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Meat Science 68 (2004) 577–585
MEAT SCIENCE
www.elsevier.com/locate/meatsci

Optimizing colour quality of modified atmosphere packed sliced meat products by control of critical packaging parameters

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Received 22 January 2004; received in revised form 14 May 2004; accepted 18 May 2004

Abstract

To study the influence of different packaging and storage parameters on the colour stability of modified atmosphere packed, cured, cooked ham, a multiplicative analysis of variance model (GEMANOVA) was developed. The critical parameters investigated were % residual-O_2, product to headspace volume ratio (P/H volume ratio), temperature, light intensity and oxygen transmission rate (OTR). The model illustrated that all the investigated parameters interacted, but especially % residual-O_2 and P/H volume ratio – i.e., the absolute O_2 content, influenced the degree of discoloration. The complex interactions of the parameters justified the selected model, as it emphasised the necessity of evaluating the parameters simultaneously instead of considering them individually. The importance of absolute O_2 content was further validated through an industrial experiment including three different kinds of sliced meat products.

Keywords: Cured cooked ham; Colour stability; Modified atmosphere packaging; Oxygen transmission rate; Multiplicative analysis of variance

1. Introduction

Modified atmosphere (MA) packaging has already gained substantially in use for meat products and still possesses a considerable potential for increased application (Sørheim & Nissen, 2000). However, during MA-packaging and storage several quality aspects must be considered simultaneously in order to obtain an optimal product quality and shelf life. Colour stability is one of the important characteristics associated with the quality of MA-packed cured, cooked ham, since it is the primary quality attribute seen by the consumer, who may use it as an indication of freshness and wholesomeness.

A number of previous studies have investigated parameters critical to the colour stability. The investigated parameters are: % residual-O_2 (Møller et al., 2003; Møller, Jensen, Olsen, Skibsted, & Bertelsen, 2000), product to headspace volume ratio (P/H volume ratio) (Møller et al., 2003), oxygen transmission rate (OTR) of the packaging material (Juncher et al., 2003; Møller et al., 2003), storage temperature (Jakobsen & Bertelsen, 2000), light intensity and product composition (Dineen et al., 2000; Møller et al., 2003; Walsh et al., 1998).

Although several parameters critical for the colour have been studied and each found to be crucial, understanding of the interactions between the parameters is less well researched. A better understanding of the interactions and their influence on the oxidation of nitrosylmyochrome and thereby the colour stability of cured, cooked ham, can be established by mathematical and statistical modelling. A mathematical model will be a useful tool to clarify to what extent alteration of an individual parameter affects the colour of MA-packed cured, cooked meat products and to choose the optimal parameter settings for MA-packaging and storage of cured, cooked meat products. Mathematical modelling has previously proven useful in relation to optimisation of colour and colour stability in fresh beef (Bro & Jakobsen, 2002; Jakobsen & Bertelsen, 2000).

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0309-1740/$ - see front matter
doi:10.1016/j.meatsci.2004.05.009

In the present study, a model was developed to explore the interactions between the investigated parameters and to identify the parameters most important for the colour stability. The parameters investigated were: % residual-O_2, P/H volume ratio, light intensity, temperature and storage time. The effect of OTR was included in the study by evaluating changes in O_2 concentration in the MA-packs derived from choosing packaging films of different OTRs. Furthermore, the cured, cooked hams used in the experiments were characterized by several chemical parameters analysed in order to evaluate if the differences in chemical composition influenced the model. The experimental work was divided into three parts: (I) a packaging experiment with cured, cooked ham providing the basis for development of the model, (II) an experiment for evaluation of the effect of packaging material OTR and (III) an application experiment at an industrial partner in order to validate the results from the model on three different sliced meat products including cured, cooked ham.

2. Methods and materials

2.1. Meat products

Cured, cooked hams used for the packaging experiment were produced at the Danish Meat Research Institute (Roskilde, Denmark). The hams were fabricated from single muscles to avoid animal related variations within hams. After cutting, boning and trimming, the muscles were injected with curing brine to a 20% weight gain by multi-needle injection. The curing process resulted in an added nitrite content of 60 ppm. After curing, the muscles were mechanically tenderised with a roller knife distance of 9 cm. The tenderising was followed by tumbling for 16 h. After draining 5.2 kg was weighed out, carefully stuffed in boiling bags and closed under vacuum. The hams were placed in moulds and heat-treated to a centre temperature of 75 °C. After heat-treatment, they were stored for 3 days at 2 °C and repacked in vacuum bags. The hams were kept in the dark at 2 °C until slicing and packaging.

For the application experiment three different kinds of sliced meat products were used: (1) cured, cooked ham; (2) cured, smoked and cooked pork loin and (3) saveloy. The products were manufactured at Tulip Food Company (Denmark), and afterward stored in the dark at 2–5 °C. Just before slicing the products were frozen to −2 to −4 °C in order to ease the slicing process.

