DETERMINATION OF CRITICAL LEVELS OF RESIDUAL OXYGEN TO MINIMIZE DISCOLORATION OF SLICED PACKAGED NORWEGIAN SALAMI UNDER LIGHT DISPLAY

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Abstract

Discoloration of sliced packaged salami is contributing to rejection of the product, food waste and economical loss. A combination of residual O_2 in the headspace of packages and light is causing photooxidation and deterioration of colour. The aim of this study was to establish maximum tolerable concentrations of residual O_2 in packages of salami slices with 100 % N_2 under light display at 4 and 20 °C. Salami sausages had variable inherent O_2 consumption rate. Storage of salami in 1 % O_2 in darkness did not induce discoloration. The upper limits for O_2 for avoiding discoloration under light were variable in the range 0.1 – 1.0 %, depending on temperature and type of salami. Display at 20 °C increased the rate of O_2 depletion compared to 4 °C. To minimize discoloration, sliced and packaged salami should be stored in darkness at approximately 20 °C until the level of residual O_2 is reduced below a critical limit.

1. Introduction

Dry-cured fermented sausages of salami type are widely produced in Europe and other parts of the world. Salami usually contains pork and occasionally other meats, as well as pork fat, sodium chloride, curing agents like nitrite and nitrate, reducing agents like ascorbic acid and ascorbate, spices, carbohydrates and starter cultures (Toldrá, 2002). The process of fermentation, ripening and drying of the sausages results in a weight loss of more than 30 % (Cevoli, Fabbri, Tabanelli, Montanari, Gardini, Lanciotti, & Guarnieri, 2014). The red to pink colour of salami is produced by nitric monoxide binding to the muscle pigment myoglobin, forming nitrosylmyoglobin, and is stabilized by reduction of the pH in the sausage (Møller & Skibsted, 2002). Sliced, packaged salami is prone to discoloration. Discolored salami and other meat products are contributing to undesirable food waste and lower commercial value at retail.

The discoloration of sliced, packaged salami is usually caused by the combination of residual O_2 in the packages and light exposure at display. Photooxidation of nitrosylmyoglobin comes from harmful light both in the ultraviolet and visible areas (Møller & Skibsted, 2002). Sliced, dry-cured Milano-type sausages were packaged in vacuum or 100 % N_2 and exposed to light and temperatures typical for retail display for 60 days (Zanardi, Dorigoni, Badiani, & Chizzolini, 2002). The vacuum packaged sausages were less red than those in N_2 at the end of display, probably due to higher residual O_2 levels in the vacuum packages, but specific O_2 concentrations were not established. Furthermore, Spanish dry fermented sausages of Salchichón type were slightly less red in vacuum than 20 % CO_2/ 80 % N_2, but only by a 0.5 a* redness value (Rubio, Martínez, García-Cachán, Rovira, & Jaime, 2008). It seems like the level of residual O_2 in the headspace of the packages was not clarifed.

The O_2 level in the headspace of the packages is a combination of several factors: residual O_2 level at time of packaging influenced by packaging machinery and operation, O_2 barrier properties of the packaging materials and oxygen consumption due to microbiological growth (Møller, Jakobsen, Weber, Martinussen, & Bertelsen, 2003). The O_2 barrier property of the packaging film is crucial for the access of O_2 to the product. Sliced, vacuum packaged salami was analysed for colour changes in films with O_2 transmission rates of 1, 11, 30, 72 and 90 ml/ m^2/ 24 hrs at 23 °C and 0 % RH, respectively (Yen, Brown, Dick, & Acton, 1988). Films with 30 ml or higher O_2 transmission rates resulted in less redness and more discoloration at light display, and the discoloration increased with longer light display, up to 8 weeks. In this study, no change in redness occurred with any of these films under dark storage. The level of residual O_2 in the headspace of salami packaged in modified atmospheres is reduced due to

65 O_2 consumption by added and inherent bacteria in the product, mainly lactic acid bacteria. A
66 study of O_2 levels of sliced, dry-cured sausages during storage in N_2 showed that the
67 reduction of detrimental O_2 was faster at 22 than 4 °C, with initial O_2 concentrations of 8 – 14
68 % over 120 days storage (Scetar, Kovacic, Kurek, & Galíc, 2013). In Norway, sliced salami is
69 mostly packaged in modified atmospheres and displayed under light either in chill cabinets or
70 at room temperatures. Cooked ham differs from dry cured sausages by having much lower
71 total bacterial counts, at least early after packaging. Previously, the O_2 headspace levels for
72 initiating discoloration of sliced, cooked ham with nitrite under light display have been set to
73 0.1 - 0.2 % O_2, partly depending on the headspace volume. (Møller, Jensen, Olsen, Skibsted,
74 & Bertelsen, 2000; Larsen, Westad, Sørheim, & Nilsen, 2006). To our knowledge, such a
75 critical level for residual O_2 in the headspace for modified atmosphere packaged sliced
76 salami has not yet been established.

