Hindawi
Journal of Food Quality
Volume 2019, Article ID 2171076, 8 pages
https://doi.org/10.1155/2019/2171076

Research Article

The Impact of Residual O_2, Temperature, and Light at Display on Sensory Attributes of Sliced, Packaged Salami

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Received 19 June 2019; Revised 2 September 2019; Accepted 11 September 2019; Published 1 October 2019

Academic Editor: Barbara Speranza

The aim of the study was to examine if small amounts of oxygen (O_2) causing discolouration of salami exposed to light in the grocery store also cause adverse changes in the flavour and odour sensory profile. Sensory properties of packaged sliced salami under different temperatures (4, 20°C, and 23°C), two lights sources (LED and fluorescent), and a low level of residual O_2 in the headspace were evaluated. The experiment consisted of nine series, which were sensory-assessed after 3 and 6 days of display. A combination of light exposure and residual O_2 causing discolouration resulted in substantial off-flavour and off-odour of the displayed salami, both on the upper slice exposed to light and the middle slice in the stack with no direct light exposure. Samples from all other series without O_2 and those displayed in various light or stored in darkness showed no changes in quality compared with control samples stored in darkness. Temperature at display did not affect sensory attributes in the series without O_2 in the headspace. Sensory results from 3 to 6 days display were similar. To minimize quality defects and food waste, producers and retailers are advised to store packages of sliced salami in darkness until nearly all residual O_2 is consumed internally by the product before placing the packages upon light in the counter.

1. Introduction

Salami and other dry-cured sausages are produced with bacteria from starter cultures to improve food quality and safety [1]. Previously, these products were sold as sliced and vacuum-packaged products in the grocery stores, and the quality was maintained using packaging materials with low oxygen (O_2) transmission rates. These products are today frequently sold at retail as sliced products in modified atmosphere packages (MAP), which are filled with nitrogen (N_2) or mixtures of carbon dioxide (CO_2) and N_2. By changing from vacuum to MAP, a new factor is introduced, namely, the importance of residual O_2 in the package headspace. Low levels of residual O_2 in the headspace of the MAP will lead to light-induced oxidation of nitrosomyoglobin when the packages are exposed to illuminated retail exposure [2]. By packaging defaults or subsequent leakages, small volumes of air with O_2 can enter the headspace of the packages and thereby be a risk to the product quality. Sørheim et al. [3] demonstrated a negative effect on salami colour within the range 0.1% to 1% residual O_2 in the package headspace, depending on the bacterial O_2 consuming activity of the salami and the display temperature. The O_2 consumption was much faster at 20°C compared with that at 4°C. To avoid discolouration for salami packages with residual O_2 levels above 0.1% O_2, Sørheim et al. [3] suggested that these packages should be stored at 20°C in darkness for a few days until all the residual O_2 in the headspace is consumed before exposure to light takes place.

Storage in darkness is another strategy to avoid salami discolouration, but this is not a preferred marketing solution. Hence, most salami products are exposed to light for variable length of time, from hours up to a week, which could pose a risk to quality deterioration. In Norway, commercial salami packages are rarely exposed to light for more than 6 days, due to continuous purchase by customers in the stores. Grocery stores in Norway promotes sliced packaged salami either in chill cabinets at approximately 4°C

or at open display cabinets without chilling at approximately 20°C; the latter provided that the products are shelf stable with a water activity below 0.90. Energy-saving light-emitting diode (LED) light is frequently replacing the traditional fluorescent light in grocery stores and is used for both ceilings and in display cabinets. LED light is now a common light source for display of meat products. An analysis of different LED spectra on discolouration of sliced bologna sausage showed that the blue to green fractions of the spectra below 520 nm was more detrimental to colour stability than the red fraction at 635 nm [4].

Consumers are sensitive to off taste by lipid oxidation [5]. Several researchers have studied the effect of packaging in N_2 atmosphere or vacuum on lipid and colour stability [3, 6–8]. None of these works evaluated the odour and/or flavour of discoloured salami using descriptive analysis, even though taste is regarded as the most important factor for consumer acceptance [9, 10]. In particular, to our knowledge, no studies are available on the effect of small amounts of residual O_2 on salami sensory profile, including evaluation of several flavour and odour attributes. However, the work by Summo et al. [11] showed that the quality of salami and other dry cured sausages are subject to changes, either in dark storage or under light display. They stored unsliced, vacuum–packaged, ripened sausages for up to 5 months at 4°C and thereafter analysed for quality [11]. Overall acceptability, spicy flavour and a* redness values decreased, whereas acid taste, pungent flavour, and rancid flavour/smell increased over time. Information about the changes in the sensory profile, which most likely occur during storage, are important to both producers and distributors to achieve and maintain a high-quality product. The production of dry cured products, like salami, are resource demanding and costly. Maintaining a high quality will contribute to less food waste and reduce the economic loss.