2.2. Slicing and packaging

In the packaging experiment cured, cooked ham pieces of 1 cm thickness (approximately 60 g) were placed in polystyrene trays, measuring $13 \times 10.5 \times 2$ cm (FÆRCH PLAST, Holstebro, Denmark), randomised and packed in barrier pouches measuring 22.5×15.5 cm (NEN 40 HOB/LLDPE 75, Amcor Flexible Europe, Lyngby, Denmark) with an OTR of 0.45 $cm^3/m^2/atm/24$ h. The packages were vacuumised, filled with gas mixture and sealed using a Multivac gas/vacuum packaging machine (Multivac A/S, Vejle, Denmark). Different P/H volume ratios were obtained by inflating different amounts of gas to reach P/H volume ratios of 1/1, 1/1.5 and 1/3. The applied gases were premixed (AGA A/S, Copenhagen, Denmark) containing 20% CO_2 and balanced with N_2. Four levels of O_2 were used: 0%, 0.5%, 1% and 1.5%. To obtain 0% O_2 an O_2-scavenger (GM-20, Mitsubishi Gas Chemical America, New York, USA) was placed in the packages. Gas composition was measured during storage in empty packages as well as packages containing ham and having a P/H volume ratio of 1/1.5.

In the OTR experiment two different types of pouches were applied. One with a medium O_2 barrier: OPA12/PE with an OTR of 38 $cm^3/m^2/atm/24$ h (Amcor Flexible Europe, Lyngby, Denmark) and one with a high O_2 barrier: NEN 40 HOB/LLDPE 75 with an OTR of 0.45 $cm^3/m^2/atm/24$ h (Amcor Flexible Europe, Lyngby, Denmark). The pouches were vacuumised, filled with mixed gas and sealed by the means of a KOMET gas/vacuum packaging machine (type X2000, KOMET, Stuttgard, Germany) equipped with a MAP mix 9000 gas-mixer (PBI–Dansensor A/S, Ringsted, Denmark). The pouches were packed using 20% CO_2 and 80% N_2.

During the application experiments, the meat products were sliced and packed at Tulip Food Company (Denmark). Different P/H volume ratios were achieved by varying the number of slices in the package. The packaging material used for the bottom was identical for all packages: PET/PE with an OTR of 12 $cm^3/m^2/atm/24$ h (NEOPLASTICA AG, Mägenwil, Switzerland). The foil used for the bottom was thermoformed to a depth of 2.5 cm ending up with dimensions of $10 \times 10 \times 2.5$ cm. Two types of lid materials were used: OPA/PE with an OTR of 38 $cm^3/m^2/atm/24$ h (Bemis Packaging, Horsens, Denmark) and a laminate consisting of polyester and EVOH with an OTR of 2 $cm^3/m^2/atm/24$ h (E-K PACK FOLIEN, Ermengerst, Germany). The packages were vacuumised, filled with gas and finally the lid was welded on. The gas composition was 30% CO_2 and 70% N_2.

2.3. Storage

After packaging, the cured, cooked hams for the packaging experiment were placed in open forced air chill cabinets for 35 days. The temperatures were adjusted to 5, 8 and 10 °C, respectively. Some of the packages were kept in darkness and others were illuminated with 600 or 1200 lx measured at the surface of the product. The packages to be used for measurement of gas composition were stored at 1200 lx and 5 °C.

The pouches applied for the OTR experiment were stored for 45 days at 1 and 11 °C and illuminated with 1200 lx.

The packages used for the application experiments were stored for 35 days at 5 and 8 °C using light intensities of 600 and 1200 lx. The packages to be used for measurement of gas composition were stored at 1200 lx and 6 °C.

The chill cabinets used in all three experiments defrost once a day resulting in a short-period increase in temperature to approximately 12 °C. All packages were illuminated for $9\frac{1}{2}$ h a day using fluorescent tubes (Philips New Generation TLD, 18W/830, Copenhagen, Denmark). The packages in the chill cabinets were rotated on a regular basis to assure a uniform illumination and temperature distribution.

2.4. Analyses

2.4.1. Gas composition

The gas composition (% O_2 and % CO_2) was analysed using a CheckMate gas-analyzer (PBI-Dansensor A/S, Ringsted, Denmark).

During the packaging experiment, gas composition was measured in duplicate using a new package for each measurement. During storage, the gas composition was measured five times for packages containing ham and three times for empty packages.

In the OTR experiment, the gas composition was analyzed eight times and in the application experiment five times during the storage period.

2.4.2. Colour measurements

Surface colour was measured by a tri-stimulus colorimeter (Minolta Chroma Meter Measuring Head CR-300 equipped with Data Processor DP-301; Minolta, Osaka, Japan) with a measuring area of 8 mm and expressed as CIE a^*-values. Before each measurement, the apparatus was calibrated against a white tile ($L = 97.43$; $a = -5.16$ and $b = 6.97$). The measurements were performed through the transparent packaging material, and for each piece of ham measurements on five different locations were averaged.

Colour was measured 12 times during the storage period on day 0, 1, 2, 4, 7, 9, 11, 15, 20, 25, 30 and 34. The CIE a^*-value was used for describing the red colour. An a^*-value around 7 corresponds to an acceptable red colour while a low or negative a^*-value corresponds to a discoloured sample.

2.4.3. Volume (headspace)

Determinations of the gas volume in the packages were performed by immersing the packages into a beaker containing water and reading the increase in water level. By deducting the weight of meat inclusive the packaging material and tray (setting their density to 1 kg/L), the residual amount of increased water level represents the gas volume in the package.

2.4.4. Chemical analyses

The content of water, salt, total fat, total iron, nitrite and vitamin E were analysed. The pH and the fatty acid composition were also determined. The analyses were performed or modified after the methods described in Jensen et al. (1997), Folch, Lees, and Stanley (1957), Jart (1997), Norwitz and Keliher (1987), Binstok, Campos, and Gerschenson (1996), Miranda, Espey, and Wink (2001), AOAC (2000), 973.31 and Dansk standard (1982), DS259, DS263.

