DRY-CURED MEDITERRANEAN HAMS: LONG PROCESS, SLOW CHANGES AND HIGH QUALITY: A REVIEW[1]

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ABSTRACT

The term "curing", in the Mediterranean region of Europe, means a long period of aging where an intense enzymatic action develops the distinctive flavor of dry-cured hams. The traditional process consists of rubbing a mixture of dry curing ingredients over the entire surface of the hams, allowing time for uniform distribution of the curing ingredients, and finally, a ripening stage where the product is submitted to different cycles of temperature, humidity and time. The final unique taste and flavor (a complex of sensations resulting from the stimulation of odor and taste) are achieved by proteolytic and lipolytic action. This lipolytic and oxidative degradation joined with the catabolism of amino acids produce volatile compounds, particularly during ripening under high temperature, which are responsible for the typical aroma of dry-cured hams. Raw material (the use of Duroc genetic material in growing pigs and feeding of acorns) and ripening conditions play an important role in dry-cured ham production in this area of the world.

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INTRODUCTION

As meat consumption in most European countries has widely expanded, particularly fresh pork or processed pork products (Fischer and Palmer 1995), extensive effort has been directed toward developing a quality pork product Lately, Spain has become the leading European country in the production of dry cured hams (Ferrer-Falcón 1990). Its ham production began in the 2nd century BC. History suggests that Cantabria and Cerdeña were the first and most important ham producing regions, and exportations were directed to Rome and the Orient (Gonzalez Blasco 1998)

The dry-curing process was originally used as a preservation method, however this process has been improved to develop a more desirable flavor and a firmer texture producing the characteristic Mediterranean Hams. In the Mediterranean regions of Europe, the term "cured" is used when they produce hams utilizing a long period of aging (usually between 6 to 12 months) where enzymatic action occurs and a distinctive flavor is developed. However, in the northern region, the term "cured" is limited to products that receive nitrite during processing (Flores 1997). A dry-cured product is one subjected to drying and ripening after the addition of dry ingredients and a time for these ingredients to equalize throughout the tissues (Flores and Toldrá 1993).

The quality of the dry-cured ham depends on multiple factors, such as animal breeding, animal age, feeding, environmental conditions previous to slaughtering (antemortem factors) and refrigeration and transportation of the product (postmortem factors). However, the most important factors that influence the sensory properties of hams are the raw materials and the ripening conditions (Toldrá *et al.* 1997; Toldrá 1998). Spanish (Iberian and Serrano) hams, Italian (Parma and San Daniele) hams, and French (Bayonne) hams are representatives of high-quality dry-cured hams of the Mediterranean areas.

Dry-cured Ham Technology

The Spanish Iberian hams are produced from the Iberian breed of hogs from the Southwestern region of Spain that were finished in pastures with acorns. The product achieves a high degree of marbling, firm texture and typical dry cured-ham flavor. The term flavor is defined as a combination of taste and aroma sensations (Doty *et al.* 1961; Toldrá 1998). The Serrano hams are produced from crossbred white pigs with a low marbling score, firm texture and a typical dry-cured-ham flavor, which depends on the length of ripening (Toldrá *et al.* 1997). In both Iberian and Serrano hams, the high degree of marbling and amount of outside fat reduce the moisture loss during drying which increases the tenderness (Arnau 1998).

The Iberian breed of hogs, in contrast to the methodology applied for breeding

white pig crossbreeds arrive at their final weight due to a procedure system called "Montanera". Briefly, Iberian pigs are placed in "Montanera" at 8-10 months of age, weighing between of 85-90 kg. During this period (6-9 weeks) the hogs are fed a diet of acorns (*Quercus ilex*, *Quercus rotundifolia* and *Quercus suber*) on pastures. The gained weight during this period ranges from 57-69 kg, which results in a final weight of 140-160 kg. The acorn is composed of 70-72% carbohydrates and 6-8% of fat, and is considered a high-energy nutrient. Acorn fat is rich in oleic acid (> 60% of the fatty acids) and low in linoleic acid (< 16-18%). As a consequence of the high energy level of the acorn, the age of slaughter is 10-12 months. Also, this diet has a tendency to deposit fat between the muscles and results in the Iberian breed of hogs having a high subcutaneous and intramuscular fat content (Ventanas *et al.* 1998).

