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Quality alterations of turkey and pig meat during storage in modified atmosphere or vacuum packages

Veränderungen der Qualität von Puten- und Schweinefleisch während der Lagerung in Schutzgas- oder Vakuumverpackungen

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Summary

During retail storage pig and turkey meat is often stored in vacuum or modified atmosphere with a high oxygen content to improve appearance and shelf life. The aim of the present study was to determine, how different packaging conditions and meat species influence meat quality during storage. Therefore, turkey and pig meat were packaged either in vacuum or high oxygen modified atmosphere packages (MAP, 80 % O_2, 20 % CO_2) and stored for 12 days at 3 °C. Lightness (L*), redness (a*), pH, electrical conductivity and total aerobic plate counts were determined at day 1 (before packaging) and at storage days 4, 8 and 12. Moreover, samples for analysis of thiobarbituric acid reactive substances (TBARS) and total volatile basic nitrogen were collected on the same days. On the last three sampling days sensory parameters and liquid losses were also determined. At these days pig and turkey meat in MAP had higher a* and better sensory results as well as lower liquid losses. However, meat in MAP presented at day 12 higher TBARS results than the vacuum meat. Pig meat had generally lower L*, pH and poorer sensory results as well as higher a* and liquid loss values than turkey meat. TBARS values were at day 12 higher in MAP and vacuum stored turkey meat compared to pork. For turkey and pig meat MAP storage is advantageous but quality differences between meat of different animal species exist.

Keywords: colour, microbiology, thiobarbituric acid reactive substances, liquid loss, sensory analysis

Zusammenfassung

Im Einzelhandel werden Puten- und Schweinefleisch häufig in Vakuum- oder Hochsauerstoffschutzgasatmosphäre angeboten, um deren Erscheinungsbild und Haltbarkeit positiv zu beeinflussen. Ziel der gegenwärtigen Studie war es, zu untersuchen, wie verschiedene Verpackungsbedingungen die Fleischqualität beeinflussen und inwiefern diese Ergebnisse durch die Tierart modifiziert werden. Dazu wurde Puten- und Schweinefleisch in Vakuum- und Hochsauerstoffatmosphäre (MAP, 80 % O_2, 20 % CO_2) verpackt und für 12 Tage bei 3 °C gelagert. Helligkeits- (L*), Rotwerte (a*), pH-Werte, elektrische Leitfähigkeit und aerobe mesophile Gesamtkeimzahlgehalte wurden an Tag 1 (vor dem Verpacken), 4, 8 und 12 bestimmt. An denselben Tagen wurden Proben zur Bestimmung der Konzentrationen an thiobarbitursäure-reaktiven Substanzen (TBARS) und gesamtem flüchtigen Basenstickstoff genommen. Sensorische Parameter und der Flüssigkeitsverlust wurden an Tag 4, 8 und 12 bestimmt. An diesen Tagen hatten Schweine- und Putenfleisch in MAP höhere a*-Werte, wurden sensorisch besser bewertet und hatten niedrigere Flüssigkeitsverluste. Jedoch hatte Fleisch in der MAP Verpackung an Tag 12 höhere Gehalte an TBARS im Vergleich zu vakuumverpacktem Fleisch. Schweinefleisch hatte generell niedrigere L*-, pH-, schlechtere Sensorik, höhere a*-Werte und Flüssigkeitsverluste als Putenfleisch. Die TBARS Werte waren für die Putenschnitzel an Tag 12 in beiden Verpackungsvarianten höher im Vergleich zum Schweinefleisch. Für Puten- und Schweineschnitzel ist die MAP Lagerung die vorteilhaftere Lagerungsvariante, dennoch existieren Qualitätsunterschiede zwischen den Spezies.

Schlüsselwörter: Farbe, Mikrobiologie, thiobarbitursäure-reaktive Substanzen, Flüssigkeitsverlust, sensorische Analyse

Introduction

An increasing amount of meat is stored in modified atmosphere (MAP) or vacuum packages for self-service purchase (Al-Nehlawi et al., 2013). These packaging variants have advantages and disadvantages concerning different quality parameters. For example, storage in high oxygen atmospheres positively influences the meat appearance by producing a bright red colour, but may enhance oxidative spoilage (Zakrys et al., 2009). To assess the stage of chemical spoilage, indicators like thiobarbituric acid reactive substances and the total volatile basic nitrogen content can be used (Fraqueza et al., 2008). A positive correlation between the evolution of lipid oxidation products and oxygen content of the surrounding gas atmosphere during storage of fresh pork sausages was already observed by Martínez et al. (2006). In contrast to this, vacuum packaging, which also prolongs the shelf-life of meat, produces a meat colour which is less acceptable (Gómez and Lorenzo, 2012). Colour is a central aspect for assessing meat quality parameters because consumer's acceptance of meat products is mostly determined by this characteristic (Omana et al., 2012). During storage, meat alterations are influenced by exogenic factors like initial microbial and chemical contamination as well as by endogenic parameters like colour or pH of the meat (Mastromatteo et al., 2009). As meat from different species varies with regard to structure and composition and related factors like pH and colour, it could be suggested that these differences result in varying changes of the meat during storage under equal conditions. Publications that directly compare quality changes of packaged meat from different species are rare. Therefore, aim of the present study was to investigate alterations of turkey and pig meat during storage in high oxygen atmosphere respectively vacuum packages.

