meats during display is ascribable to muscle pigment oxidation (oxymyoglobin to metmyoglobin). This is influenced by oxygen concentration, pH and secondary products of lipids peroxidation (PAPUC *et al*., 2017). In case of nitrites addition, as in the processing of Coppa di Parma PGI (Protected Geographical Indication), nitrosylmyoglobin formation occurs; this is an unstable pigment that, in presence of oxygen in cured meat, is oxidized to brownish nitrosylmetmyoglobin NOMMb (FOX, 1966): this evidence was confirmed in scientific literature, in which the discolouration of nitrosylmyoglobin has been linked to the combination of the presence of both oxygen in the headspace surrounding the product and light exposure during the display life (MØLLER and SKIBSTED, 2002; ZANARDI *et al*., 2002). Indeed, lipid oxidation, which takes place in intramuscular fat and/or membrane phospholipids, besides causing an unpleasant odour and flavour, brings about the loss of desirable colour, thereby reducing display life (BUCKLEY *et al*., 1995; PAPUC *et al*., 2017; RUIZ *et al*., 1999) and has deleterious effects on the organoleptic properties of meat and meat products as well as the digestibility of main nutrients (GARCÍA-LOMILLO *et al*., 2017; PATRAKOVA and GURINOVICH, 2015). Therefore, preventing or delaying both pigment and lipid oxidation enables the duration in which the meat maintains its bright-red colour to be extended. The oxidation of both lipids and pigments in meats are strictly related to similar processes (FAUSTMAN *et al*., 1989; PAPUC *et al*., 2017) and, in this regard, light may play a critical role. In fact, oxidative reactions can be initiated also by physical factors such as radiation and light (AMARAL *et al*., 2018). The effect of light on lipid oxidation has been shown in various foods, such as oils, butter, milk and meat (AURAND *et al*., 1977; CHAHINE and DEMAN, 1971; KIRITSAKIS and DUGAN, 1985; LUBY *et al*., 1986; WHANG and PENG, 1988); UV-light is more effective than visible light in inducing oxidation of lipids and pigments (ANDERSEN and SKIBSTED, 1991; BERTELSEN and BOEGH-SOERENSEN, 1986; ZHU and BREWER, 1998). Although the amount of radiation below 400 nm is small in fluorescent lamps used in display cabinets, it must be taken into account due to its deleterious effects on the display-life of meat (DJENANE *et al*., 2001). Meat products on retail shelves are provided in transparent packaging and with residual oxygen inside the packages; in association with the cabinet display light, these can cause discolouration of the packaged meat products (GIBIS and RIEBLINGER, 2011; MCMILLIN, 2008). To overcome this problem, in the last few decades the use of modified atmosphere packaging (MAP) for meat and sliced meat products is increasingly widespread as a tool to extend their shelf-life. However, the effect of lighting on the shelf-life of cured seasoned pork products has not been widely investigated. In particular, the Coppa di Parma PGI has never been studied under this profile. Coppa di Parma PGI is obtained from subjects of at least nine months of age weighing approximately 160 kg. After hand-salting, the muscular portion of the neck adhering to the cervical and the first two thoracic vertebrae is placed in a closed-ended beef gut casing and hand-tied with string. After two/three months of curing, Coppa is marketable. The product, cylindrical in shape, is 25-40 cm long and weighs at least 1.3 kg.
The aim of this work was to study the effects of display under different lighting times and lamps on the colour parameters and oxidative stability of Coppa di Parma PGI packaged in air as well as in a modified atmosphere.

2. MATERIALS AND METHODS

For the purposes of the study, a total of 18 Coppa di Parma PGI, obtained from a local retailer, were used. Three distinct trials were carried out. For each trial, three replications were performed. In each replication, 2 different Coppa were sampled and sliced.
In the first two trials, the slices of Coppa were air-packaged in trays made of a PET/EVOH/PE structure (oxygen permeability < 0.5 cm^3 m^{-2} $24h^{-1}$ bar^{-1}), lidded with a PET/PE film (oxygen permeability 80 cm^3 m^{-2} $24h^{-1}$ bar^{-1}). In the third trial, sliced Coppa was packaged with the same material (bottom and top) in a modified atmosphere (nominally 70/30 N_2/CO_2), using CAVECO equipment and working with the technique of vacuum compensation. The initial and final atmosphere composition was determined by a Handheld Gas Analyzer Checkpoint (Dansensor, Denmark).
In each replication, 26 trays were filled with 10 slices each of Coppa. Twenty-four trays were put in refrigerators at 4±1°C. Six trays were maintained in the dark, the other 18 were put into another refrigerator, divided into 3 sections separated by horizontal black screens. Each section (estimated area of 0.33 m^2) was illuminated with a specific lamp, whose characteristics are summarized in Table 1.

