Review

Nutritional composition of dry-cured ham and its role in a healthy diet

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A B S T R A C T

Dry-cured ham is a traditional product with a strong presence in markets in the Mediterranean area. It is very popular with European consumers and is of enormous economic importance for the meat industry in the Mediterranean area. Although the great palatability of ham largely outweighs other considerations, aspects relating to health and wellbeing are increasingly important factors in consumer decisions. The potential role of ham in a context of healthy nutrition has not been clearly elucidated, especially considering that origins and production methods of dry-cured hams can induce differences in composition. The object of this review was on the one hand to provide an analysis of the components of dry-cured ham and their role in a healthy diet, and on the other hand to suggest possible strategies for improving its nutritional composition.

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1. Introduction

Traditional salting and drying technologies have been used since ancient times to produce high-quality dry-cured hams in Mediterranean countries. The meat industry uses these processes to produce a wide range of shelf-stable and nutritious muscle foods which are very popular among European consumers because of their particular sensory traits (Estevez, Morcuende, Ventanas, & Ventanas, 2008; Gandemer, 2002). There are basically two kinds of dry-cured hams, differentiated by the origin of the raw material and the ripening process: dry-cured hams from rustic and free-range-reared genotypes (like the famous Iberian ham, Corsican or Cinta Senese); and hams from intensively-reared white pigs, such as Serrano, Parma or Bayonne hams. In both cases there is a fattening period entailing intense development of adipose tissue, and a high level of intramuscular fat (IMF) in particular is sought in order to achieve high-quality products (Gandemer, 2009; Ventanas, Ventanas, Ruiz, & Estevez, 2005). Also, the typical colour, texture, taste and aroma are achieved in part through a moderate salting and a long ripening period, of around 7–14 months for dry-cured hams from white pigs and over 20 months for Iberian hams (Ruiz, Ventanas, Cava, Andrés, & García, 1999; Toldrá, Flores, & Sanz, 1997). These products have gained a large market share, mainly because their sensory traits, especially in some countries like Spain, with more than 40 million dry-cured hams per year is the world’s largest producer (Cruz, 2009; Estevez et al., 2008). For that reason, numerous studies over the last few decades have been devoted to optimizing the quality of the raw material and controlling the biochemical reactions that take place during processing (Toldrá, 2009). There is growing evidence that dietary fat content plays a significant role in the prevention and treatment of a number of chronic disorders, particularly coronary heart disease. Recommendations for optimal intake of total and unsaturated fatty acids have been proposed by a number of scientific authorities and nutritional organizations including the World Health Organization (WHO, 2003). Dietary fat intake should ideally account for between 15% and 30% of total diet energy, saturated fatty acids (SFA) no more than 10%, polyunsaturated fatty acids (PUFA) between 6% and 10% (n–6, 5–8%; n – 3, 1–2%), around 10–15% from monounsaturated fatty acids (MUFA), and less than 1% from trans fatty acids. It is also recommended to limit cholesterol intake to 300 mg/day.

2. Dry-cured ham components and health implications

There are various factors (pig breed, animal production practices, production methods) which produce considerable differences in qualitative and quantitative aspects of fat, protein levels, presence of salt (sodium), etc., that are responsible for the sensory and nutritional characteristics of hams and their potential implications for human health. The following subsections look at aspects concerning the various components.

2.1. Lipids, fatty acids and cholesterol

There is growing evidence that dietary fat content plays a significant role in the prevention and treatment of a number of chronic disorders, particularly coronary heart disease. Recommendations for optimal intake of total and unsaturated fatty acids have been proposed by a number of scientific authorities and nutritional organizations including the World Health Organization (WHO, 2003). Dietary fat intake should ideally account for between 15% and 30% of total diet energy, saturated fatty acids (SFA) no more than 10%, polyunsaturated fatty acids (PUFA) between 6% and 10% (n–6, 5–8%; n – 3, 1–2%), around 10–15% from monounsaturated fatty acids (MUFA), and less than 1% from trans fatty acids. It is also recommended to limit cholesterol intake to 300 mg/day.

Table 1

Lipid content* and fatty acid profile (percentage of total fatty acids) of the different dry-cured hams.

