OPTIMISATION OF COLOUR STABILITY OF SLICED HAM DURING PACKAGING AND RETAIL DISPLAY BY A MULTIFACTORIAL DESIGN

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BACKGROUND:
The colour of cured meat products is of great importance for consumers' purchase. Hence, the colour stability during storage is crucial to meat processing industries and retailers. The widespread use of modified atmosphere (MA) packaging for cured meat products has resulted in problems with the colour stability of especially cured meat products stored under illumination during retail display.

Several studies have been performed regarding the effect of individual factors on discoloration of MA- or vacuum-packaged cured meat products. The following factors have been investigated separately in storage experiments: (i) Light exposure (Yen et al, 1988; Andersen et al., 1988) and light intensity or illuminance (Ramsbottom et al., 1951), (ii) Oxygen transmission rate (OTR) of the packaging material (Yen et al., 1988), (iii) Non-oxygen gas composition (Ahvenainen et al., 1989), and (iv) Residual level of headspace oxygen (Rikert et al., 1957; Møller et al., 2000). In addition, the level of nitrite has been investigated with respect to colour formation and stability of cured meat products (Walsh & Rose, 1956; Froehlich et al., 1983). Each of these factors except gas composition have been found to affect the colour stability of cured meat. Regarding the gas composition Ahvenainen et al. (1989) found no differences in colour stability of cured ham, when varying gas mixtures of nitrogen and carbon dioxide are used.

OBJECTIVES:
The main objective was to optimise colour stability with respect to the following five parameters: *Residual oxygen*, Oxygen Transmission Rate (*OTR*) of packaging material, product to headspace *volume ratio, illuminance* level and *nitrite* content. Therefore, an incomplete block design with a $3^3 \times 2^2$ factorial structure with 10 blocks was designed. The response variable analysed was the a-value obtained from tristimulus colour measurement.

METHODS:
A standard recipe was used to produce cured ham (98% lean) containing either 60 or 150 ppm sodium nitrite. A 5 kg piece of cured ham was divided into three cuts of 5×10×40 cm. These cuts were sliced in slices of different thickness: 3, 1.2 and 0.6 cm to yield three different ratio of product to headspace volume, namely 1:1, 1:3 and 1:5. Laminated packaging materials with OTR of 0.5, 10 and 32 cm^3/m^2/atm/24h measuring 12×20 cm were used. An electronic VacuMIT gas/vacuum-packaging machine (VacuMIT Machinenbau, Duggendorf, Germany) was used to flush with various gas mixtures and close the pouches. Premixed gasses containing 20% carbon dioxide and balanced with nitrogen were obtained from AGA A/S (Copenhagen S, Denmark). Three levels of residual oxygen were used: 0.01%; 0.25% and 0.49% O_2.

The packages were placed in forced flow chill cabinets at 5°C. Fluorescent tubes were used as light source and the illuminance over the cabinets was adjusted to 500 or 1000 lux, respectively, at sample surface by varying the distance between the fluorescent tubes and the sample surface. Illuminance was measured using an Illumination Meter IM-1 (Topcan, Tokyo, Japan). Measurements of gas composition (PBI Dansensor A/S, Ringsted, Denmark) and tristimulus colour (Minolta Chroma Meter, Osaka, Japan) were performed on duplicate samples at day 1, 3, 6, 9 and 14.

The experimental design consisted of six factors. A full factorial design of the five factors results in 108 treatment combinations, but the design was reduced to 90 combinations of treatment which all were included in duplicates. A new package was used for every measurement resulting in 90 x 5 x 2 = 450 x 2 packages. The 900 packages were divided into 10 blocks (cooling cabinets).

Data relating to red colour (a-values) were analysed. To obtain variance homogeneity the a-value was transformed to $(a+3)^2$ (3 was added to the a-value in order to obtain positive values, since a-values were found in the range ÷2.6-11.1). The O_2 level (%) was measured before opening the package. After excluding leaking packages and missing observations average was taken over duplicates and the resulting data set consists of 415 out of the original 450 treatment combinations. Subsequently, data was analysed through analysis of variance and development of Response Surface Models using Unscrambler 7.5 (Camo AS, Trondheim, Norway).