77 The purpose of this study was to determine the maximum levels of residual O_2 in the
78 headspace of N_2 atmospheres to avoid discoloration of sliced Norwegian type salami
79 displayed under light at 4 and 20 °C. The study comprised two types of commercial salami
80 sausages, however, without investigating processing factors of the salamis in this study.

81

82 ## 2. Materials and methods

83

84 ### 2.1. Products for the experiment

85 Sausages from two batches of dry fermented salami were supplied by two Norwegian meat
86 companies, and called A and B for this study. The recipes for both sausage types contain
87 meat of pork and beef, pork fat, sodium chloride, spices, garlic, sodium nitrite, sodium
88 ascorbate (A only), rosmarin extract (B only), carbohydrates and starter cultures. The
89 sausages were stuffed in 85 wide mm synthetic casings, and weighed approximately 4 kg
90 each after drying. Salami A consisted of 35 % fat, 21 % protein, 6 % sodium chloride and 38
91 % water. Salami B consisted of 35 % fat, 18 % protein, 5 % sodium chloride and 41 % water.
92 The sausages A and B were sliced and packaged approximately 1 and 2 months after
93 completed production, respectively.

94 ### 2.2. Experimental set-up

95 In a first small experiment, packages with sliced salami were injected with air to obtain 1.0 %
96 O_2 in the headspace, and then the reduction of residual O_2 was followed for 7 days. The

97 experiment included salami sausages A and B, and was performed under light display and in
98 darkness, both at 4 and 20 °C, amounting to 8 x 4 replicates = 32 samples in total.

99 The second main experiment was a full factorial setup of the experimental factors, including
100 type of salami (A and B), O_2 level (0, 0.10, 0.25, 0.40, 0.75, 1.0 and 20.95 %) and
101 temperature (4 and 20 °C). The concentrations of O_2 were chosen to mimic common levels at
102 packaging (0.1 – 0.4 %), elevated levels by malfunction of packaging (0.75 and 1.0 %) and
103 complete leakage (21 %). All samples were subjected to light, and in addition, the 1 %
104 samples were stored in darkness for comparison. Three replicates were made of each
105 experimental condition, amounting to 32 x 3 = 96 samples in total. Instrumental colour
106 analysis was performed on all samples at day 1, 2, 4 and 7, and visual colour evaluation on
107 one of the replicates at days 1, 2 and 4.

108 2.3. Slicing, packaging and light display

109 All these operations took place at the Nofima pilot plant. The sausages were sliced on a
110 Bizerba VS12D machine (Bizerba, Balingen, Germany). The slices were 1.0 mm thick and
111 weighed ca. 5 g. Two stacks with 14 slices each were used for one package, yielding ca. 140
112 g of sausage per package. The holding time for the stacks from slicing to completed
113 packaging was approximately 45 minutes at 18 – 20 °C.

114 Packaging was performed on a Multivac R145 thermoforming machine (Multivac,
115 Wolfertschwenden, Germany). The black base film was of type Multipet 450 and the
116 transparent top film of type Biaxer 65 XX HFP AFM (both Wipak, Nastola Finland) with O_2
117 transmission rates of 10 and 5 ml/ $m^2 \cdot$ day, 1 atm at 23 °C and 50 % RH, respectively. The
118 base film was formed into trays 21.5 cm long, 10.8 cm wide and 1.8 cm high. The slices were
119 packaged in 100 % N_2 (AGA, Oslo, Norway). The gas to product or sausage volume ratio
120 (G:P) was approximately 2 to 1. After packaging, the levels of residual O_2 in headspaces
121 were 0.1 – 0.4 %. All packages with salami slices were first stored in darkness at 4 °C for 14
122 days to allow for complete removal of residual O_2 from the headspaces. To obtain packages
123 with elevated levels of O_2 in the headspace, variable volumes of air were then injected into
124 the packages using syringes with needles through self-sealing septas of type 644209
125 (Dansensor, Ringsted, Denmark). Packages with air or 20.95 % O_2 were punctured once with
126 a needle. The light display trial started within one hour after supply of air. Storage time for
127 sufficient removal of O_2 and level of injection of air for suitable O_2 concentrations were
128 established through pre-trials.

129 The light display was standardised to approximately 930 lux continuously at the surface of
130 the salami slices for up to 7 days, both at 4 and 20 °C. The fluorescent lamps at 4 °C were

Natura de luxe L36W/76 (Osram, Munich, Germany) and at 20 °C Auralight T5 Supreme HO 49W/830 (Auralight International AB, Karlskrona, Sweden) both typically used for illumination of meat products in display cabinets and from ceilings in food shops in Norway. The light intensity simulating retail conditions was obtained by adjusting the distance between the light sources and the salami surfaces. The packages under light display were rotated on days 1, 3 and 5 to expose the different samples to nearly uniform levels of light.

