Effect of light, packaging condition and dark storage durations on colour and lipid oxidative stability of cooked ham

Demewez Moges Haile · Stefaan De Smet · Erik Claeys · Els Vossen

Revised: 21 February 2011 / Accepted: 23 February 2011 / Published online: 2 May 2011
© Association of Food Scientists & Technologists (India) 2011

Abstract The colour and lipid oxidative stability of sliced cooked ham stored at 4 °C were studied in relation to dark storage duration, lighting and packaging conditions. Colour stability was monitored by instrumental colour measurement (CIE L*a*b* colour space) whereas lipid stability was measured by the determination of the 2-thiobarbituric acid reactive substances (TBARS). A significantly higher discoloration observed in products wrapped in foil and kept in light than products wrapped in foil and kept in dark. Colour loss was estimated by loss of redness (a*), a*/b*, nitrosomyoglobin, chroma (C); or increase of lightness (L*), MetMb, hue angle (H°). Colour loss was more dependent upon photochemical process than dark storage duration and packaging types. Lipid oxidation was not significantly affected by light exposure. However lipid oxidation was significantly affected by dark storage duration as noticed from better lipid stability of products stored for short duration in dark. Better colour stability was

observed on products packed in MAP with less residual oxygen.

Keywords Ham · Color oxidation · Lipid oxidation · TBARS · CIE L*a*b* · Light · Dark storage duration

Introduction

Meat quality covers inherent properties decisive for the suitability of the meat for further processing and storage including retail display. The main attributes of interest are color, fat content and composition and oxidative stability (Pearson 1995 & Gray et al. 1996). Lipid and pigment oxidation are the two main causes of quality deterioration limiting the quality and acceptability of meat and meat products (Morrissey et al. 1996). According to Estévez et al. (2003) and Baley et al. (2005) lipid and pigment oxidation leads to discoloration, drip losses, off odor development, the production of potentially toxic compounds and modification of nutritional characteristics.

Lipid oxidation primarily affects fatty acids in general and polyunsaturated fatty acids (PUFA) in particular. The level of fat in meat products is closely associated with numerous quality traits and may affect the nutritional, technological, sensory characteristics and oxidative stability of the product (Estévez et al. 2005). Nowadays, lipid oxidation reaches high importance due to the possible relationship between oxidized fat intake and the development of heart disease and cancer (Estévez et al. 2003). Monitoring and controlling lipid oxidation during meat processing and storage of finished products are increasingly important due to increased demands for pre-cooked convenient meat products for home, fast-food, and institutional uses (Raharjo et al. 1992).

D. M. Haile (✉)
Laboratory of Animal Products Processing and Quality (LAPPQ),
School of Chemical and Food Engineering, Engineering Faculty,
Bahirdar University,
P.O. Box: 26, Bahirdar, Ethiopia
e-mail: demewez2003@yahoo.com

D. M. Haile
e-mail: haile@bdu.edu.et

D. M. Haile
e-mail: lappq.food@bdu.edu.et

S. De Smet · E. Claeys · E. Vossen
Laboratory for Animal Nutrition and Product Quality
(LANUPRO), Department of Animal Production,
Faculty of Bioscience Engineering, Ghent University,
Proefhoevestraat 10,
9090 Melle, Belgium

Several methods have been developed to assess lipid oxidation products in muscle foods. The thiobarbituric acid (TBA) test is among the most widely used to quantify lipid oxidation products in meat and meat products because it is simple and fast (Tarladgis et al. 1960). The TBA test determines the amount of malondialdehyde (MDA), a major secondary byproduct of lipid oxidation, in a sample to generate an adduct of red color, which can be detected spectrophotometrically.

The other quality attribute that influence fresh as well as cured meat purchasing decisions is color because consumers use discoloration as an indicator of lack of freshness and wholesomeness (Abril et al. 2000; Barbut 2001 & Nicolalde et al. 2005). According to Mancini and Hunt (2005), a 15% price reduction of retail meat is reported due to surface discoloration. To document treatment effects on colour and determine meat colour we can use one of the three major approaches i.e. using panelists (Visual inspection), colour measuring instrument (Instrumental) and measuring myoglobin concentration (Chemically) (Leon et al. 2006). Colour standards are often used as reference material to carry out more objective colour analysis. Unfortunately this method requires more specialized training of the observers and for this reason the use of colour measuring instruments such as the widely used $L^*a^*b^*$ colour space is recommended (Hunt et al. 1991; Wulf and Wise 1998 and Leon et al. 2006).