The aim of the present study was to examine if small amount of O_2 causing discolouration also causes adverse changes in the flavour and odour sensory profile. The experiment was designed to mimic industrial Norwegian salami distribution with different temperatures and light exposure conditions.

2. Materials and Methods

2.1. Salami Sausages and Compositional Analyses. The study consisted of three industrial batches of salami from one commercial meat plant, with two batches for the main study to even out possible production variations between batches, and one for a pretrial. The pretrial was used for establishing appropriate concentrations and volumes of residual O_2 in the headspace of the packages in the main study. An O_2 level of 7.5 ml (equal to 5% O_2 in the package headspace with a gas to product ratio of 1 : 1) resulted in a visible discolouration, and this level was chosen for the main experiment. The recipe for the salami constituted of meat from pork and beef, pork back fat, sodium chloride, spices, garlic, sodium nitrite, ascorbic ascorbate, carbohydrates, and starter culture. Packages of 150 g of sliced salami (see Figure 1) were flushed with 70% CO_2/30% N_2 in a thermoforming machine at the meat plant. The top and base films were laminates with ethylene vinyl alcohol as gas barrier layer, and the O_2 transmission rate for both films was 2 ml/m^2 per day measured at 23°C and 0% relative humidity. After packaging, the sliced salami packages were transported from the meat plant to the research institute Nofima for experimental display and analyses.

The two salami batches for the main study were analysed for chemical composition of protein by the Kjeldahl nitrogen method, fat by the Schmid–Bondzynski–Ratslaff method, water by drying, and NaCl by chloride titration. pH was measured directly in the sausages with an Ingold Xerolyt electrode (Mettler-Toledo, Greifensee, Switzerland). Water activity of the sausages was analysed at 25°C with an AquaLab CX-2 instrument (Decagon Devices Inc., Pullman, Washington, USA).

2.2. Experimental Setup. In Norway, the salami packages are on average stored in dark at the production site for 6 weeks at 4°C before distribution. Hence, in our experiment, the packages for the different retail conditions were held for 6 weeks in darkness at 4°C before light exposure. The experimental design, presented in Table 1, includes nine series of salami packages with variation in temperatures and light conditions, in addition to different O_2 level (with or without O_2) in the headspace.

2.2.1. Display, Residual O_2, and Light Conditions. Two out of the nine series were dark storage controls without O_2 at 4°C and 20°C, coded AN4D and AN20D, respectively. This condition is also valid for packages in the shade of light in display cabinets. Normally, it is only the package in front or on top of a shelf that is directly exposed to light, whereas the packages behind are in a dark shade.

At the meat production plant, random samples are measured for residual O_2. The average residual O_2 level should be below 0.5%, and the starter culture will consume the O_2 during 6 weeks of storage before distribution. However, occasionally, some packages will have higher residual O_2 level after packaging or a leakage, primarily in the sealing. These packages will develop discolouration when exposed to light in the grocery store. Hence, in the experimental design, packages from series OX4L, OX4M, and OX20L were added 7.5 ml according to the findings in the pretrial as described under 2.1.

The elevated residual O_2 were injected through self-sealing septa of type 644.029 (Dansensor, Ringsted, Denmark) with 50 ml of air and 50 ml of a gas mixture of 60% CO_2/40% N_2 to contain approximately 5% O_2/50% CO_2 and 45% N_2 in the headspace at the start of illumination. The packages for all other series were designated to contain no O_2, either at start or during display of the packages.

The slices from series AN4L, AN20L, OX4L, OX4M, and OX20L were all displayed under LED light at 4 or 20°C. The slices in OX4M were sampled from the middle of the stacks (Figure 1) and were only exposed to O_2 and light at the edge of each slice. The samples under LED light at 23°C (AN23L) is comparable to elevated summer temperatures in food