2.4. Analyses

The concentration of O_2 in the headspace of the packages was obtained with a Dansensor Checkmate 3 instrument (Dansensor, Ringsted, Denmark) by the use of a small vacuum pump and a needle inserted through self-sealing septas (Dansensor), withdrawing 7 ml of gas. All packages were analyzed at days 0, 4 and 7 of display, while spot tests were performed on days 1 and 2.

Instrumental values (L* - lightness, a* - redness and b* - yellowness) were obtained with a Minolta Chroma Meter CR-400 (Konica Minolta, Inc., Tokyo, Japan) with a 8 mm viewing port, 2^0 viewer angle and illuminant D_{65}. The instrument was calibrated against a white tile (L* = 97.16, a* = 0.25 and b* = 2.09). The samples were measured in intact packages at the product surface through the transparent film. The instrumental colour measurements were performed in four replicates on all samples.

Visual colour evaluation was performed by a 6 member trained panel. The colour of the salami slice surfaces was assessed on a scale of 1 = very red, 2 = slightly red, 3 = slightly brown, 4 = moderately brown and 5 = very brown, adapted from AMSA (2012). Additional standard samples exhibiting scores of 1 and 5 were used at all sampling days as examples for the assessors. During the evaluation, the samples were randomly displayed under PlusLux 3000 warm white light (Thorn, Durham, England) with a light intensity of 1600 lux at the salami surfaces.

Fading of the sausages was analyzed on a Foss XDS Opti Probe Analyzer Reflection and Immersion instrument (Foss NIRSystems Inc., Laurel, Maryland, USA). Spectra of 400 – 700 nm with 10 nm intervals were measured in samples from one replicate at day 4 of display directly through the top film of intact packages. The ratio 650/570 nm expressed the degree of fading of cured meat products with scale ca. 1.1 = no cured colour, ca. 1.6 = moderate fading, 1.7 - 2.0 = noticeable cured colour and 2.2 - 2.6 = excellent cured colour (AMSA, 2012).

163 pH was measured directly in the sausages with an Ingold Xerolyt electrode (Mettler-Toledo,
164 Greifensee, Switzerland). Water activity of the sausages was analysed at 25 ºC with an
165 AquaLab CX-2 instrument (Decagon Devices Inc., Pullman, Washington, USA).

166 2.5. Statistics

167 The colour parameters were evaluated by a fixed-effects ANOVA model with main effects
168 type of salami, temperature, O_2 level and days of storage. All two-factor interactions were
169 also included in the ANOVA model. The samples with 21 % O_2 and the samples stored in
170 darkness were kept out of the ANOVA analysis, but included in the figures for comparison.
171 The analysis was performed in MATLAB (R2014b, The Mathworks, Inc., Natick. MA, USA, at
172 www.mathworks.com).

173

174 3.Results and discussion

175 3.1. Consumption rate for residual O_2

176 A fast consumption of initial residual O_2 by the salami sausages is of importance for avoiding
177 later light induced discoloration. As shown for both salamis type A and B, the reduction in
178 concentration of headspace O_2 from the initial 1.0 % was faster at 20 than 4 ºC, and faster in
179 light than in darkness at the lowest temperature (Fig. 1 i and ii). These findings are in
180 agreement with a study of dry cured sausage packaged in N_2 and which had a faster removal
181 of residual O_2 at 22 than 4 ºC (Scetar et al., 2013). A higher rate of O_2 consumption under
182 light than in darkness is consistent with results from a similar study of cooked cured sausage
183 (Böhner, Hösl, Rieblinger, & Danzl, 2014), demonstrating O_2 consumption by photooxidative
184 reactions.

185 The rate of O_2 depletion was higher for salami A than B at 4 ºC, meaning that salami A
186 needed shorter time to reach a certain level of residual O_2 than salami B at this low
187 temperature. The specific cause or causes for this difference in O_2 consumption rate
188 between the two salamis are not known, because there are a number of differences in
189 recipes and processes. Salamis A and B had a pH of 5.02 and 4.88 ($p < 0.05$), and an a_w of
190 0.875 and 0.897 ($p < 0.05$), respectively. Bacterial O_2 consumption is likely to contribute
191 considerably to removal of O_2 in this system (Toldrá, 2002). Starter cultures added to
192 Scandinavian-type fermented sausages varied in metabolic activity (Klingberg, Axelsson,
193 Naterstad, Elsser, & Budde, 2005). In the present study, salamis A and B were used for the
194 packaging test approximately 1 and 2 months after production, which could contribute to
195 reduced bacterial activity and O_2 consumption for the latter salami.