<table>
<thead>
<tr>
<th>Ham (feeding system)</th>
<th>Fat*</th>
<th>SFA</th>
<th>MUFA</th>
<th>PUFA</th>
<th>PUFAs / SFA</th>
<th>n – 6/n – 3</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Iberian (acorn)</td>
<td>11.28</td>
<td>32.51</td>
<td>59.37</td>
<td>8.12</td>
<td>0.25</td>
<td>12.1</td>
<td>Petrón, Muriel, Timón, Martín, and Antequera (2004)</td>
</tr>
<tr>
<td>2. Iberian (acorn)</td>
<td>9.51</td>
<td>33.97</td>
<td>54.60</td>
<td>11.43</td>
<td>0.33</td>
<td>18.1</td>
<td>Ventanas, et al. (2007)</td>
</tr>
<tr>
<td>3. Iberian (commercial feed)</td>
<td>5.47</td>
<td>35.15</td>
<td>51.39</td>
<td>13.44</td>
<td>0.38</td>
<td>31.2</td>
<td>Ventanas, et al. (2007)</td>
</tr>
<tr>
<td>4. Iberian (acorn)</td>
<td>(17.23)</td>
<td>34.9</td>
<td>57.2</td>
<td>7.66</td>
<td>0.19</td>
<td>9.4</td>
<td>Fernández et al. (2007)</td>
</tr>
<tr>
<td>5. Serrano (commercial feed)</td>
<td>4.8</td>
<td>32.7</td>
<td>52.7</td>
<td>10.2</td>
<td>0.31</td>
<td>16.2</td>
<td>Jiménez-Colmenero et al. (2009)</td>
</tr>
<tr>
<td>6. Serrano (commercial feed)</td>
<td>3.5</td>
<td>33.4</td>
<td>55.6</td>
<td>11.0</td>
<td>0.33</td>
<td>12.7</td>
<td>Gandemer (2009)</td>
</tr>
<tr>
<td>7. Bayonne (commercial feed)</td>
<td>2.6</td>
<td>36.4</td>
<td>52.9</td>
<td>10.7</td>
<td>0.29</td>
<td>14.1</td>
<td>Gandemer (2009)</td>
</tr>
<tr>
<td>8. Bayonne (commercial feed)</td>
<td>3.5</td>
<td>36.5</td>
<td>47.4</td>
<td>15.3</td>
<td>0.42</td>
<td>29.6</td>
<td>AIR Project Report CT93-1757 (1997)</td>
</tr>
<tr>
<td>9. Corsican (chestnut)</td>
<td>12.3</td>
<td>35.0</td>
<td>53.8</td>
<td>11.2</td>
<td>0.32</td>
<td>–</td>
<td>AIR Project Report CT93-1757 (1997)</td>
</tr>
<tr>
<td>10. Corsican (commercial feed)</td>
<td>5.3</td>
<td>34.9</td>
<td>55.4</td>
<td>9.7</td>
<td>0.28</td>
<td>8.7</td>
<td>Gandemer (2009)</td>
</tr>
<tr>
<td>12. Parma (commercial feed)</td>
<td>(18.4)</td>
<td>37.9</td>
<td>52.0</td>
<td>9.9</td>
<td>0.26</td>
<td>–</td>
<td>D’Evoli et al. (2009)</td>
</tr>
<tr>
<td>13. San Danielle (commercial feed)</td>
<td>(23.0)</td>
<td>38.5</td>
<td>51.9</td>
<td>9.6</td>
<td>0.25</td>
<td>–</td>
<td>D’Evoli et al. (2009)</td>
</tr>
<tr>
<td>14. Cinta Senese (acorn)</td>
<td>–</td>
<td>33.26</td>
<td>51.35</td>
<td>15.38</td>
<td>0.46</td>
<td>14.2</td>
<td>Pugliese (2009)</td>
</tr>
<tr>
<td>16. Iberian (feed with MUFA)</td>
<td>7.08</td>
<td>34.79</td>
<td>54.21</td>
<td>11.00</td>
<td>0.38</td>
<td>28.20</td>
<td>Ventanas, et al. (2007)</td>
</tr>
<tr>
<td>17. Serrano (feed with corn oil)</td>
<td>–</td>
<td>32.60</td>
<td>47.77</td>
<td>19.58</td>
<td>0.60</td>
<td>8.2</td>
<td>Santos et al. (2008)</td>
</tr>
<tr>
<td>18. Serrano (feed with n – 3 and MUFA)</td>
<td>–</td>
<td>33.06</td>
<td>47.40</td>
<td>19.98</td>
<td>0.60</td>
<td>1.97</td>
<td>Santos et al. (2008)</td>
</tr>
<tr>
<td>19. Parma (feed with corn oil)</td>
<td>–</td>
<td>31.82</td>
<td>50.20</td>
<td>17.83</td>
<td>0.56</td>
<td>20.5</td>
<td>Pastorelli et al. (2003)</td>
</tr>
<tr>
<td>21. Parma (commercial feed)</td>
<td>–</td>
<td>35.09</td>
<td>54.04</td>
<td>19.36</td>
<td>0.26</td>
<td>26.94</td>
<td>Lo Fiego et al. (2005)</td>
</tr>
<tr>
<td>22. Parma (supplement with CLA)</td>
<td>–</td>
<td>38.99</td>
<td>53.08</td>
<td>7.33</td>
<td>0.18</td>
<td>29.39</td>
<td>Lo Fiego et al. (2005)</td>
</tr>
</tbody>
</table>

* Expressed as g IMF/100 g of the muscle Biceps femoris or g fat/100 g of the lean fraction of the slice with remaining intermuscular and 5 mm of subcutaneous fat (in bracket).
Dry-cured ham presents different fat levels. This is due to the genetic features of the pig breed and differences in feeding systems (Table 1). Iberian hams contain much more IMF (9.5%) than varieties made from white pigs like Bayonne (2.6%) or Parma (3.6%) dry-cured hams. Moreover, adipose tissues other than IMF are also present in dry-cured hams, varying in quantity and composition according to type of ham. However, on average the total lipid contents of ready-to-eat slices of different hams do not differ greatly from the value reported by Jiménez-Colmenero et al. (2009) for Iberian hams (19.2%). Similar lipid contents (17–19%) have been reported by Honikel (2005) for German (Rohschinken) and French dry-cured hams, and by D’Evoli et al. (2009) for Parma (18.4%) and San Danielle hams (23.0%).

