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Review

Quality of meat and meat products produced from southern European pig breeds

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ABSTRACT

Genetic and environmental effects on the quality of meat from southern European pig breeds are discussed. In the literature, it is evident that the breeds native to southern Europe have an interesting quality of products with respect to improved pigs. The free-range system increases the value of animal products due to the influence of outdoor rearing on the chemical, physical and organoleptic characteristics of the product. Traditional food products of high quality, such as those obtained from animals reared outdoor, are in high demand. The studies carried out on native pig breeds in southern Europe have focused on various aspects, ranging from studies of population genetics aimed at averting the danger of extinction and reducing inbreeding to studies of the factors affecting the quality of products. The purpose of this review is to analyse the literature on pig breeds native to southern Europe, with particular reference to the effects of genetics and breeding systems on the quality of products.

Contents

1. Introduction

The importance of biodiversity and the recovery of endangered germplasm have been emphasised for a long time, but it wasn't until the 1992 Convention of Rio de Janeiro that experts indicated that the conservation of biological diversity is “a common concern of humankind” and an integral part of the development process at the global level. Strong economic, cultural and scientific motivations are the basis for the recovery of genetic resources.

In the early decades of the last century, there was a wide variety of native pig breeds in southern Europe. The post-war transformations in the agricultural system, the intensification and industrialisation of pig farming, the modification of land use and the massive utilisation of higher-producing breeds caused native breeds to decline in importance. Most of the breeds native to southern Europe come from small populations and require collective management both for maintenance of the breed and to avoid inbreeding. This is a major issue for the future because most of the native breeds are not presently managed in a secure way. For these reasons, southern European countries spend heavily to support this sector of the agricultural economy.

In some European countries, the typical products from native pigs are a good example of the strong cooperation between public institutions, producers and scientists. Thanks to this synergy, products made from native pigs are well known throughout Europe.

2. The main breeds of native pig in southern European countries

Table 1 lists some native breeds reported by the United Nations' Food and Agriculture Organization (FAO) in the Domestic Animal

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Table 1
Local breeds of some Southern Europe countries listed by FAO.
Modified from http://dad.fao.org/.

France	Italy	Spain	Portugal	Greece	Slovenia	Croatia
Bayeux	Apulo-Calabrese	Celta	Alentejana	Greek	Krskopolje	Black Slavonian
Blanc de l'Ouest	Bergamasca nera	Chato Murciano	Bisaro			Turopolje
Carélie	Casertana	Gochu Asturcelta				
Corse	Cinta Senese	Ibérico				
Creole	Macchiaiola Maremmana	Ibérico (Dorado Gaditano)				
Gallia	Mora Romagnola	Ibérico (Mamellado)				
Gasconne	Napoletana Fulva	Ibérico (Negro Entrepelado)				
Pie Noir du Pays Basque	Nero dei Lepini	Ibérico (Negro Lampiño)				
Porc de Saint Yriex	Nero dei Monti Dauni Meridionali	Iberico (Retinto)				
	Nero Reatino	Ibérico (Torbiscal)				
	Nero Siciliano	Manchada de Jabugo				
	Parmigiana Nera	Negra Canaria				
	Pugliese	Negra Mallorquina				
	Sarda					
	Siciliano					
	Suino dei Nebrodi e Madonie					

Diversity Information System (http://dad.fao.org/). According to the FAO database, the breeds listed in the table exist currently, but many are actually extinct or nearly so. Moreover, in each of these countries, only some of the extant breeds have a real chance of survival, primarily related to producing products with high added value.

In Spain, although several native breeds are reared at present, the Ibérico, that is the Spanish generic name for Iberian breeds, is certainly the most famous, and it can be considered the best example of the strong cooperation between public institutions, producers and scientists. Thanks to this synergy, Iberian pig products are renowned throughout Europe. According to Lopez-Bote (1998), over time, and particularly from the 1950s to 1970, a number of factors linked to urban development and the intensification of animal production diminished the consistency of Iberian pigs. In recent years, demand for Iberian pig products has increased, which is attributed to a revaluation of traditional, top-quality products.

In Portugal, according to the FAO database, two native pig breeds – Bisara and Alentejano, are reared, but actually, Malhado de Alcobaca are more commonly reared (Vicente, Pereira, Carolino, & Gama, 2006). In recent years, there has been an expansion of pigs native to Portugal, with many changes in production, processing and marketing taking place (Matos, 2000).

In France, the main native breeds are: Blanc de l'Ouest, Limousin, Porc Gascon, Bayeaux, Porc Basque and Nustrale (former Porc Corse). The conservation of these breeds is intended, as in other European countries, to maintain genetic variation within breeds and to obtain economic advantages through the production of high-quality products (Labroue et al., 2000). In fact, the management and recovery of native breeds in France is done primarily to obtain Protected Designations of Origin (PDO) (Lambert-Derkimba, Verrier, & Casabianca, 2011).