196 The O_2 consumption in packages of salami is depending on the gas to meat ratio. In this
197 experiment, the G:P ratio was relatively high at 2:1, where O_2 concentrations of 0.2, 0.4, 0.6,
198 0.8 and 1.0 % corresponded to O_2 headspace volumes of 0.56, 1.12, 1.68, 2.24 and 2.80 ml,
199 respectively. With a low volume of O_2 the gas is removed faster, and the packages with
200 salami can sooner be ready for light exposure. In a modelling of five factors contributing to
201 the discoloration of cooked ham, the headspace to product volume was one of the crucial
202 factors (Møller et al., 2003). Even with low percentages of residual O_2 in the headspace, but
203 combined with high G:P ratios, there will be sufficient O_2 for colour deteriorating processes to
204 take place. For the preservation of the preferred red colour of sliced cooked or dry cured
205 meat products, it is beneficial to try to obtain low G:P ratios at the time of packaging.

206 3.2. Concentrations of initial residual O_2

207 The main experiment consisted of 7 concentrations of O_2 that were obtained by injecting
208 various volumes of air, except the samples with pure air, which were made by puncturing the
209 packages. The average initial levels of 0, 0.10, 0.25, 0.40, 0.75, 1.0 and 20.95 % O_2 were
210 reached with only minor deviations from targets, although with some variations within each
211 O_2 group (Table 1).

212 3.3. Effects of residual O_2 on visual and instrumental colour

213 The ANOVA analysis of the main experiment demonstrated that the type of salami, A or B,
214 explained much of L* lightness (Table 2). Storage temperatures of 4 or 20 °C influenced the
215 colour attributes, and most for a* redness. Initial level of residual O_2 in the headspace
216 explained a high degree of the variation in visual colour, a* values and ratio 650/570 nm for
217 fading. b* yellowness was not influenced by level of residual O_2 or type of salami. The day of
218 display, 1, 2, 4 and 7, had a bearing on b*, but had almost no effect on visual colour, L* and
219 a*.

220 The correlation between visual redness score and a* instrumental redness values was high,
221 with R^2 of 0.97 (Fig. 2). The panel for visual colour evaluation established a maximum score
222 of 2, corresponding to an a* value of 13.5, of which a noticeable difference in colour or slight
223 discoloration was observed for both sausages, A and B.

224 The visual colour evaluation at day 4 of the experiment showed that in order to keep the
225 salami at or below an acceptable score of 2, a higher level of initial residual O_2 under light
226 could be tolerated at 20 than 4 °C (Fig. 3). In addition, salami A was more robust and could
227 maintain an acceptable colour at higher levels of O_2 than salami B. Therefore, the specific
228 requirements for maximum residual O_2 were variable, depending on the type salami and
229 storage temperature. Approximate maximum O_2 level for salami A at 4 ° C was 0.30 % and at

20 °C 1.0 %, while for salami B at 4 °C it was 0.15 % and at 20 °C 0.35 %. Samples of salami with 1.0 % O_2 stored in darkness were all red and had visual colour scores of approximately 1.

The a* redness colour values at day 4 of display of the salamis A and B stored at 4 and 20 °C are shown in Fig. 4 i. Data for a* values at 1 and 2 days of light display showed a similar discoloration as for 4 days, but to a less degree, and slightly more at 7 days (results not shown). Increasing level of initial O_2 in the headspace of the packages reduced a* values for both salamis and temperatures. The sausage controls with 0 % O_2 in light, as well as those with 1 % O_2 in darkness, both had high a* values of approximately 16. Decreasing a* values were measured for O_2 levels from 0.1 to 21 %, with ultimate a* values as low as approximately 4. The most rapid decline in a* was observed at 4 °C and for salami B. This high degree of discoloration can be linked to a slower reduction in residual O_2 levels in this type of samples (Fig. 1). To keep the sliced salami sausages above a critical a* value of 13.5 after 4 days storage, salami A at 4 °C needed to be below approximately 0.35 %, salami A at 20 °C below 1.0 %, salami B at 4 °C below 0.10 % and salami B at 20 °C below 0.25 % at this sampling time. The limits for maximum acceptable residual O_2 were almost similar for the a* values and visual colour evaluation (Fig. 3).

L* lightness values were consistently 3 - 4 units higher for salami B than A ($p < 0.01$) and 1 - 2 units higher at 4 than 20 °C ($p < 0.01$) (Fig. 4 ii). The lighter colour for sausage B could be due to fat properties or a higher fraction of pork versus beef in the recipe. The L* values were not affected by level of initial O_2, except increased values for samples in 21 % O_2.

b* yellowness values did not vary between the different treatments or types of salami in this experiment (results not shown).

The results for fading of the salami are shown in Fig. 5. The ratio 650/570 nm is expressing the degree of cured colour, with samples with high numbers having a red, typical cured colour (AMSA, 2012). Again, the samples stored at 20 °C and from sausage A were higher in 650/570 nm values than those at 4 °C and from sausage B. Values at or above 2.2 with excellent cured colour were noted for salami A at both temperatures and salami B at 20 °C with 0 and 0.1 % O_2 in light and 1 % O_2 in darkness. Samples of salami B at 4 °C were considerably lower than salami A in 650/570 ratios at all O_2 levels with light, as well at 1.0 % O_2 in darkness ($p < 0.05$). The results on fading for these salami B samples differed slightly from a* values and visual colour scores, and indicates that changes in the pigment may have occurred, although not evident to the human eye.

