Modified atmosphere packaging for lamb meat: evaluation of gas composition in the extension of shelf life and consumer acceptance

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Abstract Convenience foods like chilled meat usually have a short shelf life. Modified atmosphere packaging (MAP) can be used together with refrigeration to retard meat degradation. This work evaluated the effect of MAP on the preservation and consumers acceptance of lamb meat. Lamb loins *Longissimus lumborum* were packed in five conditions: 15% O₂ + 85% CO₂ (O15), 30% O₂ + 70% CO₂ (O30), 45% O₂ + 55% CO₂ (O45), 60% O₂ + 40% CO₂ (O60), and Vacuum (control). Physico-chemical, sensory, and microbiological analyses were carried out along 21 days of refrigerated (1 ± 1 °C) storage. Treatments O30, O45 and vacuum presented the lowest oxidation values: 0.60, 0.61 and 0.30 Malonaldehyde Kg⁻¹ respectively. Treatment O45 showed the highest a* until the seventh day of storage (16.64). In the sensory preference ranking test, O30 and O45 received best scores in the first and second weeks of storage, respectively. Treatments O30 and O45 delivered products with lower microbial counts than the other ones. Considering a balance between consumer preference and microbiological results, we propose the use of 45% O₂ + 55% CO₂ gas composition to extend the shelf life of lamb loin.

Keywords MAP · Color · Oxidation · Spoilage

Introduction

The pursuit for convenience foods increased consumers demand for chilled meat (Trindade et al. 2013). However, the high level of water activity, the pH value favorable for most microorganisms, high nutrient content and lack of antimicrobial constituents contribute to reducing the shelf life of this product (Franco and Landgraf 2003). Indeed, Camo et al. (2008) propose that the shelf life of chilled lamb meat does not exceed 10 days due to microbial spoilage.

Packaging is a technology that can be used together with refrigeration in order to delay meat degradation (Ubaldi et al. 2015). One type of packaging that has come to prominence is modified atmosphere packaging (MAP). This technology consists of removing or replacing the atmosphere around the product with a known mixture of gases. Vacuum is a type of MAP, which maintains an oxygen-deficient environment around the product, decreasing the growth of CO₂ tolerant bacteria and preventing the growth of strictly aerobic bacteria (Bellés et al. 2017; Rubio et al. 2016).

The most common gases used in MAP for fresh chilled meat are oxygen (O₂), nitrogen (N₂), and carbon dioxide (CO₂) (Bellés et al. 2017; Esmer et al. 2011). When CO₂ is applied in combination with other gases, there is an increase of the shelf-life of this product due to the bacteriostatic action of CO₂ (Zhang et al. 2015). On the other hand, O₂ favors the development of bright red color, caused by the formation of oxymyoglobin, which is attractiveness to consumers (Li et al. 2012; Liu et al. 2014). Nevertheless, the high levels of O₂ can promote oxidative changes in the meat, inducing cross-links between protein molecules (Jongberg et al. 2014). These reactions may subsequently negatively affect the tenderness and juiciness

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of the meat. The presence of oxygen also leads to an increase of lipid oxidation, which causes undesirable changes in color and taste (Lorenzo et al. 2014).

The most used MAP for red meat is the mixture of 70–80% O₂ and 20–30% CO₂ (Bellés et al. 2017; Esmer et al. 2011; Kim et al. 2012a; Lund et al. 2007) due to the visual appeal to consumers caused by the reaction of oxygen with the myoglobin, which favors the bright red color of the product promoted by the presence of oxymyoglobin (Kim et al. 2010). Most researchers reported the use of MAP in beef, with some results for chicken, pork or foal (Arvanitoyannis and Stratakos 2012; Gómez and Lorenzo 2012; Kim et al. 2010; Lorenzo and Gómez 2012). Although it is widely consumed in other countries, lamb meat is relatively unpopular in Brazil, which reinforces the need to study methods for the preservation of this product.