Lipid and pigment oxidation may be catalyzed or accelerated by factors involved with processing and storage procedures such as exposure to light, free iron and copper; and presence of oxygen and/or gas composition in the package (Akamittath et al. 1990 & Baley et al. 2005). Understanding and controlling the processes which leads to lipid and pigment oxidation is a major challenge for meat scientists because of a greater demand by consumers for foods perceived as natural, fresh, healthy and more nutritious (Morrissey et al. 1996).

Thus, this research has been therefore conducted to investigate the effect of dark storage duration, light, and packaging conditions on surface discoloration and lipid oxidation of cooked hams.

Materials and methods

Manufacturing of the studied cooked ham

The model cooked hams were prepared at the Food Chemistry and Meat Technology laboratory, Katholieke Hogeschool Sint-Lieven, Technologie campus Gent Belgium. For the manufacturing of cooked ham a selected hog meat parts were mixed with 18 gm/kg NaCl, 0.12 gm/kg NO_2^- , 5 gm/kg glucose, 0.5 gm/kg Sodium ascorbate (purchased from Sigma-Aldrich NV/SA Bornem, Belgium) and 12 gm/kg water.

The mixture was tumbled (1280 turns for tumbling duration of 16 h) for better distribution of the brine and rests for 50 min in vacuum. The meat was stuffed in a sterile casing under vacuum and cooked until an internal temperature of 72 °C was reached and then cooled to 4 °C. Based on the percentage of vacuuming and percentage of gas mixture flushed in modified atmosphere package (MAP) the cooked hams were grouped into two groups. Accordingly the cooked ham packaged in a MAP flushed with a dose of 50% gas mixture (30% CO_2 and 70% N_2) after 80% vacuuming of the plastic pouches was named as cooked ham A. Whereas the cooked ham packaged in a MAP flushed with a dose of 75% gas mixture (30% CO_2 and 70% N_2) after 98% vacuuming of the plastic pouches was named as cooked ham B. The percentage of vacuuming before gas flashing was strictly controlled during vacuuming by setting vacuum percentage on vacuum control command of the vacuum machine. Similarly, the percentage of gas mixtures was controlled by setting the gas flushing percentage of the sealing machine.

Experimental design

The experiment was a $2 \times 3 \times 3 \times 2$ factorial design with two groups of cooked ham (Cooked ham A & Cooked ham B), three packaging and storage conditions (MAP, wrapped in Foil & stored in dark and wrapped in foil & stored under light), three dark storage times at 4 °C before the start of experiment (0, 21 and 35 days) and two replications of the entire experiment.

For this experiment a total of 36 slices were prepared (18 slices of Cooked ham A, 18 slices of cooked ham B). Each time 12 slices were wrapped by transparent & permeable to gas foil and stored under light of 1000 lux (named foil light), where as the other 12 slices were wrapped by transparent & permeable to gas foil and stored under dark condition of zero L^* value (named Foil dark). The dark environment was created in a cabinet and the environment was regularly checked by measuring lightness value using hunter $L^*a^*b^*$ mini scan device. The remaining 12 slices were packed in MAP flushed with gas mixture according to the procedure described before (named MAP). All the samples were stored in chiller room (4 °C) of laboratory of animal nutrition and animal product quality, Ghent University, Belgium.

Analysis and measurements

Instrumental color measurement

Surface color of the slices was measured by using a tristimulus colorimeter (Hunter Lab Mini scan device: D65 illuminant, 10° standard observer, 45°/0° geometry, 1 in. light surface). The measurements were performed

through the transparent packaging material in duplicate from different position on the surface for all samples at 0, 2, 4, 6, 8, 24 and 48 h.

Before each measurement the apparatus was standardized against a black and white calibration tiles. The three color scale indices L^* (lightness), a^* (redness) and b^* (yellowness) and reflectance values at different wave lengths from 470 to 700 nm were obtained from the instrumental measurement. The percentages of nitrosomyoglobin and nitrosohemichrome were estimated by using the ratio of reflectance values at specific wave lengths such as (650/570 nm) and (630/580 nm) respectively (Hunt et al. 1991).