Fat content is believed to be one of the most crucial quality traits of cured hams (the higher the fat content, the greater the acceptability of cured hams), but what most affects the appearance, texture (juiciness) and intensity and persistence of flavour of dry-cured hams is the IMF content (Gandemer, 2009; Ruiz, Ventanas, Cava, Andrés, & García, 2000). Both IMF and subcutaneous fat also help moderate salt uptake and slow down moisture loss during processing thanks to a lower water diffusion rate. From a sensory standpoint, it is the long ripening period that allows long-matured hams to fully develop their particular taste and smell. However, consumer choice may be affected by health considerations as well as sensory characteristics. In this respect, any detrimental effect on quality could be avoided by physical removal of the fat after processing. A considerable amount of external fat is removed during cutting and slicing of hams for packaging or immediately before consumption (about 25% of weight in Iberian hams).

The muscle lipids of dry-cured hams contain triacylglycerols (TAG), located in the fat cells, and membrane lipids as phospholipids (PL) and cholesterol. In addition, the free fatty acid (FFA) fraction can reach 9–20% of total lipids at the end of processing. TAG is rich in MUFA and to a lesser extent in SFA; in contrast, PLs characteristically contain high proportions of PUFAs, one-third of which are long-chain PUFAs with 4, 5 or 6 double bonds. The FFA profile is close to that of PL fatty acids and contains almost all the long-chain PUFAs initially esterified in PL of fresh meat, suggesting that hydrolysis of PL protect these long-chain PUFAs from oxidation (Gandemer, 2009).

On average, the fatty acid composition of lipids of dry-cured hams from white pigs includes 35–40% of SFA, 45–50% of MUFA and 10–15% of PUFAs (Table 1). Iberian hams present a higher proportion of MUFA (54–58%), and a lower percentage of SFA (30–35%) and PUFAs (8–12%), which is explained by the high proportion of oleic acid in the acorns eaten by the pigs during fattening (Isabel et al., 2003). However, Ruiz et al. (2000) reported that the high IMF content of Iberian hams positively influenced the ratio of oleic acid to PUFAs (TGA is rich in MUFA as compared with PL); other authors (Gandemer, 2009; Isabel et al., 2003) also reported a similar trend in white pigs in relation to differences in fatness. The most abundant saturated fatty acids in dry-cured hams are palmitic acid (25%), followed by stearic acid (12%) and myristic acid (1.5%) (Fernández et al., 2007). Some SFA (<18-carbon atoms chain length) raise blood total cholesterol and low-density lipoprotein (LDL) and the HDL/LDL ratio, which are associated with a high risk of cardiovascular disease (Mattson & Grundy, 1985). On the other hand, MUFA reduce the level of plasma LDL–cholesterol without depressing the strong antiatherogenic activity of HDL–cholesterol lipoproteins (Mattson & Grundy, 1985).

The proportion of PUFAs in lipids is consistently lower in dry-cured Iberian hams (6–8%) than in dry-cured hams from white pigs (12–15%) (Table 1). Nutritionists currently tend to focus more on the PUFAs:SFA balance and the n−6/n−3 PUFAs ratio rather than the absolute content or individual levels of fatty acids. PUFAs-rich diets reduce LDL–cholesterol levels in blood whereas SFA exert the opposite effects, and so a PUFAs:SFA ratio above 0.4 is recommended for healthy foods and diets (UK Department of Health, 1994). The PUFAs:SFA ratios in dry-cured hams range from 0.17 to 0.35, the highest levels occurring in hams from white pigs, such as Serrano or Parma hams (Table 1). However, a high proportion of PUFAs is not necessarily healthy in itself if there is not a balanced n−6/n−3 ratio; which should not exceed 4 (Simopoulos, 2002) or 6 (British Nutrition Foundation, 1992). Excessive amounts of n−6 PUFAs and very high n−6/n−3 PUFAs ratios promote pathogenesis of many kinds, including CVD, cancer and inflammatory and autoimmune diseases, whereas increased levels of n−3 PUFAs (and low n−6/n−3 PUFAs ratios) exert suppressive effects (Simopoulos, 2002). Dry-cured hams contain higher n−6/n−3 ratios than recommended; this runs close to actual Western diets, where the n−6/n−3 ratio ranges from 15 to 20 (Simopoulos, 2002). The n−6/n−3 ratio in dry-cured hams are generally near the upper limits of the recommended ratio (Table 1). Genetic and feeding strategies have proven to be effective in producing dry-cured hams with PUFAs:SFA and n−6/n−3 ratios characteristic of healthy fats (see Section 3.1.2). Dry-cured hams contribute significantly to recommended daily allowances (RDA) of n−3 long-chain PUFAs (19.2–21.2% in Iberian hams and 15.4–17.3% in white hams), whereas they contribute very little to total n−3 PUFAs (2–3%) (Fernández et al., 2007). These proportions are covered by the intake of 100 g of ham.

Cholesterol levels in dry-cured hams range around 70 mg/100 g in Serrano hams (Moreiras, Carbajal, Cabrera, & Cuadrado, 2006; MSC, 1995), and from 62 to 76 mg/100 g in Parma hams (Zanardi, Novelli, Ghiretti, & Chizzolini, 2000). Cholesterol contents are lower in fresh ham from Iberian pigs (41–42 mg/100 g), decreasing to 32–34 mg/100 g in the same samples after two years of ripening (dry-cured Iberian hams) (Petrón, García-Regueiro, Martín, Muriel, & Antequera, 2003). The consumption of 30 g of dry-cured ham contributes less than 8% of the maximum cholesterol intake goal (300 mg/day, WHO, 2003), and around 3% in the case of Iberian hams.