The traditional dry-curing process consists of a mixture of curing adjuncts that are applied to hams without any added water. In this process, the curing mixture is permitted to penetrate by diffusion aided by the original moisture of the meat. A long ripening procedure is utilized and the product is not smoked. For the first four months, the hams are held under controlled low temperature and high relative humidity, but during the last 14-20 months they are exposed to the same natural environmental conditions found in the mountain ranges of Spain (Córdoba *et al.* 1994a). The current steps involved in the dry-curing procedure are briefly explained in the following outline (Flores and Toldrá 1993; Cordoba *et al.* 1994 a, b, Flores 1997; Toldrá, *et al.* 1997; Arnau 1998).

(1) Green State: Usually the hams are held for 48 h at 0-4C after the hogs are slaughtered. Then they are partially skinned, but the hoof, bones and nearly all the fat remain on the ham.

(2) Salting Stage: Hams are placed fat side down in the salting chamber, entirely covered by a mixture of curing ingredients, that includes sodium chloride, potassium nitrate and (or) nitrite (trace amounts), sugar (sucrose and dextrose) and ascorbic acid. Then, the hams are arranged in a single layer, to avoid touching each other, or stacked in piles in the curing mixture. The room is held at 2-4C for a period of time (depending on the size of the hams) of 1-1.5 days/kg for usually, 8-10 days. The curing mixture and the procedure utilized varies according to the type of ham and location of the production. As an example, hams could be pre-salted with 200 gm of a mixture of sodium chloride: dextrose: nitrate (46%: 50%: 4%) for 24 h at 3C, and then covered with sodium chloride and stacked for a period depending on the weight of the fresh ham (Oliver *et al.* 1994)

(3) Post Salting Stage 1: After removing the excess salt, the pieces are placed under refrigeration (1-4 C) at 90% relative humidity for 20-60 days to get a more uniform distribution of the cure adjuncts.

(4) Post Salting Stage 2: The hams are taken to a chamber for 45 days, where temperature is progressively raised to 18C and the relative humidity decreased to 80%.

(5) Drying Stage: During the summer, hams are kept at environmental conditions for 45 days in drying rooms, at 30C with a relative humidity of 45 to 70%.

(6) Ripening: The hams are left in natural or air-conditioned drying chambers and subjected to a relative humidity of 60-70%. Different time-temperature cycles are used depending on the time of the year. The ripening stages vary with the type of hams. The longer the period the wider the variation in process conditions. Usually the longer the ripening period the better the quality of the final product. Half-ripened hams (rapid process), requires at least 6 months at 14 to 16C, but for fully ripened hams (slow process) requires another 6 or more months at 16 to 22C. The Serrano ham is ripened for 9 to 12 months while the Iberian ham may be held for 18 to 24 months. The complexity and combination of biochemical reactions occurring during the ripening stage determine the sensory characteristics of the hams (Verplaetse 1994; Flores 1997).

Development of the Final Flavor and Taste

Proteolytic Action. The intense proteolysis observed during the dry-curing process in Spanish style hams is, in part, a result of the action of muscle proteinases, especially calpains and cathepsins. Both proteolytic systems have been widely studied in fresh and aged meat from different species (Zeece *et al.* 1986; Etherington *et al.* 1987; Ouali *et al.* 1987; Koohmaraie 1988, Koohmaraie *et al.* 1988; Zeece and Katoh 1989; Etherington *et al.* 1990; Whipple *et al.* 1990; Koohmaraie 1992, Ouali 1992; Whipple and Koohmaraie 1992). The volume of research during the last ten years, on dry-cured hams has been rapidly increasing (Toldrá and Etherington 1988; Parreño *et al.* 1990, 1994; Gil *et al.* 1991, Rico *et al.* 1991; Toldrá *et al.* 1991, 1993; Sárraga *et al.* 1993; Virgili *et al.* 1995).

