Dry cured ham quality as related to lipid quality of raw material and lipid changes during processing: a review

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1. INTRODUCTION

Many quality traits of dry cured hams depend on lipids of muscle and adipose tissues of raw material and on their changes during processing (Gandemer, 2002). That is why numerous studies were devoted to lipids in ham both in fresh meat and in ham during processing. Lipids are largely involved in sensory traits of the final dry products. Thus lipids play a key role in aroma of dry-cured hams through both ways: (i) lipids, mainly triacylglycerols (TAG) located in adipose tissues and intermuscular adipose cells, are solvent of many aroma components (ii) lipids, mainly phospholipids located in membrane of muscular cells and, to a lesser extend triacylglycerols, are precursors of many volatiles affecting aroma of hams through a complex set of chemical reactions.

Lipids are also strongly correlated with other sensory traits such as aspect and texture (Ventanas et al., 2007).

Lipid traits of raw material are strongly related to rearing systems of pigs (Buscailhon and Monin, 1994b; Lopez-Bote, 1998; Coutron-Gamboti et al., 1998). This includes many factors among them breed, feeding system and some physiological parameters such as age at slaughter and physical exercise appear as the main ones. In several areas in Europe, producers have developed specific rearing systems which involve local breeds and extensive feeding systems based on natural feed resources (chestnuts, grass, and acorns) to have raw materials with original traits of composition (Léon-Camacho et al., 2004).

During processing of dry-cured ham, lipids undergo numerous alterations through two main sets of reactions: lipolysis and oxidation (Gandemer, 1999 and 2002). The intensity of these reactions depends on many parameters of the technology including the length of the different periods of processes, the level and the way of salting, the ambient conditions during ripening (Buscailhon and Monin, 1994a; Toldra and Flores, 1998). Many works were devoted to find the optimal conditions of processing between traditional practices and more modern technological options to adapt the products to consumer demands.
In European countries, mainly in southern ones, a large scale of dry-cured hams with typical traits is available on the market. This diversity is the consequence of alchemies found by the producers between traits of raw material and options selected in the process.

This paper is an overview of the present knowledge on lipids and quality of dry-cured hams, focused on the lipid traits of raw material and the changes in lipids during the processing as related to aroma of final products.

2. LIPID TRAITS OF MUSCLES AND ADIPOSE TISSUES

In European countries, most of the dry-cured are manufactured from muscles and adipose tissues from pigs reared in intensive systems. Pigs are from industrial genotypes reared indoors and fed a commercial concentrated diet. These diets mainly consist in cereals and soya meal and contain a low amount of fat (3-4%). Pigs have a fast growth rate and are slaughtered at 100-120 kg around 5-6 months of age. Selected against fatness since half a century, carcasses of these animals are very lean (Girard et al., 1988a). Sometimes, pigs are slaughtered heavier (160-180 kg) and older (9-12 months; i.e. Parma area) (Bosi et al., 2000). Muscle and adipose tissues of these pigs show very similar compositional traits. In some limited areas of Europe, pigs are produced in traditional rearing systems: the most famous ones are Iberian and Corsican ones (Benito et al., 2000; Secondi et al., 1999a). These systems rely on local breeds (Iberian, Corsican) reared outdoors and on a feeding strategy based on the availability of natural resources (acorns, grass, roots, oaks). The pigs are slaughtered between 18 and 24 months of age because they have a low growth rate and are subjected to alternating periods of scarcity (summer) and abundance (autumn) (Coutron-Gambotti et al., 1999a, 1998a; Lopez-Bote, 1998). Pigs are fattened under chestnut grooves or oak plantations eating large quantities of chestnuts or acorns for 4-6 months during the winter. During this period, adipose and muscle tissues acquire their typical chemical traits (Narvaez-Rivas et al., 2008a) which are characterized by a large development of subcutaneous adipose tissue and a sharp increase in intramuscular lipid content leading to raw matter very different from those of industrial pigs (Coutron-Gambotti et al., 1998a; Lopez-Bote, 1998).