Table 1. Characteristics of the different lamps used.

Lamp identifier (code)	Colour temperature °K	Colour rendering	Wattage (W)	Luminous flux (lm)	Illuminance* (lx)
640 Basic Cool White (CW)	4000	62	18	1200	3640
827 Lumilux Interna Warm White (WW)	2700	80	18	1350	4090
76 Natura Neutral White (NW)	3500	75	18	750	2270

*The Illuminance (lx) values have been calculated simply dividing the nominal Luminous flux (lm) of each lamp by the exposed area (0.33 m^2) of the fridge shelves.

The distance between the lamp and the samples was about 40 cm. The samples contained in the remaining 2 trays were immediately assigned to the analyses (described below).
The samples were exposed either to continuous lighting (24/24 hours) (trial 1), or to a 12 hours on/12 hours off light cycle (trials 2 and 3). Eight trays (two for each lighting condition) were removed from the refrigerators after 24, 48, and 120 hours and then submitted to the analytical determinations.
On each Coppa, the lipid content was determined according to A.O.A.C. (1995) and the average lipid content was 29.3±5.5. Lipid oxidation was measured by the 2-thiobarbituric acid reactive substances (TBARS) method (SIU and DRAEPER, 1978). Each sample was minced, and an aliquot of 2.5 g was homogenised in 12.5mL of distilled water at 9500 rpm for 2 min, using an Ultra Turrax tissue homogenizer and then vortexed for 1 min at high speed. Samples were centrifuged for 20 min at 2000 rpm at 4°C with 12.5 mL of 10% trichloroacetic acid (TCA) and the supernatant decanted through a paper filter (Whatman 541). Four mL of clear filtrate were transferred into 15 mL pyrex screw cap test tubes and 1 mL of 0.06M 2-thiobarbituric acid (TBA) was added. A distilled water-TCA-TBA reagent

blank was prepared and treated in the same way as the samples. The samples were heated in a water bath at 80°C for 90 min and then cooled. Absorbance was measured at 532 nm in spectrophotometer (Jasco model V550, UV/VIS, Tokyo, Japan). Results were expressed as mg of malondialdehyde (MDA)/kg.
The surface colour of Coppa slices was determined using a CM-600d spectrophotometer (Konica Minolta Holdings, Inc., Osaka, Japan) with a window diameter of 8 mm and D65 as the source of illumination. Before colour measuring, carried out on both lean and fat tissue, the spectrophotometer was calibrated against a white plate supplied by the manufacturer. Colour measurements complied with the CIE colour convention (CIE, 1986), where the three fundamental outputs are L^*- "lightness", a^*- "redness", b^*- "yellowness" values. Chroma (C^*), also referred to as saturation index and colour intensity, was calculated as: $[(a^{*2}+b^{*2})]^{0.5}$ and Hue angle (h^*) calculated as follows: $\tan^{-1}(b^*/a^*)$. Overall colour change (ΔE) was calculated as $[(\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2})^{0.5}]$ where ΔL^*, Δa^* and Δb^* are the difference between time 0 and the values L^*, a^* and b^*, respectively, at 24 (ΔE1), 48 (ΔE2) and 120 (ΔE3) hours. The average values for both fat and lean were the mean of 25 determinations in each fraction.
The data were submitted for analysis of variance, with the lamps and exposure times as independent variables (SAS, 1996). In addition, interaction effect between exposure time and lamp was evaluated; this was statistically significant for none of the examined parameters (P>0.05) and was thus removed from the model.