The calcium dependent protease system involves cystein endopeptidases located mainly in the cytosol and in the Z-disk area of the muscle sarcomere. The protease system is composed mainly of Calpain I and Calpain II enzymes, which require low and high calcium concentrations, respectively, for activation. Calpastatin another compound of this system, is the endogenous calpain inhibitor, activated by Zn^{2+}, and may also play a part in this process. Maximal enzyme activity is achieved at neutral pH. Thus, it is postulated that only a little enzyme activity occurs in the ham at a pH of 6.0. The enzyme system is responsible for the fragmentation of myofibrils along the Z-line by acting primarily on troponin T and I, tropomyosin, C-protein, filamin, vinculin, desmin, titin and nebulin (Goll *et al.* 1983, 1992; Koohmaraie 1988, 1992; Dransfield *et al.* 1992; Ouali 1992). Studies focused on the incidence of calpains in the curing process revealed that calpain activity could not be detected in hams after 2.5 months of treatment, and that the activity level during the salting stage was significantly lower than in fresh muscle (Sárraga *et al.* 1993). It is postulated that the instability of the proteases involved is an important key in this long salting process.

Lysosomal proteinases include mainly cathepsins B, D, H and L. They are cysteine proteinases (B, H and L) and aspartyl proteinase (D) which are responsible for the degradation of different myofibrillar proteins in vitro, at acidic pH values.

Cathepsin D is stable at a high temperature and exhibits maximum activity with myofibrils at 45C and a pH of 5.5. The enzyme rapidly degrades myosin heavy chains (MHC), titin, and C- and M-proteins. Actin and myosin light chains are also degraded but at a much slower rate (Zeece and Katoh 1989). The proteins of the muscular regulatory complex, α-actinin, tropomyosin and troponins T and I are cleaved by cathepsin D but in the area of pH 3 (Matsumoto *et al.* 1983). In fact, only one part of MHC degradation could be due to the enzyme since only a low percentage of the initial enzyme activity level remains at the end of the curing process and this almost disappeared after 5-10 months of processing. In general, enzyme activity is strongly affected by both salt and pH during the dry-curing process (Ouali *et al.* 1987; Toldrá and Etherington 1988; Toldrá *et al.* 1991, 1992, 1993; Sárraga *et al.* 1993).

Similarly, cathepsin B can degrade myosin and actin (Schwartz and Bird 1977, Noda *et al.* 1981), although this proteinase usually degrades only low-molecular-weight proteins such as troponins I and C (Ouali *et al.* 1987). A decrease in enzyme activity has been found from 2.5 to 3 months of curing in the Semimembranosus (SM) muscle (30-40% of residual activity). While in the *Biceps femoris* (BF) muscle, the decrease has been detected at a later stage of the curing process (approximately 5.5 months), probably due to an irregular salt distribution in this heterogene muscle (Toldrá and Etherington 1988; Sárraga *et al.* 1993). Nevertheless, enzyme activity has been recovered in part (10-15%) at the end of the curing process in both muscles (Sárraga *et al.* 1993).

A comparison of this activity in the same two muscles but in two different processes, short aging (4 months) and long aging (8 months), has revealed that the ratio of cathepsin B: cystatin in the short process increases, probably because cystatin falls faster than cathepsin B activity. However, in the long process this ratio decreases slightly suggesting a modification of cathepsin B activity according to the curing process used (Parreño *et al.* 1994).

Cathepsin L produces myosin heavy chain (MHC) degradation giving peptides, which also disappears during the process (Ouali *et al.* 1987). In fact, it is postulated that the disappearance of the MHC could be due to both cathepsins D and L, although D has the handicap of an earlier and greater reduction of its activity. Actin, α-actinin and troponin T and I can also be degraded by cathepsin L (Matsukura *et al.* 1981; Toldrá *et al.* 1993). The combined cathepsins B+L activity shows a similar pattern to cathepsin B activity described previously (Toldra and Etherington 1988; Sárraga *et al.* 1993). However, when this activity is compared in different length processes, the results indicate that cathepsin L loses its activity more rapidly than cathepsin B, which is more stable throughout the curing process

(Parreño *et al.* 1994).

