Modified atmosphere packaging and osmotic dehydration effect on pork quality and stability

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Abstract
Objective of this study was to evaluate the effect of food dehydration and modified atmosphere packaging on the quality characteristics and shelf-life extension of pork meat. Meat was osmotically dehydrated in solution of sugar beet molasses. Half of the samples were packed in atmospheric conditions while other half was packed under modified atmosphere. Samples were stored for 2 months under 4°C. Microbiological, physico-chemical (pH, a_w, moisture, proteins, fat, carbohydrate, thiobarbituric acid) and sensorial parameters, as parameters of shelf-life changes, were monitored. Sugar beet molasses solution improved quality stability during subsequent refrigerated storage, in terms of microbial growth, nutritional profile and sensorial degradation, resulting in a significant shelf-life extension. Samples packed under modified atmosphere showed higher level of stability compared to samples packed in atmospheric conditions. Although osmotic dehydration can provide shelf-life extension, combination of osmotic dehydration and modified atmosphere packaging was more effective in terms of microbial and sensorial meat quality.

Key words: osmotic dehydration, packaging, shelf-life, pork meat

Introduction

Food dehydration is still one of the most relevant and challenging unit operations in food processing [1]. During the osmotic dehydration (OD), water flows from the product into the osmotic solution, while osmotic solutes are transferred from the solution into the product [2]. OD is an effective technique to reduce the water content in processed product to improve sensory, functional, nutritional properties [3] and reduce or inhibit microbial growth [4]. Compared to the other preservation treatments, OD shows significant advantages: environmentally acceptability, energy efficiency, providing stable and quality products [5]. Sugar beet molasses is an excellent medium for osmotic dehydration, due to the high dry matter and specific nutrient content. From nutrient point of view, an important advantage of sugar beet molasses, as hypertonic solution, is enrichment of the food material in minerals and vitamins [6]. OD optimization implies as much as possible low temperatures and treatment times that could make the process efficient and practical [7, 8].

Modified atmosphere packaging (MAP) is used in the meat industry to extend the product shelf-life [9] especially in meat and meat products for the past two decades [10]. Variables that influence shelf life properties of packaged fresh meat are product type, gas mixture, packaging materials and headspace, packaging equipment, storage temperature and additives.
It was found that the extension of shelf life of meat samples augmented in the order: air<vacuum pack<40%CO₂+30%N₂+30%O₂<80%CO₂+20%air<100%CO₂ [10]. In this experiment chosen optimal gas ratio was 30%CO₂:70%N₂ in order to satisfy previous facts. The quality of packaged meat is also greatly influenced by properties of packaging materials. Mc Millin briefly reviews materials that could be used as packaging according to their water vapor and O₂ transmission rate, tensile strength, impact strength, heat seal temperature, etc [12].

Meat is a rich nutrient matrix with high percentage of water content which has the significant impact on the physico-chemical, sensory and technological properties of meat (Barat et al., 2009). Microbial growth, colour and lipid oxidation are factors important to shelf life and consequently to consumer acceptance of fresh meat and poultry [13, 14]. In this work we examined effects of OD and MAP as mild preservation techniques. We applied highly barrier materials and MAP in order to evaluate shelf-life of OD meat during 2 months in comparison with OD meat packed in atmospheric conditions (ATM).

**Materials and Methods**

**Experimental setup:** Fresh pork (*Musculus brachii*) (48h post mortem) was trimmed of external fat and connective tissues and manually cut into approximately (1x1x1) cm cubes. Samples were osmotically treated in sugar beet molasses solutions (80 kg l⁻¹) at 22°C for 5 hours. Solution to sample ratio was 5:1 (w/w) to avoid significant dilution of the medium by water removal, which would lead to local reduction of the osmotic driving force during process [15]. Atmosphere modification and package sealing were performed using a packaging machine CFS COMPAKT 420. Packaging molds were formed of two different foils kindly provided from national leading meat products company “Neoplanta”. The first foil (transparent PVC//PE–EVOH-PE) was in the form of tray, (foil 1) and second foil (PET//PE-EVOH-PE) was cover, (foil 2). Samples received gas treatment: 30%CO₂+70%N₂. Packaged meat samples were stored at (4±0.5) °C and sampled after 2, 4, 6 and 8 weeks for analyses.