Unsaturated fatty acids and cholesterol may undergo oxidation during the processing of dry-cured hams and are among the main causes of flavour, colour and texture deterioration. Of oxidation products, those derived from cholesterol (COP) and hydroperoxides have received considerable attention due to their undesirable biological properties such as atherogenic, cytotoxic, mutagenic and carcinogenic effects (Ventanas et al., 2005). Petrón et al. (2003) were the first to report the presence of COPs in dry-cured Iberian hams, at levels consistent with those previously reported in other meat products like salami, bologna sausage, Coppa and Parma hams (Zanardi et al., 2000). Although dry-curing of hams involves numerous pro-oxidative factors, the COP content is below the recommended maximum level of 1 ppm; that is lower than reported for products containing egg, dairy products or cooked meats (Eder, Müller, Kluge, Hirsch, & Brandsch, 2005).

Peroxide values of ham generally show a continuous increase during the first months, reaching a peak (2–4 months) after the start of the process. In the latter stages of processing, the general oxidation level in muscle and adipose tissue tends to decrease causing the peroxide value to fall to below 20 mEq/kg (Antequera et al., 1992). Also, oxidation-derived volatile compounds like hexanal in Iberian hams and Parma hams increase during the initial and intermediate phases and decrease at the end of ripening (Hinrichsen & Pedersen, 1995; Ruiz et al., 1999).

2.2. Proteins, amino acids and peptides

Dry-cured ham is an excellent source of high-biological-value proteins because it contains essential amino acids in appropriate
ratios. These amino acids are very important in a diet of poor nutritional quality when the caloric intake is low, or for certain populations with specific needs like children, invalids and old people (Reig & Toldrá, 1998). The presence of animal proteins in the diet favours absorption of minerals like haem iron and trace elements. Protein content in dry-cured ham is about 30 g/100 g depending on the extent of drying and the fat content (Toldrá, 2002).

Dry-cured hams also contain a large proportion of free amino acids resulting from extensive proteolysis (Toldrá et al., 1997). This proteolysis is characteristic of all types of hams and the extent of amino acid release depends on the processing time. The responsible enzymes are aminopeptidases that act on the N-terminal of peptides and proteins (Toldrá, 2002, 2006a). Thus, large amounts of free amino acids are generated in hams at levels of hundreds of milligrams per 100 g (Toldrá, Aristoy, & Flores, 2000). The large increase of lysine, around 700 mg/100 g, indicates that the ham proteins are readily digestible (Toldrá & Aristoy, 1993). Furthermore, this amino acid may be susceptible to further Maillard reactions, racemization or cross-linking (Swaisgood & Catignani, 1991). Free amino acids can be absorbed through the intestinal mucosa and are largely bioavailable.

Some of the amino acids present in dry-cured ham may produce additional benefits for the nervous system (Gaul, 1990); examples include taurine, which is present at 80 mg/100 g, and glutamine which has relevance for metabolic processes and potential preventative effects for certain diseases (Neu, Shenoy, & Chakrabarti, 1996), although its content decreases to below 5 mg/100 g in the course of processing (Toldrá et al., 2000). Other amino acids have been associated with recovery from mental fatigue (tryptophan), physically exhausting activity (leucin, isoleucine, valine), etc. (Ventanas, 2006).

Dry-cured ham contains a variety of histidine-based dipeptides, with antioxidant activity, like carnosine and anserine. These dipeptides help control oxidation through the prevention of lipid oxidation by inactivating catalysts and/or free radicals in the cytosol (Decker & Crum, 1993). They also perform a buffering function in the muscle, especially the glycolytic muscles where they are present in larger amounts. Carnosine and anserine contents are greater in glycolytic-type muscles like M. semimembranosus, the outer muscle of the ham, where carnosine can reach 300 mg/100 g and anserine 18 mg/100 g, and are smaller in oxidative-type muscles where they do not reach 20 mg/100 g (Aristoy & Toldrá, 1998). The function they perform is to reduce rancid taste and improve colour stability (Chan & Decker, 1994). These dipeptides are also very resistant to the action of muscle proteases (proteolysis); they are highly stable and contents do not vary in the course of dry-curing (Toldrá, 2006b).

There have been recent reports of a large number of peptides resulting from the degradation of specific myofibrillar and sarcoplasmic proteins. Proteomic tools have been used to identify numerous long-chain peptides resulting from proteolysis of actin (Sentandreu et al., 2007), titin and myosin light chain (Mora, Sentandreu, Koistinen, et al., 2009) and creatin kinase (Mora, Sentandreu, Koistinen, et al., 2009). Research is currently in progress on the effect that these peptides may produce in dry-cured ham.

2.3. Micronutrients

Dry-cured ham contains an array of micronutrients, some in substantial amounts and readily bioavailable, with potential benefits for health and wellbeing.

2.3.1. Minerals

Dry-cured ham is a good source of iron and zinc, has considerable concentrations of phosphorus and potassium and significant amounts of other elements such as magnesium and selenium.

Dry-cured ham contains between 1.8 and 3.3 mg iron/100 g (Table 2). Because it is highly bioavailable, its relative contribution to dietary intake is considerable, and moreover it favours absorption of non-haem iron from other foods. Iron deficiency produces anaemia, which is one of the principal public health problems, affecting a quarter of the world’s population in both industrialized and developing countries. It occurs in all age-groups and particularly affects pregnant women and children (Benost, 2001). In Spain, dietary iron intake in 2006 did not exceed 80% of the recommended level for women aged 20–39 (MARM, 2008).