The aim of this work was to study different gaseous combinations, not studied earlier, ideal for lamb meat in order to prevent lipid oxidation, to maintain the color and to delay spoilage. Various MAP conditions were applied to refrigerated lamb meat and the effects on quality parameters and consumers acceptance were evaluated.

Materials and methods

Two hundred and fifty-five lamb loins (*Longissimus lumbarum*) were used for this research. Three groups of 85 loins were purchased separately, so that the experiment was repeated three times (three repetitions). Seventeen loins allocated randomly were used for each of the five treatments in each repetition. Extra loins were used for sensory tests. The lambs were male, from Texel × Santa Ines breed, slaughtered at 5 months of age and with a carcass weight around 18 kg. The loins were cut between the 1st and 6th lumbar vertebrae, deboned, trimmed of all apparent fat and collagen tissues, packed under vacuum and kept refrigerated (1 °C) before transportation to the College of Animal Science and Food Engineering at the University of Sao Paulo. Packaging under modified atmosphere was done at 48 h after slaughter.

The loins (weighing around 150 g each), were individually packed in polystyrene trays of the type Dry-lock (LINPAC Brand, Model 21P LinStar), measuring 140 × 178 × 25 mm and with a water absorption capacity of 25 ± 5 g. The trays were placed individually in plastic bags (dimensions of 200 × 400 mm) made of a high-barrier film, special designed for chilled meat, containing seven layers based on EVA (ethyl vinyl acetate), PVDC (polyvinylidene chloride), and EVOH (ethylene vinyl alcohol) with (Type BB2800, Brand CRYOVAC). The properties of this multilayer packaging were: 48–62 µM of

nominal thickness; Maximum permeability rate of 2.5 cm³ O₂ m⁻² day⁻¹ (1 atmosphere—atm, 23 °C, 0% RH) and maximum rate of permeability to water vapor of 10 g H₂O m⁻² day⁻¹ (1 atm, 38 °C, 90% RH). Individual loins were stored in five different conditions (treatments) of MAP: 15% O₂ + 85% CO₂ (O15); 30% O₂ + 70% CO₂ (O30); 45% O₂ + 55% CO₂ (O45); 60% O₂ + 40% CO₂ (O60); and Vacuum (control). The gas:loin ratio inside the package was 5:1 (v:w). Since the goal of the present study was to evaluate only the influence of different MAPs on lamb meat characteristics, loins were stored in the dark for 21 days at 1 ± 1 °C in biochemical oxygen demand (BOD) greenhouses (Brand Fanem, model 347CD).

The physicochemical parameters were evaluated weekly (0, 7, 14, and 21 days). Microbiological analyses were performed at initial time, 3, 7, 11, 14, 18 and 21 days of storage. Sensory evaluation was carried out only at 2 and 9 days of refrigerated storage.

Gas composition

Gas composition inside the packages was determined using a portable gas analyzer (Brand Dansensor, model Check-point O₂/CO₂).

Physicochemical analyses

Seventeen loins were used in each repetition. The loins were divided as follows: 7 loins for microbiological analyses, 4 loins for texture analyses and 4 loins for objective color, pH and lipid oxidation analyses. The last three tests were carried out in the order mentioned, in order to reuse the loins. The gas composition tests, which did not involve destruction of the sample, were carried out before opening the packages for the other tests. The remaining two loins were used for the determination of the lamb meat proximate composition. This was done in the three repetitions of the experiment.

Proximate composition

AOAC Official (1997) methods were applied for protein (981.10), fat (991.36), moisture (950.46) and ash (920.153) determinations. In each repetition, two loins were homogenized in a food processor (Brand Philips Walita, Model RI7636) and the mixture was used for analyses.

Measurements of pH value

The pH value measurements were performed using a pH meter (Brand Hanna, Model HI 99163, Woonsocket, USA); three readings were taken at different loins points of each

treatment. The equipment was calibrated with 4.0 (cod. PH09787SO, Exodo Cientifica, Hortolandia, Sao Paulo, Brazil) and 7.0 buffer solutions (cod. PH09791SO, Exodo Cientifica, Hortolandia, Sao Paulo, Brazil).

