Arch Lebensmittelhyg 61,
173–178 (2010)
DOI 10.2376/0003-925X-61-173

ISSN 0003-925X

Korrespondenzadresse:
anelef@ap.teithe.gr

[1]Laboratory of Meat Technology, Department of Animal Production, School of Agricultural Technology, Alexander Technological Educational Institute, Thessaloniki, Greece;
[2]Laboratory of Hygiene and Technology of Food of Animal Origin, Veterinary Research Institute of Thessaloniki, National Agricultural Research Foundation, Greece

Changes in lipid oxidation and fatty acid composition in pork and poultry meat during refrigerated and frozen storage

Änderungen der Lipidoxidation und der Fettsäurezusammensetzung im Schweinefleisch und im Geflügelfleisch während der Kühllagerung und der Gefrierkühllagerung

A. Eleftheriadou[1], G. Samouris[2], M. Ioannidou[2], E. Kasapidou[1]

Summary

This experiment studied changes in lipid oxidation and fatty acid composition in pork (m. longissimus dorsi) and chicken breast (muscle and skin tissue) samples during refrigerated (4 °C) and frozen storage (–18 °C). Pork samples were analysed after 0, 1, 3, 7, 10 and 14 days of refrigerated storage and chicken samples were analysed after 0, 1, 2, 5 and 7 days of refrigerated storage. Pork and chicken samples were analysed after 15, 30, 90 and 180 days of frozen storage.

Lipid oxidation increased (P<0.05) during refrigerated and frozen storage in pork muscle samples. Refrigerated storage did not affect oxidation levels in chicken muscle samples whereas there was an increase (P<0.05) in chicken skin samples. Oxidation levels increased significantly (P<0.05) during frozen storage for both skin and muscle samples.

The levels of monounsaturated fatty acids of pork and chicken breast skin samples increased (P<0.05) during refrigerated storage. In chicken breast muscle samples the levels of saturated fatty acids increased and the levels of polyunsaturated fatty acids decreased under refrigeration. Frozen storage resulted in decreases in the levels of saturated fatty acids in pork (P<0.05) and chicken breast (P<0.05) muscle samples. The levels of polyunsaturated fatty acids increased (P<0.05) under frozen storage conditions in pork muscle samples. Slight differences were observed only in the levels of saturated and monounsaturated fatty acids in frozen stored chicken breast skin samples.

Keywords: storage, lipid oxidation, fatty acid composition, pork meat, poultry meat

Zusammenfassung

Diese Studie untersucht Veränderungen der Lipidoxidation und der Fettsäurezusammensetzung in Schweinefleischproben (M. longissimus dorsi) und Brustproben (Muskelgewebe und Hautgewebe) von Masthühnern während einer Kühllagerung (4 °C) und einer Gefrierlagerung (–18 °C). Die gekühlten Schweinefleischproben wurden nach 0, 1, 3, 7, 10 und 14 Tagen Lagerung analysiert, die gekühlten Masthühnchenproben wurden nach 0, 1, 2, 5 und 7 Tagen Lagerung untersucht. Nach 15, 30, 90 und 180 Tagen wurden die tiefgefrorenen Schweinefleisch- und Masthühnchenproben analysiert.

In den Schweinefleischproben erhöhte sich die Lipidoxidation (P<0.05) während der Kühllagerung und der Gefrierlagerung. Die Kühllagerung beeinflusste die Oxidation in den Masthühnchen-Muskelproben nicht, während es in den Masthühnchen-Hautproben eine Oxidations-Zunahme (P<0.05) zu verzeichnen gab. Während der Gefrierlagerung erhöhte sich die Lipidoxidation signifikant (P<0.05) in den Haut- und Muskelproben der Masthähnchen.

Die Konzentration der einfach ungesättigten Fettsäuren in den Schweinefleischproben und Masthühnchen-Hautproben erhöhten sich (P<0.05) während der Kühllagerung. In den Masthühnchen-Muskelproben erhöhte sich der Gehalt an gesättigten Fettsäuren während der Kühllagerung, der Gehalt an mehrfach ungesättigten Fettsäuren nahm gleichzeitig ab. Durch die Gefrierkühllagerung nahm der Gehalt an gesättigten Fettsäuren in den Muskelproben des Schweinefleisches (P<0.05) und der Masthühnchen (P<0.05) ab. Die Konzentrationen der mehrfach ungesättigten Fettsäuren erhöhten sich (P<0.05) unter Gefrierkühllagerungsbedingungen in den Schweinefleischproben. Geringfügige Unterschiede wurden nur in den Gehalten von gesättigten und einfach ungesättigten Fettsäuren der gefrorenen Masthühnchen-Hautproben beobachtet.