Dry-cured ham is an excellent source of Zn, with concentrations of around 2.2–3.0 mg/100 g (Table 2). Although also present in plant foods, zinc is less bioavailable there than in meat products; however, zinc bioavailability improves when vegetables are consumed along with animal proteins (Higgs, 2000). Zinc is an essential mineral in the diet; it is involved in the composition and activity of over 200 enzymes. Zinc deficiency affects morbidity, mortality, growth and development, pointing to a need to improve the quality of diets by increasing the consumption of foods containing it (Neumann, Harris, & Rogers, 2002), for example products like dry-cured ham. It was recently noted that recommended zinc intake levels are not being reached in the USA and the UK as a result of falling meat consumption among adolescents (Mulvihil, 2004). In Spain, the amount of zinc in the diet is barely 75% of the recommended intake (MARM, 2008).

Dry-cured ham is an intermediate food in terms of magnesium levels, which are between 17 and 24 mg/100 g (Table 2). Magnesium acts as a cofactor of various enzymatic and metabolic pathways, with major implications in neuromuscular activity. Its presence has been associated with the development of various disorders (cardiovascular disease, osteoporosis, diabetes, etc.) (Fleet & Cashman, 2003).

Pot contains approximately 10–14 μg of selenium per 100 g (Higgs, 2000; Mulvihil, 2004), while Iberian ham contains 29 μg/100 g (Table 2). Selenium is a relatively new object of interest and thanks to the part that it plays in antioxidant defence mechanisms, which afford considerable protection against cardiovascular diseases and cancer (Higgs, 2000). A recent study shows that selenium intake is declining in Europe, to below recommended levels in some cases (Biesalski, 2005).

A large percentage of the population has a hereditary predisposition to high blood pressure, whose incidence is aggravated by

<table>
<thead>
<tr>
<th>Micronutrients</th>
<th>Amount per 100 g</th>
<th>RDAa Percentage of RDA</th>
<th>Percentage of RDAc</th>
<th>Percentage of RDAc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca (mg)</td>
<td>12–35</td>
<td>800</td>
<td>1.5–4.4</td>
<td>0.4–1.3</td>
</tr>
<tr>
<td>Fe (mg)</td>
<td>1.8–3.3</td>
<td>14</td>
<td>13–23</td>
<td>3.9–6.9</td>
</tr>
<tr>
<td>Zn (mg)</td>
<td>2.2–3.0</td>
<td>10</td>
<td>22–30</td>
<td>6.6–9.0</td>
</tr>
<tr>
<td>Mg (mg)</td>
<td>17–18</td>
<td>375</td>
<td>4.5–4.8</td>
<td>1.3–1.4</td>
</tr>
<tr>
<td>K (mg)</td>
<td>153–160</td>
<td>2,000</td>
<td>7.6–8.0</td>
<td>2.3–2.4</td>
</tr>
<tr>
<td>P (mg)</td>
<td>157–180</td>
<td>700</td>
<td>22–26</td>
<td>6.7–7.7</td>
</tr>
<tr>
<td>Se (μg)</td>
<td>29</td>
<td>55</td>
<td>52</td>
<td>15.8</td>
</tr>
<tr>
<td>Na (mg)</td>
<td>1,100–1,800</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Thiamin (B1)  (mg)</td>
<td>0.57–0.84</td>
<td>1.1</td>
<td>51–76</td>
<td>15.5–22.9</td>
</tr>
<tr>
<td>Riboflavin (B2) (mg)</td>
<td>0.20–0.25</td>
<td>1.4</td>
<td>14–18</td>
<td>4.3–5.3</td>
</tr>
<tr>
<td>Niacin (Equiv.)</td>
<td>4.5–11.8</td>
<td>16</td>
<td>28–73</td>
<td>8.4–21.9</td>
</tr>
<tr>
<td>Vitamin B6 (mg)</td>
<td>0.22–0.42</td>
<td>1.4</td>
<td>16–30</td>
<td>4.8–9.0</td>
</tr>
<tr>
<td>Folic acid (μg)</td>
<td>Tr–13.40</td>
<td>200</td>
<td>6.7</td>
<td>2.0</td>
</tr>
<tr>
<td>Vitamin B12 (μg)</td>
<td>Tr–15.68</td>
<td>627</td>
<td>188</td>
<td>–</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>0.08–1.5</td>
<td>12</td>
<td>0.7–12</td>
<td>0.21–3.6</td>
</tr>
</tbody>
</table>


c Covered by the intake of 100 g of ham.

d Covered by the intake of 30 g of ham.
overweight and high sodium consumption. In dry-cured ham, current levels of salt, added in the curing process, produce sodium concentrations in excess of 1200 mg/100 g (Table 2) depending on a number of factors (e.g., concentrations are higher in white hams). Currently the daily sodium adult intake is approximately three times the recommended daily allowance and public health and regulatory authorities are recommending reducing dietary intake of sodium to 2.4 g/day (Desmond, 2006). WHO (2003) recommends a maximum value of 2000 mg/day as intake goal. This limits the suitability of dry-cured ham for consumption by those sectors of the population that suffer from high blood pressure (Morgan, Aubert, & Brunner, 2001), although the high concentration of potassium (Table 2) helps to maintain a more reasonable Na–K balance (Ventanas, 2006).

3.2. Vitamins

Dry-cured ham is an excellent source of the B group: thiamine (B₁), riboflavin (B₂), niacin, vitamin B₆ and vitamin B₁₂. It does not contain major amounts of vitamins A, C, D, E or K.