3. RESULTS AND DISCUSSION

3.1. Trial 1

In this trial, the samples were packaged in air and illuminated 24h/d (Table 2). L^* values did not vary with lighting conditions, either in the lean fraction or in the fat. However, the values of most of the other colour parameters differed between the samples kept in the dark and those exposed to the lamps. In fact, in the lean component, light exposure led to a significant reduction of both a^* (P<0.01) and C^* (P<0.05) values and an increase in the h^* value (P<0.01), whereas the b^* value was unaffected. Very similar trends were reported for fresh pork studied by ZHU and BREWER (1998). CIERACH and NIEDŹWIEDŹ (2014) reported a decrease of 4-7 units of a^* values in *Semitendinosus* muscle of beef after few days of light exposure using a lamp of 3000 K and 3 lightning intensity (500, 1000 and 1500 lux), demonstrating that intensity of 500 lx has less influence on the beef colour changes. In the scientific literature on this topic, light intensity has been chosen as a parameter to be standardized, by adjusting the lamp to product distance (BÖHNER *et al*., 2014; BÖHNER and RIEBLINGER, 2016; HAILE *et al*., 2013; SØRHEIM *et al*., 2017). In our work a fixed lamp to product distance has been chosen, in order to simulate the actual lighting condition of packaged Coppa in the retail display. It is evident that, despite the lighting intensity values, the simultaneous presence of oxygen (20.9%) and the continuous lighting over 120 hours deeply affect the colour of the product, without no appreciable difference among the three lamps used.
Display time, too, had no effect on the L^* value, as reported by other Authors (CIERACH and NIEDŹWIEDŹ, 2014); however, all the other colour characteristics in the lean fraction changed significantly during the 120 hours display period (Table 2). The a^* value decreased over time (P<0.01), while the b^* value increased, significantly (P<0.05) only at 48 hours of storage.

Table 2. Effect of lighting and display time on colour parameters and TBARS values (mg MDA/kg) in air packaged Coppa di Parma PGI with 24 hours lighting/day.

Trial 1	Lighting /Lamp				Time of display (h)			R-MSE (df 66)
	Darkness	CW	WW	NW	24	48	120	
Lean:								
L^*	44.40	45.90	44.78	45.36	43.65	45.87	45.80	5.02
a^*	16.58^{A}	12.06^{B}	12.81^{B}	12.41^{B}	14.69^{A}	13.99^{A}	11.72^{B}	1.69
b^*	16.62	17.76	17.05	17.26	16.16^{b}	18.32^{a}	17.03^{ab}	3.24
C^*	23.76^{a}	21.65^{b}	21.64^{b}	21.51^{b}	22.15^{AB}	23.38^{A}	20.90^{B}	2.86
h^*	44.50^{B}	55.31^{A}	52.04^{A}	53.62^{A}	47.37^{Bb}	51.80^{ABa}	54.93^{Aab}	6.16
Fat:								
L^*	63.90	65.17	63.26	62.32	63.58	63.71	63.69	4.41
a^*	8.17^{A}	4.52^{B}	5.76^{B}	5.47^{B}	6.23	6.27	5.44	2.06
b^*	12.96^{b}	13.94^{ab}	14.30^{a}	14.03^{ab}	13.21^{b}	14.31^{a}	13.89^{ab}	1.87
C^*	15.53	14.87	15.63	15.28	14.93	15.85	15.20	2.38
h^*	59.32^{B}	73.63^{Aa}	69.56^{Ab}	70.48^{Aab}	66.68^{b}	67.75^{ab}	70.31^{a}	5.74
TBARS	0.288^{Bb}	1.414^{Aa}	0.741^{ABb}	0.717^{ABb}	0.323^{B}	0.413^{B}	1.635^{A}	0.91

^{a,b}: P<0.05; ^{A,B}: P< 0.01. CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

The opposite trends of a^* and b^* values brought about a significant increase of the h^* value during storage (P<0.01). The value of C^* decreased significantly (P<0.01) between 48 and 120 hours. Changes in a^*, b^*, C^* and h^* values, and hue angle (h^*) indicated that the lean fraction of the samples tended to be less red and more grey as storage time increased, probably due to a progressive loss of nitrosylmyoglobin and the consequent increase of NOMMb, according with the findings of other Authors (BÖHNER *et al*., 2014; HAILE *et al*., 2013).
As shown in Fig. 1, 24 hours under the Basic Cool White (CW) led to an a^* value lower (P<0.05) than under the other lamps, whereas at 48 and 120 hours a^* values were similar regardless the lamps.
Also with regard to the fat fraction (Table 2), the light lowered the a^* value (P<0.01), which did not differ among lamps; instead, it increased the values of b^* (P<0.05) and h^* (P<0.01) without affecting the C^* value. Indeed, storage time led to an increase of b^* and h^* values (P<0.05), as observed in the lean fraction. Overall, the lipid fraction of the sliced Coppa tended to yellow, as a consequence of both light exposure, oxygen in contact with the product and storage time, which promote the fat fraction oxidation.
Samples under the CW lamp showed TBARS values significantly higher than those kept in the dark (P<0.01) or illuminated by the other two lamps (P<0.05).
At 24 and 48 hours, TBARS values were similar, while they increased significantly at 120 hours (P<0.01).
The evolution of TBARS values during display, depending on the different lighting conditions, is shown in Fig. 2.