Schlüsselwörter: Lagerung, Lipidoxidation, Fettsäuremuster, Schweinefleisch, Geflügelfleisch

Archiv für Lebensmittelhygiene 61, Heft 5 (2010), Seiten 165–196

Introduction

Lipid oxidation is the major process other than microbial spoilage resulting in a significant loss of quality in muscle foods. The undesirable effects of lipid oxidation are not restricted to the financial losses caused by the development of rancid odours and flavours but are extended also to changes in the texture and the nutritional value of meat (Buckley et al., 1995; Gray et al., 1996). Lipid oxidation primary and secondary products such as lipid peroxides, hydroxy fatty acids, carbonyl compounds such as malondialdehyde, polymers and oxidized sterols have been identified as having toxic effects in animal experiments and humans (Pearson et al., 1983; Gray et al., 1996; Grigioni et al., 2000). The toxicity levels and the extent to which consumption of oxidized fat can affect human health is difficult to determine since the high dietary intake of oxidized fat that has an adverse impact on laboratory animals may not represent the typical intake in humans. Further epidemiological research is needed (Addis, 1986; Kubow, 1990).

Refrigerated or frozen storage of muscle food is employed to prevent or delay microbial growth and to delay lipid oxidation extending the shelf life of meat. The rate and the degree of lipid oxidation are influenced by a number of factors such as lipid content, content of unsaturated lipids, balance between prooxidants and antioxidants, storage temperature, processing mode and packaging conditions (Buckley et al., 1995; Morrissey et al., 1998; Monahan, 2000).

The fatty acid composition of intramuscular fat and particularly the levels of polyunsaturated fatty acids are the principal factors affecting the development of lipid oxidation (Kanner 1994; Gray et al., 1996).

Intramuscular fat from pork and poultry meat is more unsaturated in comparison to fat from ruminant species (Wood and Enser, 1997; Barroeta, 2007). In addition, nutritional guidelines recommend a reduction in the total fat consumption, a reduction in the intake of saturated fatty acids and an increase on the intake of the polyunsaturated fatty acids to prevent obesity, cardiovascular disease, cancer and other life-style diseases (Department of Health, 1994; Sanderson et al., 2002). Therefore, animal diets are manipulated to improve the nutritional value of the produced meat in terms of the tissue fatty acid composition i. e. higher degree of unsaturation (Wood et al., 1999). This practice leads to higher risk of oxidative deterioration during storage and subsequently to greater destruction and loss of the nutritionally important unsaturated fatty acids.

During refrigerated or frozen storage lipolytic enzymes such as lipases, esterases and phospholipases remain active affecting the oxidative stability of stored meat. Lipolysis is the cause of the changes in the fatty acid composition and the release of free fatty acids during refrigerated storage of pork (Monin et al., 2003; Ramírez and Cava, 2008) and poultry meat (Alasnier et al., 2000). Similar changes in the fatty acid composition have also been observed during frozen storage of pork (Hernandez et al., 1999) and poultry meat (Conchillo et al., 2004).

Adequate information is available about changes in lipid oxidation and fatty acid composition during refrigerated storage. Regarding changes in oxidative stability and fatty acid composition during frozen storage the available information is rather limited. In addition, there is no information about the oxidative stability and the fatty acid composition of chicken skin during refrigerated and frozen storage.

The aim of this experiment was to study the changes in the levels of lipid oxidation and the relative changes in the fatty acid composition of saturated, monounsaturated and polyunsaturated fatty acids in chicken muscle and skin, and pork muscle during refrigerated (4 °C) and frozen (–18 °C) storage.

Materials and methods

Sampling procedure

Six pork loin muscles (m. *longissimus dorsi*) and six chicken breasts (m. *pectoralis major* and adherent skin) were used. Pork loin muscles from different animals were purchased from a local abattoir the same day. Chicken samples were bought from a poultry abattoir the same day. At 24 h post slaughter pork loins were trimmed of all visible external/adjacent fat and connective tissue and subsamples for each test day were prepared. Similarly, skin tissue was carefully excised from the chicken breast samples and separate subsamples from skin and breast muscle were also prepared for each test day. Samples aimed for analyses during refrigerated storage were packed in a high barrier film (Nylon/Binding layer/L.LDPE 70 µm thickness, oxygen permeability <15.5 cm^3 m^{-2} d^{-1} atm^{-1} at 25 °C/75 % RH) whereas samples aimed for analyses during frozen storage were vacuum packed using the same type of high barrier film. Pork and chicken (muscle and skin) subsamples were placed in the dark at either 4 °C or –18 °C. Changes in lipid oxidation levels and fatty acid composition during refrigerated storage were determined on day 0 (control), 1, 3, 7, 10 and 14 for pork samples, and on day 0 (control), 1, 2, 5 and 7 for chicken samples. Similarly, during frozen storage changes in lipid oxidation levels and fatty acid composition were determined on day 15, 30, 90 and 180 for both pork and chicken samples. Pork and chicken (muscle and skin) samples were analysed in duplicate for lipid oxidation and fatty acid composition.