RESULTS AND DISCUSSION:
Measurement of gas composition shows a significant decrease in headspace O_2 level for samples with OTR of 0.5 over storage time. Regarding packages with OTR of 10 and 32, respectively, the amount of headspace O_2 remains fairly constant during the 14 days of storage. Figure 1a and 1b show plots of average a-values with respect to the factors: Residual oxygen and volume ratio. Correspondingly, plots of a-values observed for varying OTR of packaging material and illuminance are shown in Figure 2a and 2b, respectively. In general, plots of a-values versus storage time show that each of the factors in question influence colour stability. An analysis of variance also proves that every single factor has significant effect of the red colour (a-value). However, it is difficult to mutually rank

the factors in relation to their quantitative impact on the resulting colour stability. Therefore, a new statistical model incorporating the measured O_2 level is developed, whereby the residual oxygen, OTR, volume ratio and measured O_2 all are involved in describing the total amount of oxygen present in the package headspace. Subsequently, an analysis of variance allows the factor OTR to be excluded from the model, as this factor becomes insignificant. Interestingly, the analysis of variance also reveals two significant interactions involving measured O_2 and volume ratio or illuminance, respectively.

Further details regarding the significant two-factor interactions are pursued by development of Response Surface Models yielding information about the a-value of the ham at various combinations of factors involved. Preliminary results (not shown) suggest that it is not enough solely to keep the O_2 level low Therefore, it is necessary both to keep the O_2 level low and the product to headspace volume ratio high in order to maintain a high a-value throughout the storage period. The volume ratio becomes less important at increased O_2 levels, and above approx. 0.85% O_2 there is high availability of O_2 molecules regardless of the volume ratio, and consequently the a-value is <2.84 at all volume ratios. Similar conclusions can be drawn from the Response Surface Model made for the interaction of measured O_2 and illuminance (results not shown).

Conclusion:

The present study emphasises the importance and complex interactions of several factors on the colour stability of MA packaged cured meat. All factors have to be considered when optimising the colour stability of cured ham, as non-ideal conditions concerning a single factor may compromise other measures taken to preserve colour during packaging and storage of cured ham. The most important finding in this study is the effect of product to headspace volume ratio. Normally, the focus is on the residual O_2 level in the package headspace. However, it is commonly overlooked that the total amount of oxygen available for oxidation processes is defined by both the O_2 level and the volume ratio in combination.

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Data:

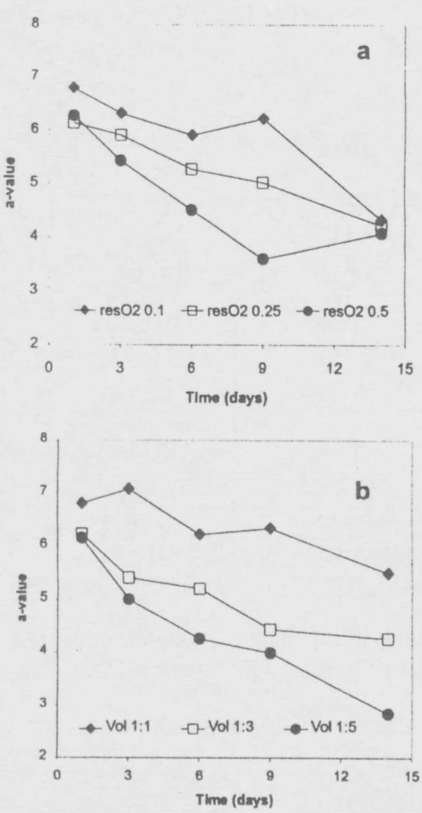

Figure 1. Average a-value for light exposed sliced ham packaged in modified atmosphere with three levels of residual oxygen (a) or product to headspace volume ratio (b) during 14 days chill (5°C) storage.

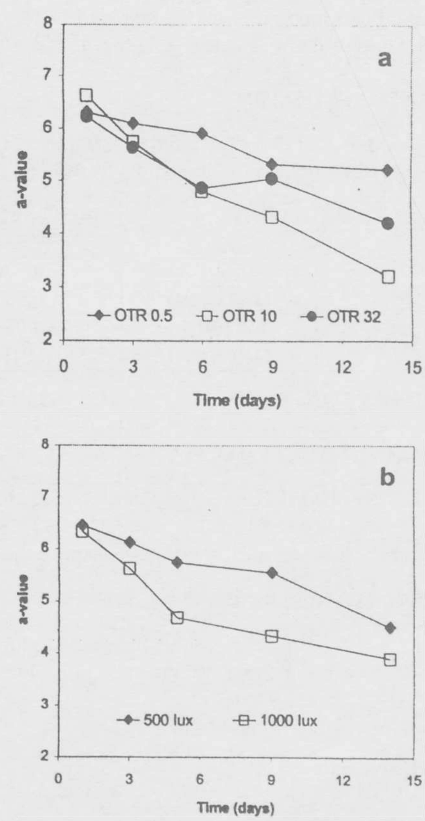

Figure 2. Average a-value for light exposed sliced ham packaged in modified atmosphere with different levels of oxygen transmission rate (a) or illuminance (b) during 14 days chill (5°C) storage.