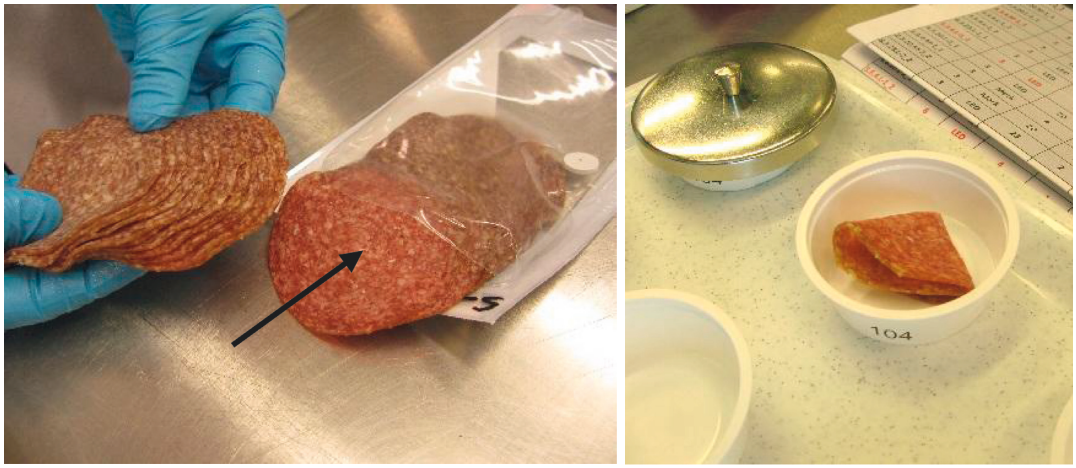

Figure 1: The middle slice of salami (arrow) used in the series OX4M (a), and how the slices were folded when served to the assessors (b).

Table 1: O_2, temperature and light conditions for the nine series of sliced packaged salami.

O_2 level	Type of light	Display temp. (°C)	Code	Comments, simulating conditions of
0%, Anoxic (AN)	Dark (D)	4	AN4D	Control
0%, Anoxic (AN)	Dark (D)	20	AN20D	Control
0%, Anoxic (AN)	LED (L)	4	AN4L	Light in display chill cabinets
0%, Anoxic (AN)	LED (L)	20	AN20L	Ceiling light in food stores
0%, Anoxic (AN)	Fluorescent (F)	20	AN20F	Ceiling light in food stores
5% (OX)	LED (L)	4	OX4L	Light in display chill cabinets
5% (OX)	LED (L)	20	OX20L	Ceiling light in food stores
5% (OX)	LED (M)	4	OX4M	Display chill cabinets, no direct light on middle slices

stores, as a deviation from targeted room temperature. An elevated temperature was selected because the fat in the salami product is known to start melting when the temperature increases above approximately 22°C. Packages of sliced salami from series AN20F were displayed under traditional fluorescent light at 20°C. Fluorescent illumination is still used for display of meat products but to a decreasing extent.

Commercial salami packages are rarely exposed to light for more than 6 days, due to continuous purchase by customers in the stores. The salami slices from all the nine series were therefore analysed after 3 and 6 days of storage. In addition, samples from series AN20D were analysed after 14 days in darkness, to simulate extended storage at room temperature.

The light sources were selected to be similar to commercial lights in Norwegian stores. For series AN4L, AN20L, OX4L, and OX20L, the LED light was of type GIR-1200 LED 7000 DALI 830 (Glamox AS, Oslo, Norway). For series AN23L, the LED light was of type WS-T8A 10AA (BAHAG AG, Mannheim, Germany), and for series AN20F, the fluorescent light source was GIR T5 249 DALI silver-coated reflector 2×49W (Glamox AS) with Narva LT 49WT5/076 HQ Nature Superb fluorescent tubes (Narva e.V., Berlin, Germany). The three LED lights had high intensities in the blue and red regions of the spectra, whereas the fluorescent light was a full variable spectra light. The packages were continuously illuminated through the fully transparent base film. The light intensity at the surface of the packages was approximately 1100 lux measured with a CL-500A illuminance spectrophotometer (Konica Minolta, Inc., Tokyo, Japan) for all four light types. The positions of the illuminated packages were rotated 3 times during display to facilitate equal light intensity.

2.3. Gas and Instrumental Colour Analyses. The concentrations of O_2 in the headspace of the packages of series OX4L, OX4M, and OX20L were analysed with a Dansensor Checkmate 3 instrument (Dansensor) through self-sealing septas (Dansensor). The packages were measured at the time of packaging and after 1, 2, 3, 4, and 6 days of display. Spot samples of packages from the other series were taken to validate that these were free of O_2. Instrumental colour values for CIE L^* (lightness), a^* (redness), and b^* (yellowness) were obtained with a Minolta Chroma Meter CR-400 (Konica Minolta, Inc.) with an 8 mm viewing port, 2° 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 top slice directly through the fully transparent base packaging film. The instrumental colour measurements were performed on the two batches, with four packages and three replicates per unit at day 0, 3, and 6 in all series, except series OX4M, which was unavailable for direct instrumental colour analysis because it was the series representing slices in the middle of a stack in intact packages.

2.4. Sensory Analysis. A highly trained panel of 10 assessors (10 women; aged, 37–64 years) at Nofima performed a

sensory descriptive analysis (DA) according to the "Generic Descriptive Analysis" as described by Lawless and Heymann [12] and the ISO standard 13299 [13]. The assessors are regularly tested and trained according to ISO standard 8586 [14], and the sensory laboratory follow the practice of ISO standards 8589 [15]. The assessors agreed upon 11 attributes describing the salami samples: sourness odour, meaty odour, metallic odour, cloying odour, rancid odour, sourness flavour, meaty flavour, metallic flavour, cloying flavour, rancid flavour, and colour intensity. Samples of one folded slice of salami per assessor were served in a white plastic container with a lid at a temperature of 18°C ± 2°C. Only the top slice of the illuminated packages was analysed, except for series OX4M, where a slice from the middle of the stack was used (Figure 1).