Dry-cured ham contains considerable quantities of thiamine and riboflavin (0.57–0.84 and 0.20–0.25 mg/100 g, respectively) (Table 2). Thiamine acts as a cofactor in various enzymatic reactions affecting appetite and the nervous system (Mulvihil, 2004). Dry-cured ham is also an excellent source of vitamin B₆ and niacin, which thanks to its origin (largely from tryptophan) is absorbed by the organism faster than the vitamin B₆ bound to the glucose in plant foods (Higgs, 2000). Iberian ham contains around 15 μg/100 g of vitamin B₁₂, which is much higher than the concentration in fresh meat and other meat products (Moreiras et al., 2006). This is of particular interest in that foods of animal origin are the only dietary source of vitamin B₁₂ (Higgs, 2000). This vitamin acts as a cofactor in various enzymatic reactions and plays a prominent role in the normal functioning of the central nervous system (Mulvihil, 2004).

Pork contains 5 μg/100 g of folates (Moreiras et al., 2006). Concentrations in dry-cured ham range from trace levels to 13.5 μg/100 g (Table 2). Folate deficiency has been associated with megaloblastic anaemia and defects in the neuronal tube. Folate presents the presence of cigarettes that contain a high proportion of vitamin K, which thanks to its origin (largely from tryptophan) is absorbed by the organism faster than the vitamin B₆ bound to the glucose in plant foods (Higgs, 2000). Iberian ham contains around 15 μg/100 g of vitamin B₁₂, which is much higher than the concentration in fresh meat and other meat products (Moreiras et al., 2006). This is of particular interest in that foods of animal origin are the only dietary source of vitamin B₁₂ (Higgs, 2000). This vitamin acts as a cofactor in various enzymatic reactions and plays a prominent role in the normal functioning of the central nervous system (Mulvihil, 2004).

3.3. Strategies for optimizing concentrations of meat component with potential health implications

The foregoing shows that while ham is a product with high protein content and moderate caloric value, presents a interesting lipid profile and is a good source of vitamins and minerals, there are still aspects of its composition that could be improved. There are various measures that can be taken in animal production and processing systems to augment or reduce the concentrations of certain compounds with health implications. Obviously any optimization must seek to achieve a healthier product without affecting quality.

3.1. Strategies based on production approaches

This option includes genetic selection in combination with management and feeding practices, which largely determine the most influential quality traits of the raw material like fat content and fatty acid composition.

3.1.1. Genetic strategies

Although lean and fat content are polygenically determined traits, a limited amount is known about the various genes that are involved, and especially about mutations that affect their distribution in meat (Carrion, Sosnicki, Klont, & Diestre, 2004, chap. I). One of the main goals for dry-cured ham production will be to find pig genes that serve to enhance the IMF content of meat pieces intended for curing, with moderate fattening of carcasses. In this respect, pig selection schemes have hitherto been based on morphological parameters of pure-bred Iberian or white sows, and crossing with Duroc or Duroc–Jersey sires. Duroc-based pork contains more IMF than European white breeds (Carrion et al., 2004, chap. I). However, numerous studies indicate that loin and ham muscles from Iberian pure-breed pigs contain significantly higher amounts of IMF, haem pigments and iron than those of crossed Iberian × Duroc pigs, and could be more suitable for the production of dry-cured products (Ventanas, Ruiz, et al., 2007).

The last few years have seen growing interest in the genotyping of pig populations intended for dry-cured ham production. The halotane gene, the RN gene and the MC4R gene have been shown to bear mutations relevant to meat quantity and quality (Garnier, Klont, & Plastow, 2003). More specifically, MC4R status has been shown to positively affect the level of subcutaneous and IMF in ham (Carrion et al., 2004, chap. I). Carrideeguas et al. (2005) and Burgos et al. (2006) have designed an RT-PCR assay to explore the possibilities of using IGF2 and MC4R as a selection marker to predict the fattening capacity of Iberian and Duroc intended for production of PDO dry-cured hams, with practical implications. Also, López-Buesa et al. (personal communication) propose to study the capacity of the PEPCK (phosphoenolpyruvate carboxykinase) gene for over-expression of IMF content in striated muscle of present vitamin E like γ-tocopherol. Although this compound is absorbed by the organism and is not converted to α-tocopherol, it plays an important role in the prevention of processes implicated in atherosclerosis (Jiang, Cristen, Shigenaga, & Ames, 2001) and in vascular endothelial dysfunction (Carr & Frei, 2000; Jiang et al., 2001). Dry-cured ham can therefore constitute a source of γ-tocopherol, a compound of particular interest for its role in the prevention of vascular disorders.

According to EU legislation (Directive 90/496/EEC, 2008), dry-cured ham can be considered a natural source of iron, zinc, phosphorus, selenium, thiamine, riboflavin, niacin and vitamins B6 and B12, since it contains significant amounts (>15% RDA in 100 g) of these micronutrients (Table 2).
mice to enhance the triglyceride content in muscle and reduce subcutaneous and abdominal fat. In addition, Rodríguez (2009) have reported the effects of the Leptin receptor gene (LEPR, implicated in the regulation of voluntary feed intake in mammals) on average daily growth, back fat thickness and IMF in Iberian × Duroc pigs.

Genetic strategies also present interesting opportunities to improve the fatty acid profile (increased n−3 content and reduced n−6/n−3 ratio) of pork and pork products (Lai et al., 2006).