Material and Methods

Materials, packaging analyses and sample collections

At three different times, 36 approximately 1.5 cm thick cutlets, cut from *Musculus pectoralis superficialis* of commercial fast-growing turkey toms (Aviagen Turkeys Ltd, Chester, UK), and 24 cutlets, cut from the *Musculus semimembranosus* of commercial crossbreed pigs, were obtained within 24 h after slaughtering from commercial German slaughterhouses and transported to the meat technological unit of the Institute of Food Quality and Food Safety, Hannover, Germany, at 3 °C within 2 h. Microbiological samples were taken from all cutlets 24 h after slaughtering (24 h p.m.) to determine the initial aerobic plate count numbers (APC). Lightness (L*) and redness (a*) values were determined directly on the meat surface, followed by removal of approx. 70 g samples from each cutlet. These samples were homogenised and frozen at –20 °C until analysis of thiobarbituric acid reactive substances (TBARS) and the total volatile basic nitrogen (TVB-N) concentrations. Subsequently, the remaining sample pieces were weighed and pH and electrical conductivity (EC) were determined. The samples were then in consideration of the species randomly subdivided into two different packaging variants and packaged in polypropylene trays (ES Plastic GmbH & Co. KG, Passau, Germany) either with high oxygen (80 % O_2, 20 % CO_2; MAP) atmosphere, or in vacuum (V). Each tray contained two samples and was sealed with a Multivac t100 packaging machine (Sepp Haggenmueller GmbH & Co. KG, Wolfertschwerden, Germany) using polyethylene/EVOH/polypropylene transparent layers with a high impermeability to O_2 and CO_2 (permeability: O_2=1.5 cm^3/m^2 d bar, 23 °C, 35 % relative humidity (r. H.); CO_2=5.5 cm^3/m^2 d bar, 23 °C, 35 % r. H. N_2=1 cm^3/m^2 d bar, 23 °C, 35 % r. H.; SUEDPACK GmbH & Co. KG, Ochsenhausen, Germany). Packages were stored in the dark at 3 °C. At storage days 4, 8 and 12 lightness (L*) and redness (a*) values of the meat were determined through the transparent layer. At the same days, two (pig) or three (turkey) packages of each packaging variant were randomly chosen and opened. Immediately after opening the trays, sensory aberrations were determined and microbiological analyses were performed from every meat sample. Liquid loss was estimated after reweighing, followed by determination of EC and pH and collection of samples for TBARS and TVB-N analysis as described above. The oxygen and carbon dioxide concentrations of the MAP packages was controlled at days 1, 6 and 12 of storage in all packages which were opened at day 12 to ensure that for gas analysis the same packages were analysed on every sampling day.

Methods

Chemical and physical examinations

Oxygen (O_2) and carbon dioxide (CO_2) concentrations of the MAP were analyzed with a CheckMate 9900 O_2/CO_2 (PBI Dansensor A/S, Ringsted, Denmark) by inserting the needle through a gas tight septum (PBI Dansensor). After analysis an additional septum was stuck on the first one to prevent gas leakage through the injection side during further storage. Control packages without meat were kept to ensure that during measurement no gas escapes. L* and a* values of the meat were determined with a chroma meter (Minolta CR 400, Minolta GmbH, Langenhagen, Germany) through the transparent layer. The determination was carried out by the method of the Commission Internationale de l'Eclairage. Before colour analysis the packages were turned, so that the meat had direct contact with the layer during measurement. Each L* and a* value was an average of four determinations.

The pH values were measured with a portable pH meter (Knick Portamess, Knick GmbH, Berlin, Germany) equipped with a glass electrode (InLab 427, Mettler-Toledo, Urdorf, Switzerland). For determination of the pH value, the electrode was inserted in the centre of the muscle once until the pH value was stable for ten seconds.

The EC values (in mS/cm) were analysed with a portable EC meter with two parallel stainless steel electrodes (LF Star; Matthäus GmbH, Nobitz, Germany). For determination, the electrodes were inserted into the meat transverse to fiber direction.