All attributes were evaluated on an unstructured 15 cm line scale with labelled end points going from "no intensity" (1) to "high intensity" (9). Each assessor evaluated all samples at individual speed on a computer system for direct recording of data (EyeQuestion, Software Logic8 BV, Utrecht, the Netherlands). Both batches of the 9 series were evaluated at 3 and 6 days of storage. In addition, series AN20D was evaluated at day 14. All series were analysed in replicates, which resulted in 76 samples (Figure 2). All samples were served to the panel coded with a three-digit number in a balanced block design for each storage time. Tap water, unsalted crackers, cucumber, and honey melon was available for palate cleansing. In a pretest session before the main test, the assessors were calibrated on samples that were considered the most different on the selected attributes typical for the salami samples to be tested.

2.5. Statistics. Data from the sensory descriptive analysis were evaluated with analysis of variance (ANOVA). Least significant differences were calculated by Tukey's HSD test ($P < 0.05$). The model terms product, batch, replicate, and interactions including these terms were considered fixed, whereas the assessor and interaction effects including assessor were considered random. The analysis was performed on the descriptive sensory data from the trained panel to identify the sensory attributes that discriminated between samples. A principal component analysis (PCA) on the average of the sensory descriptive data was done with mean centred data and no standardization. The statistical software used for the sensory analysis was EyeOpenR (Logic8 BV). For the multivariate data analysis, Unscrambler X Version 10.4.1. was used for the PCA.

3. Results and Discussion

3.1. Chemical, Physical, and Gas Data. The salami sausages of the two batches of the main experiment contained on average of 33.8% fat, 22.3% protein, 36.2% water, 5.1% NaCl, and had a pH of 4.98 and a water activity of 0.88 with no significant differences in chemical composition between the two batches ($P > 0.05$) (results not shown). The packages with approximately 7.5 ml O_2 added at the start of display had a much faster O_2 depletion during display at 20 than at 4°C, as shown for series OX4L and OX20L in Figure 3. The

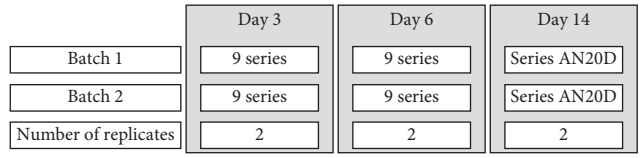

Figure 2: Experimental setup for the sensory evaluation of the samples. For each storage time (3, 6, and 14 days), samples were served in a balanced block design within each day.

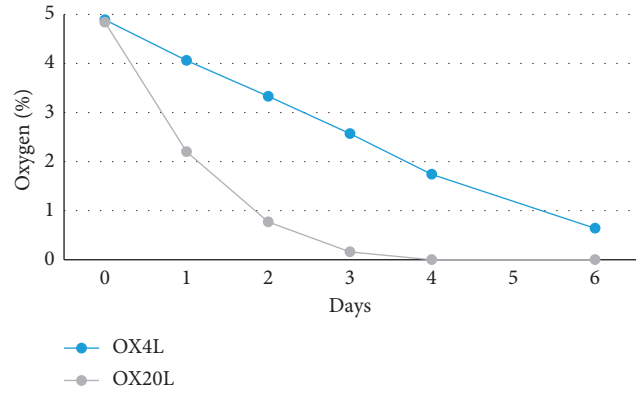

Figure 3: Concentration (%) of O_2 during illuminated display of salami packages in two series with O_2 at 4°C and at 20°C (OX4L and OX20L, respectively), both series inserted with 7.5 ml O_2 at the start of display.

O_2 consumption is due to a combination of bacterial activity and photooxidative reactions [1, 3]. Sørheim et al. [3] demonstrated a higher O_2 consumption at 20°C compared with that at 4°C.