**Material analysis:** Water vapor permeability (WVP) was determined gravimetrically according to the ASTM method [16] and permeability of gasses was measured using method by Lyssy, according to DIN [17]. Results were presented as mean ± SD from 5 measurements. **Physicochemical analysis:** Water content was determined by the ISO standard [18] and water activity (aw) was measured using a water activity measurement device TESTO 650 with an accuracy of ±0.001 at 25°C.

pH measurements was determined by ISO [19]. Soluble solids content of the molasses was measured using Abbe refractometer at 20 °C while mineral matters content was determined in accordance to ISO [20]. ISO standard method was used for determination of AV [21]. TBA values were obtained using the procedure of Tarladgis et al. [22]. For each determination measurements were performed in triplicate.

**Microbiological analysis:** Total Viable Counts (TVC) and Enteroabcteriaceae were determined in accordance with ISO standards [23, 24].

**Colour measurements:** The coloured images were recorded with digital Canon PowerShot A550 camera. Basic colour informations expressed in RGB colour system were converted to CIEL Lab colour coordinates (illuminant D65, 10° observer angle), using developed computer program.

**Sensory evaluation:** Dehydrated meat in molasses was assessed by a panel of six members and ISO standards were applied [25, 26]. Panelists identified descriptors and set up Romanian Biotechnological Letters, Vol. 18, No. 2, 2013
descriptive profiles [27]. The selected descriptors were rated using a 5-point intensity scale, where: 0-is not observed, and 5-strong in relation to the selected property.

**Statistical analysis:** Descriptive statistical analyses for calculating the means and the standard error were performed using MicroSoft Excel software. All obtained results were expressed as the mean ± standard deviation (SD). Regression analysis and the evaluation of one-way analysis of variance (ANOVA) of obtained results were performed for comparison of means, and significant differences are calculated according to post-hoc Tukey’s HSD test at 95% confidence limit, using StatSoft Statistica 10.0.

**Results and Discussions**

**Osmotic dehydration**

The treatment with sugar beet molasses solution caused a significant moisture loss from meat samples. Water content, water activity and pH are presented in Table 1.

**Table 1.** Water content (%), water activity ($aw$) and pH of pork meat before osmotic treatment, after osmotic treatment (at the beginning of storage period), at the end of storage period for ATM and MAP packed meat samples

<table>
<thead>
<tr>
<th></th>
<th>Before OD (fresh meat)</th>
<th>After OD</th>
<th>Beginning of the storage (OD meat)</th>
<th>After 8 weeks of storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>75.957±0.045&lt;sup&gt;d&lt;/sup&gt;</td>
<td>40.433±0.244&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.030±0.019&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.080±0.030&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>$aw$</td>
<td>0.938±0.002&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.872±0.001&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.871±0.001&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.870±0.000&lt;sup&gt;5a&lt;/sup&gt;</td>
</tr>
<tr>
<td>pH</td>
<td>6.047±0.006&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.693±0.011&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.364±0.010&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.387±0.006&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b,c,d</sup> Values with the same letter are not statistically different at the p<0.05 level (Tukey’s HSD test)

The post HOC Tukey’s HSD test was used for water content, $aw$, and pH comparison between samples. Statistically significant differences were found between all samples, before and after OD, p<0.05 (Table 1). The water activity values decreased during the osmotic treatment. Obtained values after OD are in agreement with Filipović & al. [28]. The decrease of $aw$, leads to more microbiologically stable product without significant quality and nutritional damage, observed with traditional drying methods.

Growth of lactic acid bacteria resulting in lactic acid production is the major factor in pH decrease in packaged meats [29]. pH values also decreased during storage time. pH decreases more in MAP than in ATM. Low storage temperature (4°C) should be also taken into account as a factor that impacts pH decrease [30].

**Material analysis**

Results related to water vapor permeability (WVP) (ml·m⁻²·24h⁻¹) were 6.9±0.18 and 9.5±0.06, respectively for foil 1 and 2. According to composition it is obvious that PVC contribute the most to excellent barrier property (WVP for PVC is 1.5-5). In case of foil 2, WVP of PET and PE are similar [12].

Gas permeability (ml·m⁻²·24h⁻¹) for CO₂, O₂, N₂ and air were 23.8±1.93; 15.5±0.64; 0 and 3.6±0.12 for foil 1, respectively whereas gas permeability for CO₂, O₂, N₂ and air were
23.85±1.4; 26±0.57; 26.85±1.46 and 26.65±1.62 for foil 2, respectively. Since these materials will be used for MAP, special attention should be taken care with CO₂ and O₂ permeability.

**Physicochemical analysis**

**The content of mineral matters**

Real evaluation of OD treatment impact on nutritional improvement could be noticed through influence of beet molasses composition on the chemical and nutritional characteristics of fresh pork. Specific chemical composition of used molasses is presented in Table 2. Mineral quantities increase in meat was pronounced after OD, thus final meat nutritive quality was enhanced. From the Table 2 it could be noticed that amount of tracked minerals was approximately 4 times increased, while only Mg amount was 3 times increased. The comparison between samples, concerning minerals content, were done using post-hoc Tukey’s HSD test, and statistically significant difference was found in all samples, p<0.05 (Table 2).