For liquid loss analysis cutlets were dried carefully by using a cloth and reweighed. This weight, after adding 5 g (loss through microbial sample weight), and the initial sample weight – determined at day 1 – were used to calculate the percental liquid loss.

The samples, which were homogenized with a Grindomix homogenizer (Typ GM200®, Retsch, Haan, Germany) on days 1, 4, 8 and 12, were used for analysis of TBARS and TVB-N.

The TBARS content (in µg malondialdehyde/g meat) was determined as described by Popp et al. (2013). As a

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final step, the colour reaction between malondialdehyd and thiobarbituric acid was measured photometrically.

Concentrations of TVB-N (in mg TVB-N/100 g meat) were determined according to the European Commission regulation (EG) No. 2074/2005 (European Union, 2005). In brief, 10 g of the meat homogenate was homogenised with 110 ml perchloric acid (0.6 M) for 2 minutes using a Polytron homogenizer Type PT 2100 (Kinematica GmbH, Luzern, Switzerland). The extract was filtrated through folded round filters (Typ 11A 185, Carl Roth GmbH) and 50 ml of the extract were filled into a Kjeldahl flask (C. Gerhardt GmbH & Co. KG, Königswinter, Germany). Sodium hydroxide (20 %) was added to the sample until it was basic. The TVB-N were absorbed in boric acid (0.3 %) (Carl Roth GmbH) and the concentration determined by titration with hydrochloric acid (0.01 M). For further procedure, a Vapodest (C. Gerhardt GmbH & Co. KG) was used. TVB-N was calculated by multiplying the volume of titrated hydrochloric acid with 2.8.

All chemicals were purchased from Applichem GmbH, Darmstadt, Germany, unless otherwise indicated.

Microbiological analysis

For microbiological analysis 2 g of each sample was collected before packaging and six meat samples were pooled. At days 4, 8 and 12 from every cutlet 5 g were removed and the two samples from one package were pooled for microbiological analysis. The 12 g (day 1) and 10 g (days 4, 8 and 12) were transferred to 100 mL respectively 120 mL sterile saline solution with peptone (0.85 % NaCl, 0.1 % peptone) and homogenised (Seward Stomacher 400 circulator, Steward Limited, West Sussex, United Kingdom) for 2 minutes and 30 seconds. Dilutions were prepared extending from $1:10^1$ (bacterial solution: saline solution and peptone) to $1:10^4$ referring to expected bacterial growth results. The dilutions were spread in duplicate via pour plate technique on PCA (Plate count nutrient agar, Merck KGaA, Darmstadt, Germany) for analysis of APC. The plates were incubated for 72 h at 30 °C. Counts were expressed as $\log_{10}$ colony forming units (CFU) per g meat.

Sensory attributes

At days 4, 8 and 12, directly after opening the packages, a panel of three persons evaluated appearance and odour of the meat samples according to the standards of the German Agricultural Society (Hildebrandt et al., 2012). Depending on the aberration in quality, points from 1 (unsatisfactory – not acceptable) to 5 (very good – no aberration in quality) could be given for both categories. The appearance points were multiplied with 3 and summated with the odour results. The sum was divided by 10 (maximum sensory points: 2.0).

Statistical analysis

The data were analyzed with the software Statistica 10.0 (StatSoft, Hamburg, Germany) considering the independent variables "packaging variant" (MAP, V) and species (turkey, pig). The Shapiro-Wilk-test was used to ensure that the data were normally distributed. Normally distributed data were analysed using ANOVA and the TUKEY-HSD-post-hoc-test. Non-normally distributed data (Liquid loss, pH, EC, a*, TBARS, sensory analysis) were analysed with the Mann-Whitney U test. A probability error of $\alpha = 5$ % was taken into account.

Results and discussion

Gas analysis

The O_2 content differed significantly ($P<0.05$) between all days during storage of pork meat in MAP. Oxygen levels decreased with increasing storage days. The CO_2 concentrations showed inverted results and increased significantly ($P<0.05$) between day 1 and 6 and day 6 and 12. However, no changes of the gas concentrations were observed during storage of turkey meat in MAP (data not shown). Variable results concerning gas composition were stated by other authors. Irkin et al. (2011) also observed during storage of minced beef meat a decrease of oxygen and an increase of CO_2. However, Pfeiffer and Menner (1999) observed an initial decrease of carbon dioxide before the following increase. Changes in gas composition during MAP storage are caused by factors like respiratory activity of the meat, solution of carbon dioxide, microbial activity or permeation of the gases through the transparent layer (Pfeiffer and Menner, 1999).