3.4. Practical consequences for packaging of salami

One of the main experiences from this study is that for each sliced salami-type product in modified atmosphere packages it is important to learn the rate of reduction in residual O_2 in the headspace. The packages with salami should be stored in darkness until all residual O_2 is consumed, and then the packages can safely be displayed under light. The present study only addressed packaging and display factors, for example level of initial O_2 and storage temperature on the rate of O_2 consumption. To obtain a more complete understanding of the system, future studies should include processing factors like the type and activity of starter cultures, influence of raw materials and ingredients, and fermentation and drying processes.

For this shelf stable dry salami, a display temperature of approximately 20 °C favours a rapid O_2 consumption. In situations where the level of initial residual O_2 is too high, it is advisable to store the sliced salami packages at 20 °C in darkness, to facilitate a fast decline in O_2 levels before exposure to light takes place. The holding time to reach acceptable concentrations of residual O_2 depends on factors like initial O_2 level, G:P ratio and O_2 depletion rate, and should be determined by gas measurements. However, the temperature should not be increased much over 20 °C, where partial melting of fat from the salami can cause consumer rejection of the product, depending on the content of various fatty acids.

4. Conclusions

The strategies for maintaining a red colour of sliced, packaged salami are two-fold: either shielding the sausage from light or ensuring that the concentration of residual O_2 comes below a critical level at the time the light exposure is starting. The present experiment demonstrates that the limit for maximum residual O_2 in the headspace of salami packages at the start of illumination should be in the range 0.1 to 1.0 % O_2, and depending on the O_2 consuming activity of the sausages and the display temperature. The two batches of salami in this experiment were different in their ability to consume O_2 and hence the extent of discoloration. Possible causes for this difference have been indicated above, but more research is required on the mechanisms of O_2 consumption in a product like salami.

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299 References

300 AMSA (2012). Eds. Hunt, M.C. & King, A. Meat color measurement guidelines (2nd ed.)
301 Champaign, Illionois, USA: American Meat Science Association (pp. 1 – 136). Retrieved
302 14.10.2015 at www.meatscience.org.

303 Böhner, N., Hösl, F., Rieblinger, K., & Danzl, W. (2014). Effect of retail display illumination
304 and headspace oxygen concentration on cured boiled sausages. *Food Packaging and Shelf*
305 *Life*, 1, 131 – 139.

306 Cevoli, C., Fabbri, A., Tabanelli, G., Gardini, F., Montaniari, C., Lanciotti, R. & Guarnieri, A.
307 (2014). Finite element model of ripening process and successive storage in package. *Journal*
308 *of Food Engineering, 132*, 14 – 20.

309 Klingberg, T.D., Axelsson, L., Naterstad, K., Elsser, D. & Budde, B.B. (2005). Identification of
310 potential probiotic starter cultures for Scandinavian-type fermented sausages. *International*
311 *Journal of Food Microbiology, 105*, 419-431.

312 Larsen, H., Westad, F., Sørheim, O., & Nilsen, L.H. (2006). Determination of critical oxygen
313 level in packages for cooked sliced ham to prevent color fading during illuminated retail
314 display. *Journal of Food Science, 71*, 407 – 413.

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

318 Møller, J.K.S. & Skibsted, L.H. (2002). Nitric oxide and myoglobins. *Chem. Rev., 102*, 1167 –
319 1178.

320 Møller, J.K.S., Jakobsen, M., Weber, C.J., Martinussen, T., Skibsted, L.H., & Bertelsen, G.
321 (2003). Optimisation of colour stability of cured ham during packaging and retail display by a
322 multifactorial design. *Meat Science, 63*, 169 – 175.

323 Rubio, B., Martínez, B., García-Cachán, M.A., Rovira, J., & Jaime, I. (2008). Effect of the
324 packaging method and the storage time on lipid oxidation and colour stability on dry
325 fermented sausage salchichón manufactured with raw material with a high level of mono and
326 polyunsaturated fatty acids. *Meat Science, 80*, 1182 – 1187.

Scetar, M., Kovacic, E., Kurek, M., & Galíc, K. (2013). Shelf life of packaged sliced dry fermented sausage under different temperature. *Meat Science, 93*, 802 – 809.

Toldrá, F. (2002). Principles of dry-fermented sausage-making. In *Dry-cured meat products (63 – 88).* Trumbull, Connecticut, USA: Food & Nutrition Press, Inc.

Yen, J.R., Brown, R.B., Dick, R.L., & Acton, J.C. (1988). Oxygen transmission rate of packaging films and light exposure effects on the color stability of vacuum-packaged dry salami. *Journal of Food Science, 53*, 1043 – 1046.