Cooking loss and shear force

Loins were weighed and then cooked in an electric oven (Venax Eletrodomésticos Ltd., Venâncio Aires, RS, Brazil) at 180 °C until a core temperature of 72 °C. The loins were removed from the oven and left at room temperature for 30 min to reach room temperature, and weighed again to determine the weight loss from cooking (Eq. 1):

$$WL = \frac{[(\text{Initial weight} - \text{Final weight}) / \text{Initial weight}] \times 100}{(1)}$$

These same loins were then cut into eight $2 \times 1 \times 1$ cm parallelepiped samples, parallel to the muscle fibers direction, to perform the shear force test. The “Warner–Bratzler” accessory (Salter Brecknell, 2356×, Manhattan, Kansas, USA) was used to determine the shear force, which was expressed in Kgf.

Lipid oxidation

After measuring pH and color, the same loins were ground and the method of Vyncke (1970) was used to measure the development of thiobarbituric acid reactive substances (TBARS). The results were expressed in mg of malonaldehyde kg^{-1} of the sample (MDA kg^{-1} of the sample). Six measurements were made.

Instrumental color

The lamb meat color was evaluated by reading the L^* , a^* , and b^* parameters of CIE Lab system with a portable spectrophotometer (Brand HunterLab, mod. MiniScan EZ-4500L, geometry 450/0). The illuminant D65, 10° of observation angle, and cell gap of 25 mm was selected. Values of L^* , a^* and b^* were calculated as means of six readings taken after 30 min of exposure to the atmospheric air, in order to allow the blooming of the samples.

Microbiological analyses

Lactic acid bacteria (LAB), anaerobic and aerobic psychrotrophs, thermotolerant coliforms, Coagulase-positive Staphylococci and Salmonella were determined. Lactobacilli DeMan, Rogosa and Sharpe (MRS) (Acumedia, Neogen Corporation) agar was used to plate lactic acid

bacteria; the plates were incubated at 37 °C for 48 h. Aerobic Count Plate, 6400 (Petrifilm™ 3 M Health Care, St. Paul, MN, USA), was used for anaerobic and aerobic psychrotrophic organisms, and enumeration was performed after the plates were incubated at 21 °C for 72 h. Anaerobiosis was maintained by keeping the plates in an anaerobic jar (Probac do Brazil, Sao Paulo, Brazil) with an anaerobiosis generator (Anaerobac, Probac do Brazil, Sao Paulo, Brazil). For thermotolerant coliforms, Coliform count plates (6410, Petrifilm™ 3 M Health Care, St. Paul, MN, USA) were utilized with incubation at 45 °C for 24 h. Coagulase-positive Staphylococci were counted after 24 h of incubation at 37 °C using STX count plates (6490, Petrifilm™ 3 M Health Care, St. Paul, MN, USA). For Salmonella analysis, previous enrichment procedure was performed by diluting 25 g of the sample in 225 ml of enriched peptone water (Merck KGaA, Darmstadt, Germany) followed by incubation at 37 °C for 24 h before performing the readings using DuPont Qualicon BAX System equipment. Kit Bax for Salmonella (DuPont Nutrition and Health, Wilmington, USA) was used to determine the presence of Salmonella by polymerase chain reaction (PCR).

Sensory evaluation

Acceptance test (9-point hedonic scale) and visual analyses (preference ranking test) were carried out after 2 and 9 days of storage. For acceptance test, loins were dipped into NaCl brine at (5 g of NaCl/100 mL of water) for 30 min followed by cooking in an electric oven at 180 °C until reaching a core temperature of 72 °C. After cooking, loins were kept in a greenhouse (Titã Eletrocomerciais, Model Veneza 48, Brazil) at 60 °C for up to 20 min before serving in a complete randomized block design. Consumers tasted all the five treatments (five samples per person) and scored each sample using a 9-point hedonic scale (1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much; and 9, like extremely) for aroma, texture, juiciness, flavor and overall quality attributes (Meilgaard et al. 1991).