2.5. Data handling

The packaging experiment was a full factorial design consisting of the six factors: Time $\times$ Oxygen $\times$ P/H volume ratio $\times$ Temperature $\times$ Light $\times$ Animals. Each factor was varied on several levels as shown in Table 1.

The data cube is thus $12 \times 4 \times 3 \times 3 \times 3 \times 8 = 10,368$ measurements and only one sample was missing. The response variable used is the colour (redness) of the meat expressed as the a^*-value.

Each measurement is the average of 5 readings on different locations on the ham. The measurement error for each piece of ham is $1.58/\sqrt{5} = 0.7$ a^*-values, where the 1.58 colour unit is an estimated pooled standard deviation.

The developed model is a GEMANOVA model (GEneralized Multiplicative ANalysis Of VAriance). The R^2-value for the GEMANOVA model is 0.92. Details on the model type and previous applications are discussed in Bro and Heimdal (1996), Bro (1997), Bro and Jakobsen (2002) and Bro et al. (2002). The model is multiplicative and can be expressed as one higher order interaction term.

$$a^*\text{-value} = C_0 \times C_A \times C_{02} \times C_{P/H} \times C_T \times C_L \times C_D \qquad (1)$$

where C_0 is a constant and C_A is taken as the average contribution over the eight animals. C_{02}, $C_{P/H}$, C_T, C_L

Table 1
Factors and levels used for the packaging experiment

Factor	Number of levels	Level
Time, D (days)	12	0, 1, 2, 4, 7, 9, 11, 15, 21, 25, 30, 34
Oxygen, O_2 (%)	4	0.0, 0.5, 1.0, 1.5
Product/headspace volume ratio, P/H	3	1/1.0, 1/1.5, 1/3.0
Temperature, T (°C)	3	5, 8, 10
Light, L (lx)	3	0, 600, 1200
Animal, A	8	1–8

and C_D are contributions from the different packaging and storage factors in Table 1.

3. Results and discussion

3.1. The packaging experiment

To evaluate the eventual variation between the hams prepared from eight individual pigs, principal component analysis (PCA) was performed on the results obtained from the chemical analyses. Three principal components were sufficient to explain the variation between animals. A 3D score plot (not shown) reveals that there were no extreme animals, i.e., the muscles from the eight pigs did not differ substantially from each other in chemical composition. Consequently, none of the chemical composition parameters were to be included in the final model. The chemical analyses will not be discussed further.

Although the muscles did not differ in chemical composition, both the initial a^*-value and the colour fading during storage varied between muscles. The cause of variation might arise from differences in the amount of enzymes present in muscles, which are capable of regenerating the pigment and thereby the pink colour (Taylor, 1996).

To identify the packaging parameters critical for the colour stability of cured, cooked ham, a mathematical model was developed. The colour was measured as the CIE a^*-value (Andersen, Bertelsen, Boegh-Soerensen, Shek, & Skibsted, 1988), where a high value (redness) is judged more attractive by the consumers. The packaging and storage parameters were: storage days (D), % residual-O_2 (O_2), P/H volume ratio (P/H), light intensity (L) and temperature (T).

When fitting a GEMANOVA model to the data the following model was obtained

$$a^*\text{-value} = C_0 \times C_A \times C_{02} \times C_{P/H} \times C_T \times C_L \times C_D = 589 \times 0.35 \times C_{02} \times C_{P/H} \times C_T \times C_L \times C_D. \quad (2)$$

The model parameters are presented graphically in Fig. 1. For a specific setting of the experimental packaging parameters the estimate of the colour can be calculated by reading the ordinates (value on the y-axis) on the corresponding graphs and multiply them together. An example of calculation is given below, setting $D = 5$, $O_2 = 1.5$, $P/H = 1/1$, $L = 1200$ and $T = 10$:

$$a^*\text{-value} = 589 \times 0.35 \times C_{02} \times C_{P/H} \times C_T \times C_L \times C_D = 589 \times 0.35 \times 0.47 \times 0.62 \times 0.58 \times 0.52 \times 0.29 = 5.25.$$

The best colour is obtained by choosing parameter settings corresponding to high ordinate values. In this way an (graphical) optimization of the different packaging parameters can be carried out. In Table 2 calculated a^*-values for worst-case and optimal settings are shown. Day 5 is chosen as setting point for the parameter "Time". For both settings calculated a^*-values are shown for P/H volume ratios of 1/1 and for 1/3.

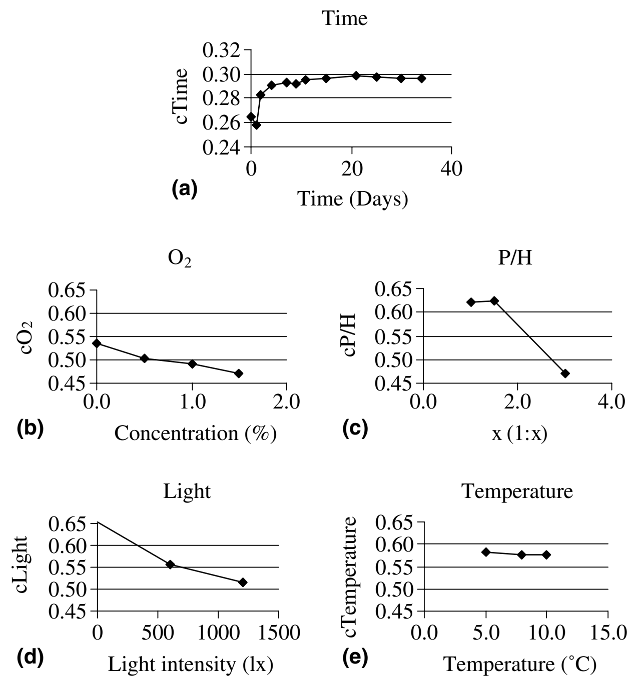

Fig. 1. Plots providing the basis of the GEMANOVA model. Alteration of the colour due to the parameter: (a) storage time; (b) oxygen; (c) P/H volume ratio; (d) light intensity and (e) temperature.