Briefly, pigs reared in traditional systems (Iberian, Corsican) are fatter than industrial ones. They have very thick adipose tissues and more intramuscular fat. The former exhibit backfats with a thickness between 25 and 50 mm (Benito et al., 2000; Secondi et al., 1992). Their muscles have higher intramuscular lipid content than those of industrial pigs (Table 1). This is mainly the consequence of triacylglycerol (TAG) accumulation while phospholipids (PL) content is very similar in the muscles of both local and industrial genotypes of pigs (Gandemer, 1997). The main cause of the high TAG content in muscles of local genotypes is the fattening period which takes place when pigs are old (16-18 months) and have a low capacity to deposit muscle in carcass. Consequently these pigs deposit a large amount of the feed energy as fat in both adipose tissue and muscles. PL content of muscles is not greatly affected by rearing conditions.

Fatty acid compositions of TAGs from both local and industrial pigs show high proportions of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) and low proportion of polyunsaturated fatty acids (PUFA) (Table 2) (Bout et al., 1988a; Tejeda et al., 2001). Numerous rearing factors have been described as factors affecting fatty acid composition (Girard et al., 1988a). Factors like age because they have a low growth rate and are selected against fatness since half a century, carcasses of these animals are very lean (Girard et al., 1988a). Sometimes, pigs are slaughtered heavier (160-180 kg) and older (9-12 months; i.e. Parma area) (Bosi et al., 2000). Muscle and adipose tissues of these pigs show very similar compositional traits. In some limited areas of Europe, pigs are produced in traditional rearing systems: the most famous ones are Iberian and Corsican ones (Benito et al., 2000; Secondi et al., 1999a). These systems rely on local breeds (Iberian, Corsican) reared outdoors and on a feeding strategy based on the availability of natural resources (acorns, grass, roots, oaks). The pigs are slaughtered between 18 and 24 months of age because they have a low growth rate and are subjected to alternating periods of scarcity (summer) and abundance (autumn) (Coutron-Gambotti et al., 1999a; Lopez-Bote, 1998). Pigs are fattened under chestnut grooves or oak plantations eating large quantities of chestnuts or acorns for 4-6 months during the winter. During this period, adipose and muscle tissues acquire their typical chemical traits (Narvaez-Rivas et al., 2008a) which are characterized by a large development of subcutaneous adipose tissue and a sharp increase in intramuscular lipid content leading to raw matter very different from those of industrial pigs (Coutron-Gambotti et al., 1998a; Lopez-Bote, 1998).