Lipid oxidation

Lipid oxidation was determined on the basis of the formation of malondialdehyde using a selective third-order derivative spectrophotometric method (Botsolou et al., 1994). Samples were blended in a domestic food processor (Moulinex®-Moulinette). Subsamples were homogenised with aqueous trichloroacetic acid in the presence of hexane containing butylated hydroxytoluene and the mixture was centrifuged. The top hexane layer was discarded and an aliquot of the bottom layer was mixed with aqueous 2-thiobarbituric acid. The mixture was incubated for 30 min at 70 °C. After incubation the mixture was cooled in a cold water bath and the absorbance was measured at 521.5 nm against the blank sample using a Shimadzu model UV-1601 (Tokyo, Japan) spectrophotometer. The concentration of malondialdehyde in analysed samples was calculated on the basis of the height of the third order derivative peak at 521.5 nm by referring to slope and intercept data of the computed least squares fit of a standard calibration curve prepared using 1,1,3,3-tetraethoxypropane. Lipid oxidation is expressed as nanograms of malondialdehyde (MDA) per gram of muscle.

Fatty acid composition

Tissue fat was extracted with petroleum ether in an automated Soxhlet extraction system (Soxtec 2050, Foss, Teca-

tor, Denmark). The fatty acid methyl esters were prepared with boron trifluoride in methanol solution. An appropriate quantity of the extracted fat was saponified by the addition of NaOH in methanol followed by heating at 100 ºC for 15 minutes. Fatty acid methyl ethers were prepared by incubation at 100 ºC for 5 minutes in boron trifluoride methanol reagent. The produced fatty acid methyl esters were extracted by the addition of hexane after vigorous agitation and washing with a saturated solution of potassium hydroxide (Christie, 2003). The fatty acid methyl esters were analyzed using a HP 5890 (Hewlett-Packard) gas chromatograph equipped with flame ionisation detector and a DB-23 (60 m x 0.25 mm x 0.25 µm) column (J & W Scientific, Inc., Folsom, California, USA). The GC (Hewlett-Packard, model 5890) conditions were: carrier gas He; packed mode injection; injector and flame ionisation detector temperatures 250 °C and 280 °C respectively; initial oven temperature 50 °C for 1 min, increased at 25 °C per min to 175 °C, increased at 4 °C per min to 230 °C, held at 230 °C for 5 min.

A 37 component mixture (Supelco, Bellefonte, Pennsylvania, USA) of fatty acids methyl esters (FAME) was used as a reference standard. The mixture was purchased as a 100-mg neat mixture, containing C4–C24 FAMEs (2 %–4 % relative concentration). Fatty acids methyl esters were identified by comparing their retention times with the retention times of the FAME mixture. Fatty acids were quantified by peak area measurement and the results are expressed as percent (%) of the total fatty acids present in the sample.

Statistical analyses

One-way analysis of variance (ANOVA) was used to analyse differences between treatments. Post-hoc analysis was undertaken using Tukey's test at a 5 % level of significance. Statistical software package SPSS version 13.0 (2004) for Windows (SPSS, Chicago, IL, USA) was used.

Results and discussion

Lipid oxidation

Lipid oxidation in pork samples during refrigerated and frozen storage is presented in Figure 1. Lipid oxidation increased ($P<0.05$) as the storage period was extended in both conditions. Lipid oxidation remained virtually unchanged during the first 10 days of refrigerated storage whereas at day 14 there was a 2 fold increase in the concentration of MDA than the values initially observed (days 0–7). Regarding frozen storage, lipid oxidation was almost stable for the first 90 days. At 180 days of storage lipid oxidation increased 1.8–2.3 times than the values observed during the first 90 days of storage.

Lipid oxidation changes for chicken muscle and skin samples under refrigerated and frozen storage are illustrated in Figure 2. Lipid oxidation was overall higher in skin tissue due to its higher content of unsaturated and particularly polyunsaturated fatty acids (Tab. 1). Refrigerated storage did not affect oxidation in chicken muscle samples whereas there was a change ($P<0.05$) in chicken skin samples. Chicken muscle samples were very stable to lipid oxidation unlike chicken skin samples that lipid oxidation exhibited a 3.6 times increase between refrigeration days 0 and 7.