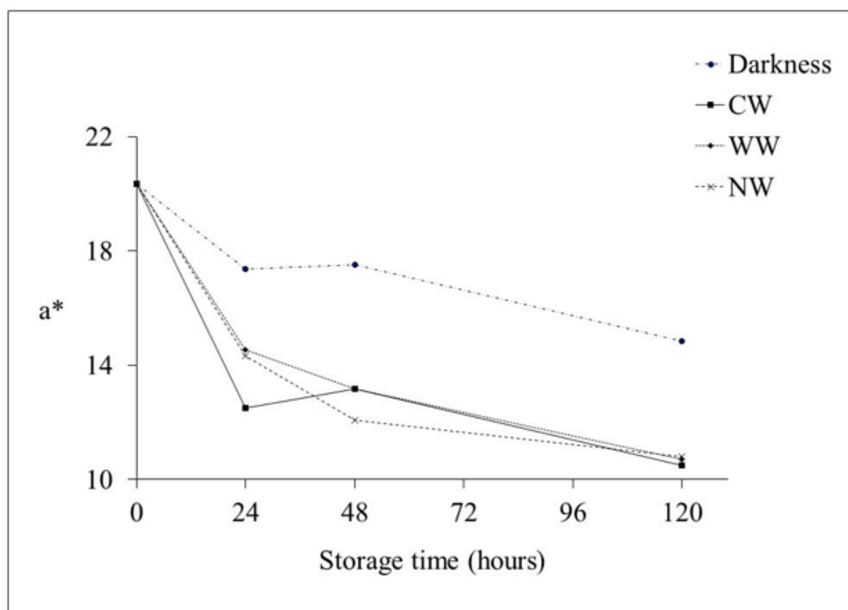

Figure 1. Values of CIE *a** (redness) in Coppa di Parma PGI packaged in air, displayed under continuous lighting.
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

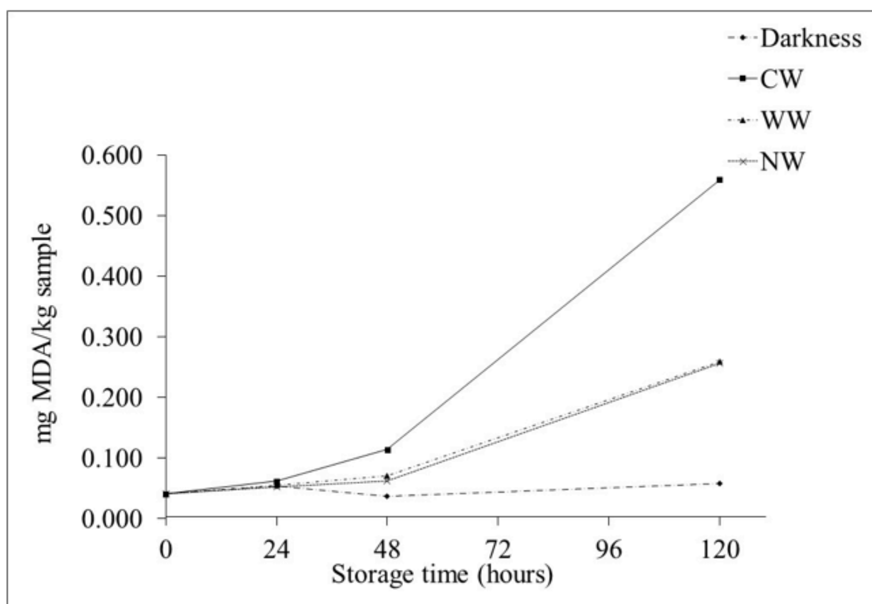

Figure 2. TBARS values (mg MDA/kg) in Coppa di Parma PGI packaged in air, displayed under continuous lighting.
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

Lipid oxidation did not develop in the dark. During storage, TBARS values increased in all the lighted samples. At 120 hours, the samples under the CW lamp gave values higher (P<0.01) than those under the other two lamps. These results may be explained considering the different emission spectra of the three lamps tested in this work (data from technical data sheet by OSRAM). Cool White (CW) has a strong emission in the short wavelengths (blue and green zone of the spectrum – from 430 to 560 nm); instead, Warm White (WW) and Natura Neutral White (NW) lamps are characterized by an emission in the blue zone significantly lower respect to CW; NW also shows a good emission in the red zone (630-700 nm). Some Authors underlined the importance of the lamps' emission spectra and the correlated energy. BÖHNER and RIEBLINGER (2016) demonstrated that shorter wavelengths and higher irradiance provoke increased oxygen absorption with concomitant colour changes of Bologna sausages. The continuous lighting promotes also lipid oxidation, but low energy emitting lamps will affect to a lesser extent this product degradation, as demonstrated in Figure 2, where the TBARS values in Coppa stored under NW and WW lamps are lower than those determined on the samples stored under CW lamp.