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sensitive lipase (HSL) and an acid lipase located in the blood vessel, cytosol and lysosomes, respectively (Belfrage et al., 1984). A monoacylglycerol (MG) lipase ends the process hydrolyzing the MGS. The activity of the MG lipase is higher than that of HSL. This explains why MGS do not accumulate in tissues. In both backfat and muscles of dry cured ham, lipases have been described as neutral and basic lipases corresponding probably to HLS and LPL. In addition, muscles present an acid lipase activity which is probably a lysosomal lipase (Motilva et al., 1993a). These lipases have activities that decrease during dry-cured processing but remain active during the whole process (Hernandez et al., 1999; Motilva et al., 1993b). In adipose tissues, HSL remains active over 12 months suggesting this lipase is the main enzyme involved in lipolysis in adipose tissue (Motilva et al., 1993c; Toldra and Flores, 1998). In muscles, the activities of HSL and LPL are high during the first 3-4 months of the process then, decline slowly. Acid lipase has low activity during the entire process (Motilva et al., 1993b). Very little is known about the factors affecting the activity of these enzymes. The activity of these enzymes varies according to the anatomical location of muscles (Flores et al., 1996; Hernandez et al., 1998). Oxidative muscles have a higher activity of both acid lipase and HSL than glycolytic muscles (Flores et al., 1996). These enzymes have similar activity in light and heavy pigs (110-110 kg versus 160-170 kg) (Toldra et al., 1996). PLs are hydrolysed by specific enzymes, phospholipases and lysophospholipases. Phospholipases are divided into three main groups. Phospholipases A1 and A2 hydrolyse fatty acids in 1 and 2 of the glycerol backbone of PLs, respectively. A monoacylglycerol (MG) lipase ends the process hydrolyzing the MGS. The activity of the MG lipase is higher than that of HSL. This explains why MGS do not accumulate in tissues. In both backfat and muscles of dry cured ham, lipases have been described as neutral and basic lipases corresponding probably to HLS and LPL. In addition, muscles present an acid lipase activity which is probably a lysosomal lipase (Motilva et al., 1993a). These lipases have activities that decrease during dry-cured processing but remain active during the whole process (Hernandez et al., 1999; Motilva et al., 1993b). In adipose tissues, HSL remains active over 12 months suggesting this lipase is the main enzyme involved in lipolysis in adipose tissue (Motilva et al., 1993c; Toldra and Flores, 1998). In muscles, the activities of HSL and LPL are high during the first 3-4 months of the process then, decline slowly. Acid lipase has low activity during the entire process (Motilva et al., 1993b). Very little is known about the factors affecting the activity of these enzymes. The activity of these enzymes varies according to the anatomical location of muscles (Flores et al., 1996; Hernandez et al., 1998). Oxidative muscles have a higher activity of both acid lipase and HSL than glycolytic muscles (Flores et al., 1996). These enzymes have similar activity in light and heavy pigs (110-110 kg versus 160-170 kg) (Toldra et al., 1996). PLs are hydrolysed by specific enzymes, phospholipases and lysophospholipases. Phospholipases are divided into three main groups. Phospholipases A1 and A2 hydrolyse fatty acids in 1 and 2 of the glycerol backbone of PLs, respectively. Lysophospholipases hydrolyse the remaining fatty acid after phospholipases A action (Waite, 1987). Very little is known on these enzymes and their post-mortem activity in skeletal muscles. A work of Alasnier and Gandemer (2000) showed that phospholipases and lysophospholipases were more efficient for distinguishing hams according to the rearing conditions (Riaublanc et al., 1999; Gandemer et al., 2000; Viera-Alcario et al., 2007 and 2008).

### 3. Lipid changes during meat processing

Typical dry-cured ham process includes these steps: salting, post-salting and ripening-drying. However, the conditions in which each step of the process is managed vary largely according to the area of production and the type of product expected. The main differences within each step are time-temperature cycles and relative humidity. These conditions largely affect the kinetics of meat component degradation during processing (Toldra and Flores, 1998).

#### 3.1. Lipolysis in adipose tissues and muscles

Lipolysis is one of the main processes of lipid degradation during dry-cured ham processing (Toldra and Flores, 1998). Lipolysis is governed by a set of specific enzymes: lipases and phospholipases. It forms free fatty acids (FFA) from TAGs in adipose tissue and from both TAGs and PLs in muscles. TAGs and diacylglycerols are hydrolysed by three lipase systems: lipoprotein lipase (LPL), hormone-sensitive lipase (HSL) and an acid lipase located in the blood vessel, cytosol and lysosomes, respectively (Belfrage et al., 1984). A monoacylglycerol (MG) lipase ends the process hydrolyzing the MGS. The activity of the MG lipase is higher than that of HSL. This explains why MGS do not accumulate in tissues. In both backfat and muscles of dry cured ham, lipases have been described as neutral and basic lipases corresponding probably to HLS and LPL. In addition, muscles present an acid lipase activity which is probably a lysosomal lipase (Motilva et al., 1993a). These lipases have activities that decrease during dry-cured processing but remain active during the whole process (Hernandez et al., 1999; Motilva et al., 1993b). In adipose tissues, HSL remains active over 12 months suggesting this lipase is the main enzyme involved in lipolysis in adipose tissue (Motilva et al., 1993c; Toldra and Flores, 1998). In muscles, the activities of HSL and LPL are high during the first 3-4 months of the process then, decline slowly. Acid lipase has low activity during the entire process (Motilva et al., 1993b). Very little is known about the factors affecting the activity of these enzymes. The activity of these enzymes varies according to the anatomical location of muscles (Flores et al., 1996; Hernandez et al., 1998). Oxidative muscles have a higher activity of both acid lipase and HSL than glycolytic muscles (Flores et al., 1996). These enzymes have similar activity in light and heavy pigs (110-110 kg versus 160-170 kg) (Toldra et al., 1996). PLs are hydrolysed by specific enzymes, phospholipases and lysophospholipases. Phospholipases are divided into three main groups. Phospholipases A1 and A2 hydrolyse fatty acids in 1 and 2 of the glycerol backbone of PLs, respectively. Lysophospholipases hydrolyse the remaining fatty acid after phospholipases A action (Waite, 1987). Very little is known on these enzymes and their post-mortem activity in skeletal muscles. A work of Alasnier and Gandemer (2000) showed that phospholipases and lysophospholipases were more efficient for distinguishing hams according to the rearing conditions (Riaublanc et al., 1999; Gandemer et al., 2000; Viera-Alcario et al., 2007 and 2008).