Quality of the meat before packaging

$L^*_{24\ h\ p.m.}$ values were significantly ($P<0.05$) higher in turkey than pork meat whereas $a^*_{24\ h\ p.m.}$ values were higher ($P<0.05$) in pork meat (Tab. 1). However, the differences were more distinct concerning the a* value. Colour mainly depends on the myoglobin (Mb) content and its rates of oxy-, met- and deoxymyoglobin (Lindahl et al., 2001). Poultry breast meat contains 0.1–0.4 g Mb/kg meat and pork 2.2–6.0 g Mb/kg meat (Feiner et al., 2006). This might explain the darker and redder appearance of the pork in the present study.

Turkey meat had significantly ($P<0.05$) higher pH values than the pork (Tab. 1) but differences were not very marked. The lower pH values in pork might be related to the higher glycolytic potential (GP) values (Ø 149 µmol/g meat, Hamilton et al., 2003) in comparison to turkey meat (Ø 118 µmol/g meat, El Rammouz et al., 2004). The GP is a summary of all muscle compounds which can be converted into lactic acid. Thereby it limits the capacity of a potential pH decrease during post-mortem glycolysis (Hamilton et al., 2003). The buffering capacity of meat, which is influenced by the dipeptides carnosine and anserine, also has an impact on the meat pH. A high buffering capacity could slow down pH reduction. Results by Puolanne et al. (2000) showed lower buffering capacities in pigs

TABLE 1: *Least square means (LSM) and standard deviations (SD) of different meat quality results of the turkey and pork meat, determined 24 hours after slaughtering of the animals (24 h p.m.).*

	Pork (n = 36) LSM ± SD	Turkey (n = 54) LSM ± SD
Lightness (L*)	50.58 ± 3.58^b	51.87 ± 2.40^a
Redness (a*)	11.08 ± 2.14^a	4.35 ± 1.11^b
pH	5.50 ± 0.13^b	5.74 ± 0.08^a
EC[1]	8.33 ± 2.99^a	6.49 ± 1.40^b
TBARS[2]	0.07 ± 0.03^b	0.08 ± 0.06^a
TVB-N[3]	23.97 ± 3.65^b	26.66 ± 3.70^a
TVC[4]	3.61 ± 0.41^a	3.67 ± 0.30^a

[1]EC = electrical conductivity [mS/cm]; [2]TBARS = thiobarbituric acid reactive substances [µg MDA/g meat]; [3]TVB-N = Total volatile basic nitrogen [mg/100 g meat]; [4]TVC = Total viable counts [$\log_{10}$ colony forming unit/ g meat]; [ab]LSM with different letters within a row differ significantly ($P<0.05$)

(45 mmol $H^+pH^{-1}kg^{-1}$) compared to broiler (58 mmol $H^+pH^{-}1kg^{-}1$). This might explain the species differences found in this study.

The significantly (P<0.05) higher EC values in pork compared to turkey meat (Tab. 1) seem to be related to the pH differences between the species. Low pH values lead to denaturation and shrinkage of proteins and thereby increase the extent of water that drains out and appears as drip loss (Huff-Lonergan and Lonergan, 2005). Along with this pH dependent liquid loss the permeability of cell membranes increases resulting in higher EC values due to the higher ion concentration in the intercellular space (Pliquett et al., 2003). However, the variation in pH might not be sufficient to explain all of the EC difference. Further investigations are necessary to explain the species specific differences.

TBARS concentrations were significantly (P<0.05) lower in pork in comparison to turkey meat (Tab. 1) but differences were not very pronounced. It could be suggested that they are related to the higher concentrations of unsaturated fatty acid in turkey meat compared to pork (Kim et al., 2002). Higher unsaturated fatty acid levels lead to an increased release of malondialdehyde which are analysed during the TBARS reaction.

The TVB-N content differed significantly (P<0.05) between the species with higher values in the turkey meat compared to pork (Tab. 1). As TVB-N is a spoilage parameter related to the bacterial degradation of proteins to volatile substances like trimethylamine or ammonium, the data indicate slightly higher spoilage in the turkey meat 24 h p.m. However, the TVB-N differences could not be clearly related to bacterial parameters, as the APC content of the meat did not differ between species (Tab. 1). For this reason other influence factors on the TVB-N content except for bacterial contamination should be taken into account, too. For example, protein degradation can also take place due to cathepsin activity. Cathepsin shows varying levels of activity in meat of different animal species (Etherington et al., 1987; Sipos, 2003).