In contrast, cathepsin H degrades very few of the myofibrillar proteins (Ouali *et al.* 1987). The range of pH activity is 5.5 to 6.5 and cathepsin H is commonly defined as an endo-aminopeptidase (Koohmaraie 1988). Results of cathepsin H are controversial since some scientists have not found any difference between the activity of cathepsin H and that of the other cystein proteinases studied (Toldrá and Etherington 1988; Toldrá *et al.* 1991). Furthermore, Toldrá *et al.* (1992) have demonstrated that cathepsin H has low activity (16.5%) in the first stage of the dry-curing process due to the inhibitory action of the salt used, but then the activity is recovered during the drying stage. On the contrary, Parreño *et al.* (1994) have shown that the activity in fresh muscle falls sharply and is practically negligible (less than 4%) throughout the rest of the curing process.

The profile of cystatin like activity (cystein proteinases inhibitor) decreases slowly but progressively during the curing process and this might result in an underestimation of the cathepsin activities. However, both have a similar developmental pattern and it seems that the inhibitor has little influence on this proteolytic action during ripening (Parreño *et al.* 1994).

The slow losses of enzyme activity during the ripening process, and the recovered activities of the cathepsins B, H, and L at the end of the process indicate that enzyme proteolytic action remains active at the final stage of the curing process (in some cases even after 15 months). This observation is attributable to the stabilized action of the curing salts against further denaturation (Toldrá and Etherington 1988; Toldrá *et al.* 1993).

According to the evolution of enzyme activity and to the protein degradation profiles, cathepsins B and L play an important role throughout the processing of dry-cured hams. Cathepsin L acts mainly in the initial stage with fresh muscle to the postsalting stage and cathepsin B has an intermediate role in degrading low-molecular-weight proteins into amino-acids. Cathepsin H seems to display little activity during the ripening process and it is not known if it participates in protein degradation. Participation of cathepsin D would be restricted to the first few months of processing when it is still active (Toldrá *et al.* 1993; Parreño *et al.* 1994). The specific role of cystatins is not well documented and needs more research.

Changes in muscle proteins and structure during the dry-curing process can be explained by considering a synergistic action of both lysosomal and calcium-dependent proteinases. The contribution of calpains to the proteolytic action is restricted to the earlier breakdown of myofibrillar proteins either by cleaving only the large peptides (Goll *et al.* 1983, 1991) or by degrading muscle to small peptides and amino acids (Harris *et al.* 1995). The most important action performed by cathepsins during the dry-curing process is to collaborate with the initial muscle protein degradation exerted by the calcium-dependent protease system.

Cathepsins and calpains are not thought to be entirely responsible for the final taste and flavor of the product since protein degradation occurs mainly in the first steps of the dry-curing procedure. Nevertheless, they could supply the substrate for the consequent action of other enzymes, which are able to produce greater degradation.

Muscle exopeptidases (metallo-proteins) seem to be involved in the latter stages of the proteolytical degradation. Studies with aminopeptidases (leucyl, arginyl, alanyl, pyroglutamyl, and tyrosyl-enzymes) demonstrated that they are localized in the cytosol, are activated at neutral pH (optimal at 6.5–7.5) and at a temperature range of 10–25C; however, the optimum temperature is 37C (Toldrá *et al.* 1992, 1997). Enzymes are much more stable during the dry-curing process even though salt principally, and then ascorbate and nitrite, have inhibitory effects on most enzyme activities (Toldrá *et al.* 1991, 1992, 1993). Muscle aminopeptidases act on many different substrates (proteins and peptides) which would support their participation in the free amino acid liberation and account for most of the desirable flavor of dry-cured hams (Toldrá *et al.* 1997).

The effect of proteolytic enzymes on flavor and texture of dry cured hams depends on the quantity of free amino acids and low-molecular-weight compounds produced. However, when proteolysis is in excess it imparts a bitter and metallic taste, develops abundant white crystals on the cut surface and increases softness (Virgili *et al.* 1995, 1998a).