In Italy, of the several native pigs listed by the FAO, only six – Apulo-Calabrese, Casertana, Cinta Senese, Mora Romagnola, Nero Siciliano and Sarda – survived the transformations in agriculture that happened in the last century. These breeds have been recognised in the Pedigree Register. The other native populations included in the FAO database have no official recognition (some of them are actually the same breed) and a very high number of populations are declared extinct (Bittante, 2011). The recovery of genetic variability represents an advantage for breeders; they can offer to consumers products with high added value due to the quality of the meat and cured meat products of native breeds. Moreover Italian consumers have an increasing interest in "niche products" (Franci & Pugliese, 2004).

The Greek pig is a domestic breed that looks like a wild boar, and it survives in the northern areas of Greece. The rearing of this breed is now expanding; during the 1980s, strong competition from "improved" genotypes and crossbreeding with the wild boar nearly caused the breed to become extinct. Greek pigs are generally reared outdoors and grazed in oak forests (Bonanzinga et al., 2010).

In Slovenia, only one native breed is recognised. The Krskopolje, or "blackbelted", originated in Dolenjska, in the south-eastern portion of the country. In 1992, when the herdbook was re-established, there were fewer than 30 sows and only 3 boars. The population today consists of 150 registered sows and 30 boars (Malovrh, Planinc, & Kovač, 2010). The breed shows good adaptability to poor feeding and environmental conditions. The Krskopolje breed has average fertility, a good appetite and a high growth rate. The breed is known for high-quality meat and cured-meat products (Planinc, Malovrh, & Kovač, 2010).

In Croatia, the main native breed is the Black Slavonian, which was created in the second half of the 19th century. Until the 1950s, it was the most widespread breed in Slavonia, a region in eastern Croatia, and it was used mainly for the production of fat and meat products. Recently, the population was drastically reduced, and in the 1990s, the survival of the breed was endangered. Due to current protection measures, the effective population increased; in 2006, there were 46 boars and 604 sows. The breed is well adapted for outdoor keeping (Karolyi, Luković, & Salajpal, 2007).

In recent years, the productive performances of southern European native breeds have been investigated by several authors who have taken into account many factors. In this review, the effects of genotype and rearing system will be discussed, as they are the main factors that affect the quality of products from native breeds.

3. The quality of meat and fat

3.1. The genetic effect

A recent review (Bonneau & Lebret, 2010) regarding the influence of production systems on the quality of pork, identified 84 pork production systems in 23 European countries, of which 40 were considered "conventional", and the remaining 44 were regarded as "differentiated", on the basis of several claims. In one third of the "differentiated" production systems, native breeds were used and, most often, their meat was found to be of higher quality than the meat of conventional "improved" genotypes.

The term "improved" generally refers to the cosmopolitan pig breeds that have undergone genetic improvements aimed at enhancing their productive performance, according to industrial criteria. Some scientific studies have compared native pigs with "improved" ones, so it is possible to verify the actual gap between the two genetic types and to evaluate the effects of genetic improvement in swine during the last half century. Other trials have compared the native breeds to one another (Barone, Castellano, Colatruglio, Zullo, & Matassino, 2007; Fortina et al., 2005; Labroue et al., 2000; Porcu et al., 2007; Zullo et al., 2007).

A comparative review of trials is difficult and should be interpreted with caution, because the studies were carried out under different conditions, particularly when animals were reared outdoors. However, an overview of the principal characteristics of these breeds and the differences between them can be useful.

Table 2 gives the halothane gene frequencies of several native breeds. The halothane gene is a recessive gene that affects an animal's susceptibility to stress. This stress-syndrome is due to a mutation in the gene controlling the calcium release channel (Ryanodine receptor, RYRl) of the sarcoplasmic reticulum. This gene causes a higher incidence of pale, soft, and exudative (PSE) meat (Zhang, Kuhler, & Rempels, 1992).

Generally, the southern European pig breeds seem not to have the halothane gene, as reported by Matassino et al. (2000) in Calabrese, Casertana and Nero Siciliano pigs and by Ramos et al. (2000) in Manchado de Jabugo breeds. However, in the Nero Siciliano (Russo et al., 2004) and Cinta Senese breeds (Crovetti, Bozzi, Nardi, Franci, & Fontanesi, 2007), a very low frequency (0.01% and 0.02%, respectively) of T alleles at the RYR1 locus was found; the frequency was also very low (0.07) in the Portuguese breeds (Pinheiro et al., 2007). In French native breeds, a large variation in frequency (from 0 to 44%) of the same halothane-sensitive allele was found by Labroue et al. (2001). This investigation indicates the possibility of some introgression of this gene from the commercial breeds (Landrace or Pietrain) into several native breeds and suggests the importance of recovering the primitive germplasm and of monitoring the native populations to avoid indiscriminate crossbreeding that happened during a period of severe size reduction.