Zanardi, E., Dorigoni, V., Badiani, A, & Chizzolini, R. (2002). Lipid and colour stability of Milano-type sausages: effect of packing conditions. *Meat Science, 61*, 7 – 14.

Text to figures

Fig. 1.

The reduction in concentration of residual O_2 (%) in the headspace of packages with sliced salami over 7 days storage in darkness (i) and light (ii). All packages were injected with air volumes to 1.0 % O_2. Symbols: x = 4 °C, 0 = 20 °C, unbroken line = salami type A, dotted line = salami type B.

Fig. 2.

Correlation between visual colour score and a* redness values for sliced packaged salami. R^2 was 0.97. Scale for visual colour: 1 = very red, 2 = slightly red, 3 = slightly brown, 4 = moderately brown and 5 = very brown. Acceptable colour above a* of 13.5 and below visual score of 2.

355 Fig. 3.

356 Visual colour score for sliced packaged salami at day 4 as affected by initial O_2 concentration
357 in the headspace of packages. Scale for visual colour: 1 = very red, 2 = slightly red, 3 =
358 slightly brown, 4 = moderately brown and 5 = very brown. Acceptable colour below a score of
359 2. For symbols; see Fig. 1.

360

361 Fig. 4.

362 Instrumental colour for sliced packaged salami at day 4 as affected by initial O_2 concentration
363 in the headspace of packages, and illustrated for a* redness values (i) and L* lightness
364 values (ii). Acceptable colour above an a* value of 13.5. For symbols; see Fig. 1.

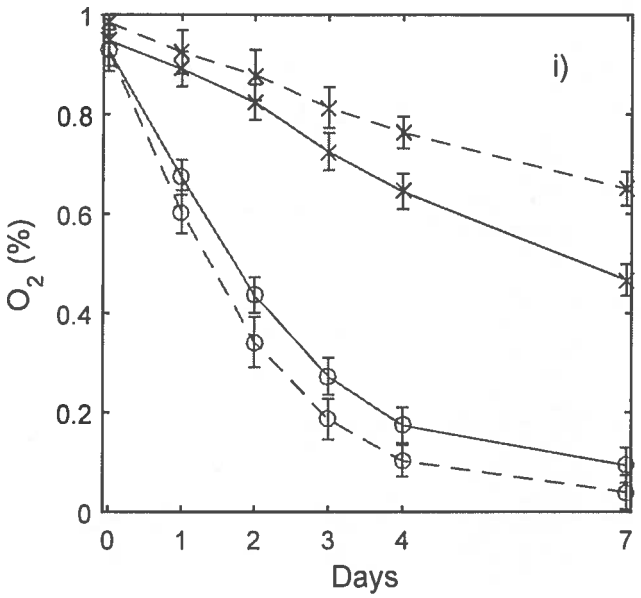
365

366 Fig. 5.

367 Fading by the ratio 650/570 nm for sliced packaged salami at day 4 as affected by initial O_2
368 concentration in the headspace of packages. Scale ca. 1.1 = no cured colour, ca. 1.6 =
369 moderate fading, 1.7 - 2.0 = noticeable cured colour and 2.2 - 2.6 = excellent cured colour
370 (AMSA, 2012). For symbols; see Fig. 1.

Highlights

- Discoloration of salami occurs by a combination of residual O_2 and light
- Maximum O_2 headspace concentrations to avoid discoloration in light were 0.1-1.0 %
- Depletion of residual O_2 from headspace was faster at 20 than 4 °C
- Keep sliced packaged salami in darkness until residual O_2 has passed a critical level


i)
O_2 (%)
Days
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0.2
0.4
0.6
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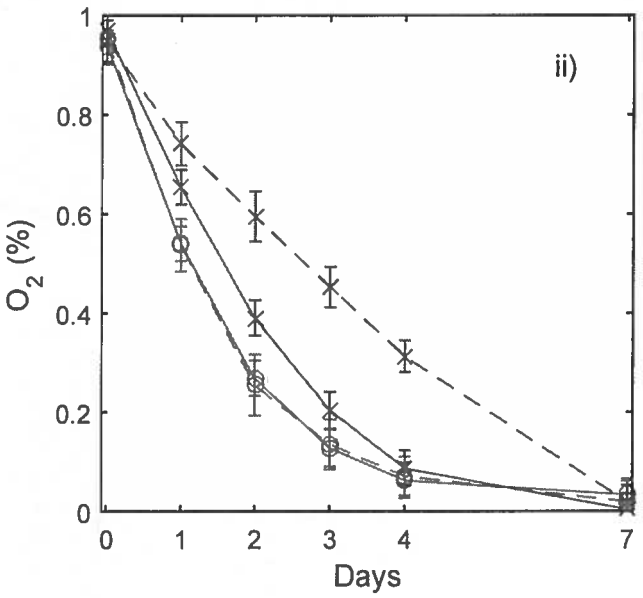
2
3
4
7