The peptide generation pattern analyzed by different methodology showed a substantial change in peptide mapping during curing as evidenced by the presence of components ranging in molecular mass of 160 to 4500 Da and by the increase in low-mass peptides (160-1200) after 3.5–5 months (Rodríguez-Nuñez *et al.* 1995). Further studies with electrophoresis in the presence of SDS, revealed a progressive reduction of the 220 kDa to the 17 kDa bands until there was a total disappearance of the 220 kDa during the ripening period, indicating intense proteolytic activity (Córdoba *et al.* 1994b).

Most of the amino acids detected in the first period increased significantly during ripening, particularly alanine and glutamic acid followed by leucine, glycine and lysine. However, the fastest increase in the concentrations of all the amino acids was achieved during the drying stage (Toldrá *et al.* 1992; Córdoba *et al.* 1994a). This period and also the salting step were the stages of maximal NPN (nonpeptide nitrogen) increase and also there was a marked reduction in myofibrillar proteins (Córdoba *et al.* 1994b). Later in the ripening process, amino acid nitrogen was the major source of NPN, probably due to further proteolytic activity induced by the relatively high temperatures maintained at this stage (Ventanas *et al.* 1992; Córdoba *et al.* 1994 a, b).

Also, amines (putrescine, histamine, and tyrosine) increased during ripening, while spermine decreased. Yet the concentrations of these biogenic amines are neither in the range of toxic levels nor enough to reach values that can be a problem in dry cured hams (Córdoba *et al.* 1994a).

Those NPN, nonvolatile amino acids and peptides produced under controlled

proteolysis, might be precursors of a whole series of volatile aroma compounds found in dry-cured hams since sensory traits are affected by moisture and the NPN content, and also the latter is increased by greater cathepsin B activity, lower salt level and higher temperature (López-Bote *et al.* 1990; Ventanas *et al.* 1992; Virgili *et al.* 1995). However, more studies need to be performed to correlate flavor to specific amino acids and peptides.

Lipolytic Action

Due to the high level of fattening of the Spanish hogs, flavor variation has been attributed to the lipid composition of fatty tissues and to the degree of lipid breakdown during processing. The enzyme lipolytic system is distributed in both adipose and muscle tissue. The most characterized adipose enzyme (Miller *et al.* 1981; Motilva *et al.* 1993 a,b) is lipoprotein lipase which is responsible for the uptake of triglyceride fatty acids from the circulation (hydrolyses primary esters and unsaturated monoacylglycerols), hormone-sensitive lipase which regulates fatty acid mobilization in the tissue (ester-bond of triacylglycerol and diacylglycerol affinity) and monoacylglycerol lipase responsible for the final production of free fatty acids and glycerol (any monoacylglycerol as a substrate). Neutral or basic pH is the optimum for maximal activity. Maximal activity is present at the beginning of processing but the processing temperature (Motilva *et al.* 1993 a,b) restricts this activity. Esterases from adipose tissue seem to be quite stable even after 7 months of processing and aminopeptidase activity has also been reported in this tissue in both raw and dry-cured hams (Toldrá *et al.* 1991, 1992).

Muscular lysosomal acid lipase hydrolyses principally neutral lipids, such as cholesterol esters and primary ester-bonds of triacylglycerols at pH 4-5 (Imanaka *et al.* 1984). Lipoprotein lipase is responsible for the hydrolysis of the di- and tri-acylglicerol components of the very low-density lipoproteins and chylomicrons at an optimum pH of 8-9. Acid phospholipase (A2) is also involved in lipid degradation (Flores *et al.* 1985; Buscailhon *et al.* 1994). In general, muscle lipases have shown better stability than those from adipose tissue during the dry-curing process (Toldrá *et al.* 1991).

A progressive increase in the concentration of free nonvolatile fatty acids has been reported in the first stages (up to 5 months) along with the high lipolytic activity during this same period (Motilva *et al.* 1993b, 1994). This free fatty acid production constitutes a first step of precursors for secondary reactions (oxidations, interactions with proteins, etc.) to achieve flavor development. Neutral and basic muscle lipases are more active at the beginning of the curing process and are affected by changes in curing conditions, while lysosomal acid lipase seems to be active through the entire process (Motilva *et al.* 1993b).