### Table 2

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<th></th>
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<th>Parma</th>
<th>Serrano</th>
<th>Iberian</th>
<th>Corsican</th>
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<tr>
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<td>Saturated</td>
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<td>36.4</td>
<td>33.4</td>
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<td>52.5</td>
<td>55.6</td>
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<td>55.4</td>
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<tr>
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<td>10.7</td>
<td>10.2</td>
<td>8.4</td>
<td>8.7</td>
</tr>
<tr>
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<td>0.4</td>
<td>0.8</td>
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<tr>
<td>Triglycerides (%)</td>
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<tr>
<td>POL</td>
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<td>8.1</td>
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P = palmitic acid, O = Oleic acid, S = stearic acid.
active post-mortem in fresh muscles. The main activities were related to basic phospholipases A and lysophospholipases (maximum activity at pH 8-9) which are probably membrane-bound enzymes while acid phospholipase A has a low activity. The activity of lysophospholipases is far higher than that of phospholipases in muscles (Alasnier and Gandemer, 2000). This result is consistent with the low proportion of lysophospholipids found in dry-cured ham. These enzymes are more active in oxidative muscles than in glycolytic ones (Alasnier and Gandemer, 2000). No data are available on the changes in the activities of these enzymes during dry-cured meat processing. However, the increase in the proportion long chain PUFA in FFA in FFA during the first 6 months of dry-cured hams processing strongly suggests that these enzymes remains active for at least 6 months (Buscailhon et al., 1994c).

Free fatty acid (FFA) amount increases during dry-cured hams processing in dry cured hams (Coutron-Gambotti & Gandemer, 1999; Motilva et al., 1993b). It sharply rises from 1-2% to 10-12% of total lipids in 10 months in adipose tissue and to 8-20% of total lipids in muscle depending on technology parameters and raw material traits (Figure 1) (Buscailhon et al., 1994c; Gandemer et al., 2000; Motilva et al., 1994). Lipolysis is fast during the first 6 months then slows down towards the end of the process in both adipose tissue and muscles (Narvaez-Rivas et al., 2007 and 2008b). In adipose tissue, lipolysis preferentially affects the TAGs containing linoleic acid such as POL (Coutron-Gambotti and Gandemer, 1999). These results could be explained by the liquid state of this TAG while most of the TAGs of pig adipose tissue are solid at the temperatures at which dry-cured hams are processed (Davenel et al., 1999). In muscle, both TAGs and PLs contribute to FFA. The relative contribution of these lipid classes depends on the TAG content in raw material. In most cases, PLs are the main substrates for lipolysis (Figure 1) (Buscailhon et al., 1994c). This conclusion is supported by the fact that the FFA composition is closer to the fatty acid composition of PLs than to that of TAGs whatever the type of ham (Figure 2) (Gandemer et al., 2000). The hypothesis of a PL origin of FFAs is consistent with the decrease in PL content in muscle during dry-cured ham processing (Buscailhon et al., 1994c).

However, TAGs also provide a significant amount of FFAs (30-50%) in muscles with very high TAG content such as muscles from Iberian and Corsican pigs (Alasnier et al., 1999; Martin et al., 1999). Lipolysis is not significantly affected by feeding system (Cava et al., 1999). Heavy and light pigs have similar pattern of lipolytic enzymes (Toldra et al., 1996). Among technological parameters, the time/temperature cycles of the different stages of processes are the most important and greatly affect FFA content and lipolytic enzyme activity. The longer is the stage and higher is the temperature, the higher is the FFA content of hams. Other parameters have obtained less attention. The use of frozen raw material instead of refrigerated one and reducing salt content in ham have no effect on lipolysis during dry-cured ham processing (Coutron-Gambotti et al., 1999b; Motilva et al., 1994). Muscles with a low initial pH (<6.1) have a higher FFA content all along the process indicating that a low initial pH promotes lipolysis (Buscailhon et al., 1994d).