3.2. Instrumental Colour Data. The colour (L^*, a^*, and b^*) of the sliced salami was measured after 3 and 6 days. The changes were most distinct for redness (a^* value), and only these values are reported (Figure 4). All the series without O_2 had a^* values around 16, which was at the same level and evaluated as very red by Sørheim et al. [3]. Our study showed that there was no significant difference for the O_2-free series in a^* value when exposed to different light sources (LED or fluorescence). The two series exposed to O_2 and light had, as expected, severe discolouration resulting in a^* values between 6 and 10. The calculated colour difference (ΔE) between two samples is clearly noticeable when the ΔE value is above 3.5 [16]. The colour difference values between the O_2-free samples (average values from AN-series) and the discoloured OX4L and OX20L samples were in the range from 5.3 to 10.6, showing clearly noticeable differences. The level of discolouration can also be seen on slice 1 in Figure 5. The discolouration after 6 days display was more severe at 4°C than at 20°C ($P < 0.05$) because the salami slices were exposed to a higher level of residual O_2 over a longer period (Figure 3). The temperature-dependent a^* value results with lower redness at 4°C were in agreement with previous findings on salami [3]. The a^* value of series OX4M was not measured instrumentally due to the fact that this sample was a slice from the middle of the salami stack. However, pictures

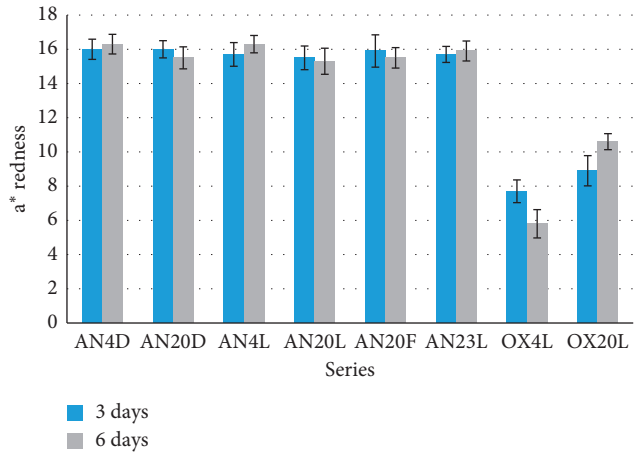

Figure 4: a^* redness values of all 9 series (except series OX4M) of salami after 3 and 6 days of illuminated display. Series OX4L and OX20L both contained 5% O_2 at the start of display. Bars show means with standard deviation.

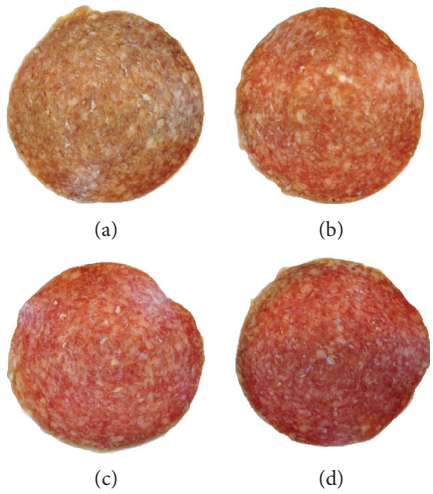

Figure 5: Visual appearance of four slices from series OX4M, where slice 1 refers the top slice of the salami stack, slice 2 refers to slice number 2 in the stack, and so on.

were taken when preparing the samples for the sensory panel (Figure 5). The pictures clearly show how the colour gradually changed from yellow/brown in the first salami slice (equal to OX4L) to red in the fourth slice. The fourth salami slice is clearly different from the first, with only a slightly yellow/brown colour at one end of the slice, the remaining being red.

3.3. Sensory Assessment. As shown in Table 2, there was no significant effect of batch after 3 days of display except for the attribute colour intensity. Differences in colour intensity might be due to a difference in fat distribution between the two batches, although there was no difference in the fat chemical composition. After 6 days of display, there was no significant effect of session (batch) (results not shown). The two batches are therefore presented as average values in the following sensory results (Tables 3 and 4; Figures 6 and 7). Principal component analysis (PCA) was used to find similarities and differences between the sensory attributes and the 9 different series of our study (Figures 6 and 7). The first and second principal component (PCs) explained 98% and 1%, respectively, which means the first PCs dominate the interpretation of the two plots, moving in the direction from rancid to sourness.

Regardless of temperature, light/darkness, or light source, all the O_2-free series had a similar sensory profile (Figures 6 and 7), and there were no significant differences between their sensory attributes either at 3 or at 6 days of display. Sourness and meat odour and flavour had high intensity, whereas rancid odour and flavour were almost not detectable. In addition, the colour intensity was high and corresponded to the a^* values measured. The series without residual O_2 showed no signs of odour and/or flavour quality deterioration and that all series without O_2 kept their quality during 3 and 6 days of display regardless of light and temperature. Samples from series AN20D were also analysed for sensory attributes after 14 days storage in darkness at 20°C but scores were similar to those after 3 and 6 days (results not shown).