Among the qualitative traits of meat, evaluating intramuscular fat content (IMF) seems to be the best way to separate native pigs from "improved" ones (Table 3). Cinta Senese (Franci et al., 2005) and Nero Siciliano breeds (Pugliese et al., 2004) had IMF higher than 3% in the *Longissimus*, a muscle with moderate fatness; the corresponding value in Large White pigs was less than 1% (Franci et al., 2005). In Casertana meat, IMF content was nearly 4% (Zullo, Barone, Colatruglio, Girolami, & Matassino, 2003). Labroue et al. (2000) found significantly higher levels of IMF in Basque, Gascon, Limousin and Blanc de l'Ouest pigs than in Large White pigs. It is well known that in some muscles of native breeds, the IMF can reach 10%, as found in Iberian (Mayoral et al., 1999), Chato Murchano (Poto, Galián, & Peinado, 2007) and Corsican pigs (Coutron-Gambotti, Gandemer, & Casabianca, 1998) reared outdoors. Fernàndez, Garcìa-Gasco, De Pedro, Siliò, and Rodriguez (2007), analysing 2664 samples of *Longissimus dorsi* muscle from Iberian pigs, found that IMF values ranged from 3.27% to 29.21%. Considering that the organoleptic traits of raw meat are linked to IMF and that 2–2.5% IMF is believed to be the minimum acceptable level (Affentranger, Gerwig, Seewer, Schwiirer, & Kiinzi, 1996), it is evident that genetic improvement to produce leaner meat in swine reduces the meat quality.

According to Gandemer (2002), IMF affects several quality traits of dry-cured hams, especially of slices. In particular, the colour and tenderness are related to IMF: redness, brightness scores and the shear force of hams decrease as IMF increases. Moreover, hams produced from genotypes with high levels of IMF have more intense fat aroma, because intramuscular triacylglycerols are a good solvent for most aromatic compounds. The higher the intramuscular triacylglycerol content of muscle, the more the aromatic compounds will be trapped in the ham.

The effect of genetic type on product quality was studied by comparing the native breeds with the "improved" ones as well as by comparing the former against their crosses with pure breeds.

As for the fatty acid composition of lipids (Table 4) the comparison between native and improved breeds, or their crosses, is reported. The comparison of trials is difficult because of the variability of depots and localisations analysed in the respective studies. Taking into account those studies where the comparisons between native and

Table 2
Halothane gene frequency.

Author	Breeds	Halothane gene (frequency)
Matassino et al. (2000)	Casertana	Free
	Nero Siciliano	Free
	Apulo Calabrese	Free
Ramos et al. (2000)	Manchado de Jabugo	Free
Labroue et al. (2001)	Basque	Free
	Bayeux	0.44
	Gascon	0.01
	Limousine	0.05
	Blanc de l'Ouest	0.34
Russo et al. (2004)	Nero Siciliano	0.01
Crovetti et al. (2007)	Cinta Senese	0.02
Pinheiro et al. (2007)	Bisaro	0.07

Table 3
Intramuscular fat (IMF) content according to genetic type.

Author	Breeds	IMF (% on w.b.[a])
Mayoral et al. (1999) on *Longissimus lumborum* (LL) and *Biceps femoris* (BF)	Ibérico	~10
Labroue et al. (2000) (on LL)	Basque	3.9
	Gascon	3.2
	Limousine	3.4
	Blanc de l'Ouest	2.9
Karolyi et al. (2007)	Black Slavonian	~6
Zullo et al. (2003) (means of several muscles)	Casertana	~4
Salvatori et al. (2008) on LL	Casertana	~2
Fortina et al. (2005) on *Longissimus Thoracis* (LT)	Casertana	~5
Poto et al. (2007) on LL	Chato Murciano	~10
Franci et al. (2005) on LL	Cinta Senese	>3
Coutron-Gambotti et al. (1998)	Corsican (on BF)	8.2
Fernández et al. (2007) on LL	Ibérico	~10 (minimum 3.27–maximum 29.21)
Fortina et al. (2005) on LT	Mora Romagnola	~6
Pugliese et al. (2004) on LT	Nero Siciliano	>3

[a] w.b. = weight basis.

Table 4
Fatty acid composition according to genetic type (% of the total fatty acids).