The proportion of the three myoglobin (Mb) redox forms (Mb, metmyoglobin (Metmb) and Oxymyoglobin (MbO₂))

at the surface of the samples was also determined from the measurement of reflex attenuance at the iso-bestic point by using the method of Krzywicki (1979):

$$\%Mb = 2.375 \cdot (1 - (A^{473} - A^{730}/A^{525} - A^{730}))$$

$$\%Metmb = 1.395 \cdot (1 - (A^{572} - A^{730}/A^{525} - A^{730}))$$

$$\%MbO_2 = 100 - (\%Mb + \%Metmb)$$

Where: A=Millmolar absorbance

From the $L^*a^*b^*$ values Chroma (C) and Hue angle (H°) were obtained by using the following equations:

$$C = (a^2 + b^2)^{0.5} \text{ (a measure of saturation where high values indicate more vivid color)}$$

$$H^\circ = \arctg b^*/a^* \text{ (departure from the true red axis of the CIE color space in degree)}$$

Because of the variability in redness value observed at the start (0 h), for this experiment the rate of change (slope) of L^* , a^* , a^*/b^* , chroma, hue angle, nitrosomyoglobin, nitrosohemichrome and Metmyoglobin during 48 h storage were used to monitor surface discoloration. Because the studied product was faded too much with constant redness (a^*) value after 48 h storage, only colour measurement data's during the first 48 h were consider to study the treatment effect.

Lipid oxidation analysis

The 2-thiobarbituric acid (TBA) assay has become nearly as common as the peroxide value (PV). It must be taken into account that the TBA value represents the aldehydes level in the lipidic fraction of foods which has been autoxidized. From this point of view, the TBA value is a representative parameter for the secondary oxidation step (Sans and Chozas 1998). Moreover, high correlations between the thiobarbituric acid reactive substances (TBARS) and sensory evaluation of oxidized flavors have been well-documented for meat and meat products (Igene et al. 1985 & Brewer et al. 1992).

For the measurement of TBARS samples were kept at -20°C for two weeks and TBARS level was determined in duplicate for each samples at times 0, 24, 48 and 216 h. Lipid oxidation was evaluated through the determination of TBARS using the method of Salih et al. (1987).

The frozen sample weighed 5 g was grinded and dispensed in a plastic pot of 100 ml and homogenized with 30 ml cold perchloric acid (HClO₄, 0.6 M) and 1 ml of Butylated hydroxytoluene (BHT) (Sigma-Aldrich NV/SA Bornem, Belgium) using ultra-turrax (Ika laboratory tech-

nology) at 1300 rpm for about 30 s. The slurry was filtered through a folder filter (S & S 595 1/2) and centrifuge (5 min, 2500 r/min) (Hermle Labortechnik). Standard working solution of MDA was prepared following the procedure of Shlafer and Shepard (1984).

5 ml meat sample extract (aliquots), distilled water (blank) and standard working solution were transferred in heat resistance glass test tubes in duplicate and mixed with 1 ml TBA reagent (Sigma-Aldrich NV/SA Bornem, Belgium). The test tubes were placed in boiling water bath (100°C) (Julabo technik GmbH) for 35 min together with tubes for the standard curve. After cooling to room temperature in tap water, the absorbance was measured spectrophotometrically at 532 nm against a blank. The standard curve was prepared by using dilutions prepared from a 20 times diluted 14.4 μl 1, 1, 3, 3-tetramethoxypropane (Sigma T-1642) in 0.6 M HClO₄. The MDA concentration was converted to TBA number (μg MDA/g meat sample) as follows:

$$\text{TBA number} (\mu\text{g MDA/g sample}) = C \times 6 \times 72/G \times 1000$$

Where: 72=molecular weight of MDA

G=Weight of the sample in g and

C=Concentration of MDA per 5 ml extract based on the regression line of the standard curve.

The sample was kept as cold as possible during the treatment to prevent oxidation. During the analysis standard curves were prepared for each TBARS measurement to avoid the effect of variations during pipetting, weighing, incubation and other steps. Because of the variability in TBARS value observed at the start (0 h) the difference in

TBARS between 0 h (start) and 216 h (end) was used to see the effect of the treatments. Mean values are reported as μg MDA/g of meat.

Data handling and statistical analysis

Summary statistics (mean and standard deviation) were computed for each dependent variable. In order to find differences between treatments the slope and time evolution of L^* , a^* , a^*/b^* , MetMb%, chroma, hue angle, nitrosomyoglobin, nitrosohemichrome, and TBARS value was used as a variable. Data obtained from instrumental measurement and chemical analysis was all submitted to General Linear Model (GLM) procedure from SPSS 15.0 (SPSS 2006) statistical software package to determine the effect of light, dark storage times and packaging condition. The treatments whenever found significant, the tukey test was used for pair wise comparisons among the different treatments at the 5% ($p < 0.05$) significant level. Whenever it was found necessary Pearson correlation coefficient was also calculated.