In the series with residual O_2 and light exposure, the sensory profile of the salami had significantly changed in a negative direction compared with the O_2-free series. They both had high intensity in the negative sensory odour and flavour attributes cloying and rancid. As shown in Figure 3, the O_2 depletion was slower in the OX4L than in the OX20L. A consequence is seen in the sensory results already at day 3 for these two samples, which shows significantly differences between the two in cloying, metallic and rancid odour, and flavour, where OX4L had the highest values. Consumers would most likely have rejected this sample already after 3 days of display. The sensory evaluation of colour intensity for these two samples corresponds well with the measured a^* value, and has significantly lower sensory colour intensity compared with the O_2-free series. Series OX4L is positioned alone in the PCA plot (Figure 6) mainly due to the very high intensities for cloying odour/flavour and rancid odour/flavour. The OX4L had the lowest colour intensity score and significantly lower score than OX20L. This supports the findings of Sørheim et al. [3]. In addition to agreement with their results, our results further indicate that the more severe the discolouration is, the more negatively the sensory profile tends to be.

As mention previously, only a narrow edge of the middle slice in series OX4M had visual discolouration. This is reflected in the sensory evaluation where this series have been evaluated significantly higher in colour intensity than the two other series with O_2, which were highly discoloured. Series OX4M were lower but not significantly lower in colour intensity from series AN20L and AN20F, indicating a red colour. Even though there was an absence of discolouration in OX4M, surprisingly, the sensory profile showed high score in the negative attributes and low in the positive attributes. Unfortunately, the middle slice of salami was not evaluated as two separate parts, one evaluation should have assessed the discoloured edge and the other the

Table 2: Evaluation of the panel performance of the descriptive analysis at 3 days of display, as P values.

Attribute	Product	Judge	Batch	Replica	Product: judge	Product: session	Product: replica	Judge: replica	Judge: session
Sourness odour	**<0.001**	**<0.001**	0.419	0.293	**<0.001**	**0.030**	0.279	0.879	0.279
Meaty odour	**<0.001**	**<0.001**	0.835	0.537	**<0.001**	**0.032**	0.747	0.389	0.257
Metallic odour	**<0.001**	**<0.001**	0.127	0.110	**<0.001**	0.108	0.772	0.922	0.314
Cloying odour	**<0.001**	**0.016**	0.722	**0.026**	**<0.001**	**0.023**	0.084	0.980	0.590
Rancid odour	**<0.001**	**0.009**	0.369	0.958	**<0.001**	**0.003**	0.984	0.372	0.931
Sourness flavour	**<0.001**	**<0.001**	0.887	0.882	**<0.001**	**<0.001**	0.781	0.345	0.066
Meaty flavour	**<0.001**	**<0.001**	0.243	0.734	**<0.001**	**0.040**	**0.033**	0.217	0.810
Metallic flavour	**<0.001**	**<0.001**	0.115	0.544	**0.001**	**0.044**	0.608	0.514	0.937
Cloying flavour	**<0.001**	**0.003**	0.206	0.145	**<0.001**	**0.001**	0.299	0.476	0.054
Rancid flavour	**<0.001**	**0.001**	0.215	0.546	**<0.001**	**<0.001**	0.841	0.154	0.814
Colour intensity	**<0.001**	**<0.001**	**0.034**	**0.023**	**<0.001**	0.432	0.704	0.558	**<0.001**

Values in bold letters indicate a significant difference between samples ($P < 0.05$).

Table 3: Sensory analysis of sliced packaged salami at 3 days display.

Series no.	Sourness odour	Meat odour	Cloying odour	Metallic odour	Rancid odour	Sourness flavour	Meat flavour	Cloying flavour	Metallic flavour	Rancid flavour	Colour intensity
AN4D	5.50^{a}	4.16^{a}	1.98^{d}	4.16^{cd}	1.13^{d}	5.43^{a}	4.60^{a}	1.97^{d}	4.40^{cd}	1.30^{c}	6.28^{a}
AN20D	6.16^{a}	4.52^{ab}	1.26^{d}	3.98^{d}	1.12^{d}	6.06^{a}	4.83^{a}	1.36^{d}	4.35^{d}	1.14^{c}	6.38^{a}
AN4L	5.58^{a}	4.47^{ab}	1.90^{d}	4.13^{cd}	1.23^{d}	5.21^{a}	4.61^{a}	1.90^{d}	4.43^{cd}	1.20^{c}	6.31^{a}
AN20L	5.79^{a}	4.78^{a}	1.54^{d}	4.12^{cd}	1.19^{d}	5.61^{a}	4.76^{a}	1.55^{d}	4.34^{d}	1.19^{c}	6.39^{a}
AN20F	5.38^{a}	4.60^{a}	1.94^{d}	4.04^{cd}	1.20^{d}	5.17^{a}	4.44^{abc}	2.10^{d}	4.58^{cd}	1.22^{c}	6.31^{a}
AN23L	6.09^{a}	4.80^{a}	1.31^{d}	4.07^{cd}	1.13^{d}	5.77^{a}	4.68^{ab}	1.28^{d}	4.42^{cd}	1.08^{c}	6.41^{a}
OX4L	1.01^{c}	2.32^{d}	8.31^{a}	5.45^{a}	7.85^{a}	1.04^{c}	2.75^{d}	8.03^{a}	5.55^{a}	7.69^{a}	4.11^{c}
OX20L	2.98^{b}	3.73^{bc}	4.20^{b}	4.64^{bc}	3.11^{c}	2.83^{b}	4.00^{bc}	4.49^{c}	4.87^{bc}	3.65^{b}	5.68^{b}
OX4M	1.66^{c}	3.34^{c}	6.40^{b}	4.95^{ab}	5.21^{b}	1.94^{bc}	3.84^{c}	5.99^{b}	5.16^{ab}	4.67^{b}	5.81^{b}