Muscle esterases show an excellent stability during processing. However, it seems that the enzyme does not play a key role in the lipolysis of dry-cured ham in view of the absence of adequate substrates and the low amount of volatile free fatty acids produced (Motilva *et al.* 1993b; Buscailhon *et al.* 1994; Toldrá *et al.* 1997).

Volatile Components

Typical aroma of dry-cured ham is correlated with the lipolytic and oxidative degradation of unsaturated fatty acids or with the catabolism of amino acids. Consequently, these reactions generate volatile compounds especially during the latest stage of ripening, due to high temperature developed along with long processing of Spanish hams (Flores *et al.* 1985; López-Bote *et al.* 1990; Buscailhon *et al.* 1994; Verplaetse 1994). The chemical reaction involved is the Maillard reaction, in which a protein compound (peptides, amines and mainly amino acids) reacts with a sugar compound, followed by different chemical reactions such as condensation, dehydration, degradation, etc. to form furans, furfural, aldehydes, ketones, etc. Finally, they react among themselves or with products of lipids reactions to produce volatile compounds (Toldrá 1998).

Capillary gas liquid chromatography-mass spectral chromatograms show more than 70 individual peaks ranging from Mw of 84 to 310. The compounds identified belong to alkanes, branched alkanes, aldehydes, ketones, aliphatic alcohols, carboxylic acids, esters, lactones, furans and sulfur compounds and other miscellaneous groups (Berdagué *et al.* 1991; Garcia *et al.* 1991; Dirinck *et al.* 1997).

N-alkanes, aromatic compounds and branched alkanes are present in these hams. They may be products of the autooxidation of lipids. The branched alkanes are also found in fresh meat, probably coming from the oxidation of branched fatty acids in animal tissue or from the unsaponificable fraction from the feed consumed by the animals (acorns). Because of their relatively high threshold value, hydrocarbons probably are not significant contributors to the flavor of the raw hams (Rembold *et al.* 1989; Devos *et al.* 1990).

Aldehyde compounds make up the major class of volatiles and the identified hexanal is the most abundant. They may be formed by the breakdown of hydroperoxides derived from unsaturated fatty acids, sugar catabolism or meat proteolysis. Because of their low threshold values and distinctive odor characters they may be the major contributors to the ham's flavor (Hertz and Chang 1970; Frankel 1985; Dirinck *et al.* 1997). Of the alcohols identified, 3-methylbutanol, 1-octen-3-ol, pentanol, hexanol, heptanol and phenylethanol, the latest seems to be responsible for a floral note and the 1-octen-3-ol produces a potent mushroom odor (Berdagué *et al.* 1991; Garcia *et al.* 1991; Dirinck *et al.* 1997).

Ketones are represented basically by methyl ketones, which are products of decarboxylation of β ketoacids or of saturated fatty acid β oxidation. Among the bifunctional ketones, 3-hydroxy-2-butanone might be important as a contributor

to the buttery notes (Berdagué *et al.* 1991; García *et al.* 1991; Durinck *et al.* 1997).

The free carboxylic acids come from the hydrolysis of the triglycerides and phospholipids (Berdagué *et al.* 1991). A large number of esters found have not been properly identified, but they probably arise from the esterification of alcohols and carboxylic acids and are generally associated with fruity flavors (García *et al.* 1991).

The lactones identified are the products of the dehydration and cyclization of the hydroxyacids of the animal fats. They would be related to buttery, oily, fatty, fruity and coconut-like flavors (Baines and Mlozniewicz 1984).

Sulfur containing compounds were found in low concentration. However, among the identified components, the dimetyl di-, tri- and tetra-sulfide compounds might influence overall flavor (Durinck *et al.* 1997).

The amount of olfactory volatiles found in Spanish hams suggests an intense enzyme action during maturation; in particular, hpolysis and lipid oxidation are considered to be the major processes in the volatile flavor production (López-Bote *et al.* 1990; Verplaetse 1994). Some of the peaks found in the chromatograms have been identified and associated with the characteristic smell of the product. However, several molecules with a weak chromatographic signal remain unidentified and need more research to determine which are really components in the dry-cured flavor.