Results and discussion

Effect of dark storage duration on lipid and color oxidation

Mean and standard error of the mean (SEM) of colour and TBA measurements of the studied products at different dark storage days are given in Table 1.

Dark storage days showed significant ($P < 0.05$) difference on TBARS values. A decrease in TBARS value as the dark storage day's increase observed over the 21 days and stabilized. A TBARS value from 0 days dark storage durations was significantly higher than both 21 and 35 days of dark storage. Whereas there is no significant difference between 21 and 35 days dark storage (Table 1 and Fig. 1). This decline in TBARS value as dark storage day's increase

Fig. 1 Effect of dark storage days on TBARS value (MDA $\mu\text{g/g}$) All values are means four measurements ($n = 4$)

is in agreement with previous work on dark storage of cooked pâtés by Gokalp et al. (1983) where they reported the same trend after 90 days of storage. However this decline in TBARS value in disagreement with Gonzalez et al. (1992) and Yu et al. (2002) where they reported an increase in TBARS value as storage time increase during 12 days and 3 days storage of cooked turkey and fish oil respectively. The most probable reason for this decline in TBARS value as dark storage duration increase could be the instability or transitory nature of MDA (secondary product from lipid peroxidation) that react with TBA to generate a red colour (Wang et al. 2002). This Possibility of subsequent conversion of TBARS most probably to aldehydes was also reported by Igene and Pearson (1979), Gokalp et al. (1983) and Kosugi et al. (1987) as cited in Gonzalez et al. (1992).

Table 1 Colorimetric parameters and TBARS values of cooked ham during 0, 21 and 35 days dark storage durations

Dark storage days	ΔL^*	Δa^*	$\Delta a^*/b^*$	Δ Chroma	ΔH°	Δ MetMb%	$\Delta 650/570$ nm	$\Delta 630/580$ nm	Δ MDA ($\mu\text{g/g}$)
0	0.01	-0.03	-0.003	0.000 ^a	0.13	0.12	-0.004	-0.003	0.45 ^a
21	0.02	-0.06	-0.006	-0.01 ^b	0.24	0.15	-0.006	-0.005	0.06 ^b
35	0.02	-0.06	-0.005	-0.02 ^b	0.22	0.15	-0.007	-0.006	0.02 ^b
<i>p</i> -value	0.664	0.324	0.289	0.004	0.410	0.777	0.358	0.376	0.005
SEM	0.004	0.008	0.001	0.002	0.034	0.024	0.001	0.001	0.052

Means followed by different superscripts within columns show statistically significant ($p < 0.05$) differences

$\Delta 650/570$ nm=nitrosomyoglobin value, $\Delta 630/580$ nm=nitrosohemichrome value

SEM=Standard error of the means

All values are means four measurements ($n=4$)

During the present study the samples were stored for extra two weeks in addition to the treatment dark storage times until the TBARS assay done. However, Gutersperger and Escher (1994) suggested determination of TBARS should be done during the first two weeks of storage as during advancing oxidation the rate of MDA decomposition surpass that of its formation.

The other probable reason for this decrease in TBARS value as dark storage duration increase may be due to the tendency of MDA to form complex with amino acids, glycogen and residual nitrite in case of cured products such as cooked hams we used for this study. This interference of other compounds was also reported by Igene and Pearson (1979); Gokalp et al. (1983); and Shahidi (1998).

Regarding discoloration there was no significant difference between the dark storage days for the traits commonly used to evaluate discoloration (L^* , a^* , a^*/b^* , Hue angle, Metmb%, nitrosomyoglobin & nitroshemichrome). Møller et al. (1999) explained this colour stability as the effect of dark storage on reducing residual oxygen level. Chroma was the only exception from discoloration indicators where a significant difference ($p<0.05$) was observed between products stored for 0 days and the other days where as there is no significant difference between products stored for 21 and 35 days (Table 2). The storage temperature (4 °C) may contribute for this saturation decrease. During a study on high-oxygen modified atmosphere packaged ground beef Daly and Acton (2003) suggested to avoid any discoloration products should be stored near 0 °C. In their study they reported doubling of discoloration as storage temperature increased to 5 °C and they suggest an increase in oxygen consumption and a decrease in oxygen solubility may be the reason.

The response of the two groups of cooked ham to dark storage days revealed that “cooked ham A (CHA)” showed significantly ($p<0.05$) different TBARS value for the three dark storage days. Whereas “cooked ham B” showed non-significant ($p>0.05$) difference for the three dark storage days (Table 2). The significant difference observed on “cooked ham A” may be justified from the higher residual oxygen due to low level of vacuuming and gas flushing in the MAP used for this product.