3.2. Trial 2

In this trial, the slices of the Coppa were also packaged in air, but using a 12 hours on/12 hours off light cycle. As observed in trial 1, the *L** value (Table 3) did not vary in any tissue, either with the type of illumination or with the storage time. For the other colour parameters studied, the trends observed did not differ markedly from the first trial, though only *a** and *h** values varied significantly.

Table 3. Effect of lighting and display time on colour parameters and TBARS values (mg MDA/kg) in air packaged Coppa di Parma PGI with 12 hours lighting/day.

Trial 2	Lighting /Lamp				Time of display (h)			R-MSE (df 66)
	Darkness	CW	WW	NW	24	48	120	
Lean:								
*L**	40.63	42.46	41.61	42.00	40.74	41.35	42.93	3.86
*a**	18.23^{A}	14.72^{B}	15.73^{B}	15.04^{B}	17.67^{Aa}	15.83^{ABb}	14.29^{B}	2.81
*b**	14.95	15.86	15.55	15.38	14.99	15.05	16.27	3.80
*C**	23.77	21.93	22.38	21.75	23.38	22.10	21.89	4.19
*h**	38.56^{Bb}	46.60^{A}	43.67^{ABa}	44.58^{A}	39.55^{B}	42.23^{B}	48.28^{A}	5.88
Fat:								
*L**	61.70	62.34	60.16	59.74	59.77	61.86	61.32	6.73
*a**	9.39^{Aa}	6.32^{B}	7.45^{ABb}	7.98^{AB}	8.97^{A}	7.78^{AB}	6.60^{B}	2.50
*b**	12.85	14.07	13.89	14.33	13.20	14.56	13.59	0.83
*C**	16.23	15.80	16.13	16.72	16.34	16.88	15.44	2.82
*h**	54.13^{B}	66.78^{A}	63.52^{A}	62.31^{A}	57.29^{Bb}	62.66^{ABa}	65.12^{A}	7.95
TBARS	0.340^{A}	1.044^{B}	0.790^{AB}	0.658^{AB}	0.340^{B}	0.519^{B}	1.258^{A}	0.73

^{a,b}: P<0.05; ^{A,B}: P< 0.01. CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

The statistical data processing demonstrates that illuminated samples showed a lower a^* value (P<0.01) and a higher h^* value (P<0.05) in the lean fraction; whereas, only h^* changed in the fat fraction (P<0.01), and no significant differences were found among the lamps.
At increased storage time, a^* values decreased, significantly at 120 hours (P<0.01), both in lean and fat components, with a corresponding increase (P<0.01) of the h^* values in both tissues.
In Fig. 3, the a^* value evolution on the surface of Coppa slices exposed to different light sources or stored in the dark is reported. The colour of samples stored in the dark changes, even if slightly, probably because of high partial pressure of oxygen in the headspace of the packages. If the samples stored under light are considered, it is possible to observe a different influence of the lamps used. Samples stored under CW lamp shows a more pronounced decrease of the a^* value between 48 and 120 hours of discontinuous lighting in comparison with the results obtained with WW and NW lamps. Discontinuous lighting also affects the colour of Coppa slices, but highlights the influence of different emitting lamps on the product colour fading.