Author	Breed	SFA	MUFA	PUFA
Comparison among pure breeds				
Labroue et al. (2000), on fresh subcutaneous fat	Basque	43.1a	45.2a	11.7a
	Gascon	46.6b	43.5b	9.9b
	Limousine	46.3b	43.9b	9.9b
	Blanc de l'Oueste	41.3b	46.8a	12.0a
	Large White	41.7c	42.4c	16.0c
Franci et al. (2005), on fresh subcutaneous fat	Cinta Senese	36.2a	50.3a*	10.4a
	Large White	37.6b	48.5b*	11.1b
Madonia et al. (2007), on salami	Nero Siciliano	33.39a	53.29a	13.33a
	Large White	37.71b	47.42b	14.87b
Comparison between pure and cross breeds				
Carrapiso et al. (2003), on fresh subcutaneous fat	Ibérico	36.91	49.78*	7.72**
	Ibérico × Duroc	38.21	48.87*	7.89**
Salvatori et al. (2008), on fresh subcutaneous fat	Casertana	39.60	41.31a	17.84a
	Casertana × LW	39.72	38.41b	21.12b
Coutron Gambotti et al. (1998), on fresh BF	Corsican	36.9a	57.4a	5.6
	Corsican × LW	39.6b	54.4b	6.0
Elias et al. (2000), on dry-cured subcutaneous fat	Alentejano	43.2	47.7*	5.1**
	Alentejano × (LW × D)	43.7	46.3*	5.7**

On the same column, within each trial, means with different letters differ significantly.
*Only oleic acid.
**Only linoleic acid.

“improved” breeds (or their crosses) were carried out under the same rearing conditions, it is possible to conclude that both French (Coutron-Gambotti et al., 1998; Labroue et al., 2000) and Italian (Franci et al., 2005; Madonia et al., 2007; Salvatori et al., 2008) native pigs show a high predisposition to depot of MUFA, mainly oleic acid, whereas “improved” pigs contain higher quantities of saturated fatty acids or, in the case of extreme leanness, of linoleic acid. The highest level of monounsaturated fatty acid in native breeds could be a consequence of differences in *de novo* lipid synthesis and turnover. Moreover, their capacity to deposit monounsaturated fatty acids increases with age (Edwards, 2005).

These differences are attenuated when the comparison is between native breeds and crossbreeds, as demonstrated by Elias, Sanabria, and Tirapicos-Nunes (2000) and Carrapiso, Bonilla, and Garcìa (2003) on Alentejano and Iberian pigs, respectively.

The practice of crossbreeding is widely used in several regions. According to Bonneau and Lebret (2010), the eating quality of crossbreeds is usually between that of the parent breeds and higher than that of conventional pigs. In southern Europe, local breeds are often crossed with selected breeds to exploit additive and non-additive genetic variances, as in the production of Corsican × Large White (Coutron-Gambotti et al., 1998) and Iberian × Duroc (Carrapiso et al., 2003) pigs.

Crossing with the Duroc breed is often used to improve the productivity of the animals without greatly affecting their hardiness or reducing their level of IMF. This is particularly important for processed products, such as dry hams, where marbling is a recognised criterion of quality (Edwards, 2005).

In the production of Iberian dry-cured ham, the rule of the Protected Designation Origin (PDO) allowed, until now, crossbreeding between Iberian and Duroc breeds. As reported by Carrapiso et al. (2003), the pigs crossbred from Iberian and Duroc pigs are usually used to improve some productive characteristics, and Iberian pigs with up to 50% Duroc genes can currently be used in the production of Iberian hams with PDO.

The Duroc breed, therefore, could play a key role in all types of outdoor rearing systems, where the organoleptic benefits conferred by its genetic predisposition to deposit IMF are widely recognised and valued (Edwards, 2005).

In other situations, the crossbreeding of native breeds, such as Cinta Senese pigs, with conventional ones is not permitted by the PDO rule.

Some comparative studies were also conducted on the sensory traits of dry-cured products to evaluate the differences between several native Italian breeds (Zullo et al., 2007) and between French and Spanish pigs (Lebecque, Giraud, Amblard, Lucan, & Poma, 2007). Labroue et al. (2000), in a comparison between native French breeds and Large White pigs, found the best sensory traits in the meat of native pigs; they justify this result with reference to the IMF levels in native pigs. Girard, Bout, and Salort (1988) stressed the positive relationship between meat flavour and intramuscular fat percentage. It must be underlined that these comparisons between breeds were not always carried out under the same rearing conditions.

3.2. Environmental effects: the importance of the rearing system

The environmental effects on the quality of products from native breeds should be broadly considered. Due to the rearing systems that characterise the native breeds (almost always outdoors), the environmental effects on product quality are the combined result of both the farming system and the feeding regimen.

Southern European pig breeds are reared with different modalities that range from systems that, even if outdoors, supplement the total food supply with concentrate, to more extensive systems where the fattening phase is carried out using only the resources of the natural environment. The latter is typical of the “Montanera” system, where Iberian pigs are fattened in the “Dehesa” (Lopez-Bote, 1998) and the native Portuguese pigs in the “Montados” (Tirapicos-Nunes, 2007).