The same consumers also evaluated the different treatments appearance through a preference ranking test of the lamb loins still packaged in different MAP conditions. This test was carried out with the purpose of simulating the conditions of purchase of the product. Raw samples of the five treatments, each inside their respective package, were simultaneously presented to each consumer for appearance observation. Samples were presented to each consumer applying completely randomized blocks. The samples were ranked by the consumers in ascending order of overall appearance preference. The sensory analyses were only

undertaken in the first and second weeks of storage in order to ensure consumers' safety. From the third week on, some treatments exhibited high microbial counts. For each time 60 consumers were recruited, totalizing 120 consumers.

Statistical analysis

Randomized split-plot design was used. Both treatments and storage time were considered fixed-effect factors when analyzing physicochemical and microbiological parameters. For statistical purposes each repetition was considered a block. The effect of blocks was tested by analysis of variance (ANOVA) in order to verify differences among the replicates. For the statistical analysis of the sensory acceptance test results, the treatments were considered fixed-effect factors and the consumers as random effect factors. The effect of different repetitions (block effect) was also tested. To perform the data analysis (ANOVA and Tukey's test) the plot mixed procedure (SAS 2014. SAS/STAT® 13.2) was used. Linear regression was performed to explain the behavior of responses over time. The consumer preference-ranking test was analyzed using the Friedman rank procedure with 5% of significance. Least significant ranked difference (LSRD) values were calculated to evaluate which samples were preferred.

Results and discussion

Gas composition

There were no significant differences among the blocks (repetitions) for any measured attribute ($P > 0.05$).

The treatment that showed the largest variation in gas composition (CO_2 and O_2) over the storage period was O60 (Fig. 1). Significant variation ($P < 0.05$) in gas content was detected for these samples and for samples O45 ($P < 0.05$). The same pattern has been observed by Rubio et al. (2016) and Fernandes et al. (2014). Variations in the gas composition occurred mainly due to absorption of the gas by the muscle, microbial activity, and meat biochemical reactions during the storage period (Jakobsen and Bertelsen 2000).

Physicochemical analyses

Proximate composition, pH value, cooking loss and shear force

The average composition of lamb loins was $73.6 \pm 0.5\%$ moisture, $21.3 \pm 0.3\%$ protein, $3.3 \pm 0.3\%$ fat and $1.07 \pm 0.06\%$ ash. The results are comparable to those reported by Fernandes et al. (2014) (75% moisture, 21.20%

Fig. 1 Representative curves of oxygen (a) and carbon dioxide (b) content in the headspace of packaging systems for lamb loins in five MAP conditions during 21 days of storage at 1 °C. Treatments: 15% O_2 + 85% CO_2 (O15); 30% O_2 + 70% CO_2 (O30); 45% O_2 + 55% CO_2 (O45); 60% O_2 + 40% CO_2 (O60)

protein, 2.48% fat and 1.05% ash) who also studied MAP for lamb loins.

There was no significant difference ($P > 0.05$) among treatments for pH values. A representative curve of this behavior is shown in Fig. 2a. Regarding the various storage periods, an increase (over the first 14 days) followed by a reduction (21 days) in pH values was observed ($P < 0.05$). The increase in the pH values at the beginning of storage is a result of the meat maturation process that involves enzymatic degradation of the myofibrillar structure. According to Karabagias et al. (2011), increasing pH reflects the degradation of proteins for the production of free amino acids, which lead to the formation of NH_3 and amines, alkaline reacting compounds. The latter reduction in pH values might be due to the development of lactic acid bacteria and consequent production of lactic acid (Rubio et al. 2016), which is supported by the microbial counts measured during this period (Fig. 4).