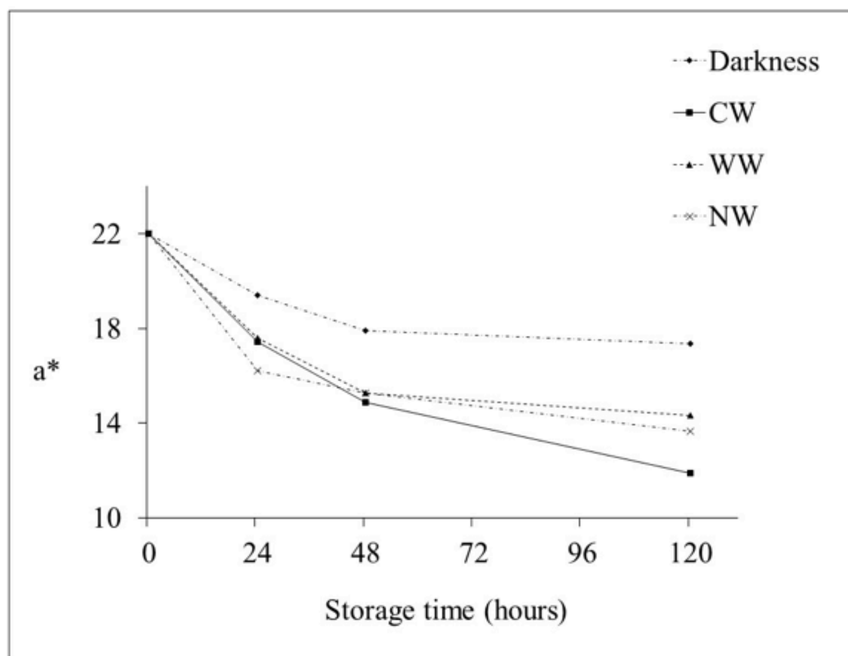

Figure 3. Values of CIE a^* (redness) in Coppa di Parma PGI packaged in air, displayed under 12 h/d lighting.
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

TBARS values showed the same path observed in trial 1. Thus, the samples kept in the dark provided the lowest values, but only the CW lamp caused significantly higher values (P<0.01). Moreover, as in trial 1, TBARS increased with time, significantly at 120 hours (P <0.01).
TBARS evolution during storage under different lighting conditions is shown in Fig. 4: darkness preserved samples from oxidation, which developed more markedly in the

illuminated samples, showing the highest value under the CW lamp. These data are consistent with those obtained for the colour changes.

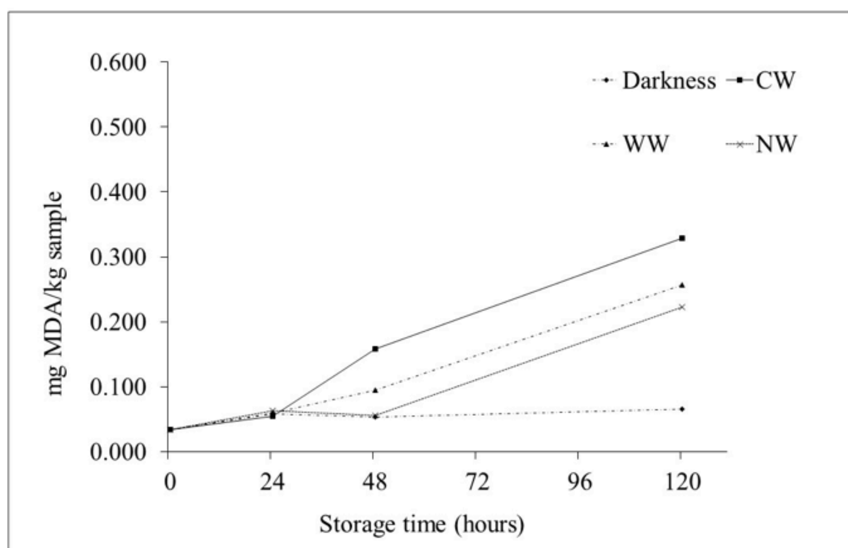

Figure 4. TBARS values (mg MDA/kg) in Coppa di Parma PGI packaged in air, displayed under 12h/d lighting.
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

3.3. Trial 3

In Table 4 are shown the data concerning the samples packaged in modified atmosphere (MAP) exposed to continuous lighting 12h/d. As regards the effect of the type of lighting, the results showed no statistically significant variation (P>0.05) of the values of the parameters taken into account, neither in the lean nor the fat fraction. As concerns the *a** value, our results agree with the findings of MARTÍNEZ *et al*. (2007) on fresh pork sausages and of DJENANE *et al*. (2001; 2003) on fresh beef steaks, and partially with the results of HAILE *et al*. (2013) on colour stability of cooked ham. The effect of residual oxygen and light exposure on the quality of cured boiled sausages (BÖHNER *et al*., 2014) and of Norwegian salami (SØRHEIM *et al*., 2017) has been studied. In our work the residual oxygen inside the MA packages was not measured, so we can only hypothesize a complete oxygen depletion during the packaging process, which makes irrelevant the lighting of the product concerning the colour fading. Another consideration is that the cured products examined in the cited works differ from Coppa, and it is well known that the type of meat and the production process may influence the specific sensitivity against oxygen and light.
If storage times are considered, the few significant differences observed in the lean fraction showed an erratic path, difficult to explain. These same considerations also apply to the evolution of *a** value in the samples displayed under different lightings; as Fig. 5 clearly shows, MAP maintained the red colour, regardless of light exposure and source; though it must be noted that the *a** values at 0 hours were lower in this trial.