Effect of light and packaging conditions on lipid and colour oxidation

The effect of light and packaging conditions on the physical colour variables (L^* , a^* , a^*/b^* , chroma, H° , Metmb%, nitrosomyoglobin & nitroshemichrome) & TBARS values is summarized in Table 3.

Discoloration showed statistically significant ($p<0.05$) differences among the packaging and storage methods. The decrease in a^* , a^*/b^* , chroma, nitrosomyoglobin and

Table 2 TBARS values (MDA $\mu\text{g/g}$) of the two groups of cooked ham in response to dark storage durations

Dark storage days	Products	
	CHA	CHB
0	0.723 $\pm$ 0.140 ^a	0.63 $\pm$ 0.500
21	0.093 $\pm$ 0.050 ^b	0.02 $\pm$ 0.080
35	0.015 $\pm$ 0.007 ^b	0.07 $\pm$ 0.090
P-Value	0.001	0.076

Means followed by a different superscripts within columns show statistically significant ($p<0.05$) differences

All values are means four measurements $\pm$ standard error of the mean

CHA=Cooked ham A, CHB=Cooked ham B

nitroshemichrome content in all the packages and storage treatments (foil light, foil dark and MAP) equates with a decrease in sample redness and pinkness. In all colorimetric parameters foil light showed the higher discoloration and was significantly different with foil dark and MAP (Fig. 2 and Table 3). Except Chroma and L^* in all cases foil dark was also showed significant ($p<0.05$) discoloration from MAP where foil dark revealed the lowest discoloration score and magnify the effect of light.

An increase in Metmb %, L^* and H° observed during the 48 h storage time where foil light showed higher discoloration and it was significantly ($p<0.05$) different with foil dark and MAP. Foil dark and MAP also showed significant difference in all case foil dark revealed better colour stability (Table 3).

As indicated in Table 3 and diagrams (Fig. 2) a decrease in nitrosomyoglobin, a^* and a^*/b^* show simultaneous increase in hue angle, MetMb% and L^* . In all case there was a strong negative correlation between these two groups of colorimetric parameters. There was a very strong negative correlation between the losses in nitrosomyoglobin and an increase in MetMb% and hue angle as evidence from the Pearson correlation value ($r=-0.842$; $r=-0.865$ respectively at $p<0.01$). Whereas the correlation was relatively low for L^* with a^* , a^*/b^* and nitrosomyoglobin ($r=-0.5$; -0.43 and -0.576 respectively at $P<0.01$). Møller et al. (2005) in their study on autoxidation of nitrosomyoglobin reported that the formation of cured pigment (nitrosomyoglobin) is a result of the reaction between the metmyoglobin formed and a reductant such as ascorbic acid subsequently with residual nitrite. They further suggested this process is very sensitive to exposure of light. This fact is reflected during this experiment as indicated on the diagrams (Fig. 2) where the formation of MetMb was stabilized around the 6th hour and the loss of nitrosomyoglobin also stabilized around this time. This relation between MetMb and nitrosomyoglobin have a

Table 3 Physical colour variables and TBARS value in response to light exposure and packaging conditions (foil light, foil dark and MAP)

Packaging and storage	L*	a*	a*/b*	Chroma	H°	Metmb%	650/570 nm	630/580 nm	MDA (µg/g)
Foil L	65.9 ^a	6.6 ^a	0.5 ^a	15.8 ^a	64.5 ^a	42.5 ^a	1.7 ^a	1.5 ^a	0.2
Foil D	63.5 ^b	11.2 ^b	1.0 ^b	16.5 ^b	45.9 ^b	31.0 ^b	2.3 ^b	2.0 ^b	0.3
MAP	63.0 ^b	10.1 ^c	0.9 ^c	16.5 ^b	50.3 ^c	33.4 ^c	2.2 ^c	1.9 ^c	0.1
p-value	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.414
SEM	0.175	0.09	0.014	0.103	0.485	0.253	0.015	0.011	0.063

Means followed by different superscripts within columns show statistically significant ($p < 0.05$) differences

$\Delta 650/570$ nm=nitrosomyoglobin value,

$\Delta 630/580$ nm=nitrosohemichrome value

All values are means four measurements ($n = 4$)

SEM=Standard error of the means

pearson correlation coefficient of $r = -0.842$ at $p < 0.01$. The possibility of reestablishment of the cured meat colour was reported by Skibsted (1996). This result is in agreement with the study conducted by Møller et al. (2000) on sliced, pasteurized ham packaged in modified atmosphere, where they reported exposure of nitrosomyoglobin and nitrosohemichrome to light even at low oxygen level promote oxidation to metmyoglobin which impose dull greyness to meat.