<table>
<thead>
<tr>
<th>Mineral content (mg·100 g⁻¹)</th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
<th>K</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet molasses</td>
<td>6.80±0.30</td>
<td>89±10</td>
<td>655±48</td>
<td>2574±70</td>
<td>1221±67</td>
</tr>
<tr>
<td>Fresh pork meat</td>
<td>1.23±0.04a</td>
<td>28.02±0.87a</td>
<td>6.67±0.11a</td>
<td>376.07±10.1a</td>
<td>52.56±1.79a</td>
</tr>
<tr>
<td>OD pork meat</td>
<td>3.28±0.10b</td>
<td>112.40±2.09b</td>
<td>33.18±0.89b</td>
<td>1224.48±29.4b</td>
<td>210.90±7.32b</td>
</tr>
</tbody>
</table>

| Values with the same letter are not statistically different at the p<0.05 level (Tukey’s HSD test) |

**AV and TBA analysis**

The thiobarbituric acid reactive substances (TBA-RS) measure is an index of the range of fat oxidation that has occurred in pork cuts stored at low temperatures. Tsaknis & al.[31] reported that oxidative reactions can decrease the nutritional quality of food [32]. Ordóñez & Ledward [33] stated that the concentration of O₂ in the package atmosphere is the determining factor for the rate of lipid oxidation so O₂ exclusion or limitation in the MAP limits oxidation and lowers TBA values. Lopez-Lorenzo & al. [34] reported that CO₂ decreased lipid oxidation rate in pig meat. It is widely known that packaging meat in highly barrier material [32], storage time [9] and temperature [35] have significant effect on preventing fat oxidation and TBA values.

OD was shown to be effective in preventing TBA increase (expressed as mg of malonaldehyde acid (MDA) per kilogram). MDA values varied between 0.25 mg·kg⁻¹ and 0.42 mg·kg⁻¹ (Fig 1) indicating very low degree of lipid oxidation. All values below the 0.5 mg·kg⁻¹ of MDA are considered to be good result. 0.5 mg·kg⁻¹ of MDA is limit at which undesirable flavors could be noticed as a result of rancidity [36].
Correlations between TBA and AV were observed, correlation coefficient was -0.821, statistically significant at p<0.10 level for samples packed under MAP, while correlation coefficient was -0.931, significant at p<0.05 level, for samples packed under ATM. In both cases, it could be noticed that MDA concentration decreases after reaches peak value. MDA reacts with sugar or amino acids that exist in sugar beet molasses and initial formation of MDA started to decompose during the later stages of storage in another chemical compounds.

Microbiological analysis
Low initial value of TVC for the fresh pork meat indicated good meat quality. TVC value of 7 log CFU·g⁻¹ is considered as an upper microbiological limit for good fresh meat quality, as defined by the ICMSF and Dainty & al. [37, 38]. Since during storage time, TVC didn’t exceed 7, it is reasonable to expect good sensorial characteristics of packed meat. From the Fig 2a can be observed constant TVC decrease until the first 4 weeks of storage for meat samples packed under ATM conditions, while microbial decrease lasted for the first 6 weeks for meat samples packed under MAP. MAP had a clear effect on the inhibition of TVC, due to its higher concentration of CO₂. Correlation coefficient between samples packed in MAP and ATM for TVC was 0.985, statistically significant at p<0.01 level.

The decrease of Enterobacteriaceae throughout storage could be attributed to the initial pH lowering of the meat as microorganisms normally compete better in meat of high pH (>6.0) which is accordance with findings of Bern & al. [39] and Leygonie & al. [40]. Correlation
coefficient between samples packed in MAP and ATM for *Enterobacteriaceae* was 0.987, statistically significant at p<0.01 level.

Tracking the change of values for the TVC or number of *Enterobacteriaceae* for the meat can indicate the level of hygiene of the process and the sustainability of the produced product/semi product. The results of the reduction of total number of bacteria and number of *Enterobacteriaceae* in any dehydrated meat in comparison to the fresh meat indicate that the process of OD is hygienically safe and are in agreement with Filipović & al. [28].

**Colour measurements (Kinetics model)**

The experimental values of most frequent L, a, b coordinate (shown in Fig. 3), were adjusted to mathematical models, used to describe the process kinetics, listed in Table 3 [41, 42]. They were used for mathematical modeling and tested to select the best model for describing the kinetics equation of pork meat browning process at refrigerator temperature (4°C).