3.2.1. Effects on physical parameters

As discussed by Jonsäll, Joansson, and Ludström (2001), the effects of rearing systems on the physical parameters of meat from “improved” pigs are contradictory. Even in studies of native breeds, reported data are not always consistent. The higher value of shear force recorded in Cinta Senese pigs reared outdoors (Pugliese et al., 2005) was probably due to their older age at slaughter rather than to the rearing system; this hypothesis is confirmed by the fact that no differences in meat tenderness were found between Nero Siciliano pigs reared outdoors and those reared indoors that were slaughtered at the same age (Pugliese et al., 2004). The older age at slaughter of Cinta Senese pigs reared outdoors may also be the reason for their higher values of CIELab a^* and, consequently, of chroma, with respect to pigs reared indoors. In fact, as reported by Mayoral et al. (1999), myoglobin concentration in pig muscle increases with ageing. Very few differences were found by Lopez-Bote et al. (2008) in drip loss, heme pigment concentration, CIELab colour or rheological properties in *Psoas major* muscle between sedentary and free-range Iberian pigs; they suggest that the intensity of the exercise is not high enough to affect fresh meat quality characteristics.

The effects of the rearing system on physical parameters have been studied with Magnetic Resonance Imaging (MRI). Pérez-Palacios et al. (2010) studied the MRI-based texture characteristics of dry cured Iberian hams from pigs fed different diets (acorn plus grass *versus* high oleic acid concentrate), and it seems that ham identification from Iberian pigs fed different diets could be achieved by this analysis.

3.2.2. Effects on lipids

As previously indicated, the outdoor rearing of native pigs is carried out almost entirely in forests, so it is very different from the classic outdoor system used for “improved” pigs, where commercial feed is the basis of the diet. Consequently, the effects of food source, especially on the quality of lipids, are very strong (Tables 5 and 6).

Lipids of adipose tissues largely vary both quantitatively and qualitatively according to the rearing system (Gandemer, 2002); moreover adipose tissue reflects the diet much better than other tissues that are subject to a more strict control.

As reported by various authors (Andrés et al., 2001; Cava, Ruiz, Ventanas, & Antequera, 1999a; Cava, Ventanas, Tejeda, Ruiz, & Antequera, 2000; Coutron-Gambotti et al., 1998; Diaz, Garcia Regueiro, Casillas, & De Pedro, 1996), the lipids of pigs reared in woods are characterised by a high level of unsaturated fatty acids (Table 5). Coutron-Gambotti et al. (1998) found a higher percentage of PUFA and MUFA fatty acids in Corsican pigs fed chestnuts than those fed a commercial diet. In Iberian pigs fed acorns, higher MUFA (primarily oleic acid) and lower SFA levels (primarily palmitic and stearic acids), were found both in intramuscular fat (Andrés et al., 2001; Cava et al., 1999a, 2000) and back-fat (Dìaz et al., 1996). This result is consistent with the data on Italian breeds, such as Nero Siciliano (Chiofalo, Lo Presti, Piccolo, & Arena, 2007) and Cinta Senese (Pugliese et al., 2005). The latter, in addition, showed higher PUFA levels when reared outdoors, probably because of the consumption of chestnuts and acorns during fattening. The same results were found by Sirtori, Pugliese, Parenti, D'Adorante, and Franci (2011) in Cinta Senese after substituting concentrate for chestnut. It is well known that chestnuts have higher concentrations of polyunsaturated fatty acids than acorns (Coutron-Gambotti et al., 1998; Lopez-Bote, 1998).

Another source of PUFA in free-range conditions is the grass that, as reported by Muriel, Ruiz, Ventanas, and Antequera (2002), is characterised by high levels of linoleic acid. These authors concluded that free-range rearing leads to increased levels of total n-3 PUFA in

Table 5
Effect of rearing system on the fatty acid composition of fresh meat and fat (% of the total fatty acids).

Author	Rearing system	C18:1	C18:2	C18:3
Diaz et al. (1996) on subcutaneous fat of Ibérico	Acorn + grass	57.1a	9.4a	
	Concentrate	47.4b	8.3b	
Pugliese et al. (2005) on subcutaneous fat Cinta Senese	Pasture on wood (chestnut + acorn + grass)	52.8a	11.6a	0.87a
	Concentrate	50.3b	9.5b	0.32b
Coutron-Gambotti et al. (1998) on subcutaneous fat of Corsican	Chestnut only	49.1	7.3a	0.9a
	concentrate	47.5	5.2b	0.6b
Sirtori et al. (2011) on subcutaneous fat of Cinta Senese	Chestnut only	28.1a*	6.5a*	0.41a*
	concentrate	25.5b*	5.5b*	0.24b*
Zumbo, Lo Presti, et al. (2007) on LL of Nero Siciliano	Acorn only	50.5a	4.7a	0.23a
	Barley	43.9b	7.1b	0.90b
Andrés et al. (2001) on BF of Ibérico	Acorn + grass	53.4a	5.6	0.3
	Concentrate	50.7b	6.4	0.3
Cava et al. (2000a) on BF of Ibérico	Acorn + grass	55.1a	5.66	0.68
	Concentrate	51.9b	5.02	0.64