Many authors have postulated that lipolysis promotes lipid oxidation during dry-cured ham processing (Antequera et al., 1992; Buscailhon et al., 1994c; Cava et al., 1999). This assertion must be reconsidered on the basis of recent data that support that the two processes would not be interrelated and moreover, that lipolysis could protect long chain PUFA against oxidation. Thus, the amounts of various volatile compounds arising from lipid oxidation decrease during the last months of processing whilst FFA amounts always increase (Buscailhon 1993; Ruiz et al., 1999) and some parameters promoting lipolysis have no effect on volatiles arising from lipid oxidation or on aroma notes related to oxidation products (Buscailhon et al., 1994e). FFAs contain almost all the long chain PUFA initially esterified in PLs of fresh meat (Buscailhon et al., 1994c; Coutron-Gambotti et al., 1999). These results strongly suggest that the hydrolysis of PLs during processing protects the long chain PUFAs from oxidation. However, the exact mechanism remains unknown.

3.2. Lipid oxidation in adipose tissue and muscle

Lipid oxidation is one of the main causes of deterioration in the quality of meat during storage and processing (Morrissey et al., 1998). However, it does not only contribute to off-flavour but it is also essential to the typical aroma of many meat products (Shahidi et al., 1986).

The overall mechanism of fatty acid oxidation is a chemical process named autoxidation (Frankel, 1982, 1985). This process affects polyunsaturated fatty acids (PUFA) preferentially. This explains why PLs which contain a large amount of these fatty acids, are the main substrates of lipid oxidation in muscles (Gandemer, 1997; Wilson et al., 1976). Lipid oxidation leads to the formation of numerous volatiles through a very complex set of reaction pathways. Attention has been focused on volatile products because of their impact on aroma. The nature and the relative proportions of compounds in the volatile fraction depend on numerous factors. Among them, fatty acid structure, namely the position of the double bounds, is the most important because it determines the structure of volatiles (Frankel, 1984).

Volatile content of muscle and adipose tissues shows a continuous increase during the first months of processing (Figure 3). However, it tends to
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Serrano

Iberian

Figure 1
Changes in lipid composition of Serrano and Iberian dry-cured hams during processing.

decrease at the end of the process, mainly in long processes (over 18 months) (Buscailhon et al., 1993; Ruiz et al., 1999). Oxidation leads to a significant decrease in long chain polyunsaturated fatty acids in both FFAs and PLs during dry-cured ham processing (Buscailhon et al., 1994c; Coutron-Gambotti et al., 1999b). Many factors are involved in the control of lipid oxidation in muscles (Morrissey et al., 1998). High temperatures and long time of drying and ripening favor lipid oxidation (Toldra and Flores,
Notes such as greenish odor (hexanal). Ketones arising from lipid oxidation are mainly methylketones (C5-C10). They exhibit a large variety of aroma notes such as fruity (2-heptanone, 2-decanone, 2-undecanone), oily and fatty (2-dodecanone) or blue cheese (2-heptanone) (Shahidi et al., 1986). One of the possible origins of these methyl ketones are an incomplete β-oxidation of free fatty acids by bacteria.