Oxidation changes during frozen storage were statistically significant ($P<0.05$) for both skin and muscle samples. Lipid oxidation in both muscle and skin increased with storage time. The changes in lipid oxidation levels were also more profound in skin samples than muscle samples. At 180 days of frozen storage lipid oxidation was 1.8 and 2.8 times higher in muscle and skin samples in relation to lipid oxidation at 15 days of frozen storage.

Regarding changes in lipid oxidation during refrigerated storage, the reported results are also supported by Park et al. (2008) that investigated lipid oxidation during refrigerated storage (8 °C) of air packed pork m. *longissimus dorsi* samples and reported similar changes in the MDA values. Min et al. (2008) reported a similar pattern for the

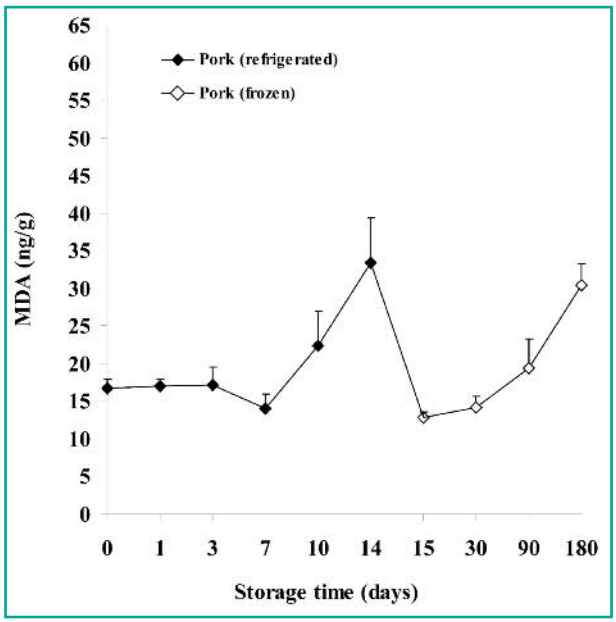

FIGURE 1: *Changes in the levels of malondialdehyde in pork samples during storage at 4 °C and at –18 °C.*

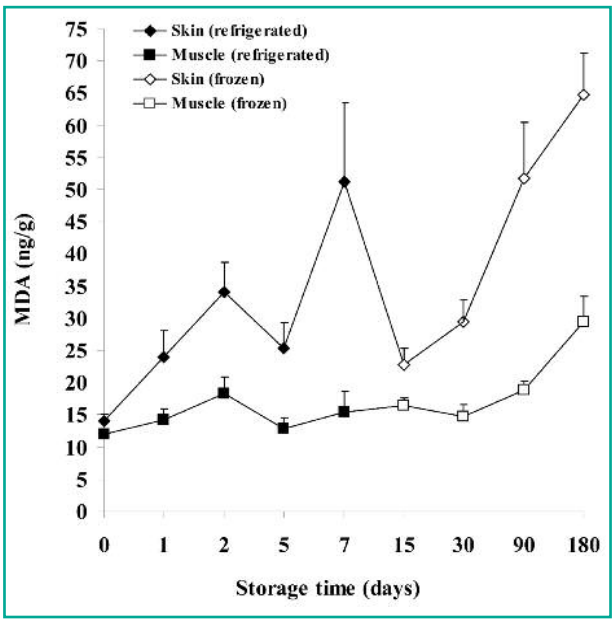

FIGURE 2: *Changes in the levels of malondialdehyde in chicken breast (muscle and skin tissue) samples during storage at 4 °C and at –18 °C.*

Archiv für Lebensmittelhygiene 61, Heft 5 (2010), Seiten 165–196

TABLE 1: *Fatty acid composition (mean ± standard deviation) of pork muscle, chicken skin and chicken breast muscle on storage day 0 (control samples).*