<table>
<thead>
<tr>
<th>No</th>
<th>Models</th>
<th>( L^<em>, a^</em>, b^* = )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Newton - Lewis model</td>
<td>( \exp(-kt) )</td>
</tr>
<tr>
<td>2</td>
<td>Page's model</td>
<td>( \exp(-k^*t) )</td>
</tr>
<tr>
<td>3</td>
<td>Linear</td>
<td>( y_0 - k_0 \cdot t )</td>
</tr>
<tr>
<td>4</td>
<td>Quadratic</td>
<td>( a_0 + k_0 \cdot t + k_1 \cdot t^2 )</td>
</tr>
<tr>
<td>5</td>
<td>Henderson and Pabis</td>
<td>( a \cdot \exp(-kt) )</td>
</tr>
<tr>
<td>6</td>
<td>Logarithmic</td>
<td>( a \cdot \exp(-kt) + c )</td>
</tr>
<tr>
<td>7</td>
<td>Two-term model</td>
<td>( a \cdot \exp(-kt) + b \cdot \exp(-gt) )</td>
</tr>
<tr>
<td>8</td>
<td>Two term exponentional</td>
<td>( a \cdot \exp(-kt) + (1 - a) \cdot \exp(-kt) )</td>
</tr>
<tr>
<td>9</td>
<td>Modified Henderson and Pabis</td>
<td>( a \cdot \exp(-kt) + b \cdot \exp(-gt) + c \cdot \exp(-ht) )</td>
</tr>
<tr>
<td>10</td>
<td>Midilli and Kucuk</td>
<td>( a \cdot \exp(-k^<em>t^</em>) + k_0 \cdot t )</td>
</tr>
</tbody>
</table>

The color coordinates of experimental data obtained were fitted to the 10 commonly used regression models by using non-linear least squares regression solved by a Levenberg–Marguardt numerical method. Results were examined using standard statistical error tests, i.e., coefficient of determination \( (R^2) \), the mean relative percent error (MPE), the root mean square error (RMSE) and the reduced chi-square \( (\chi^2) \). The higher the values of \( R^2 \) and the lower the values of MPE, RMSE and \( \chi^2 \), the better is the goodness of fit. These parameters can be calculated as follows:

\[
MPE = \frac{100 \cdot \sum_{i=1}^{n} \frac{|y_{exp,i} - y_{pre,i}|}{y_{exp,i}}}{N},
\]

\[
RMSE = \left[ \frac{1}{N} \sum_{i=1}^{n} \left( y_{exp,i} - y_{pre,i} \right)^2 \right]^{1/2},
\]

\[
\chi^2 = \frac{\sum_{i=1}^{n} (y_{exp,i} - y_{pre,i})^2}{N - n}
\]
where, $y_{exp_i}$ is the $i^{th}$ experimentally observed frequency color coordinate or lightness, $y_{pre_i}$ is the $i^{th}$ predicted frequency color coordinate or lightness, $N$ the number of observations and $n$ is the number model constants.

Analysis performed for MAP packed samples showed that the best regression curve is Henderson and Pabis model: $L^* = 30.053 \cdot \exp(-0.003 \cdot t)$, $a^* = 17.720 \cdot \exp(-0.005 \cdot t)$ and $b^* = 5.313 \cdot \exp(-0.004 \cdot t)$ (No 5, from Table 4). Curve No 5 gave the best fitting model for pork meat browning, and the testing parameters obtained the following values: $R^2 = 0.983$; MPE=-7.89·10^{-7}, RMSE=1.77·10^{-6} and $\chi^2=2.04\cdot10^{-3}$ (for $L^*$), $R^2 = 0.908$; MPE=-2.41·10^{-7}, RMSE=5.38·10^{-6} and $\chi^2=2.66\cdot10^{-3}$ (for $a^*$), and $R^2 = 0.957$; MPE=2.20·10^{-7}, RMSE=6.95·10^{-3} and $\chi^2=4.24\cdot10^{-1}$ (for $b^*$).