Quality of the meat after packaging

Colour

L* values in vacuum and MAP stored turkey and pig meat mainly showed no significant differences. Only at day 4, MAP stored turkey samples showed significantly higher L* values than the vacuum meat (P<0.05). At days 4 and 8 vacuum packaged turkey meat had significantly (P<0.05) higher L* values than the pork meat. Differences of the L* values in MAP could be obtained at days 4, 8 and 12 with higher results in the turkey meat (Tab. 2). However, these differences were not very distinct. At all days MAP stored pig and turkey meat had significantly (P<0.05) higher a* results compared to the vacuum packaged cutlets. With regard to the species at all days pork had generally higher (P<0.05) a* values than turkey meat independent of the storage conditions (Tab. 2). Cayuela et al. (2004) also showed comparable L* values of high oxygen and vacuum stored pork loins and Mastromatteo et al. (2009) found comparable lightness values after storage of poultry patties in high oxygen or vacuum packages. However, Veberg et al. (2006) found significantly (P<0.05) higher L* values of turkey and pork meat stored in high oxygen atmosphere in contrast to vacuum. Higher a* values of high oxygen in contrast to vacuum stored meat were also presented by Cayuela et al. (2004) or Viana et al. (2005), whereas no significant differences of the a* values of pork were observed in the study of Veberg et al. (2006). Besides the myoglobin content, the colour differences concerning the different packaging variants depend on the redox status of the heme subunit of this protein. If meat is exposed to oxygen, Oxymyoglobin (Oxy-Mb) is formed leading to a bright red colour, whereas during storage in vacuum a purple colour is occurring (Lindahl et al., 2001; Huang et al., 2005). Bright red colour is associated with increased a* values (Lindahl et al., 2001; Gómez and Lorenzo, 2012). The a* value differences between both species can be attributed to the initial difference of total myoglobin.

Sensory analysis

At all storage days pig meat samples except for day 4, - turkey meat stored in MAP showed significantly (P<0.05) higher sensory values than the respective vacuum stored pig and turkey samples. In general, MAP and vacuum stored turkey meat had significantly (P<0.05) higher sensory scores during the whole storage period compared to the pig cutlets in the same packaging atmosphere (Tab. 2). Balamatsia et al. (2007) observed better odour scores for chicken fillets in oxygen containing atmosphere than in vacuum. However, most authors stated that at least at the end of storage the high oxygen packaged meat had lower sensory results than vacuum packaged meat (Gómez and Lorenzo, 2012; Martínez et al., 2006). In the study of Rajkumar et al. (2007) turkey meat stored in high oxygen atmosphere was evaluated inferior than vacuum stored meat. The authors assumed that the higher TBARS values of the oxygen stored meat influenced the negative sensory results. Higher TBARS values are no reason for an inferior sensory evaluation in our study, maybe because consumers already became familiar with the oxidized flavour (Zakrys et al., 2008). Martínez et al. (2006) stated that the odour score of fresh pork sausages is mainly influenced by the microbial spoilage status and thus observed in their study a higher aberrance of odour for high oxygen stored samples. Moreover, they observed a higher discoloration of the oxygen stored sausages, whereas meat in vacuum packages only showed discoloration values about 10 %. The vacuum packaged meat got deductions in sensory assessment because of its high liquid loss. We could not observe signi-

TABLE 2: *Least square means (LSM) and standard deviations (SD) of the lightness (L*), redness (a*) and sensory results of the turkey and pork meat stored in vacuum or modified atmosphere (MAP, 80 % O_2, 20 % CO_2).*

	Vacuum (pork, n = 6) LSM ± SD	MAP (pork, n = 6) LSM ± SD	Vacuum (turkey, n=9) LSM ± SD	MAP (turkey, n=9) LSM ± SD
L* day 4	48.32 ± 3.19^{c}	48.76 ± 2.89^{bc}	49.76 ± 2.17^{b}	50.99 ± 1.65^{a}
L* day 8	48.71 ± 2.76^{b}	48.72 ± 2.55^{b}	50.13 ± 1.62^{a}	51.22 ± 1.55^{a}
L* day 12	48.92 ± 3.42^{bc}	47.46 ± 1.78^{c}	50.52 ± 2.20^{ab}	51.48 ± 1.50^{a}
a* day 4	7.25 ± 1.51^{b}	10.66 ± 1.55^{a}	3.63 ± 0.72^{d}	4.97 ± 1.00^{c}
a* day 8	7.22 ± 1.36^{b}	10.45 ± 1.21^{a}	3.81 ± 0.69^{d}	4.60 ± 1.09^{c}
a* day 12	7.01 ± 1.35^{b}	9.58 ± 1.35^{a}	3.89 ± 0.70^{d}	4.26 ± 1.06^{c}
Sensory day 4	1.33 ± 0.08^{c}	1.68 ± 0.16^{b}	1.87 ± 0.13^{a}	1.99 ± 0.03^{a}
Sensory day 8	1.25 ± 0.05^{c}	1.55 ± 0.08^{b}	1.51 ± 0.09^{b}	1.87 ± 0.05^{a}
Sensory day 12	1.13 ± 0.08^{c}	1.53 ± 0.10^{b}	1.46 ± 0.05^{b}	1.79 ± 0.03^{a}