Table 2 illustrates that when using optimal settings for the packaging and storage parameters (column 4) an estimated a^*-value of 7.56 is obtained, which corresponds to an attractive pink colour. When increasing the gas volume, e.g., decreasing the P/H volume ratio to 1/3 the a^*-value is decreased approximately 24%. Worst case settings for the parameters (column 3) results in an almost 50% reduction of the a^*-value to 3.98, illustrating that storage and packaging parameters can severely influence the colour stability. Changing the P/H volume ratio from 1/1 to 1/3, the a^*-value is reduced with approximately 24%.

Fig. 1(a) shows that no particular alteration of the colour is observed due to storage time alone. However, a transient discolouration is seen at the beginning of the storage. The sharp decline in a^*-value has also been observed in other studies (Andersen & Rasmussen, 1992; Juncher et al., 2003) and might be explained by oxidative processes, which stop when all the O_2 has been consumed by reducing substances present in the product. When all available O_2 is consumed, no further oxidation of the pigment nitrosylmyochrome will occur, leading to a reformation of the colour (Skibsted, 1996). However, the colour will never reach its starting point.

Table 2
Calculated a^*-values by means of the multiplicative model for worst-case and optimal parameter settings

	Worst settings		Optimal settings	
	$P/H = 1/1$	$P/H = 1/3$	$P/H = 1/1$	$P/H = 1/3$
Oxygen (%)	1.5	1.5	0.05	0.05
P/H	1/1	1/3	1/1	1/3
Light (lx)	1200	1200	Dark	Dark
Temperature (°C)	10	10	5	5
Time (days)	5	5	5	5
a^*-value	5.25	3.98	7.56	5.72

This is not demonstrated, as it was impossible to measure the colour immediately after packaging due to practically reasons.

To summarize the parameter "Time" does not seem to have any particularly influence, when using a high barrier packaging material. Using a material with medium OTR would probably cause a reduction in colour with time and thereby a deterioration in a^*-value. Juncher et al. (2003) found that using a packaging material with an OTR of 40 cm^3/m^2/atm/24 h resulted in a decrease in the a^*-value of roasted ham. When using a high barrier material (OTR of 0.5 cm^3/m^2/atm/24 h) no further deterioration in a^*-value was seen after re-establishment of the initial colour.

The influence of O_2 can be interpreted from Fig. 1(b). A declining curve shows that increased O_2 leads to a degradation of the pink colour. Møller et al. (2000) found that to avoid fading of the pink ham colour, initial O_2 content ($P/H = 1/3$) should be less than 0.5%.

Fig. 1(c) illustrates that increasing the P/H volume ratio from 1/1.5 to 1/3 results in a pronounced reduction in colour, while reducing the ratio from 1/1.5 to 1/1 does not really affect the colour.

To maintain an optimal colour the cooked ham should be stored in darkness, as a fading of the pink colour is already observed when illuminating the packages with a light intensity of 600 lx – Fig. 1(d). Increasing the intensity to 1200 lx caused further discoloration.

In the developed model temperatures between 5 and 10 °C – Fig. 1(e) – does not affect the colour stability considerably. However, raising the temperature from 5 to 10 °C will have an important effect on the microbial shelf life.

A comparison of the five plots in Fig. 1 reveals that the largest relative changes in a^*-values arise from changing % residual-O_2, P/H volume ratio and illumination. Sliced cooked ham is normally illuminated during retail display, and even though the problem of discolouration due to light exposure is often remedied by using a label, light is not entirely excluded. It is therefore the P/H volume ratio and % residual-O_2, i.e., the absolute O_2 content, which can be optimized to stabilize the pink colour.

Møller et al. (2003) investigated the influence of % residual-O_2, OTR, P/H volume ratio, illumination and nitrite level on the oxidative discoloration of cured ham during 14 days of chill storage. The result emphasizes the results of the present study: Interactions between headspace O_2 level, P/H volume ratio and the level of illumination may be used to control the colour stability of cured ham.

The packaging experiment was carried out using a high barrier laminate (OTR = 0.45 cm^3/m^2/atm/24 h), as the influence of oxygen transmission can be calculated theoretically. The gas composition in the package and its alteration over time is extremely dependent on the OTR of the packaging material. In relation to oxidation, the task is to select a packaging material, which will sustain a low level of O_2 inside the package throughout the required storage period (Larsen, Kohler, & Magnus, 2002). Related to this requirement a prediction of the O_2 concentration in the headspace of the package over time is of interest.