On the same column, means with different letters differ significantly.
* Fatty acid composition as g/100 of DM.

neutral and polar lipids and of individual n-3 PUFA, including EPA and DHA. The effect of outdoor pasture on acorns is not the same as the administration of acorn in a confined rearing system. Zumbo, Lo Presti et al. (2007) found higher levels of MUFA and lower levels of PUFA in the *Longissimus lumborum* of Nero Siciliano pigs fed acorns, than those fed barley (Table 6). In this trial the acorn was administrated and not pastured so the lower content of PUFA in pig fed acorn was due to the lower content of PUFA in this fruit with respect to barley.

Both α- and γ-tocopherol are provided by the free-range system and prevent lipid oxidation. Rey, Daza, Lòpez-Carrasco, and Lòpez-Bote (2006) reported that no significant differences were detected in the concentrations of γ-tocopherol between groups fed acorns or those fed acorns and grass, either free-range or in confinement; this would indicate that the rearing system did not affect the accumulation of this compound in tissues. On the contrary, the α-tocopherol accumulation in the muscle depends on the rearing condition. As reported by Rey and Lòpez-Bote (2001), muscle *Longissimus* from pigs fed extensively had higher concentration of α-tocopherol than those from pigs fed in confinement. This can be attributed to the relatively high concentration of α-tocopherol in grass. Also in Alentejano pigs, Neves, Freitas, Martins, and Nunes (2007) found higher levels of α-tocopherols in pigs reared extensively than in those reared intensively.

More recently, attention has been focused on the levels of triacylglycerols (TGs) in lipids. As reported by Petrón, Muriel, Timón, Martín, and Antequera (2004), TGs represent the chemical forms in which the fatty acids exist in adipose tissues and, even if they are not exclusive in this tissue, some of the physical and chemical properties of adipose tissues are related to the composition of TGs in the tissue.

Petrón et al. (2004) found that hams made from pigs pastured in woods and fed acorns and grass contained more OOO, OLL and OOL than pigs fed foodstuffs with the most saturated TGs (PPL, PPO, PSO, PPS and SSO), where P, O, L and S are Palmitic, Oleic, Linoleic and Stearic acids, respectively. The higher levels of saturated fatty acids of TGs in pigs fed commercial mixture has also been demonstrated in Iberian fresh ham by Díaz et al. (1996) and by Tejeda, Gandemer, Antequera, Viau, and García (2002). Riaublanc, Gandemer, Gambotti, Davenel, and Monin (1999) found higher levels of POL and OOL in Corse pigs fed chestnuts than in those fed a mixture.

Table 6
Effect of rearing system on fatty acid composition of dry-cured ham (% of the total fatty acids).

Authors	Rearing system	C18:1	C18:2	C18:3
Pérez-Palacios et al. (2010) on BF of Ibérico	Acorn + grass	53.2a	6.96a	0.64a
	H.O. concentrate*	48.8b	5.75b	0.27b
Cava et al. (1999b) on BF of Ibérico	Acorn + grass	54.4a	5.58	0.67
	Concentrate	51.9b	5.02	0.64
Pugliese et al. (2009) on subcutaneous fat of Cinta Senese	Acorn	50.8a	12.2a	0.8
	Chestnut	48.4b	13.6b	1.0
	Concentrate	46.2c	14.6b	0.84

On the same column, means with different letters differ significantly.
* High oleic content concentrate.

3.2.3. Effect on dry-cured products

The main differences between cured products from southern Europe and those from northern Europe are due to the processing techniques used. As reported by Flores (1997), typical Mediterranean products are made with a slow curing process, where salt is one of the main ingredients in the curing process; salt levels in meat products may vary between 3% and 6%. Salt addition is essential for microbiological stability, development of optimum structure and for imparting a salty taste. Moreover, salt affects the generation of volatile compounds through its influence on chemical and biochemical reactions such as lipolysis and proteolysis (Andrés, Cava, Ventanas, Muriel, & Ruiz, 2004). Despite this, in recent decades, even in regions of southern Europe, the trend is to decrease the percentage of salt in cured products, especially dry-cured hams, for dietary reasons. Several studies of salt in meat curing have been carried out on cured products from native pigs, such those of Corsican, currently Nustrale (Coutron-Gambotti, Gandemer, Rousset, Maestrini, & Casabianca, 1999), and Iberian breeds (Andrés et al., 2004; Martín, Córdoba, Antequera, Timón, & Ventanas, 1998).