^{abcd}LSM with different letters within a row differ significantly (P<0.05)

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ficant (P<0.05) differences concerning microbial counts between the packaging variants in our study. However, flora composition might have influenced the results. Moreover, no considerable discoloration could be observed in the present study for the meat stored in high oxygen. Kim et al. (2002) observed during storage in vacuum for 7 days no differences between pig and turkey meat. The better evaluation of turkey meat in our study might be due to the higher liquid loss of the pork samples, as a large amount of extravasating water was mentioned by many panellists as a negative aspect.

pH, EC, liquid loss

The pH values of the turkey meat were significantly (P<0.05) higher at all storage days in comparison to the pork cutlets. However, no impact of packaging variant within the species could be obtained (Data not shown). The initial pH values of 5.50 ± 0.16 for pork meat reached values of 5.57 ± 0.13 for the vacuum packaging variant and 5.62 ± 0.20 for the MAP variant. Concerning turkey initial values of 5.74 ± 0.08 increased to values of 5.72 ± 0.06 for vacuum stored meat and to values of 5.73 ± 0.04 for MAP stored meat. These data make obvious that differences were not very pronounced. During storage of fresh pork sausages Martínez et al. (2006) also observed comparable pH values between vacuum and high oxygen packaged meat. In contrast to that, Mastromatteo et al. (2009) observed higher (P<0.05) pH values for high oxygen in comparison to vacuum stored poultry patties between days 3 and 6 of storage, followed by comparable results. The pH values are mainly influenced by the lactate production during post mortem glycolysis, acid production of the microbial flora, carbon dioxide content of the surrounding gas atmosphere and microbial biogenic amine formation (Galgano et al., 2009; Gómez and Lorenzo, 2012). Initial pH reduction is related to glycolytic potential and buffering capacity of the meat (Bate-Smith, 1938; Hamilton et al., 2003). The pH differences between the animal species might be due to the varying glycolytic potential and buffering capacity values, as described above.

The EC values did not differ significantly between the two packaging variants in the turkey and pig meat. However, pork meat showed significantly (P<0.05) higher EC values than turkey meat at day 4. At days 8 and 12, EC values were comparable between species (Fig. 1). No studies have been published concerning EC values of meat stored in different packaging atmospheres. The species difference of the EC at day 4 might be related to the initial already higher EC values of the pork meat before packaging and the already described influence of the pH on the conductivity results. Moreover, other influences except for the pH should be considered concerning development of the EC, for example the breed. Werner et al. (2010) observed a range of EC values 24 h p.m. between 6.1 and 13.3 mS/cm dependent on the pig breed. Concerning different turkey strains EC values between 4.44 and 6.73 mS/cm were observed (Werner et al., 2008).

The liquid losses at all storage days were significantly (P<0.05) higher in both meat species during vacuum storage in comparison to MAP storage. At days 4 and 8 pig meat had significantly (P<0.05) higher liquid loss values in comparison to the turkey cutlets (Fig. 2). A higher liquid loss during vacuum storage in comparison to storage in modified atmosphere packaging was also stated by Rajkumar et al. (2007) for turkey and Huang et al. (2005) for pork. The higher drip loss during vacuum storage might be due to a higher physical compression effect (Payne et al., 1998). The observed differences in drip loss between pork and turkey meat generally agree with results of Werner et al. (2010) and Janisch et al. (2012), who observed higher drip loss of pork compared to turkey meat. The interspecies differences can be related to the pH values. Lower pH values lead to higher shrinkage of the myofibrils and protein denaturation accompanied with reduced water binding properties and higher liquid losses.

TBARS

At day 12 TBARS values were significantly (P<0.05) higher in MAP compared to vacuum stored meat for both species. This difference was also found at day 4 in turkey meat. Turkey meat in MAP had generally slightly higher (P<0.05) TBARS values than pork meat, whereas TBARS results of vacuum stored pig and turkey cutlets differed only significantly (P<0.05) at day 12 (Fig. 3). The effect of packaging condition agrees with results of Veberg et al. (2006) who also found higher TBARS results of minced pig and turkey meat stored in oxygen rich MAP in comparison to vacuum packages. A higher extent of lipid oxidation in turkey meat in comparison to pork meat was also shown by Kim et al. (2002) and Veberg et al. (2006). The initial higher values of TBARS in turkey meat in comparison to pork meat are caused by its higher extent of unsaturated fatty acids (Kim et al., 2002) and maintained during storage. If meat is exposed to high oxygen concentrations these differences between species increase to a greater amount.