MAP did not affect ($P > 0.05$) cooking loss (CL), and there was no significant interaction ($P > 0.05$) among samples of different treatments during the storage period. The overall CL mean was 21.85%. Bressan et al. (2001), obtained a higher CL value (28%) when working with *Longissimus lumborum* from Santa Ines and Bergamacia lamb breeds. The water retention capacity might affect the appearance and behavior of the meat before and after

Fig. 2 Representative curves of pH (a) and TBARS (b) for lamb loins in five MAP conditions during 21 days of storage at 1 °C. T15% O₂ + 85% CO₂ (O15); 30% O₂ + 70% CO₂ (O30); 45% O₂ + 55% CO₂ (O45); 60% O₂ + 40% CO₂ (O60); and vacuum (control)

cooking, respectively, also affecting the juiciness during mastication (Lawrie 2005).

There was a significant decrease in shear force values over the storage time ($P < 0.05$) but not among treatments ($P > 0.05$). At the first day of storage, the loins showed 36.19 Newtons (N) of shear force and 27.56 N at the last day. Kim et al. (2012b) also reported a decrease of shear force along storage time in lamb loins packaged under high-oxygen modified atmosphere. This is due to the maturation of the meat, which was not affected by different gas compositions over the storage time. The shear force values were below 39.22 N, which classifies the meat as very tender (Kim et al. 2012a, b).

Lipid oxidation

Increasing TBARS values were observed throughout the storage period ($P < 0.05$) (Fig. 2b). The higher the O₂ level in the package the higher the level of TBARS. The mean on the first day was 0.46 MDA Kg⁻¹, which increased significantly to 1.20 MDA Kg⁻¹ after 7 days of storage in O60 ($P < 0.05$). Vacuum-packed samples maintained low oxidation levels throughout the storage time (0.31 MDA Kg⁻¹).

Fig. 3 Representative curves of the \ (a) and a* (b) 30 min after opening the package, for lamb loins in five MAP conditions during 21 days of storage at 1 °C. T15% O₂ + 85% CO₂ (O15); 30% O₂ + 70% CO₂ (O30); 45% O₂ + 55% CO₂ (O45); 60% O₂ + 40% CO₂ (O60); and vacuum (control)

On the 21 days, the highest ($P < 0.05$) TBARS values (1.38 MDA Kg⁻¹ sample) was for O60. This finding is in agreement with previous results (Kim et al. 2010, 2012a; Zakrys et al. 2008), which confirms that large concentrations of oxygen induce lipid oxidation. The lowest lipid oxidation level was found for samples packed under vacuum, due to the low level of residual oxygen. Levels of oxidation for treatments vacuum, 45% O₂ + 55% CO₂ and 30% O₂ + 70% CO₂ were 0.31 MDA Kg⁻¹, 0.61 MDA Kg⁻¹ and 0.60 MDA Kg⁻¹, respectively. The results obtained for the treatments O45 and O30 were similar to one another, showing intermediate TBARS values. A reduction in O₂ from 60% (O60) to 45% (O45) increased the lipid stability of the loins (from 1.38 to 0.61 MDA Kg⁻¹). At the last day of storage, the TBARS values of vacuum, O45, and O30 were below the maximum acceptable level (1 MDA Kg⁻¹) that could cause perception of rancidity (Amaral et al. 2015; Das et al. 2008).

Reductions of TBARS levels over time for the same treatment, as observed in samples conditioned in O60, have been explained by some authors. According to Maqsood and Benjakul (2010), malonaldehyde and other products of lipid oxidation are unstable and can be decomposed into

Table 1 Results of the sensory evaluation acceptance and visual preference ranking tests of lamb loins packed under different gas compositions on the 1st and 2nd weeks of refrigerated storage