ii)
O_2 (%)
Days
0
0.2
0.4
0.6
0.8
1
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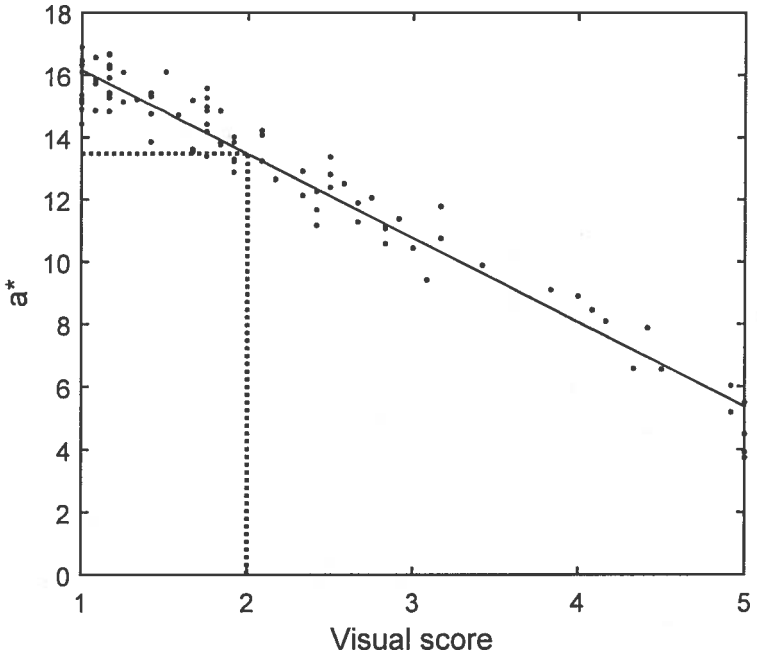
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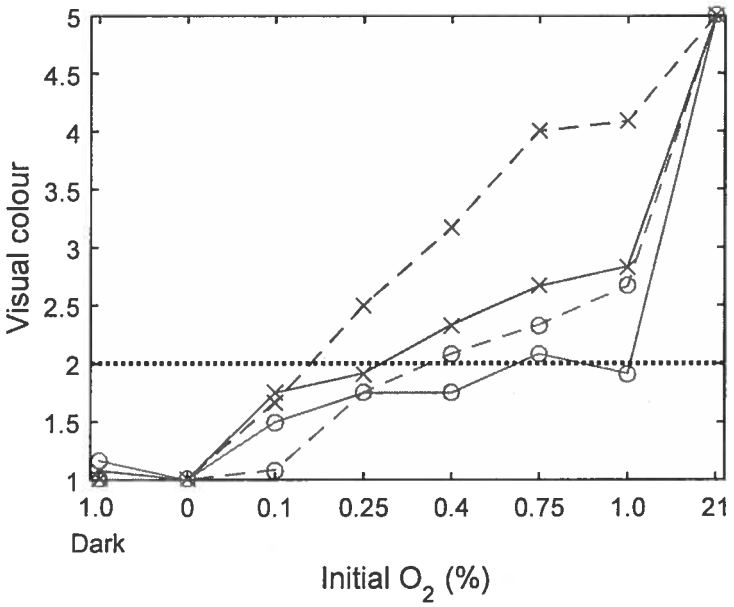
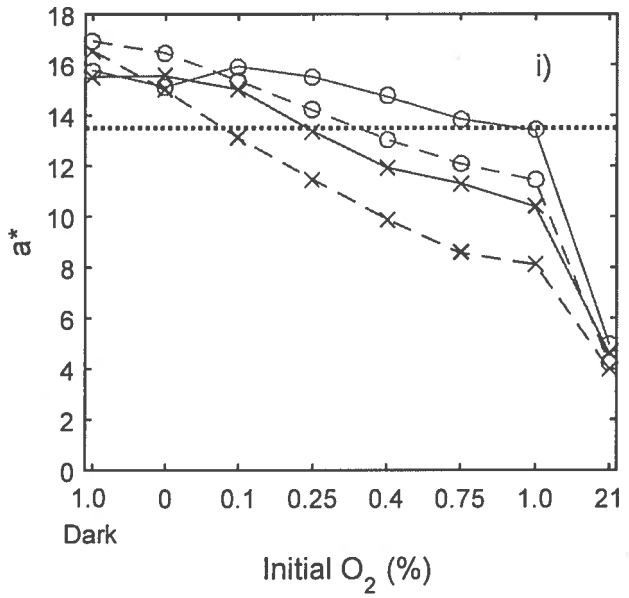
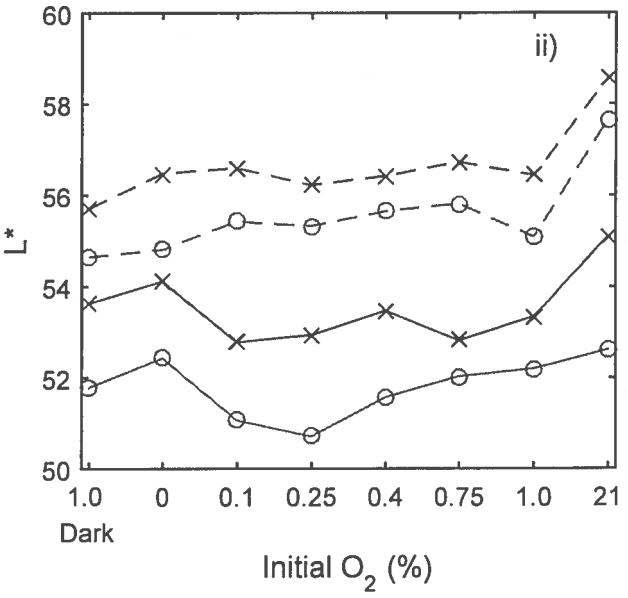
5
Visual score