Other important and significant sources of differentiation between southern and northern European cured products are the breeds used (Dirinck, Van Opstaele, & Vandendriessche, 1997) and the methods by which they are reared. The latter has been the most investigated because of its strong effect on product quality.

The effects of the extensive rearing system on the fatty acid composition of seasoned products have been studied by several authors (Table 6). Cava, Ruiz, Ventanas, and Antequera (1999b) reported high concentrations of oleic acid in Iberian ham, promoted by acorn pasturing, that, together with the typical marbling of the meat, is considered essential for appropriate ripening and flavour development of dry-cured products. In some cases, the effects of pasture in woods on the fatty acid profile were stronger in dry-cured products than in fresh meat. In a comparison between Iberian pigs reared outdoors with free access to acorns and grass and animals fed on oleic acid-enriched concentrate, Pérez-Palacios et al. (2010) found more differences in the fatty acid composition of the *Biceps femoris* muscle in dry-cured hams than those found in fresh *Biceps femoris* from the same animals (Pérez-Palacios, Ruiz, Tejeda, & Antequera, 2009).

Similar results were found in the fatty acid profiles of dry-cured ham from Cinta Senese pigs reared in woods (Pugliese et al., 2009), where higher differences in MUFA content were found than in the fresh fat of the same animals (Pugliese et al., 2006).

Many studies have been carried out on the effects of the rearing system on the volatile compounds in dry-cured products as identified by gas chromatography–mass spectrometry (GC–MS). In the fresh and seasoned lard of Nero Siciliano pigs (Zumbo, Di Rosa, Lo Presti, Pruiti, & Piccolo, 2007), in salami (Zumbo et al., 2007) and in dry-cured ham (Pugliese et al., 2009) from Cinta Senese pigs, the feeding regimen (acorns *versus* concentrate) had a significant effect on the levels of volatile compounds. The effects of the rearing system on the volatile compounds in Iberian ham have been studied (Carrapiso, Jurado, Timòn, & Garcìa, 2002; Cava et al., 1999b; Jurado, Carrapiso, Ventanas, & Garcìa, 2009; Jurado, Garcìa, Timòn, & Carrapiso, 2007; Lopez et al., 1992), but contradictory results have been reported.

Comparison between studies is difficult because of the differences in extraction techniques, in the characteristics of raw material and, in the case of dry-cured products, in the ripening conditions. As shown by Jurado et al. (2007), there are a number of factors related to the rearing system that could influence the type and level of the volatile compounds, such as the composition of the concentrate and the length of the grazing period. These factors could cause considerable heterogeneity in the results. Up to now, the rearing system has had a significant effect on the aromatic compounds when the composition of the feed is clearly different.

The difficulty inherent in characterising the aromatic compounds in cured products is also due to the fact that a limited number of volatile compounds contribute to the aroma of the product. Further, these molecules do not contribute equally to the overall flavour profile of a sample, hence, a large GC peak area generated by a chemical detector does not necessarily correspond to high odour intensities, due to differences in intensity/concentration relationships. Moreover, the interaction of flavour molecules with each other, and with other food constituents must also to be considered (d'Acampora Zellner, Dugo, Dugo, & Mondello, 2008). Over the last years, further analytical techniques for detecting volatile compounds have been developed. One of these is gas chromatography associated with olfactometry (GC–O) that can be used to identify odour-active components in complex mixtures through specific correlation with the chromatographic peaks of interest; this is possible because the eluted substances are perceived simultaneously by two detectors, one of them being the human olfactory system. Consequently, GC–O provides not only an instrumental but also a sensory analysis (d'Acampora Zellner et al., 2008).

In Iberian ham, significant differences in the olfactometric profiles were found between pigs fed acorn and those fed commercial feedstuffs, even if differences in odour were caused by variations in the concentrations of the same odour-active compounds and not to a single volatile compound that could be used as a marker of a specific feeding system (Carrapiso et al., 2002).

To explain how some chemical characteristics, affected by the rearing system, can influence the sensorial traits of dry-cured products, many researchers have recently focused on the relationships between sensorial traits, lipid composition and volatile compounds.

Carrapiso et al. (2003), with regard to the relationship between sensory profile and the fatty acid composition of subcutaneous fat, found that palmitic and oleic acids were the most significantly correlated to the largest number of sensory traits. Moreover, large correlations appeared between either stearic or oleic acids and the brightness, oiliness, juiciness, sweetness, fat hardness and cured aroma of Iberian dry-cured ham.

As reviewed by Gandemer (2009), positive aroma notes, such as “cured ham” or “aged”, have been correlated either with branched aldehydes arising from amino-acid degradation or with methylketones arising from lipid oxidation; a rancid aroma is correlated with oxidation products, mainly with aldehydes, such as nonanal and 2-hexanal.