Fatty acid	Pork (n = 6)	Chicken muscle (n = 6)	Chicken skin (n = 6)
14:0 Myristic	2.40 ± 0.965	0.85 ± 1.547	0.69 ± 0.122
16:0 Palmitic	25.97 ± 0.900	25.75 ± 0.456	26.81 ± 1.692
16:1 n-7 Palmitoleic	3.55 ± 0.603	3.61 ± 0.749	3.98 ± 0.692
18:0 Stearic	12.21 ± 3.238	7.13 ± 0.845	8.12 ± 1.280
18:1 n-9 Oleic	40.16 ± 4.605	31.86 ± 2.529	29.03 ± 3.050
18:2 n-6 Linoleic	6.89 ± 2.308	24.86 ± 0.303	25.54 ± 2.541
18:3 n-3 α-Linolenic	1.33 ± 1.516	1.82 ± 1.547	0.21 ± 0.135
20:0 Arachidic	ND[1]	ND[1]	0.41 ± 0.471
20:1 n-9 Eicosenoic	0.38 ± 0.380	ND[1]	0.27 ± 0.092
20:4 n-6 Arachidonic	ND[1]	ND[1]	0.16 ± 0.085
22:0 Behenic	ND[1]	ND[1]	0.07 ± 0.113
22:6 n-3 Docosahexanoic (DHA)	ND[1]	ND[1]	0.00 ± 0.008
SFA	41.91 ± 5.893	33.73 ± 1.808	36.09 ± 3.397
MUFA	44.09 ± 5.228	35.47 ± 0.728	33.28 ± 2.649
PUFA	6.89 ± 2.308	26.68 ± 2.823	25.91 ± 2.630

SFA: saturated fatty acids; MUFA monounsaturated fatty acids; PUFA polyunsaturated fatty acids; ND[1]: not detectable.

development of lipid oxidation in ground patties of pork loin and chicken breast samples stored in air at 4 °C for 7 days.

The levels of polyunsaturated fatty acids were much higher in chicken muscle than pork muscle samples (Tab. 1). Despite differences in the levels of polyunsaturated fatty acids, pork and chicken muscle samples were equally susceptible to oxidation during refrigerated and frozen storage. Min et al. (2008) reported no proportional correlation between lipid oxidation and the content of polyunsaturated fatty acids in raw chicken thigh meat during storage. The same workers suggested that the oxidative stability of meat may not be proportionately related to its content in polyunsaturated fatty acids.

Lipid oxidation was far below reported threshold values for the detection of rancidity by expert taste panellists. The extent of lipid oxidation is usually reported with the term TBARS or TBA number which describes the thiobarbituric acid reactive substances. Malonaldehyde is the main substance reacting with the thiobarbituric acid. TBA number within the same animal species, though, are influenced by a number of factors such as animal nutrition i. e. dietary antioxidants and dietary fat content and type, whether the meat is raw, cooked or processed, the type of muscle, the type of taste panel i. e. trained or untrained and the method used for the determination of the TBA number. Different workers have reported different values for the detection of rancidity in sensory evaluation tests. Melton (1983) reported that oxidized flavours were detectable at TBA numbers in the range 0.3–1.0 mg malondialdehyde/kg tissue in beef or pork and 1.0 or 2.0 mg malondialdehyde/kg tissue in chicken. Tarladgis et al. (1960) reported that TBA values in the range of 0.6–2.0 mg malondialdehyde/kg tissue correspond to the threshold value for detection of rancidity in pork. According to O'Neill et al. (1998) the threshold value for warmed over flavour detection in cooked, dark chicken meat could be set at TBA values equal or higher than 0.8 mg of malondialdehyde/kg tissue. Warmed over flavour and rancid flavour are closely correlated (Poste et al., 1986; Byrne et al., 2001). Moreover, detection of lipid oxidation is not related to acceptability of the meat by the panellists and the relevant TBA numbers should not be considered as a general reference number (Melton, 1983; Boles and Parish, 1990; Fernández et al., 1997).

Fatty acid composition

Fatty acid composition of pork longissimus dorsi muscle, chicken skin and chicken breast muscle for storage day 0 (control) is shown in Table 1. In all samples palmitic (16:0), oleic (18:1 n-9) and linoleic (18:2 n-6) acid were the major fatty acids in the saturated, monounsaturated and polyunsaturated lipid class respectively.

Refrigerated storage did not affect the levels of saturated, monounsaturated and polyunsaturated fatty acids in pork samples (Fig. 3). In general, after 14 days of storage the levels of monounsaturated fatty acids increased slightly. Morcuende et al. (2003) reported similar changes in the composition of neutral lipids in m. *longissimus dorsi* from free range reared Iberian pigs stored under light in aerobic conditions at 4 °C for 10 days. Monin et al. (2003) reported statistically significant changes ($P<0.05$) in the proportions of saturated fatty acids and no changes in the proportions of monounsaturated and polyunsaturated fatty acids in m. *longissimus lumborum* from Large White and Piétrain pigs that were packed under vacuum and stored at 3–4 °C for 9 days. In the latter study, the levels of polyunsaturated fatty acids were elevated in samples from both breeds compared to our study. These differences are probably linked to the genetic type of animals used in the study. Ramírez and Cava (2008) reported that refrigerated