The increase in MetMb% was also negatively correlated to redness ($r = -0.93$, $p < 0.01$). This relation between MetMb% and redness was in agreement with study conducted by Insausti et al. (1999) on Colour stability of beef and Hunt et al. (1991). They suggested this is an alternative way to measure brown colour which is difficult to measure directly. The correlation between a^* and b^* ($r = -0.541$) and L^* & a^* ($r = -0.5$) was less significant than the correlation between MetMb% and nitrosomyoglobin. Even though the a^* and b^* values were believed to be good indicator of variation in colour in this experiment from correlation value we found it is the loss of nitrosomyoglobin which is highly correlated with discoloration. Since the studied product was cured product the correlation value looks logical. This relation of MetMb and nitrosomyoglobin was also found the main cause of variation in the percentage of pigment conversion as evident from its high Pearson correlation coefficient ($r = -0.842$, $p < 0.01$). Similar behavior had been described by Caraballo et al. (1991) in their study on sliced pork bologna.

In the present study we found colour stability is more dependent up on photochemical action than storage time (Tables 2 and 4). Similar result was revealed from previous work by Caraballo et al. (1991) on sliced pork bologna. In their study on sliced meat products Nannerup et al. (2004) also reported fading of the pink colour when illuminating the packages with light intensity of 600 lux. They reported further discoloration observed when intensity increase to 1200 lux. Møller et al. (2005) also reported the sensitivity

of nitrite cured pigment and its denatured form to light exposure even in the presence of small amount of O_2 .

Unlike the dark storage duration trial we found non-significant ($p = 0.414$) difference between the storage and packaging conditions to lipid oxidation as evaluated by TBARS value. Park et al. (2007) in their study on pork meat also reported non-significant variation in lipid oxidation level attributes to exposure of light.

The two cooked hams differ in the level of vacuuming before gas flushing showed no significant ($p > 0.05$) difference in TBARS value and most colorimetric variables except L^* & nitrosomyoglobin (Table 4). The sharp decline in nitrosomyoglobin values observed in Table 4 can be explained by pigment oxidation which relied on O_2 concentration. This fact was clearly indicated in this experiment where cooked ham B which was vacuumed 98% before gas flushing and flushed with 75% of gas to reduce O_2 diffusion showed higher nitrosomyoglobin content stability as compared to the same cooked ham only differ in the level vacuuming (80%) and gas flushing (50%). Similar result was also reported previously by Møller et al. (2005) in their study on autoxidation of nitrosomyoglobin. They reported in the presence of O_2 , the cured meat pigment (nitrosomyoglobin) is converted to nitrite and metmyoglobin. Skibsted (1996) also confirmed the result observed as fading depend on the presence and concentration of oxygen. Møller et al. (2000) in their previous work on sliced, pasteurized ham also reported this negative effect of residual oxygen. They further recommend critical level of residual oxygen between 0.1 and 0.5% to avoid light induced oxidative discoloration.

Conclusions

Dark storage duration of cooked ham showed no significant effect on discoloration of a product at least in the range of

Fig. 2 Effect of light and packaging conditions on physical colorimetric variables of cooked ham during 48 h storage. All values are means four measurements ($n = 4$)

Table 4 Effect of level of vacuuming before MAP gas flushing on physical colour variables and TBARS value

Product	L*	a*	Hue angle	Metmb%	650/570 nm	MDA ($\mu\text{g/g}$)
CHA	63.4 $\pm$ 2.9 ^a	9.5 $\pm$ 2.6	48.9 $\pm$ 11.4	33.0 $\pm$ 6.6	2.1 $\pm$ 0.38 ^a	0.3 $\pm$ 0.34
CHB	61.7 $\pm$ 4.2 ^b	10.3 $\pm$ 3.0	45.9 $\pm$ 12.4	31.9 $\pm$ 6.6	2.3 $\pm$ 0.48 ^b	0.3 $\pm$ 0.4
<i>p</i> -value	0.001	0.207	0.148	0.338	0.002	0.151

Means followed by a different superscripts within columns show statistically significant ($p < 0.05$) differences

All values are means four measurements $\pm$ standard error of the mean.