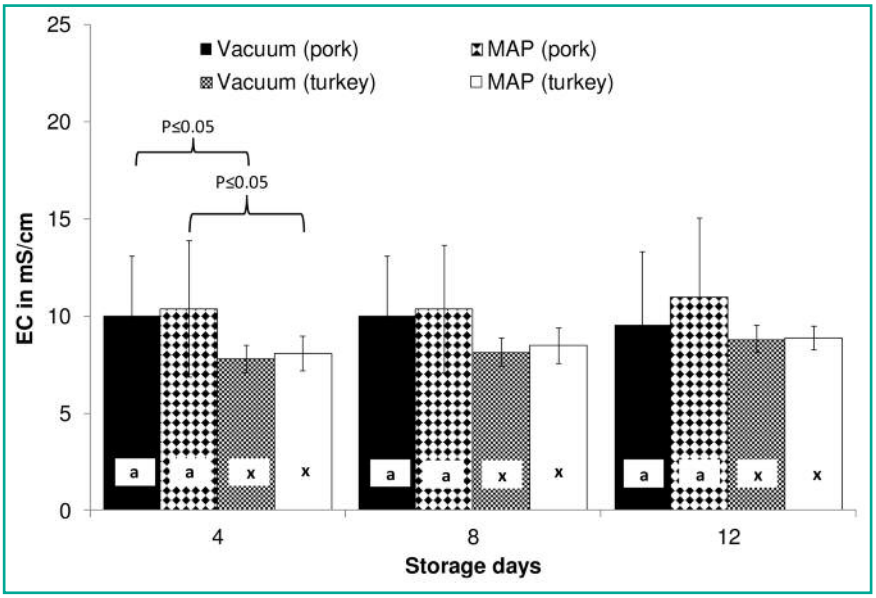

FIGURE 1: *Least square means (LSM) and standard deviations of the electrical conductivity (EC) results of turkey (n = 9 per packaging variant) and pork meat (n = 6 per packaging variant) stored in vacuum or modified atmosphere (MAP, 80 % O_2, 20 % CO_2); ^{abxy}LSM with different letters on the same day and within the same species differ significantly (P<0.05).*

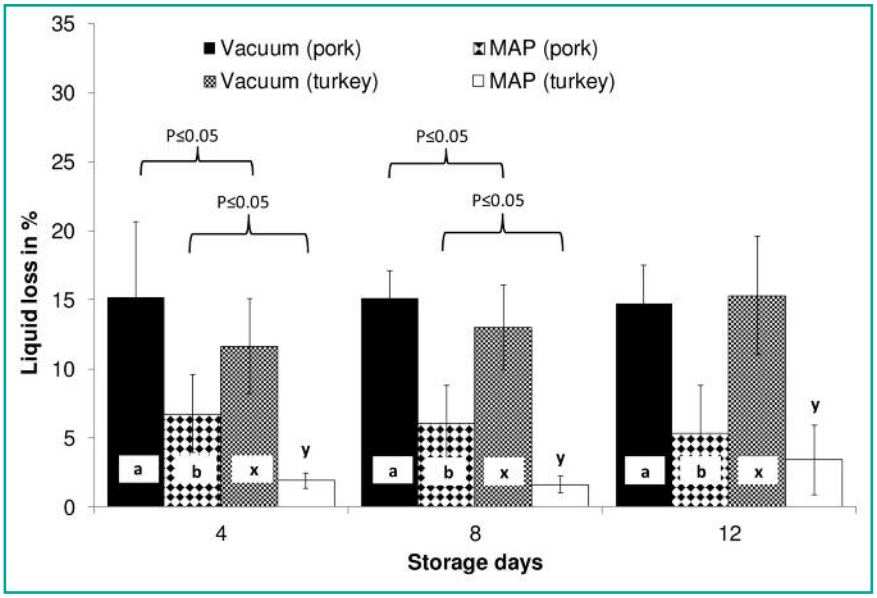

FIGURE 2: *Least square means (LSM) and standard deviation for liquid loss of turkey (n = 9 per packaging variant) and pork meat (n = 6 per packaging variant) stored in vacuum or modified atmosphere (MAP, 80 % O_2, 20 % CO_2); ^{abxy}LSM with different letters on the same day and within the same species differ significantly (P<0.05).*

TVB-N

Regarding the TVB-N content neither an influence of pakkaging variant, nor of species could be observed except for day 8 when vacuum stored turkey had significantly (P<0.05) higher TVB-N values than pork meat (Data not shown). At this day, turkey meat had TVB-N values about 28.19 ± 3.93 mg/100g, whereas in pork meat only 24.04 ± 2.94 mg/100g were estimated. At the end of storage the meat contained about 27.88 ± 4.12 mg/100g in average. As TVB-N analysis is preferably used for fish spoilage assessment, publications concerning TVB-N development in meat are rare. For example, Balamatsia et al. (2007) observed significant lower TVB-N values for MAP compared to vacuum stored broiler meat after 15 days of storage. According to Boziaris et al. (2011) or Cai et al. (2011) the TVB-N content mainly depends on bacterial spoilage and enzymatic degradation. These assumptions are in agreement with our results, as neither significant TVB-N, nor bacterial count differences could be observed. Concerning the different animals species the differing results from day 1 could not be observed during further storage.