Means in columns with different letters are significantly different ($P < 0.05$).

Table 4: Sensory analysis of sliced packaged salami at 6 days display.

Series no.	Sourness odour	Meat odour	Cloying odour	Metallic odour	Rancid odour	Sourness flavour	Meat flavour	Cloying flavour	Metallic flavour	Rancid flavour	Colour intensity
AN4D	5.73^{a}	4.65^{a}	1.27^{c}	4.22^{b}	1.15^{c}	5.46^{a}	4.68^{a}	1.48^{c}	4.59^{cd}	1.10^{c}	6.42^{a}
AN20D	5.87^{a}	4.60^{a}	1.25^{c}	4.01^{b}	1.16^{c}	5.58^{a}	4.75^{a}	1.33^{c}	4.28^{d}	1.14^{c}	6.43^{a}
AN4L	5.95^{a}	4.73^{a}	1.29^{c}	4.10^{b}	1.16^{c}	5.71^{a}	4.70^{a}	1.27^{c}	4.30^{d}	1.10^{c}	6.39^{a}
AN20L	5.77^{a}	4.63^{a}	1.29^{c}	4.16^{b}	1.10^{c}	5.40^{a}	4.57^{a}	1.29^{c}	4.36^{d}	1.10^{c}	6.32^{ab}
AN20F	5.30^{a}	4.71^{a}	1.85^{c}	4.22^{b}	1.34^{c}	4.87^{a}	4.78^{a}	1.97^{c}	4.62^{cd}	1.26^{c}	6.32^{ab}
AN23L	5.89^{a}	4.70^{a}	1.12^{c}	4.08^{b}	1.05^{c}	5.49^{a}	4.76^{a}	1.30^{c}	4.43^{d}	1.10^{c}	6.32^{a}
OX4L	1.14^{c}	2.65^{c}	8.08^{a}	5.43^{a}	7.38^{a}	1.30^{b}	2.88^{c}	7.96^{a}	5.83^{a}	7.62^{a}	4.59^{d}
OX20L	2.58^{b}	3.73^{b}	5.17^{b}	4.93^{a}	3.97^{b}	2.05^{b}	3.69^{bc}	6.09^{b}	5.17^{bc}	4.94^{b}	5.26^{c}
OX4M	1.92^{bc}	3.56^{b}	6.34^{b}	5.02^{a}	4.69^{b}	2.04^{b}	4.00^{ab}	5.93^{b}	5.24^{ab}	4.20^{b}	5.84^{b}

Means in columns with different letters are significantly different ($P < 0.05$).

core part of the slice. This may have resulted in a different sensory profile of the core part, which was not discoloured. However, the method chosen will most likely reflect consumer behaviour consuming the entire slice. Hence, one important finding from this experiment is that in a package with discoloured salami, not only the top slice but also most slices in a stack are likely to have an unattractive odour and flavour. Packages with discoloured salami are not acceptable for sale and improper packaging will lead to food waste and economic loss.

To our knowledge, previous studies of sensory quality of sliced packaged salami as influenced by residual O_2 and illumination are limited. Sliced Milano salami sausage stored in vacuum or MAP had high lipid and colour stability for the first 11 and 14 days of illuminated storage, respectively [8], supporting the present study. Longer storage times for up to 60 days of the Milano salami resulted in high brown colour scores and elevated TBAR values, demonstrating lipid oxidation. However, such long illuminated display of sliced salami packages is rare by most retailers. Lipid oxidation is expected to be responsible for much of the quality deterioration observed with exposure to low O_2 and light in our study [9]. In a sensory study of dark storage of vacuum packaged whole salami sausages at 4, 16, and 20°C for two months, the flavour profiles were very similar over time [17] and in accordance with the results of the anaerobic storage at different temperatures in the present shorter experiment. In a study combining pulsed UV light with storage of salami slices in vacuum or in a 80% CO_2/20% N_2 atmosphere, lipid and protein oxidations generally were at acceptable levels