Table 4. Effect of lighting and display time on colour parameters and TBARS values (mg MDA/kg) in Coppa di Parma PGI packaged in a modified atmosphere with 12 hours lighting/day.

Trial 3	Lighting /Lamp				Time of display (h)			R-MSE (df 66)
	Darkness	CW	WW	NW	24	48	120	
Lean:								
*L**	41.24	40.92	43.00	41.48	41.48	41.99	41.51	3.36
*a**	13.45	13.84	13.03	13.94	13.64[ab]	14.05[a]	13.00[b]	1.60
*b**	12.30	12.05	12.50	12.44	12.12	12.48	12.38	1.37
*C**	18.43	18.52	18.18	18.81	18.37[ab]	18.92[a]	18.17[b]	1.13
*h**	42.63	41.46	44.29	42.07	41.87	42.04	43.93	5.66
Fat:								
*L**	56.35	57.37	57.09	56.22	56.04	57.19	57.04	5.61
*a**	6.63	5.95	6.17	6.93	6.97[a]	6.78[ab]	5.51[b]	2.32
*b**	10.39	10.99	11.06	11.01	10.82	10.85	10.92	1.13
*C**	12.68	12.87	13.07	13.40	13.23	13.15	12.64	1.92
*h**	59.83	64.02	63.64	60.66	59.83[b]	60.90[ab]	65.38[a]	7.82
TBARS	0.312	0.306	0.283	0.277	0.254[B]	0.271[B]	0.358[A]	0.07

[a,b]: $P<0.05$; [A, B]: $P< 0.01$. CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

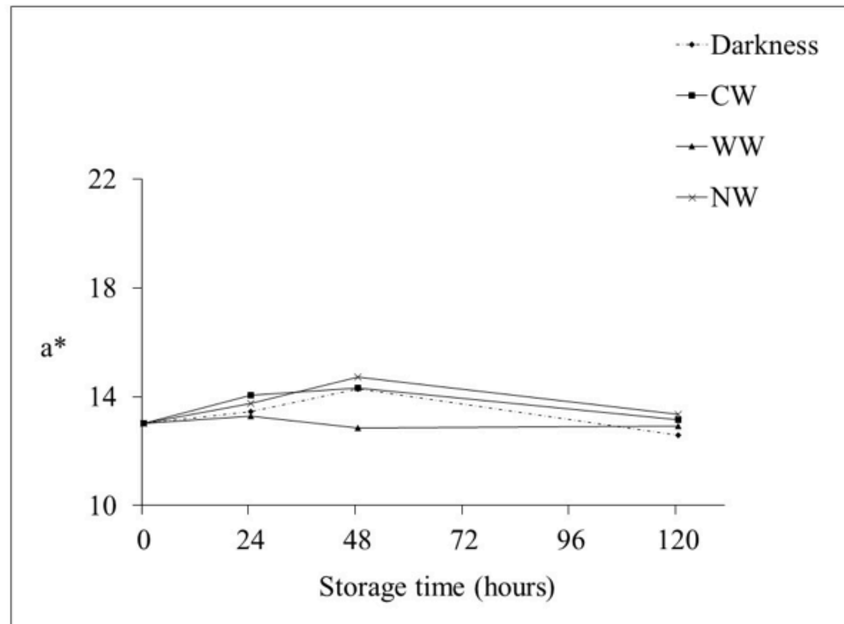

Figure 5. Values of CIE *a** (redness) in Coppa di Parma PGI packaged in a modified atmosphere, displayed under 12 h/d lighting (1c).
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

At increasing storage time, a significant decrease at 120 hours (P<0.05) of the *a** value and a corresponding significant increase (P<0.05) of the *h** value took place in the adipose fraction.
The TBARS values did not differ between the samples maintained in the dark and those exposed to light. Also in this case, as well as the colour evolution, eliminating oxygen in contact with Coppa means protect the product against lipid oxidation, even in presence of a luminous source emitting high energy wavelengths, such as CW lamp (refer to Fig. 6). Our findings are consistent with the results of MARTÍNEZ *et al*. (2007) on fresh pork sausages, with DJENANE *et al*. (2001; 2003) on fresh beef steaks and with GIMENEZ *et al*. (2004; 2005) on gilt-head sea bream and salmon fillets.
As in the two previous trials, after 120 h of storage, TBARS values increased significantly (P<0.01), though changes were rather slight. Our results conflict with those of MØLLER *et al*. (2000) who could not detect any difference among TBARS values in samples lighted or kept in the dark. The Authors stated that this could be due to the low fat content of their hams, much lower than the one found in our samples of Coppa, which was well above 29%.