Microbiology

The APC values were comparable with regard to the packaging variant as well as meat species, except for day 8. At that day the vacuum packaged turkey meat had significantly (P<0.05) higher bacterial counts than turkey cutlets stored in MAP and vacuum stored pig meat (Data not shown). Average values between 3.64 ± 0.342 $\log_{10}$ CFU/g on day 1 increased in all packaging variants for both species during storage. At the end of storage mean APC values about 5.98 ± 0.81 $\log_{10}$ CFU/g meat were reached. Rajkumar et al. (2007) observed higher total viable counts (TVC) of vacuum in comparison to high oxygen stored turkey meat during storage for 21 days. However, Mastromatteo et al. (2009) observed higher TVC values from day 3 on in high oxygen compared to vacuum stored poultry patties. With regard to the storage of pork meat no TVC differences in vacuum and high oxygen packages during 20 days of storage were observed by Taylor et al. (1990). The higher APC for vacuum pakkaged turkey meat at day 8 was not confirmed on day 12 and shouldn't be overestimated, as it wasn`t found at any other storage day.

Conclusions

The results of our study indicate that storage of pork and turkey meat in MAP is more advantageous in comparison to vacuum storage because it produces a redder colour and better sensorial results. The TVB-N and microbial results as spoilage indicators were comparable between both storage variants. However, a higher TBARS content at the end of storage for turkey meat in MAP could be observed. Thus it has to be emphasised that no negative influence of the higher TBARS results on consumer's acceptance could be determined in the present study. The main disadvantage of the vacuum storage seems to be the unfavourable higher liquid loss and though less acceptable appearance.

Comparing the effect concerning the meat species MAP seems even more suitable for the storage of pork meat. In vacuum storage the unintended effect of high liquid loss

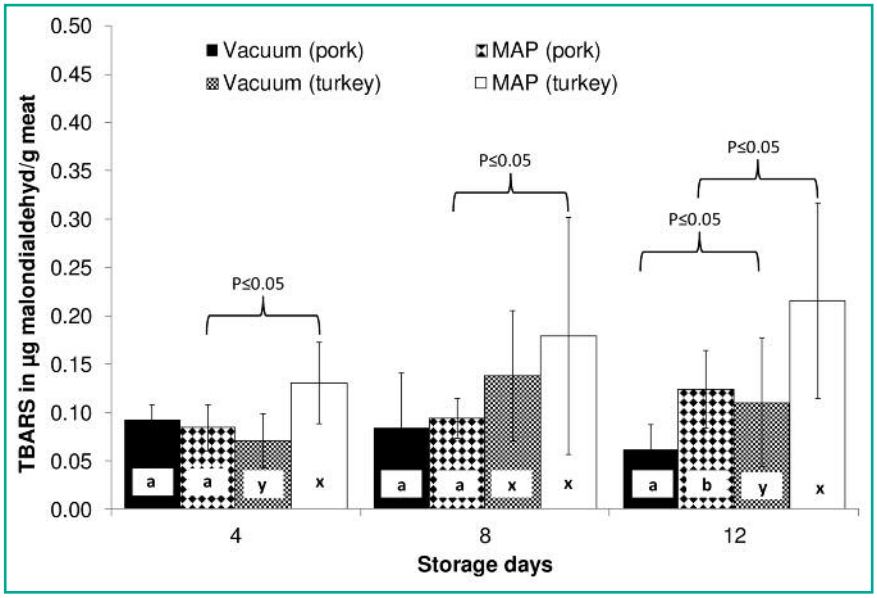

FIGURE 3: *Least square means (LSM) and standard deviations of the thiobarbituric acid reactive substance (TBARS) concentrations of turkey (n = 9 per packaging variant) and pork meat (n = 6 per packaging variant) stored in vacuum or modified atmosphere (MAP, 80 % O_2, 20 % CO_2); ^{abxy}LSM with different letters on the same day and within the same species differ significantly (P<0.05).*

production is more pronounced for pork than for turkey meat. TBARS production does not seem to be a potential limiting factor for turkey meat stored in an atmosphere with high oxygen content.

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