3.1.2. Feeding and management strategies

Feeding and management practices aimed at achieving healthier meat products are used to produce smaller proportions of SFAs and larger proportions of MUFA or PUFA, better n−6/n−3 PUFA and PUFA/SFA ratios and higher antioxidant activity.

The fatty acid composition in pig tissues depends on the proportion of fatty acids supplied by the feed (direct deposition) and those produced endogenously ("de novo" synthesis); the amount of fatty acids supplied by the feed (direct deposition) and those produced endogenously ("de novo" synthesis); the amount of energy that is consumed in relation to requirements (López-Bote, 2000). Consequently, because of the traditional system whereby Iberian pigs are reared on freely available acorn (López-Bote, 2000). Consequently, because of the traditional system whereby Iberian pigs are reared on freely available acorn and grass, Iberian hams contain a higher proportion of MUFA (55.8−57.4%) than Serrano or Teruel hams (46.9−48.7%) and significant amounts of long-chain PUFA (Fernández et al., 2007). This is a result of the high fat content (>6%) and high proportion (>60%) of oleic acid in acorns and the high proportion of linoleic acid in grass. Such a successful approach in terms of nutritional and sensory quality has also been employed to produce hams from Iberian pigs fed in confinement with a mixed diet containing high-oleic sunflower oil and α-tocopherol. This significantly increases the levels of oleic acid and antioxidants with respect to Iberian hams from non-supplemented control animals and improves some sensory attributes (appearance, texture and odour) and overall organoleptic quality (Ventanas, Ventanas, et al., 2007). Also, Isabel et al. (2003) reported positive effects of feeding with MUFA-enriched diets on levels of oleic acid in muscles and dry-cured hams from white genotypes. High-oleic supplementation at 6% in concentrate feed could make for softer fat, causing technological problems for the production of white-pig hams like Serrano or Parma, and so the amount added must be restricted to 2% (Bosi et al., 2000). Consumers very much appreciate soft, oily fat on Iberian hams, whereas in white hams these attributes could compromise consumer acceptability since they are associated with poor quality and excessive rancidity (Ruiz & López-Bote, 2004, chap. II). Recently, Martín, Antequera, Muriel, Pérez-Palacios, and Ruiz (2008) tried using combinations of MUFA and three levels of conjugated linoleic acid (CLA) in white pigs to produce CLA- and MUFA-enriched meat products. CLA supplementation makes for better oxidative stability, and a CLA-enriched product can be achieved without loss of quality. A combination of dietary CLA and a high-MUFA diet can thus offset the reported increase in the ratio of saturated to unsaturated fatty acids caused by dietary CLA. The effect of dietary supplementation with CLA has been studied in dry-cured hams (Parma) from heavy pigs (Corino, Magni, Pastorelli, Rossi, & Mourot, 2003).

Although changes in MUFA content present health benefits, they do not affect n−6/n−3 ratios, which are generally >10 (Table 1). These can be improved by using feeds enriched with polyunsaturated fats, especially of the n−3 family and preferably long-chain. PUFA-rich sources like linseed or marine meals and oils (Santos et al., 2008; Sárraga et al., 2007). This raises levels of linolenic acid and/or EPA and DHA, thus reducing n−6/n−3 ratios in dry-cured hams.

In order to prevent cholesterol oxidation and excessive lipid oxidation, several researchers have suggested increasing α-tocopherol content and preventing an excess of polyunsaturated acids in phospholipids, which are considerably affected by the feeding period prior to slaughter (Cava, et al., 1999; Daza et al., 2005; Isabel et al., 2009; Ventanas, Ventanas, et al., 2007).

3.2. Processing strategies

There are several strategies that can be followed during processing to improve the nutritional content and safety of dry-cured ham.

3.2.1. Salt reduction

Health authorities are associating high levels of sodium chloride (NaCl) intake with raised blood pressure, also known as hypertension, and that explains the current tendency to reduce sodium intake (He & MacGregor, 2003). Naturally, consumers are demanding a variety of low-salt meat products. Salt reduction is not so easy to achieve in dry-cured ham because salt has major advantages for ham such as good microbial stability through the reduction of water activity, a pleasant salty taste and partial solubilization and cohesiveness of myofibrillar proteins. Sodium chloride must therefore be reduced without altering the curing process since it is an important inhibitor of most muscle proteases (Armenteros, Aristoy, & Toldrá, 2008). For instance, a reduction in the total amount of salt has been found to cause excessive proteolysis and considerable softening due to the intense action of muscle endopeptidase enzymes (Virgili, Prolari, Schivazzappa, Soresi, & Borri, 1995). Furthermore, hams cured with 6% salt have been found to be significantly drier, harder and more fibrous than hams cured with 3% salt, which (3% salt) moreover have a better salty taste (Andrés, Cava, Ventanas, Thovar, & Ruiz, 2004). There are therefore numerous strategies for partial replacement of NaCl by other salts like KCl, CaCl2 and MgCl2, but these may entail changes in processing techniques because of their different diffusion rates. Potassium lactate has also been used recently as an alternative salt for restructured hams (Fulladosa, Serra, Gou, & Arnau, 2009). In addition, alternative salts must not exceed certain levels because they can affect the sensory quality; for instance, an excess of KCl imparts a noticeable bitterness and astrigency to the ham. In a recent study, differences in perceived quality between dry-cured loins with 50% substitution of NaCl by KCl and controls with 100% NaCl were found to be non-significant (Armenteros, Aristoy, Barat, & Toldrá, 2009).