CHA & CHB=Cooked ham A and cooked ham B

studied days. This result stresses the possibility of keeping meat products in dark without facing visual discoloration problem whenever required. However the present study noticed the possibility of lipid oxidation during prolonged storage even in dark.

In this study we confirmed light had a detrimental effect on colour stability of cooked ham. Products exposed in light showed higher L^* , MetMb% and hue angle and lower a^* , a^*/b^* , Chroma & nitrosomyoglobin value. Products wrapped in foil stored in dark was also revealed better resistance against discoloration than products packed in MAP and exposed to light that signify the effect of light.

Regarding lipid oxidation we noticed significant effect of dark storage duration as compared to light exposure. From the TBARS values in this study we noticed measurement of TBARS is not an appropriate method to assess lipid oxidation especially for cured products and products stored for long time before TBARS assay. In this study we found lower TBARS value from products stored for long and exposed to light than those stored for short time and stored in dark. This may be either the prolonged storage allow the interaction between MDA and residual nitrite or other agents so that make the MDA bound and underestimate the expected TBARS number. However further study was required to confirm whether the duration of storage in this study was enough to create such conditions. From the consistent behavior we noticed in this study we found monitoring rate of loss of nitrosomyoglobin is suitable for discoloration studies of cured products.

References

- Abril M, Campo MM, Önenç A, Sañudo C, Alberti P, Negueruela AI (2000) Beef colour evolution as a function of ultimate pH. *Meat Sci* 58:69–78
- Akamittath JG, Brekke CJ, Schanus EG (1990) Lipid oxidation and colour stability in restructured meat systems during frozen storage. *J Food Sci* 55:1513–1517
- Baley D, Vulkova T, Dragoev S, Zlatanov M, Bahtchevanska S (2005) A comparative study on the effect of some antioxidants on the lipid and pigment oxidation in dry fermented sausages. *Int J Food Sci Technol* 40:977–983
- Barbut S (2001) Effect of illumination sources on the appearance of fresh meat cuts. *Meat Sci* 59:187–191
- Brewer MS, Ikins WG, Harbers CAZ (1992) TBA values, sensory characteristics, and volatile in ground pork during long term frozen storage: effect of packaging. *J Food Sci* 57:558–561
- Caraballo J, Cavestany M, Jiménez-Colmenero F (1991) Effect of light on colour and reaction of nitrite in sliced pork bologna under different chilled storage temperatures. *Meat Sci* 30:235–244
- Daly MP, Acton JC (2003) Effects of dark storage time and W-Filtered fluorescent lighting during display on colour stability of high-oxygen modified atmosphere packaged ground beef. *J muscle foods* 15:1–22
- Estévez M, Morcuende DD, Cava R (2003) Oxidative and colour changes in meat from three lines of free-range reared Iberian pigs slaughtered at 90 kg live weight and from industrial pig during refrigerated storage. *Meat Sci* 65:1139–1146
- Estévez M, Ventanas S, Cava R (2005) Physicochemical properties and oxidative stability of liver pâté as affected by fat content. *Food Chem* 92:449–457
- Gokalp HY, Ockerman HW, Plimpton RF, Harper WJ (1983) Fatty acids of neutral and Phospholipids, rancidity scores and TBA values as influenced by packaging and storage. *J Food Sci* 48:829–834
- Gonzalez MJ, Gray JI, Schemmel RA, Welsch CW (1992) Lipid peroxidation products are elevated in fish oil diets even in the presence of added antioxidants. *J Nutr* 122:2190–2195
- Gray JI, Gomaa EA, Buckley DJ (1996) Oxidative quality and shelf life of meats. *Meat Sci* 43:S111–S123
- Gutensperger B, Escher FE (1994) Oxidative changes of heat sterilized meat in trays. *J Food Sci* 59:689–692
- Hunt MC, Acton JC, Benedict RC, Calkins CR, Cornforth DP, Jeremiah LE, Olson DG, Salm CP, Savell JW, Shivas SD (1991) Guidelines for meat colour evaluation. In: *Proceedings 44th Reciprocal Meat Conference*, 9–12 June 1991
- Igene JO, Pearson AM (1979) Role of phospholipids and triglycerides in warmed-over flavour development in meat model systems. *J Food Sci* 44:1285–1290
- Igene JO, Yamauchi K, Pearson AM, Gray JI, Aust SD (1985) Evaluation of 2-thiobarbituric acid reactive substances (TBARS) in relation to warmed-over flavor (WOF) development in cooked chicken. *J Agric Food Chem* 33:364–367
- Insausti K, Beriain MJ, Purroy A, Alberti P, Lizaso L, Hernandez B (1999) Colour stability of beef from different native cattle breeds stored under vacuum and modified atmosphere. *Meat Sci* 53:241–249
- Krzywicki K (1979) Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of meat. *Meat Sci* 3:1–10
- Leon K, Mery D, Pedreschi F, Leon J (2006) Colour measurement in $L^*a^*b^*$ units from digital images. *Food Res Int* 39:1084–1091
- Mancini RA, Hunt MC (2005) Current research in meat colour. *Meat Sci* 71:100–121
- Møller JKS, Weber CJ, Bertelsen B (1999) Factors affecting discoloration of cured meat products packaged in modified atmosphere. *Nordic Food packs Seminar 1999*, at Copenhagen, Denmark
- Møller JKS, Jensen JS, Olsen MB, Skibsted LH, Bertelsen B (2000) Effect of residual oxygen on colour stability during chill storage of sliced, pasteurized ham packaged in modified atmosphere. *Meat Sci* 54:399–405
- Møller JKS, Nannerup L, Skibsted LH (2005) Effect of carbon dioxide on autoxidation of nitrosomyoglobin. *Meat Sci* 69:71–78
- Morrissey PA, Sheehy PJA, Galvin K, Kerry JP, Buckley DJ (1996) Lipid stability in meat and meat products. *Meat Sci* 49: S73–S86
- Nannerup LD, Jakobsen M, Van denBerg F, Jensen JS, Møller JKS, Bertelsen G (2004) Optimizing colour quality of modified atmosphere packed sliced meat products by control of critical packaging parameters. *Meat Sci* 68:577–585
- Nicolalde C, Stetzer AJ, Tucker EM, McKeith FK, Brewer MS (2005) Antioxidant and modified atmosphere packaging prevention of discoloration in pork bones during retail display. *Meat Sci* 72:713–718
- Park SY, Yoo SS, Eun JB, Lee HC, Kim YJ, Chin KB (2007) Evaluation of lipid oxidation and oxidative products as affected by pork meat cut, packaging method, and storage time during frozen storage. *J Food Sci* 72:C114–C119