Attributes	O60	O45	O30	O15	Vacuum	SE
First week						
Aroma ¹	6.10 ^a	5.86 ^a	5.93 ^a	6.16 ^a	5.78 ^a	1.42
Texture ¹	6.84 ^{ab}	6.78 ^{ab}	6.44 ^{ab}	6.21 ^b	6.97 ^a	2.16
Juiciness ¹	7.14 ^a	6.95 ^{ab}	6.50 ^b	6.91 ^{ab}	6.90 ^{ab}	1.54
Flavor ¹	6.38 ^a	6.16 ^a	6.31 ^a	6.84 ^a	6.14 ^a	2.16
Overall quality ¹	6.69 ^a	6.45 ^a	6.52 ^a	6.76 ^a	6.62 ^a	1.59
Visual preference ²	190 ^b	178 ^b	229 ^a	122 ^c	177 ^b	–
Second week						
Aroma ¹	6.10 ^{ab}	5.55 ^b	6.03 ^{ab}	6.48 ^a	6.00 ^{ab}	1.35
Texture ¹	6.62 ^a	6.45 ^a	6.95 ^a	6.69 ^a	6.96 ^a	2.09
Juiciness ¹	6.83 ^{ab}	6.31 ^b	7.03 ^a	6.91 ^{ab}	6.86 ^{ab}	1.82
Flavor ¹	6.36 ^{ab}	5.93 ^b	6.50 ^{ab}	6.95 ^a	6.36 ^{ab}	1.88
Overall quality ¹	6.34 ^{ab}	6.02 ^b	6.69 ^a	6.90 ^a	6.60 ^{ab}	1.59
Visual preference ²	187 ^B	243 ^A	177 ^B	129 ^C	176 ^B	–

15% O₂ + 85% CO₂ (O15); 30% O₂ + 70% CO₂ (O30); 45% O₂ + 55% CO₂ (O45); 60% O₂ + 40% CO₂ (O60); and vacuum (control). SE standard error

^{abc}Same letter in the same row indicates that the samples were not significantly different at 5%

^{ABC}Same capital letters in the same row indicates that the samples were not significantly different at 5%

¹Results obtained through affective test by hedonic scale

²Results obtained through preference ranking test

organic forms, which are not detected by the TBARS test. Saeed et al. (1999), explained that oxidized lipids can react with proteins, which also contributes to the decrease of TBARS values during storage time. The constant generation and degradation of the products of lipid oxidation may have caused the peculiar behavior of the curve observed in samples O60 (Fig. 2b), in which the oxidation was more intense than in the other treatments due to the high amount of oxygen.

Instrumental color

Significant differences were observed ($P < 0.05$) in the L* and a* parameters with respect to storage time and among treatments. In general, L* values were between 39.34 and 50.14 (Fig. 3a). Vacuum treated samples, as well as O45, exhibited the lowest L* at the 21 days, 40.85 and 42.88 respectively, which indicates a darker color when compared to the other treatments.

There was a constant decrease in red color intensity over time ($P < 0.05$) for all treatments, except for vacuum ($P > 0.05$) (Fig. 3b). For all samples, this behavior was noticed after 7 days of storage. However, before 7 days the loins exposed to high concentrations of oxygen (O60 and O45) exhibited better color than vacuum-packed loins. This condition was also noticed by consumers through visual test, as showed on Table 1.

These results demonstrate that it is valid to use MAP aiming at maintaining the red color of lamb loins for short periods. The color of meat provided by this type of packaging is more intense and may be more attractive to consumers.

Samples packed in high O₂ atmospheres for more than 7 days showed a restriction of the oxygenation capacity of myoglobin molecules (for the formation of oxymyoglobin), and consequently, there was no generation of bright red color (Kim, Stuart, Black, and Rosenvold 2012b). This phenomenon did not occur in vacuum packed samples because when vacuum packages are opened the deoxymyoglobin formed remains able to bloom, which generates the oxymyoglobin (Li et al. 2012). In MAP conditions the conversion of oxymyoglobin to metmyoglobin lead to deterioration of the red color of the meat. Besides of that, Faustman et al. (2010) pointed that lipid oxidation and color depreciation in red meat are related. The products of the chemical reactions that lead to both oxidation of lipids and myoglobin are also responsible for accelerating these reactions in a reciprocal way. Thus, as lipid oxidation progresses, the loss of coloration may also be further enhanced, and vice versa. Jakobsen and Bertelsen (2000) affirmed that an increase above 55% in the oxygen level did not have a further improvement of the color stability, and in order to maintain the cherry red meat color oxygen levels above 20% are required.