When using a high barrier laminate for MA-packaging of cooked ham a decrease in O_2 content is observed during the entire storage period (Fig. 2). The decline could be due to microbiological respiration and

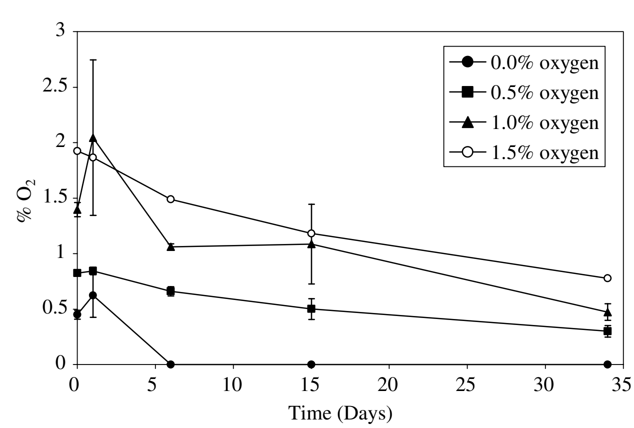

Fig. 2. O_2 content measured in packages containing cured, cooked ham during storage and using a high barrier laminate (0.45 cm^3/m^2/atm/24 h). ● are MA-packed with 0% O_2 obtained by the means of an O_2 absorber. ■, ▲ and ○ are MA-packed with 0.5%, 1.0% and 1.5% O_2, respectively.

chemical reactions involving O_2 (Andersen et al., 1988). Applying high barrier packages without ham, no decrease or increase in O_2 content during storage were seen (results not shown).

3.2. The OTR experiment

To investigate the effect of the OTR of the packaging material, measurements were carried out using empty packages; hence no O_2 is consumed by oxidative processes.

The amount of gas that permeates through a packaging material is commonly calculated by means of the following equation (Robertson, 1993):

$$Q = P/x \times \Delta p \times t \times A, \quad (3)$$

where Q is the amount of gas that permeates over the packaging material (cm^3). P/x is the theoretical permeability of the packaging material ($cm^3/m^2/24$ h/atm) with x (μ) being the thickness of the material. Δp is the difference in gas partial pressure on the two sides of the material (atm). t is the storage time (24 h) and A is the area of the package (m^2).

Based on Eq. (3), the O_2 concentration in the package cO_2 (%) can be calculated as:

$$cO_2 = \frac{O_2^i + OTR_{corr} \cdot (pO_2^a - pO_2^p) \cdot t \cdot A}{Vol} \cdot 100, \quad (4)$$

where O_2^i is the initial oxygen amount; $cO_2 \times$ Vol (ml). OTR_{corr} is the oxygen transmission rate of the material corrected to the applied temperature ($cm^3/m^2/24$ h/atm). pO_2^a is the atmospheric partial pressure of O_2 (0.21 atm). pO_2^p is the partial pressure of O_2 in the package (atm) and Vol is the gas volume of the package (ml).

In practice, the OTR value replaces the P/x value in Eq. (3). It is expected to apply for minor changes in the difference in partial pressure inside and outside the material (the driving force), i.e., for packages with a low OTR-value or for packages stored for a short period of time. To test the validity of Eq. (4) a test was performed applying two materials, both relevant for packaging of sliced cured, cooked ham (a medium OTR-value and a low OTR-value) at two different temperatures. An often applied rule of thumb says that the OTR is approximately halved for each temperature reduction of 8 °C, leading to OTR_{corr}. Measured values are plotted together with calculated values in Fig. 3.

Fig. 3 illustrates the validity of Eq. (4). The measured O_2 content is equivalent to the calculated O_2 content, although deviations are observed for the medium OTR material at 11 °C and prolonged storage. The consequence of selecting packaging materials with different OTRs can be evaluated from Fig. 3. The amount of O_2 that permeates through the packaging material is highly dependent on the OTR, and as expected an OTR of 38 compared to 0.45 results in a higher permeation of O_2.

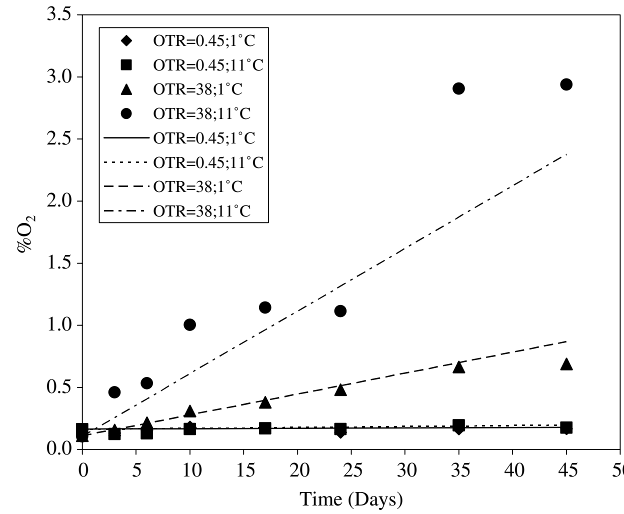

Fig. 3. Measured and calculated % O_2-contents. ◆, ■, ▲ and ● are the measured values. —, · · ·, - - - and -·- are the calculated. Two different pouches are used: a medium barrier (OTR = 38 cm^3/m^2/atm/24 h) and a high barrier (OTR = 0.45 cm^3/m^2/atm/24 h). Storage temperatures were 1 and 11 °C. All pouches contained 0.15% O_2 at initiation of experiment.

Temperature is not important for OTR = 0.45 materials, but applying the medium OTR material, the temperature dependence then becomes significant.

As most MA-packed sliced meat products have a shelf life of approximately 28 days, Eq. (4) is considered appropriate and can be applied in combination with the model. When using materials of different OTRs, the estimated O_2-concentration can be inserted in the model as a worst case estimate instead of the residual-O_2 concentration.