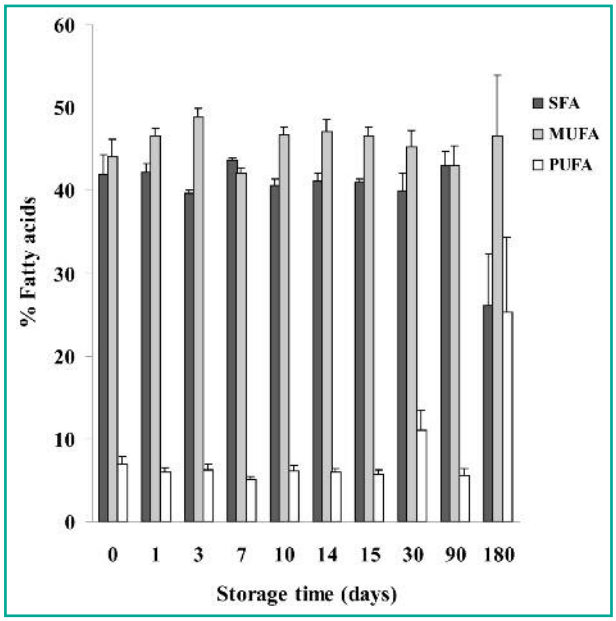

FIGURE 3: *Changes in the percentages of fatty acid lipid classes during refrigerated and frozen storage of pork samples (SFA saturated fatty acids; MUFA monounsaturated fatty acids; PUFA polyunsaturated fatty acids).*

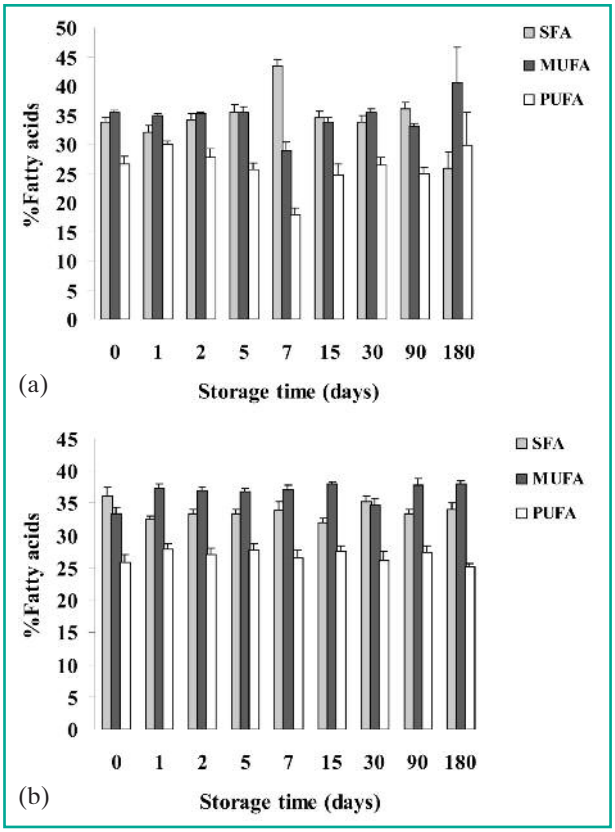

FIGURE 4: *Changes in the percentages of fatty acid lipid classes during refrigerated and frozen storage of chicken breast (a) and skin (b) samples (SFA saturated fatty acids; MUFA monounsaturated fatty acids; PUFA polyunsaturated fatty acids).*

storage did not change the fatty acid composition of m. *longissimus lumborum* from three different Iberian x Duroc genotype pigs stored under light in aerobic conditions at 4 °C for 10 days. Despite intrinsic differences in the fatty acid composition of intramuscular fat between different breeds, changes in the levels of saturated, monounsaturated and polyunsaturated fatty acids followed the same pattern in the studies reported above.

Frozen storage resulted in a decrease ($P<0.05$) in the levels of saturated fatty acids and an increase ($P<0.05$) in the levels of polyunsaturated fatty acids. The levels of monounsaturated fatty acids were not affected (Fig. 3). Hernández et al. (1999) reported no changes in the levels of saturated, monounsaturated and polyunsaturated fatty acids in the neutral lipid fraction of vacuum packed pork m. longissimus dorsi during frozen storage for 6 months. Approximately 80 % of total lipids consist of neutral lipids. Polyunsaturated fatty acids are mainly present in the phospholipid fraction. In the previous study there was a decrease in the proportion of polyunsaturated fatty acids after 6 months of storage whereas in our study an increase in the proportion of polyunsaturated fatty acids was observed.

The fatty acid composition of chicken breast muscle changed during refrigerated storage whereas there was no change in the fatty acid composition of chicken breast skin samples (Fig. 4). Chicken muscle fatty acid composition did not change during the first 5 days of refrigerated storage. Changes were observed on storage day 7 in the levels of all lipid classes.