Analysis performed for ATM packed samples showed that the best regression curve is Henderson and Pabis model: $L^* = 28.264 \cdot \exp(-0.001 \cdot t)$, $a^* = 16.080 \cdot \exp(-0.001 \cdot t)$ and $b^* = 5.291 \cdot \exp(-0.006 \cdot t)$ (No 5, from Table 4). Curve No 5 gave the best fitting model for pork meat browning, and the testing parameters obtained the following values: $R^2 = 0.985$; MPE=-8.01·10^{-7}, RMSE=1.92·10^{-6} and $\chi^2=2.12\cdot10^{-3}$ (for $L^*$), $R^2 = 0.927$; MPE=-2.32·10^{-7}, RMSE=5.71·10^{-6} and $\chi^2=3.01\cdot10^{-3}$ (for $a^*$), and $R^2 = 0.962$; MPE=2.39·10^{-7}, RMSE=7.11·10^{-3} and $\chi^2=3.98\cdot10^{-1}$ (for $b^*$).

**Sensory evaluation**

Table 4 presents results of sensorial properties during storage time in terms of colour, flavor and aroma, taste and texture. Analysis of the results of sensory evaluation shows that treatment with molasses and packing in MAP has very favorable effect on the colour, which was assessed as very strong and very pronounced, throughout the storage period. Colour was more stable parameter than aroma. MAP had highest impact on meat colour compared to ATM because all other results (flavour, aroma, taste and texture) were similar for MAP and ATM samples.
Table 4. Sensory assessment

<table>
<thead>
<tr>
<th>Sample</th>
<th>Colour</th>
<th>Flavour and aroma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meat surface</td>
<td>Adipose tissue</td>
</tr>
<tr>
<td></td>
<td>dark brown-red</td>
<td>white-yellow</td>
</tr>
<tr>
<td>OD</td>
<td>4.83 ±0.38</td>
<td>4.58 ±0.50</td>
</tr>
<tr>
<td></td>
<td>4.23 ±0.66</td>
<td>3.19 ±0.76</td>
</tr>
<tr>
<td>OD+</td>
<td>4.98 ±0.14</td>
<td>4.82 ±0.38</td>
</tr>
<tr>
<td>MAP</td>
<td>4.33 ±0.61</td>
<td>3.27 ±0.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Taste</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>of fresh meat with pronounced sweetness</td>
<td>aftertaste (the smoke - pungent, bitter)</td>
</tr>
<tr>
<td>OD</td>
<td>3.40 ±0.68</td>
<td>3.42 ±0.58</td>
</tr>
<tr>
<td>OD+</td>
<td>3.49 ±0.64</td>
<td>3.50 ±0.75</td>
</tr>
<tr>
<td>MAP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In terms of flavour, during the first storage term the aroma and flavour of molasses with mild-average intensity of smoke and very low intensity of caramel dominated. After the second and third term of storage, in addition to a fairly strong smell and flavor of molasses, both meat samples had flavour and aroma of smoke and caramel, which were rated as average or fairly strong. After last storage term, fragrance of molasses reduced and was rated as average and slightly marked, and the smell of smoke and caramel quite poor to mediocre.

The results of taste evaluation during the first 3 storage terms were evaluated as average to quite strongly expressed with a pronounced sweetness and flavour with aftertaste on smoke. After last term, taste was assessed as very poor/average expressed as specifically related to the presence of sweetness, while the residual bitter and astringent taste in the mouth was intensified.

During the first two terms of storage meat is rated quite highly elastic, and then averagely elastic. Other texture properties during all days of storage were expressed as an average. MAP samples had greater impact on meat cheewable and elasticity than the juiciness and tenderness compared to ATM samples.

**Conclusions**

This paper deals with the question of OD pork meat shelf-life packed in MAP and ATM. OD with sugar beet molasses proved to be a good preservation method to keep meat quality. Sugar beet molasses is effective medium for osmotic dehydration because of it’s high dry
Modified atmosphere packaging and osmotic dehydration effect on pork quality and stability

matter. Rich mineral content improves meat nutritional characteristics. During OD water content and water activity decreased. The water content was reduced from 75.96 % to 40.43 % after osmotic dehydration, and water activity was reduced from 0.94 to 0.87. Since these two factors contribute to the microbiological stability, it is proved that the osmotic dehydration may preserve microbiological quality during 4 weeks period. The microbiological profile showed that the osmotic dehydration is hygienically safe. Additional applications of MAP in comparison with ATM packaging decreased lipid oxidation in samples and improved sensory quality. The results of this study indicate that the shelf life of fresh pork meat stored at 4°C can be extended by packaging the product under anaerobic conditions. Microbial profile proofs stability during 6 weeks. This increase in shelf life is due to the reduction of not only microbial spoilage but also lipid oxidation. TBA values were lower in case of MAP in comparison with ATM with tendency to decrease. Moreover, the presence of MAP extends the shelf life of pork meat by stabilization of red colour measured by instrumental and sensory techniques, and maintenance of fresh meat odour by slowing down off-odour perception.

Acknowledgements

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References