Garcìa-Gonzáles, Tena, and Aparicio (2009) and Garcìa-Gonzáles, Tena, Aparicio-Ruiz, and Morales (2008) conducted a study on the relationship between odour, flavour attributes and volatile compounds in Iberian hams from diverse geographical origins. An example of these relationships is reported in Table 7.

3.3. The interactions of genotype and environment

In the extensive pig production of southern Europe, the interactions of genotype and environment result in measurable effects on pig meat quality (Edwards & Casabianca, 1997).

These strong interactions are well exploited for Iberian pigs, which are reared outdoors in Mediterranean forests such as La Dehesa, which is composed mainly of evergreen oaks (*Quercus ilex*), cork oaks (*Quercus suber*), gall oaks (*Quercus lusitanica*), arbutus (*Arbutus*) and heath (*Ericeus*). As reported by Lopez-Bote (1998), the Iberian pig and La Dehesa form an inseparable unit, so that the persistence of La Dehesa is possible due to the extensive exploitation of Iberian pigs and *vice versa*. The whole productive cycle of the animals is planned so that they are physiologically capable of utilising La Dehesa during the late fattening phase. Consequently, Iberian dry-cured ham is classified in several categories according to the rearing conditions of the animals. The Spanish Ministry of Agriculture, Fishery and Food enacted a law to regulate the market for Iberian meat products. This regulation establishes, as a function of the feeding background during the fattening period of the pigs, four commercial categories for Iberian dry-cured meat products, including pigs reared outdoors with free access to natural resources (acorns and grass), animals fed on acorns and grass but supplemented with concentrates, pigs fed outdoors with concentrates, or animals reared in confinement and fed commercial diets (Pérez-Palacios et al., 2009).

To regulate the market for Iberian meat products, last decade, the proportions of the major fatty acids (palmitic, stearic, oleic and linoleic acids) in subcutaneous fat have been used to classify Iberian pigs by their feeding backgrounds during fattening (Pérez-Palacios et al., 2010). In this regard, inspection controls were carried out based upon “on farm” inspector visits and lipid analyses performed on one fat sample taken from a group of animals from the same producer. That system is very time consuming and expensive, and it is not objective enough to fulfil the increasing demands from regional, national, and international markets (Pérez-Marín, de Pedro Sanz, Guerrero-Ginel, & Garrido-Varo, 2009). For these reasons, many studies have been carried out to find new, innovative methods of traceability, using techniques such as near-infrared spectroscopy (NIRS) (Pérez-Marín et al., 2009), an electronic nose (Garcia et al., 2003) or neophytadiene content (Tejeda, Antequera, Martin, Ventanas, & Garcìa, 2001).

The rearing of Iberian pigs is a good example of the interaction between animals and their environment, but there are other cases in which this strong link is used to enhance the quality of the product. For example, fresh meat from the Cinta Senese breed has recently

Table 7
Relationship between sensory attributes and volatile compounds qualifying dry-cured hams.

Attributes	Selected volatiles
Acorn odour	Benzaldehyde, 2-heptanone, 3-methylbutanal
Acorn flavour	3-methyl butanal, hexanol, 3-methyl butanol, 2-nonanone
Rancid odour	Hexanal, pentanol, hexanol
Rancid taste	3-methylbutanal, hexanol, octanol
Fat rancid flavour	Octanol, 3-methylbutanal, limonene
Fat pungent flavour	Octanol, limonene

obtained the PDO label, which requires that animals be reared outdoors. PDO applications have recently been submitted for the Nero Siciliano and Nustrale pigs.

In all the rearing systems discussed here, the main objective is to exploit the interactions of genotype and environment to reach the highest quality of the products, according to its widest meaning. As reported by Edwards (2005), the product quality is not only related to attributes directly and objectively measurable but also to secondary attributes, such as animal welfare, environmental impact, traceability or safety aspects, which are increasingly appreciated by consumers.

4. Conclusions

This review of the literature shows a strong and growing interest by the scientific community in the recovery of native pig breeds and enhancement of their products.

Native pigs are a valuable genetic reserve that can be used to recover the organoleptic properties of pig-meat, properties that were lost because of severe selective programmes undertaken to quantitatively improve pig production.

Analysing the current situation it is emerging that:

– Native breeds, if properly reared for the environmental context, can have a real chance of recovery and survival. This last point is crucial. Because native breeds are reared outdoors in almost all cases, it is important that the system adopted is respectful of the ecosystem.
– The quality of the products of native breeds, objectively detectable, can lose meaning if it is not placed in a context of overall quality that considers even the quality of the process.
– A number of these breeds are in search of added value through the PDO (already obtained or applied) supply chain, requiring specifications based upon the particular genotype and providing guaranties on the market.

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