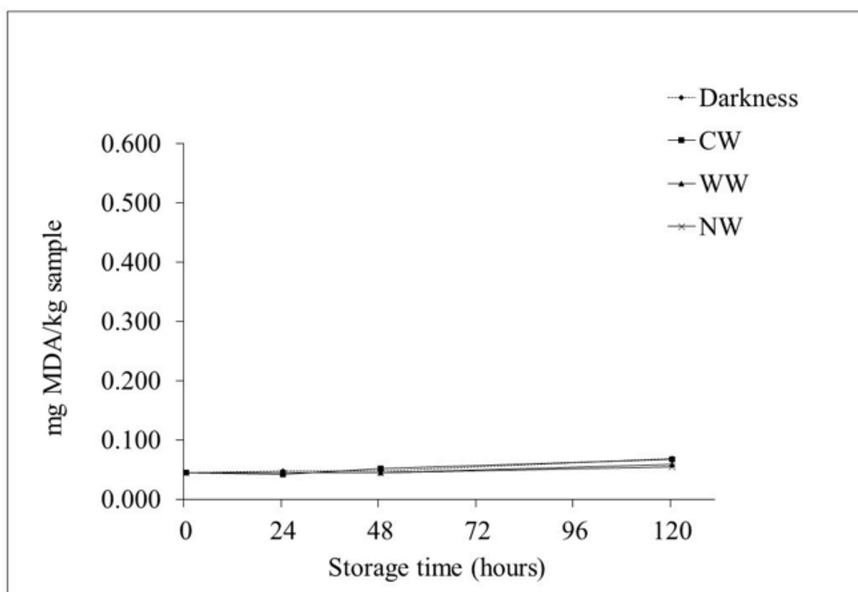

Figure 6. TBARS values (mg MDA/kg) in Coppa di Parma PGI packaged in a modified atmosphere, displayed under 12h/d lighting.
CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp.

Table 5 shows changes in the value ΔE that expresses, in the CIE *L**, *a**, *b**, the quantification of the colour difference.
As regards the type of lighting, it can be observed that at 24 hours (ΔE1) the CW lamp brought about a colour variation greater than the other lighting conditions, which was significant only when compared with the dark (P<0.01). Regarding the ΔE2 values, they were greater than ΔE1, as expected, and were significantly lower in the samples kept in the dark (P<0.05). At 120 hours (ΔE3) the colour difference was still greater and although

the samples kept into the dark gave the lowest value, no statistically significant variation among lighting conditions was found (P>0.05).

Table 5. Effect of lighting and display time on colour change (ΔE) in the lean of Coppa di Parma PGI.

	Lighting /Lamp				Treatment			R-MSE (df 66)
	Darkness	CW	WW	NW	Trial 1	Trial 2	Trial 3	
ΔE1	5.28^{B}	7.63^{A}	6.21^{AB}	6.38^{AB}	7.73^{A}	6.37^{AB}	5.02^{B}	2.60
ΔE2	5.68^{b}	8.80^{a}	8.76^{a}	8.15^{a}	9.64^{A}	8.76^{A}	5.14^{B}	3.58
ΔE3	7.73	9.54	9.10	9.08	11.59^{A}	9.98^{A}	5.01^{B}	3.69

^{a,b}: P<0.05; ^{A,B}: P< 0.01. CW: 640 Basic Cool White lamp; WW: 827 Lumilux Interna Warm White lamp; NW: 76 Natura Neutral White lamp. ΔE1, ΔE2 and ΔE3 are calculated colour differences between time 0 and 24, 48, 120 hours, respectively

With regard to the colour difference among the trials, data showed that the presence of oxygen caused a significant increase of ΔE2 and ΔE3 values (P<0.01), while at 24 hours (ΔE1) only permanent lighting gave colour changes higher (P<0.01) than in MAP stored samples. No visual evaluations have been performed, in order to establish if the colour changes can be detected by consumers, but it was demonstrated that if ΔE>2 a small difference is observed, and when ΔE>5 the changes are well distinguished (FLEISHMAN *et al.*, 1998; LINDSTRÖM, 2008).

4. CONCLUSIONS

From our results it may be concluded that the lighting with UV-free lamps negatively affects colour characteristics of Coppa di Parma PGI sliced and then packaged in air. Further, illumination causes a significant increase of lipid oxidation and the Basic Cool White lamp appears to be somewhat more detrimental. When the product is packaged in a modified atmosphere, colour and lipid stability are not affected by light exposure or source.
One hundred and twenty hours of storage led mainly to a loss of redness and to a significant increase of lipid oxidation.

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