Frozen storage resulted in a decrease ($P<0.05$) in the levels of saturated fatty acids (Fig. 4) in breast muscle. Noticeable changes occurred after 90 days of storage. Conchillo et al. (2004) reported a similar pattern in the changes of fatty acid composition in chicken breast samples stored under vacuum for either 6 days at 4 °C or 90 days at –18 °C. Regarding chicken skin samples, frozen storage did not affect the levels of polyunsaturated fatty acids. There were significant fluctuations ($P<0.05$) in levels of both saturated and monounsaturated fatty acids during storage.

Reported reasons for the changes in the fatty acid composition during refrigerated and frozen storage are the activities of lipolytic enzymes whose stability is affected by storage temperature (Rhee et al., 1996; Min et al., 2008) and storage duration (Hernández et al., 1999; Alasnier et al., 2000). Variations of the fat content and subsequently the fatty acid composition within the same muscle, as it has been reported by Cameron and Enser (1991) and Lawrie and Ledward (2006) for pork m. *longissimus dorsi,* might also affect fatty acid composition during storage. It should be also mentioned that changes in the fatty acid composition and the percentages in particular of the monounsaturated and polyunsaturated fatty acids reflect also individual variations in the animals based on their diets. In the present study, samples were randomly collected from the abattoirs and thus there is no available information about the animals (slaughter age, breed) and their diets.

Conclusions

Differences in lipid oxidation and fatty acid composition were observed during refrigerated and frozen storage of pork and chicken meat. The development of lipid oxidation was rather limited in all meat types and under both storage conditions. Chicken breast skin was most susceptible to lipid oxidation compared to pork and chicken meat. During refrigerated storage constant changes in the fatty acid composition were observed only in chicken muscle samples. Fatty acid composition was fairly stable in pork muscle and chicken skin samples. Frozen storage influenced fatty acid composition at various degrees in all tissues. Fatty acid composition was fairly stable for the first 90 days of frozen storage and any changes became apparent at 180 days of storage.

Acknowledgements

The authors gratefully acknowledge the financial support of the Research Committee of the Alexander Technological Education Institute of Thessaloniki, Greece.

References

Addis PB (1986): Occurrence of lipid oxidation products in foods. Food Chem Toxicol 24: 1021–1030.

Alasnier C, Meynier A, Viau M, Gandemer, G (2000): Hydrolytic and oxidative changes in the lipids of chicken breast and thigh muscles during refrigerated storage. J Food Sci 65: 9–14.

Barroeta AC (2007): Nutritive value of poultry meat: relationship between vitamin E and PUFA. Worlds Poult Sci J 63: 277–284.

Boles JA, Parish FC (1990): Sensory and chemical characteristics of precooked mircrowave-reheatable pork roasts. J Food Sci 55: 618–620.

Archiv für Lebensmittelhygiene 61, Heft 5 (2010), Seiten 165–196

Botsoglou N, Fletouris D, Papageorgiou G, Vassilopoulos V, Mantis A, Trakatellis A (1994): Rapid, sensitive and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissue, food and feedstuff samples. J Agric Food Chem 42: 1931–1937.

Buckley DJ, Morrissey PA, Gray, JI (1995): Influence of dietary vitamin E on the oxidative stability and quality of pig meat. J Anim Sci 73: 3122–3130.

Byrne DV, Bredie WLP, Bak LS, Bertelsen G, Martens H, Martens M (2001): Sensory and chemical analysis of cooked porcine meat patties in relation to warmed-over flavour and pre-slaughter stress. Meat Sci 59: 229–249.

Cameron, ND, Enser, MB (1991): Fatty acid composition of lipid in Longissimus dorsi muscle of Duroc and British Landrace pigs and its relationship with eating quality. Meat Sci 29: 295–307.

Christie, WW (2003): Lipid analysis. Isolation, separation, identification and structural analysis of lipids (3rd edition). The Oily Press, Bridgewater, England.

Conchillo A, Ansorena D, Astiasarán I (2004): The effect of cooking and storage on the fatty acid profile of chicken breast. Eur J Lipid Sci Technol 106: 301–306.

Department of Health (1994): Nutritional aspects of cardiovascular disease. Report on health and social Subjects no 46. London: Her Majesty's Stationery Office.

Fernández J, Pérez-Álvarez JA, Fernández-López JA (1997): Thiobarbituric acid test for monitoring lipid oxidation in meat. Food Chem 59: 345–353.

Gray JI, Gomaa EA, Buckley DJ (1996): Oxidative quality and shelf life of meats. Meat Sci 43: S111–S123.