- Pearson AM (1995) Introduction to quality attributes and their measurement in meat, poultry and fish products. In: Pearson AM, Dutson TR (eds) Quality attributes and their measurement in meat, poultry and fish products. *Advances in Meat Research Series 9*: 1–25
- Raharjo S, Sofos JN, Schmidt GR (1992) Improved speed, specificity, and limit of determination of aqueous acid extraction thiobarbituric acid method for measuring lipid peroxidation in beef. *J Agric Food Chem* 40:2182–2185
- Salih AM, Smith DM, Price JF, Dawson LE (1987) Modified Extraction 2 thiobarbituric acid method for measuring lipid oxidation in poultry. *Poultry Sci* 66:1483–1488
- Sans RG, Chozas MG (1998) The Thiobarbituric Acid (TBA) reaction in foods: a review. *Crit Rev Food Sci Nutr* 38(4):315–330
- Shahidi F (1998) Assessment of lipid oxidation and off-flavour development in meat and meat products. In: Shahidi F (ed) *Flavour of meat and meat products*. Chapman & Hall, London, pp 373–390
- Shlafer M, Shepard BM (1984) A method to reduce interference by sucrose in the detection of thiobarbituric acid-reactive substances. *Anal Biochem* 137:269–276
- Skibsted LH (1996) Chemical changes in meat and meat products during storage, transportation and retail display: Theoretical considerations. In: Taylor SA, Raimundo A, Severini M, Smulders FJM (eds) *Meat quality and meat packaging*. ECCEAMST, Utrecht, pp 169–181
- SPSS (2006) SPSS for windows: Statistical software, version 15.0
- Tarladgis BG, Watts BM, Younathan MT, Dugan LR (1960) A distillation method for the quantitative determination of malonaldehyde in rancid flavor. *J Am Oil Chem Soc* 37:44–48
- Wang B, Pace RD, Dessai AP, Bovell-Benjamin A, Phillips B (2002) Modified extraction method for determining 2-Thiobarbituric acid values in meat with increased specificity and simplicity. *J Food Sci* 67:2833–2836
- Wulf DM, Wise JW (1998) Measuring muscle colour on beef carcasses using the L*a*b* colour space. *J Anim Sci* 77:2418–2427
- Yu L, Scanlin L, Wilson J, Schmidt G (2002) Rosemary extracts as inhibitors of lipid oxidation and colour change in cooked turkey products during refrigerated storage. *J Food Sci* 67:582–585