Influence of Crossbreed Pigs

Farming, slaughtering techniques, manufacturing procedures, and consumer preferences are important factors in determining the quality of dry-cured hams (Virgili *et al.* 1998b). However, raw material is one of the key factors.

High pH levels, high levels of intramuscular fat or low-salt/moisture ratio influence texture (Parolari *et al.* 1988). Animal age affects color, fat content, muscle resistance to drying tension and proteolytic enzyme activity (Sárraga *et al.* 1993). Some studies have demonstrated the association between certain quality factors and pig breeds (Cameron *et al.* 1990; Oliver *et al.* 1993, 1994). However, chemical analyses have revealed a restricted effect of crossbreeding on the content of volatile compounds and ham flavor (Berdagué *et al.* 1993). Ninety two percent of the production in Spain is obtained from confined pork production and the rest from the Iberian breed, either pure or crossed, reared in extensive or semi-extensive conditions (Oliver *et al.* 1994). The Duroc breed was introduced in Europe to improve quality. Particularly in Spain, this breed has been used to manufacture dry-cured meat products due to its high intramuscular fat level.

Increasing Duroc genetic material in growing pigs produces a higher degree of marbling (carcass measurement) and intramuscular fat content (chemical measurement) that improves meat quality, particularly tenderness (Edwards *et al.* 1992; Oliver *et al.* 1994; Virgili *et al.* 1998b). Furthermore, the Duroc breed seems

to be ideal for crossing because of its growth characteristics, the quality of the carcass and the superior feed conversion ratio. It is also resistant to the PSE-conditions and this contributes to the high quality dry-cured ham manufacturing (Blasco *et al.* 1994; Oliver *et al.* 1993, 1994; Guerrero *et al.* 1996). The intense flavor of the dry-cured ham of the Duroc line may be associated with the larger amount of marbling and intramuscular fat observed (compare to Large White, Landrace, Pietrain, and Belgian Landrace) and with the volatile compounds formed by the oxidation of its fatty acids (López Bote *et al.* 1990; Guerrero *et al.* 1996). The increased marbling could also make salt and water diffusion more difficult and require a longer curing time. No differences between genetic types have been found in moisture and pH (Berdagué *et al.* 1993; Guerrero *et al.* 1996). Duroc (and Belgian-Landrace cross) breeding improves overall acceptability of the ham with respect to the other breed types (Belgian-Landrace x Landrace or x Large White) which are considered less desirable and producing more defective hams (Oliver *et al.* 1994).

Main Differences with Other Products

The most important differences between meat products from the northern and southern regions of Europe are found in dry-cured products. In the case of the typical Mediterranean type products, nitrate is used exclusively since such products are submitted to a long period of ripening, nitrite is not usually used, and smoking is not applied. In the northern European area meat products are cured with nitrite and smoking is almost an integral part of the curing process. Hams are smoked after the postsalting stage and subsequently ripened only over 1-3 month's period. These different methodologies applied for the curing process produce a wide variation in the sensory characteristics of the final product (Flores 1997).

American dry-cured hams also differ usually according to the location of production. During the past, some producers utilized peanuts as feed to produce more unsaturated fat, which would encourage more oxidation contributing to part of the desirable flavor. Salt, sometimes sugar, nitrate, sometimes nitrite, sometimes smoking and spice curing (often pepper) are utilized as cure and flavor adjuncts. The hams are kept in cure 1 to 1½ days per pound (0.454 kg), allowed to equalize the curing adjuncts, and aged for 3 to 12 months (more intense flavor with longer aging). American hams are usually soaked in water prior to cooking to remove some of the salt. They are usually simmered in water and then baked or sliced and fried in contrast to European hams that are often eaten uncooked.

CONCLUSIONS

The quality of the Mediterranean hams is related to the ripening time and

conditions and to the raw material utilized. During ripening, the intense proteolytic and lipolytic breakdown produces precursors of a series of important volatile aroma compounds.

Crossbreeding has been used extensively to improve ham production; particularly the Duroc line has increased marbling and intramuscular fat content. Feeding acorns is also a factor affecting fat composition and consequently ultimate flavor in Iberian style hams.

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