3.3. The application experiment

To validate the developed mathematical model and to test its practical application, three kinds of MA-packed sliced meat products were used: cured, cooked ham; cured, smoked and cooked pork loin and saveloy. Two types of packaging materials and two levels of P/H volume ratios were applied. The packages were stored for 35 days at two temperatures and two intensities of illumination. The residual O_2 content originate from insufficient evacuation and O_2 dissolved in or entrapped between the meat slices.

Fig. 4 shows the reduction in colour for the three kinds of meat products during the storage period. The temperature is 5 °C and the P/H volume ratio is 1/1. For ham 5 °C and 1/3 is also shown (Fig. 4(b)).

Fig. 4 illustrates that packages illuminated with 600 lx maintain the colour better than packages illuminated with 1200 lx. This is valid for all three products and correlates with the results obtained from the packaging experiments. The initial colour for the three products is not identical; cured, cooked ham has an initial a^*-value

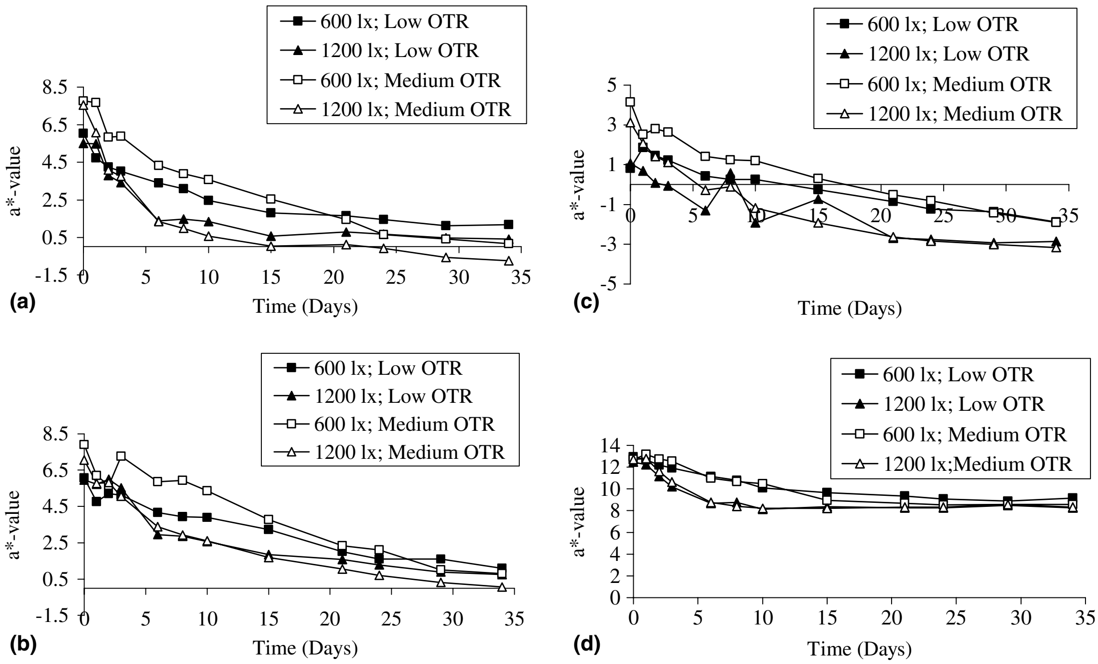

Fig. 4. Colour, measured as tristimulus a^*-values, during storage for cooked, cured ham; cured, smoked, cooked pork loin and saveloy. The storage temperature is 5 °C and the P/H volume ratio is 1/1 (plot (a), (c) and (d)). (b) Cooked ham with the P/H volume ratio = 1/3. Packages with two different barrier lid films were used: a low OTR (■, ▲) (OTR = 2 $cm^3/m^2/atm/24$ h) and a medium OTR (□, △) (OTR = 38 $cm^3/m^2/atm/24$ h).

of approximately 7 and cured, smoked, cooked pork loin and saveloy has initial a^*-values of 2 and 12, respectively. This emphasizes that when using the model, it is not the initial a^*-value itself that should be in focus, as this value depends on both product type and inter animal variations. The proper application of the model is to evaluate whether a change in one or more parameters lead to changes in a^*-value. If one factor is to be changed resulting in a decreased colour stability precautions can be taken against this by changing another factor in the opposite direction.

By changing the P/H volume ratio from 1/1 to 1/3 a more rapid decrease in colour would be expected. This was not the case in the application experiment, where a P/H volume ratio of 1/1 caused a more rapid colour deterioration compared to the P/H volume ratio of 1/3. This observation is explained by the absolute O_2 content (only the colour reduction for cured, cooked ham is depicted in Fig. 4, but the same effect is observed for all three products). In order to calculate the absolute O_2 content in the packages, gas composition and changes in gas volume for a number of samples were measured during storage. The packages were stored at 6 °C and 1200 lx. Calculating the absolute O_2 content showed that packages with a P/H volume ratio of 1/1 contained a higher absolute O_2 content than the packages with a P/H volume ratio of 1/3. Cured, cooked ham packages with a P/H volume ratio of 1/1 contained approximately 21% more O_2 than packages with a P/H volume ratio of 1/3. For saveloy packages, the difference in absolute O_2 content was approximately 38%. For cured, smoked and cooked pork loin only minor differences were observed. The P/H volume ratio was varied by adjusting the number of slices in constant volume packages, i.e., packages with a P/H volume ratio of 1/1 contained more slices than packages with a P/H volume ratio of 1/3. This would presumably lead to a higher amount of O_2 physically entrapped between slices and thereby a higher O_2 concentration (in %), large enough to result in a higher absolute O_2 content in the 1/1 packages. This observation emphasizes the results of the packaging experiment and the developed model, i.e., it is the absolute O_2 content and not the relative (% O_2), that is crucial for the colour stability.