Visual colour
5
4.5
4
3.5
3
2.5
2
1.5
1
1.0
Dark
0
0.1
0.25
0.4
0.75
1.0
21
Initial O_2 (%)


i)
a*
18
16
14
12
10
8
6
4
2
0
1.0
Dark
0
0.1
0.25
0.4
0.75
1.0
21
Initial O_2 (%)


ii)
L*
60
58
56
54
52
50
1.0
Dark
0
0.1
0.25
0.4
0.75
1.0
21
Initial O_2 (%)

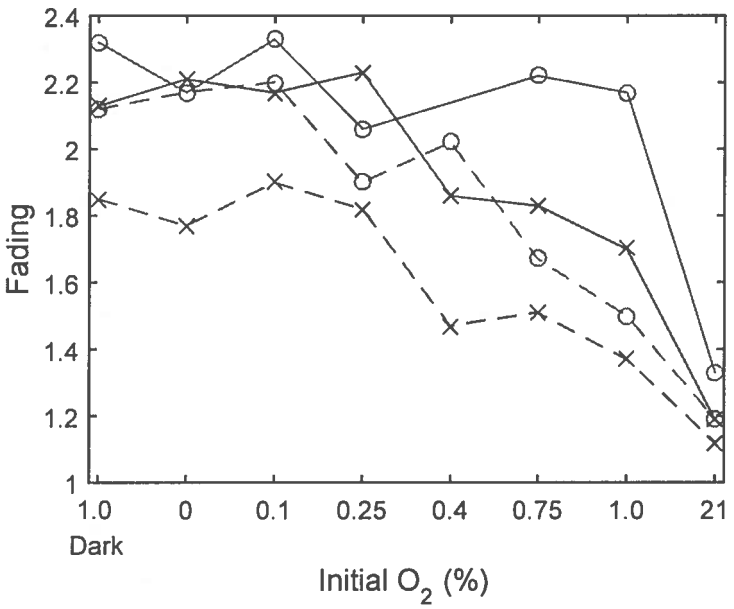

2.4
2.2
2
1.8
1.6
1.4
1.2
1
Fading
1.0
Dark
0
0.1
0.25
0.4
0.75
1.0
21
Initial O_2 (%)

Table1

Concentrations of O_2 (%) at 45 minutes after injection of air in packages of sliced salami.

Target	Minimum	Maximum	Average
0	0.000	0.010	0.005
0.10	0.086	0.111	0.102
0.25	0.200	0.305	0.246
0.40	0.374	0.469	0.417
0.75	0.701	0.809	0.769
1,0	0.975	1.240	1.039
Air	-------	-------	20.95

Table 2

ANOVA analysis for visual evaluation and instrumental color measurements. The numbers are explained variances (%), and bold numbers are statistically significant at a 5 % level. The visual evaluation is based on day 1, 2 and 4, the instrumental colour values are based on day 1, 2, 4 and 7, and fading is based on day 4 only.

	Visual colour	L* lightness	a* redness	b* yellowness	Fading
Salami type	**9.6**	**47.5**	**9.6**	0.0	**15.3**
Temp	**12.7**	**7.7**	**20.0**	**1.2**	**9.0**
StartO_2	**56.5**	**0.9**	**41.2**	**5.8**	**67.9**
Day	**3.6**	**3.6**	**2.2**	**20.0**	
Salami type x Temp	**1.2**	0.1	**0.8**	**2.3**	0.1
Salami type x StartO_2	**5.4**	**1.1**	**3.7**	**12.7**	3.0
Salami type x Day	0.3	0.1	0.0	0.1	
Temp x StartO_2	**5.1**	0.2	**3.7**	0.4	3.5
Temp x Day	0.5	**0.7**	**0.4**	**0.8**	
StartO_2 x Day	**2.6**	0.3	**1.3**	0.6	
Error	2.5	37.8	17.1	56.1	2.8
R^2_{adj}	0.95	0.61	0.82	0.41	0.86