3.2.2. Generation of bioactive peptides

Several bioactive peptides (antihypertensive, antioxidant or prebiotic peptides) derived from meat proteins have been found in postmortem meat (Arhiara & Ohata, 2008). Some may also be generated during processing of dry-cured ham and remain in the final product. Some of the most important bioactive peptides are the angiotensin I-converting enzyme (ACE) inhibitory peptides. ACE plays an important role in the regulation of blood pressure, since ACE converts an inactive angiotensin I to angiotensin II which is a potent vasoconstrictor and hence can cause arterial contraction and increased blood pressure. ACE inhibitory activities have been reported in extracts of dry-cured ham (Arhiara & Ohata, 2008). Furthermore, several small peptides have been identified in dry-cured ham (Sentandreu et al., 2003); their origin was attributed to the action of muscle dipeptidylpeptidases, enzymes that are quite active and stable during the curing process (Sentandreu & Toldrá, 2001). Some of these dipeptides (Arg-Ser, Gly-Phe, Arg-Phe and Met-Ala) have been found to inhibit over 50% of ACE activity, and Val-Tyr in particular inhibited more than 90% of such enzyme activity (Sentandreu & Toldrá, 2007a). Dipeptidylpeptidases II and IV have been identified as the enzymes chiefly responsible for the generation of bioactive peptides with stronger ACE inhibitory action (Sentandreu & Toldrá, 2007b). One promising strategy would consist in the
stimulation of the activity of both dipeptidylpeptidases to enhance the generation of such dipeptides and obtain larger amounts in the final ham.

Also, some bioactive peptides that produce improvements in immunological responses or satiety effects may be generated as a result of the intense proteolysis (Ventanas, 2006).

3.2.3. Reduction of nitrates and nitrites: nitrosamine prevention

There is a general tendency to use less nitrates and nitrites in meat products. In the particular case of dry-cured ham, nitrates are added as a reservoir for slow generation of nitrates that have a powerful preservative effect, especially at pH 6.0. This is the typical pH in dry-cured ham and hence nitrate addition is an excellent way to enable nitrates to penetrate to the inner parts of the ham where the risks are greatest (Toldrá, 2004). One drawback to the use of nitrates or nitrites is that they generate N-nitrosamines, potent carcinogens whose formation it is essential to prevent. In any case, nitrosamine formation requires the presence of secondary amines and NO\(^{-}\), whereas at pH 6.0, the level of nitrous acid would be less than 1% of the nitrates present inside the ham (Toldrá, Aristoy, & Flores, 2009). In fact reported levels of nitrosamines in dry-cured hams are very low (Demeyer et al., 2000). A key step for further prevention of nitrosamine formation is to reduce residual nitrite levels in the product by reducing the amount of initially-added nitrate and/or adding ascorbic acid to assure the conversion of nitrite into nitric oxide and achieving better control of the processing stages (Toldrá, 2002).

4. Dry-cured ham in dietary intervention studies

In response to growing interest in the influence of nutrition on the prevention of chronic diseases, researchers are seeking scientific evidence to support the association of alimentary and nutritional factors with various pathologies such as cardiovascular disorders, high blood pressure, various types of cancer, diabetes, obesity or osteoporosis. Some studies have shown that including dry-cured ham (especially acorn-fed Iberian ham) in the diet of older adults has beneficial effects on some atherogenic risk factors such as lipid profile, blood pressure and lipid peroxidation.

In clinical studies in which Iberian ham was habitually included in the diet of elderly persons, García Rebollo et al. (1998) found a significant decrease in plasma total cholesterol, triglycerides and LDL-cholesterol. Mayoral et al. (2003) concluded that including acorn-fed Iberian ham in the diet increased the concentrations of antioxidant substances and reduced lipid peroxidation, with consequent beneficial effects on atherogenic risk factors; likewise causing a decrease in blood pressure. Martínez-Gonzalez (2009) recently analysed the incidence of cardiovascular disease (coronary heart disease or stroke), hypertension and weight gain after a maximum follow-up of 6 years (mean: 4.9 years) among 13,293 initially healthy participants. The prospective and dynamic epidemiologic cohort was composed exclusively of Spanish university graduates, patterned after the models of the large multipurpose cohorts conducted at Harvard University (Nurses Health Study, Health Professionals Follow-up Study). The results of this cohort show no evidence of any association between the consumption of dry-cured ham and a high risk of cardiovascular disease, hypertension or weight gain.

5. Conclusions

Dry-cured ham is especially appreciated for its sensory characteristics; it has a well-balanced nutritional profile and is suitable, in appropriate amounts, for consumption (even 2–3 times per week in healthy individuals) as part of a balanced diet. While some epidemiological and human intervention studies indicate that eating ham can produce beneficial effects with regard to cardiovascular disorders, more scientific evidence is needed in order to assess the function that ham can perform in relation to health. The major objections in this respect arise from aspects associated with the quality of the fat and the presence of sodium. Ham contains large quantities of monounsaturated and polyunsaturated fatty acids, but because the proportion of \(n-6\) PUFA is relatively high, the \(n-6\)/\(n-3\) ratio is higher than recommended. Also, although much work has been done, it would be a good to encourage initiatives aimed at reducing sodium contents as far as is technologically viable. The sodium level is a factor that limits possible nutrition or health claims (EC, 2009).

Strategies based on animal production and processing systems make it possible to augment the concentrations of beneficial components and/or reduce the concentrations of those that have negative effects on health. Obviously any optimization has to achieve a healthier product without affecting quality, particularly hedonic aspects.

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References


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