Raising the temperature from 5 to 8 °C does not affect the colour of any of the products (not shown). This correlates well with the results obtained in the model experiment, where temperatures in the interval from 5 to 10 °C did not in particularly affect the colour.

The influence of the packaging material is seen after approximately 15 days of storage (not shown). Cured, cooked ham packages with a high barrier lid (OTR = 2 $cm^3/m^2/atm/24$ h) has a significantly better colour compared to packages containing a lid with a medium O_2 barrier. This is the case for all three kinds of sliced meat products applied for the application experiment. To evaluate the importance of the OTR, the O_2 content was measured in empty packages sealed with a high or medium barrier lid. The packages were stored for 35 days at 6 °C and 1200 lx. The result is shown in Fig. 5.

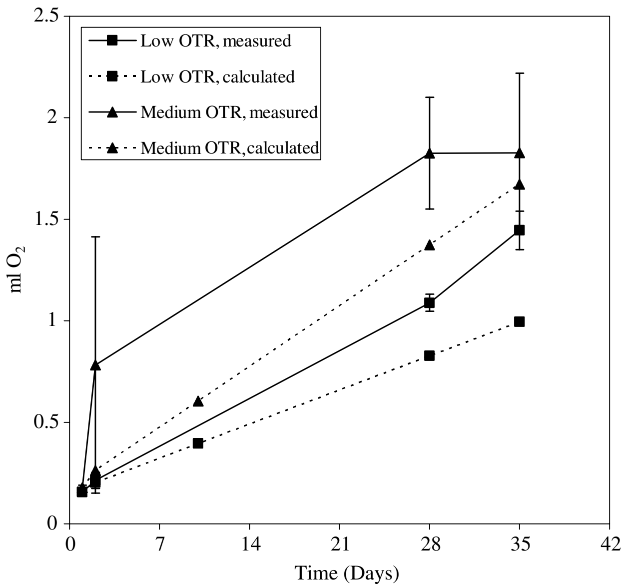

Fig. 5. The O_2 content (ml) measured in empty packages sealed with high barrier (2 $cm^3/m^2/atm/24$ h) (■) or medium barrier (38 $cm^3/m^2/atm/24$ h) (▲) lid films. The full-drawn lines represent the measured values and the broken lines the calculated ones.

Fig. 5 illustrates that when using lids with a high and medium O_2-barrier, the absolute O_2 content calculated from Eq. (4) in both cases is below the measured O_2 contents. Previous experience has shown it difficult to calculate the OTR_{corr} of thermoformed film material and under storage condition deviating from the ASTM standard conditions. Preferably, the OTR of the final package should be measured under realistic storage conditions (Larsen et al., 2002).

The application experiment confirmed the model. The parameters important for the colour predicted by the model are identical to those determined as being important for the colour obtained in the application experiment.

4. Conclusion

The present work developed a multiplicative model (GEMANOVA) to predict the relative importance of the packaging conditions (% residual-O_2, P/H volume ratio, temperature and light intensity) for the colour stability of cured, cooked ham. The model is capable of predicting if modification of one or more parameters will cause a change in a^*-value, thereby altering the colour stability of the product during retail display.

It is shown that the applied parameters interact in a complex way influencing the product colour. Moreover, % residual-O_2 and P/H volume ratio – i.e., the absolute O_2 content – are shown to be the most critical parameters. Furthermore, the model illustrates that the light intensity too, is relevant for the colour stability, while the temperature in the investigated range (5–10 °C) is unimportant. The influence of the OTR of the packaging material can be included in the model indirectly by theoretical calculations of its contribution to the O_2 concentration in the packages.

The meat industry can use the developed model as a tool to predict whether an alteration of one or more of the packaging parameters will cause severe changes in colour. A choice of packaging parameters based on prediction of a^*-values should always be validated in a practical experiment, as the model is based on results obtained from cured, cooked hams specially fabricated from single muscles prepared from eight individually pigs.

Acknowledgements

This study was part of a collaboration project sponsored by the Danish Meat Research Institute and the FØTEK programme (FØTEK 3 (93S-2444-Å00-00072)) through the Danish Ministry of Food, Agriculture and Fisheries. The authors are grateful to the Danish Meat Research Institute for producing and packaging of the cured ham and to Tulip Food Company for making available their packaging equipment, and for technical assistance by Mariann Søe.

References

Andersen, H. J., Bertelsen, G., Boegh-Soerensen, L., Shek, C. K., & Skibsted, L. H. (1988). Effect of light and packaging conditions on the colour stability of sliced ham. *Meat Science, 22*, 283–292.

Andersen, H. J., & Rasmussen, M. A. (1992). Interactive packaging as protection against photodegradation of the colour of pasteurized, sliced ham. *International Journal of Food Science and Technology, 27*, 1–8.

AOAC. (2000). Association of Official Analytical Chemists. *Nitrites in cured meat. Meat and meat products* (973.31).