Greene BE, Cumuze, TH (1981): Relationship between TBA numbers and inexperienced panellists' assessments of oxidized flavor in cooked beef. J Food Sci 47: 52–54, 58.

Grigioni GM, Margaría CA, Pensel, NA, Sánchez G, Vaudagna SR (2000): Warmed-over flavour analysis in low temperature-long time processed meat by an "electronic nose". Meat Sci 56: 221–228.

Hernández P, Navarro J, Toldrá F (1999): Effect of frozen storage on lipids and lipolytic activities in the longissimus dorsi muscle of the pig. Z Lebensm Unters Forsch 208: 110–115.

Kanner J (1994): Oxidative processes in meat and meat products: quality implications. Meat Sci 36: 169–189.

Kubow S (1992): Routes of formation and toxic consequences of lipid oxidation products in foods. Free Radic Biol Med 12: 63–81.

Lawrie RA, Ledward, DA (2006): Chemical and biochemical constitution of muscle. In: Lawrie's meat science (7th edition). Woodhead Publishing Ltd., Cambridge, UK, 75–127.

Melton SL (1983): Methodology for following lipid oxidation in muscle foods. Food Technol 37: 105–111.

Min B, Nam KC, Cordray J, Ahn DU (2008): Endogenous factors affecting oxidative stability of beef loin, pork loin, and chicken breast and thigh meats. J Food Sci 73: C439–C446.

Monahan FJ (2000): Oxidation of lipids in muscle foods: Fundamental and applied concerns In: Decker E, Faustman C and Lopez-Bote CJ (eds.), Antioxidants in muscle foods – Nutritional strategies to improve quality. Wiley and Sons, Inc, New York, USA. 3–23.

Monin G, Hortós M, Diaz I, Rock E, Garcia-Regueiro JA (2003): Lipolysis and lipid oxidation during chilled storage of meat from Large White and Pietrain pigs. Meat Sci 64: 7–12.

Morcunende D, Estévez M, Ruiz J, Cava R (2003): Oxidative and lipolytic deterioration of different muscles from free-range reared pigs under refrigerated storage. Meat Sci 65: 1157–1164.

Morrissey PA, Sheehy PJA, Galvin K, Kerry JP, Buckley DJ (1998): Lipid stability in meat and meat products. Meat Sci 49: S73–S86.

O'Neill LM, Galvin K, Morrissey PA, Buckley DJ (1998): Comparison of effects of dietary olive oil, tallow and vitamin E on the quality of broiler meat and meat products. Br Poult Sci 39: 365–371.

Park SY, Kim YJ, Lee HC, Yoo SS, Shim JH, Chin KB (2008): Effects of pork meat cut and packaging type on lipid oxidation and oxidative products during refrigerated storage (8 °C). J Food Sci 73: C127–C134.

Pearson AM, Gray JI, Wolzak AM, Horenstein NA (1983): Safety implications of oxidised lipids in muscle foods. Food Technol 37: 121–129.

Poste LM, Willemot C, Butler G, Patterson C (1986): Sensory aroma scores and TBA values as indices of Warmed-Over Flavor in pork. J Food Sci 51: 886–888.

Ramírez MR, Cava R (2008): Changes in fatty acid composition of two muscles from three different Iberian x Duroc genotypes after refrigerated storage. Food Sci Technol Int 14: 127–137.

Rhee, KS, Anderson, LM, Sams, AR (1996): Lipid oxidation potential of beef, chicken and pork. J Food Sci 61: 8–12.

Sanderson P, Finnegan YE, Williams CM, Calder PC, Burdge GC, Wootton SA, Griffin BA, Millward DJ, Pegge NC, Bemelmans WJE (2002): UK Food Standards Agency α-linolenic acid workshop report. Br J Nutr 88: 573–579.

SPSS (2004): SPSS manual, version 13.0 for Windows. SPSS Inc., Chicago, IL, USA.

Tarladgis BG, Watts BM, Younathan MT, Dugan LR (1960): A distillation method for the quantitative determination of malonaldehyde in rancid foods. J Am Oil Chem Soc 37: 44–48.

Wood JD, Enser M (1997): Factors influencing fatty acids in meat and the role of antioxidants in improving meat quality. Br J Nutr 78: S49–S60.

Wood JD, Enser, M, Fisher AV, Nute GR, Richardson RI, Sheard PR (1999): Manipulating meat quality and composition. Proc Nutr Soc 58: 363–370.

Address for correspondence:
Dr. Anastasia Elefteriadou
A.T.E.I. of Thessaloniki
School of Agricultural Technology
Department of Animal Production
P.O BOX 141
GR-574 00 Thessaloniki, Greece
anelef@ap.teithe.gr