Linear, saturated or unsaturated alcohols (C4-C8) contribute to the overall aroma of dry-cured meat products, mainly unsaturated ones such as 1-octen-3-ol (mushroom) and 1-penten-3-ol (grass) (Shahidi et al., 1986). In contrast, hydrocarbons have no significant impact on aroma because of their high odor threshold (Dirinck et al., 1997; Shahidi et al., 1986). Whatever the type of dry-cured products, volatile fractions show a similar set of oxidation products. It is not surprising because the fatty acid compositions of TAGs and PLs which determine the type of volatiles formed during oxidation are similar in all the types of hams (see part 1). So the main differences between dry-cured hams are mainly related to the quantity of volatiles formed during the process (Buscailhon et al., 1993; Dirinck et al., 1997; Garcia et al., 1991). The quantity formed depends on the content of high salt content increases oxidation product content in dry cured hams (Coutron-Gambotti et al., 1999b). In contrast, high vitamin E content in muscles prevents dry-cured hams from oxidation (Cava et al., 1999). A low initial pH in muscles favors lipid oxidation in dry-cured hams (Buscailhon et al., 1994d). The genotype of pigs has a limited effect on lipid oxidation (Berdagué et al., 1993). Volatiles arising from lipid oxidation have been extensively studied in dry cured hams of various countries (French: Berdagué et al., 1993; Italian: Barbieri et al., 1992; Bolzoni et al., 1993; Spanish Serrano and Iberian: Dirinck et al., 1997; Flores et al., 1997; Garcia et al., 1991). Whatever the type of dry-cured hams, most of the volatiles are formed through lipid oxidation. The main ones are aldehydes. These aldehydes are linear saturated (C5 to C10 alkanals), unsaturated (C5 to C11 alkenals) with some polyunsaturated ones (2,4 nonadienal and decadienal). They have a large impact on the overall aroma of dry cured meat products because of their typical aroma and their low odor threshold (Dirinck et al., 1997; Shahidi et al., 1986). These aldehydes exhibit unpleasant odors such as fatty, oily, rancid, deep fried (nonanal, t-2-heptenal, 2-pentyl-furan, 2,4 decadienal) whereas other volatiles have more pleasant odor notes such as greenish odor (hexanal). Ketones arising from lipid oxidation are mainly methylketones (C5-C10). They exhibit a large variety of aroma notes such as fruity (2-heptanone, 2-decanone, 2-undecanone), oily and fatty (2-dodecanone) or blue cheese (2-heptanone) (Shahidi et al., 1986). One of the possible origins of these methyl ketones are an incomplete β-oxidation of free fatty acids by bacteria.

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intramuscular lipids which are both solvent and precursors of volatiles (Berdagué et al., 1993). Its depends also on processing traits such as the length and temperature (Buscailhon et al., 1993; Ruiz et al., 1999), the amount of salt (Coutron-Gambotti et al., 1999b) and the antioxidative pattern of the raw meat (Dirinck et al., 1997).

4. LIPIDS AND SENSORY TRAITS OF DRY-CURED HAM

4.1. Triacylglycerol composition and physical properties of fat

More than fatty acid composition, TAG composition determines the melting point and the solid fat content of both adipose tissues and inter and intramuscular fats, parameters strongly correlated with the consistency of fat. Thus each TAG possesses a melting point depending on its three fatty acids and on their distribution on the glycerol. Solid fat content at 20 °C is strongly correlated with disaturated TAGs, mainly PSO (R² > 0.90) because these TAGs are solid at ambient temperature (Davenel et al., 1999). On average, solid fat content of adipose tissue is around 20% with a large variation (from 7 to 30%). Fat with a solid fat content at 20 °C lower than 15-17% lacks of consistency (Davenel et al., 1999). Because of the low amount of PSO and the high amount of OOO, fat of Iberian pigs presents the low solid fat content at ambient temperature (10-12%) (Gandemer et al., 2000). This lack of consistency of fat affects some quality trait of dry-cured hams. The main traits associate with low fat consistency is the oily appearance and a poor cohesiveness of cuts (Ventanas et al., 2007). When hams are hanged, fat can drip. This trait is strongly associated with the positive image of Iberian dry-cured hams.