Fig. 4 Representative curve of LAB growth for lamb loins in five MAP conditions during 21 days of storage at 1 °C

Microbiological analyses

No colony forming units (CFU) for thermotolerant coliforms and Coagulase-positive Staphylococci, and no *Salmonella* presence were detected in any samples throughout the storage period.

Lactic acid bacteria (LAB) (Fig. 4) and psychrotrophic anaerobic microorganism (Fig. 5a) counts showed no significant difference ($P > 0.05$) among treatments. However, there was an increase ($P < 0.05$) in both loadings over time.

The results obtained for psychrotrophic aerobic microorganisms are shown in Fig. 5b. Before the 14 days of storage, samples under vacuum presented the highest microbial growth rate for this class of microorganisms. Although the curves obtained for all the samples showed similar behavior, there is a clearly greater bacteriostatic effect of CO₂, even with high concentrations of oxygen. This was demonstrated by the significant difference ($P < 0.05$) and the difference of at least 1 log cycle at various time points. The best MAP condition used to avoid psychrotrophic aerobic growth was O15. These samples reached the maximum limit established by the International Commission on Microbiological Specifications on Foods (ICMSF 1986), 10^7 CFU g⁻¹, only after 18 days of storage. Vacuum-packed loins were the first samples to reach this limit (on the 11 days of storage). By this time (11 days) samples O30 and O45 showed microbial counts below that level; in fact, these lamb loins reached the established limit only on the 14 days of storage. Based on these results, it is clear that high CO₂ content inhibits microbial growth, even when high concentrations of O₂ were used.

Sensory analysis

The results of both sensory tests applied are shown in Table 1. Regarding the acceptance test (using a 9-point

Fig. 5 Representative curves of psychrotrophic anaerobic (a) and aerobic (b) growth for lamb loins in five MAP conditions for 21 days of storage at 1 °C. T15% O₂ + 85% CO₂ (O15); 30% O₂ + 70% CO₂ (O30); 45% O₂ + 55% CO₂ (O45); 60% O₂ + 40% CO₂ (O60); and vacuum (control)

hedonic scale), after 2 days of storage (first week), there was no significant difference ($P > 0.05$) among the samples for aroma, flavor and overall quality attributes. For the texture attribute, samples O15 differed significantly from the samples packed under a vacuum. The vacuum samples (control) were considered softer (6.96). As for juiciness, difference was found between O60 and O30. For appearance, O30 received higher score than the other samples.

As for the second week, also regarding the acceptance test, there was no significant difference ($P < 0.05$) in any of the MAP treatments in all parameters evaluated when compared to the vacuum treatment (Control). In general, samples O15 received the best scores (Table 1).

Preference ranking test showed that samples O45 were visually preferred over other treatments; this treatment also received significantly higher scores ($P > 0.05$) than vacuum-packed samples.

The preferred appearance of the meat, observed in samples with high oxygen concentrations in the pack, could be due to the formation of oxymyoglobin, which has a bright red color. However, when more than 45% of O₂ was present in the headspace, a reduction in acceptability was

noticed, as for instance samples O60. Maqsood and Benjakul (2010) also observed higher color liking scores for ground beef stored under high oxygen MAP, when compared to samples stored in air or under low oxygen MAP. Zakrys-Waliwander et al. (2011) have proposed that, in MAP conditions, the O_2 causes the oxidation of lipids, leading to alterations on color and flavor.

Conclusion

The presence of O_2 in the package maintained an attractive color of the loins in the first days of storage, as determined by objective color measurements. This finding was further supported by the preference ranking test, in which consumers preferred the appearance of 30% O_2 + 70% CO_2 and 45% O_2 + 55% CO_2 treatments. When the concentration of O_2 in the headspace was overly high, the color was negatively (rather than positively) affected; consumers rejected the product. 45% O_2 + 55% CO_2 treatment also showed good results for microbiological and lipid oxidation tests. A shelf life of 14 days was obtained for this treatment, and TBARS levels were below the limit of perception at all tested storage times. Thus, we recommend MAP with 45% O_2 + 55% CO_2 (O45) for the preservation of lamb loins stored under refrigeration.

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