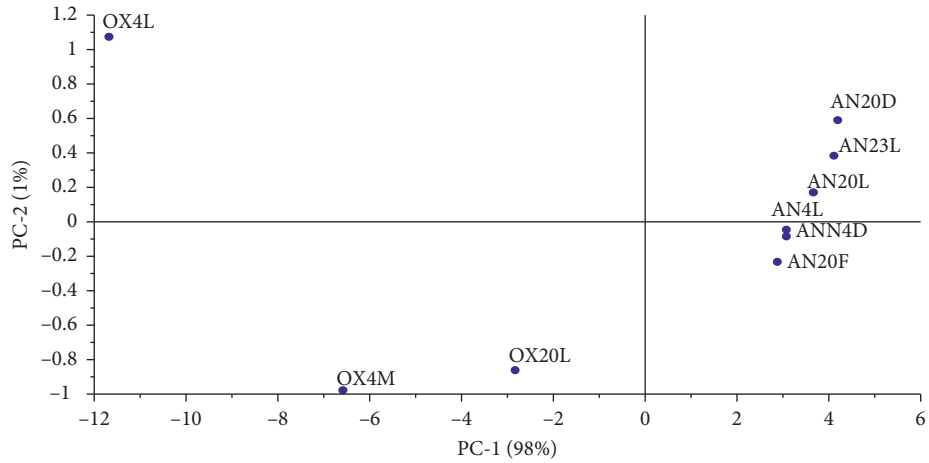

Figure 6: Principal component analysis (PCA) score plot for salami after 6 days of display. On the right side of the figure, series with no oxygen exposure during display are circled.

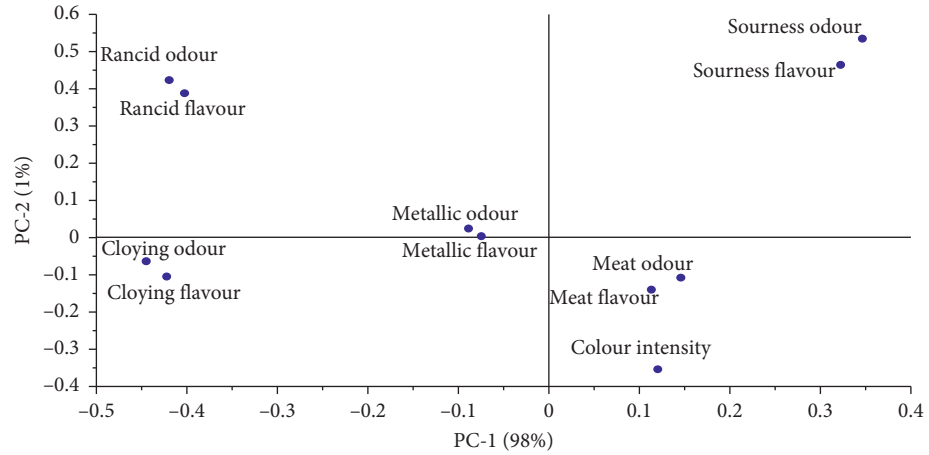

Figure 7: Principal component analysis (PCA) loading plot for salami after 6 days of display.

but were slightly higher for gas than for vacuum packaging [18]. A coating with beeswax on Italian salami sausages reduced TBAR values during storage, demonstrating that restricted exposure to O_2 improved the oxidative stability [19].

4. Conclusions

The results of this study is providing evidence that sliced salami can be packaged and displayed anaerobically in darkness or under light for up to 6 days without detrimental effects on sensory quality, including attributes of odour and flavour and instrumental colour. These results were valid at display temperatures of 4, 20, and 23°C. However, in packages where relatively small amount of residual O_2 is present in the headspace and combined with light at display, severe discolouration was detected. Our work showed that the discoloured salami also had severe odour and flavour defects related to oxidation. The middle salami slice had only a very small part with discolouration on one edge. Also, this slice showed higher levels of rancid odour and cloying flavour compared with control samples and packages with no O_2, indicating that the whole package of salami is unacceptable, even though only the top slice have been discoloured. Light-induced oxidations of lipids and heme pigments can both be avoided by storage of leak-free packages of sliced salami in darkness until all or nearly all residual O_2 in the headspace is consumed by the product. By utilizing this knowledge, specific measures to secure high product quality and avoid food waste can be implemented by producers and distributors of sliced, packaged, fermented salami.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors are grateful for financial support to the study from the projects Freshpack by the Foundation for Research

Levy on Agricultural Products (grant no. 244663/E50) and FoodMicro-Pack by the Research Council of Norway (grant no. 262306). The support from the staff at the Nortura Sogndal salami plant is highly valued. The scientific advice from Dr. Margrethe Hersleth and Dr. Ingunn Berget, as well as the technical assistance of Aud Espedal and Karen Wahlstrøm Sanden, all at Nofima, is greatly appreciated.

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