4.2. Intramuscular lipids and dry-cured ham quality

Intramuscular lipid content affects several quality traits of dry-cured hams. The first one is the aspect of slices because intramuscular lipids become visible when their content in muscles exceeds 5% (Buscailhon and Monin, 1994b). The hams with high intramuscular lipid content such as muscles from Iberian and Corsican pigs have a higher marbling score than those of Parma and Bayonne Hams (Rousset and Martin, 1998). Intramuscular lipids strongly affect color of ham slices. Thus, redness and brightness scores of ham cut decrease as intramuscular lipid content increases (Gou et al., 2009). The figure 3 shows changes in the amount of representative volatiles arising from lipid oxidation during Bayonne ham processing (As pg equivalent nonane/100 g ham).
Hams with high intramuscular lipid content are oilier. Intramuscular fat also affects texture of hams. Thus, high intramuscular lipid content has a positive impact on ham tenderness and juiciness (Ventanas et al., 2007). Hams produced from genotypes with high intramuscular lipid content have more intense and persistent aroma (Hinrischen and Pedersen, 1995, Ventanas et al., 2007) because intramuscular TAGs are a good trap for most aroma compounds (Shahidi et al., 1986). High intramuscular lipid content associated with a long ripening process gives liable for a higher rancid flavor (Ventanas et al., 2007).

4.3. Aroma arising from lipid oxidation and flavor of dry-cured ham

Lipids play a key role in the overall aroma of dry-cured hams because of the volatiles generated through oxidation. The overall aroma of hams depends on the equilibrium between volatiles arising from lipid oxidation and those arising from amino acid and carbohydrate degradation reactions. Many studies have tried to establish relationships between aroma traits of dry-cured hams described by panelists and volatile compounds extracted from the same hams. These studies lead to some consistent conclusions. Thus, dry cured hams produced through a long ripening process have the highest aroma intensity because they have the highest amounts of all kind of volatiles generated through both lipid and amino acid degradation (Ruiz et al., 1999). During ripening, the aroma of dry-cured ham changes from fat, pork, fresh meat aroma notes to dry-cured and aged aroma notes (Buscailhon et al., 1994e; Dirinck et al., 1997; Flores et al., 1997; Ruiz et al., 1999). During the first steps of processing, volatiles mainly arise from lipid oxidation while those formed during the second part of ripening stage are formed from both lipid and amino acid degradation (Hinrischen and Pedersen, 1995). Rancid aroma is correlated to oxidation products, mainly to aldehydes such as nonanal and 2-hexenal which exhibit a strong rancid odor (Berdagué et al., 1993; Ruiz et al., 1999). Positive aroma notes such as “cured ham”, “dry-cured ham” or “aged” aroma notes have been correlated to either branched aldehydes arising from amino acid degradation or methylketones arising from lipid oxidation (Buscailhon et al., 1994e; Flores et al., 1997; Hinrischen and Pedersen, 1995). All these results are consistent with the differences between the hams from different European countries (Figure 4). Thus, hams with a short processing (9-12 months) such as Bayonne and Parma hams show an aroma described as fresh meat and fresh fat aroma. In contrast, hams with a long ripening process (18-24 months) such as Corsican and Iberian hams have a more pronounced aroma with strong “rancid” and “cured” “mushroom” aroma notes (Figure 4) (Rousset and Martin, 1998). Aroma of Parma hams differs from that of other hams because of the high ester content in volatile fraction which have a pleasant fruity aroma (Barbieri et al., 1992; Careri et al., 1993).

5. CONCLUSION

Lipids are largely involved in the quality of dry-cured hams. Lipid traits of raw material strongly related to rearing conditions are content and consistency of lipids of both adipose and intermuscular fat. These traits influence aspects of cuts such as marbling, oily aspect and color. During processing, lipids undergo lipolysis and oxidation. Lipolysis affects the structure of lipids but its implication in quality traits of final products remains largely unknown. In contrast, oxidation of fatty acids generates a large amount of volatile compounds. These volatiles play a key role in
aroma of dry-cured hams. They contribute to various aroma notes. Aldehydes are responsible of rancid, fruity, and green aroma while methylketones have a more positive impact on ham aroma (aged and dry-cured ham odors).

Many papers have been devoted to describe the traits of raw material and the changes in meat and adipose tissues during processing. The quality traits of the final products result in complex interactions between characteristics of raw material such as lipid traits, enzyme equipment of the tissues and the control of the processes involved in chemical and physical changes affecting meat compounds during processing. Further studies are required for a better control of dry-cured ham processing while ensuring the taste and aroma typicity of the different types of dry-cured hams produced in European countries.

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