Binstok, G., Campos, C. A., & Gerschenson, L. N. (1996). Determination of nitrites in meat systems: An improved procedure. *Meat Science, 42*(4), 401–405.

Bro, R. (1997). PARAFAC. Tutorial and applications. *Chemometrics and Intelligent Laboratory Systems, 38*, 149–171.

Bro, R., & Heimdal, H. (1996). Enzymatic browing of vegetables. Calibration and analysis of variance by multiway methods. *Chemometrics and Intelligent Laboratory Systems, 34*, 85–102.

Bro, R., & Jakobsen, M. (2002). Exploring complex interactions in designed data using GEMANOVA. Colour changes in fresh beef during storage. *Journal of Chemometrics, 16*, 294–304.

Bro, R., Van den Berg, F., Thybo, A., Andersen, C. M., Jørgensen, B. M., & Andersen, H. (2002). Multivariate data analysis as a tool in advanced quality monitoring in the food production chain. *Trends in Food Science and Technology, 13*, 235–244.

Danish Standardization Board. (1982a). Dansk Standardiseringsråd. *Water quality – determination of metal in water, sludge and sediment by atomic absorption spectrophotometry. Special guidelines for cadmium, cobalt, iron, nickel, lead and zink*. Dansk Standard, DS 263. (1st ed.). January 1982 (in Danish).

Danish Standardization Board. (1982b). Dansk Standardiseringsråd. *Determination of metal in water, sludge and sediment – general guidelines for determination by atomic absorption spectrophotometry in flame*. Dansk Standard, DS 259, (1st ed.). January 1982 (in Danish).

Dineen, N. M., Kerry, J. P., Lynch, P. B., Buckley, D. J., Morrissey, P. A., & Arendt, E. K. (2000). Reduced nitrite levels and dietary α-tocopheryl acetate supplementation: Effects on the colour and oxidative stability of cooked hams. *Meat Science, 55*, 475–482.

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

Jakobsen, M., & Bertelsen, G. (2000). Colour stability and lipid oxidation of fresh beef. Development of a response surface model for predicting the effects of temperature, storage time, and modified atmosphere composition. *Meat Science, 54*, 49–57.

Jart, Aa. (1997). The magnetic field as an additional selectivity parameter in fat hydrogenation. *Journal of American Oil Chemist's Society, 74*(5), 615–617.

Jensen, C., Guidera, J., Skovgaard, I. M., Staun, H., Skibsted, L. H., Jensen, S. K., Møller, A. J., Buckley, J., & Bertelsen, G. (1997). Effects of dietary α-tocopheryl acetate supplementation on α-tocopherol deposition in porcine *m. psoas major* and *m. longissimus dorsi* and on drip loss, colour stability and oxidative stability of pork meat. *Meat Science, 45*(4), 491–500.

Juncher, D., Rønn, B., Hansen, T. B., Henckel, P., Karlsson, A., Skibsted, L. H., & Bertelsen, G. (2003). Effect of pre-slaughter physiological conditions on the oxidative stability of colour and lipid during chill storage of sliced, retail packed roast ham. *Meat Science, 63*, 151–159.

Larsen, H., Kohler, A., & Magnus, E. M. (2002). Predicting changes in oxygen concentration in the headspace of nitrogen flushed packages by the ambient oxygen ingress rate method. *Packaging Technology and Science, 15*, 139–146.

Miranda, K. M., Espey, M. G., & Wink, D. A. (2001). A rapid, simple spectrophotometric method for simultaneous detection of nitrate and nitrite. *Nitric Oxide, 5*(1), 62–71.

Møller, J. K. S., Jakobsen, M., Weber, C. J., Martinussen, T., Skibsted, L., & Bertelsen, G. (2003). Optimisation of colour stability of cured ham during packaging and retail display by a multifactorial design. *Meat Science, 63*, 169–175.

Møller, J. K. S., Jensen, J. S., Olsen, M. B., Skibsted, L. H., & Bertelsen, G. (2000). Effect of residual oxygen on colour stability during chill storage of sliced pasteurised ham packaged in modified atmosphere. *Meat Science, 54*, 399–405.

Norwitz, G., & Keliher, P. N. (1987). Interference of ascorbic and isoascorbic acids in the spectrophotometric determination of nitrite by the diazotisation – coupling technique. *Analyst, 112*(6), 903–907.

Robertson, G. L. (1993). *Food packaging: Principles and practice*. New York: Marcel Dekker, Inc.

Skibsted, L. (1996). Chemical changes in meat and meat products during storage transportation and retail display – theoretical considerations. In S. A. Taylor, A. Raimundo, M. Severini, & F. J. M. Smulders (Eds.), *Meat quality and meat packaging* (pp. 169–181). Bristol: European Consortium for Continuing Education in Advanced Meat Science and Technology.

Sørheim, O., & Nissen, H. (2000). Current technology for meat MAP. *Food Marketing and Technology* (August), 39–42.

Taylor, S. A. (1996). Basic considerations in meat packaging. In S. A. Taylor, A. Raimundo, M. Severini, & F. J. M. Smulders (Eds.), *Meat quality and meat packaging* (pp. 259–269). Bristol: European Consortium for Continuing Education in Advanced Meat Science and Technology.

Walsh, M. M., Kerry, J. F., Buckley, D. J., Morrissey, P. A., Lynch, P. B., & Arendt, E. (1998). The effect of dietary supplementation with α-tocopheryl acetate on the stability of low nitrite cured pork products. *Food Research International, 31*, 59–63.