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Volatile compounds of dry-cured Iberian ham as affected by the length of the curing process

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Abstract

Volatile compounds from 10 dry-cured Iberian hams ripened for two different processing times, a prolonged traditional one (600 days) and a shortened process (420 days), were analysed by purge and trap coupled to gas chromatography-mass spectroscopy. Eighty-three compounds were identified which agreed with the major classes found in other ham types. The amount of methyl branched alkanes was much higher than in other dry-cured ham types, probably due to the feeding regime. The percentages of 2- and 3-methylbutanal were higher ($p < 0.0001$ and $p < 0.0003$, respectively) in the longer aged hams, whereas the amounts of some compounds from lipid oxidation decreased from 420 to 600 days aging. In agreement with these observations, 600-day hams had higher scores for those odour and flavour traits usually considered to be positive attributes and lower scores for rancidity. A positive and significant correlation between 2-methyl butanal and cured flavour was found.

Keywords: Dry-cured Iberian ham; Volatiles; Flavour; Ripening time; 2- and 3-methyl butanal

1. Introduction

The overall acceptance of meat products depends to a large extent on their flavour, which is mainly determined by taste and odour compounds (Ramarathnam & Rubin, 1994). In the case of dry-cured products, biochemical changes involving enzymatic and non-enzymatic reactions during ripening give rise to a large quantity of volatile compounds which contribute to their characteristic flavour.

A considerable amount of research has been devoted to studies of the volatile flavour compounds in different types of dry-cured ham, such as Iberian ham (García et al., 1991; López et al., 1992; Ruiz, Cava, Ventanas, & Jensen, in press-b), Parma ham (Barbieri, Bolzoni, Parolari, & Virgili, 1992), French ham (Berdagué, Denoyer, Le Quere, & Semon, 1991; Berdagué, Bonnaud, Rousset, & Tourialle, 1993), American country-style ham (Lillard & Ayres, 1969; Piotrowski, Zaika, & Wasserman, 1970) and Spanish "serrano" type hams (García-Regueiro & Díaz, 1994). Among the factors affecting the volatile profile of hams, processing time is a major one (Bolzoni, Barbieri, & Virgili, 1996; Buscailhon, Berdagué, & Monin, 1993; Flores, Grimm, Toldaá, & Spanier, 1997; Hinrichsen & Pedersen, 1995). Although the length of the curing process is different for each ham type, in all of them sufficient ripening time is needed to allow the development of a desirable flavour.

Cured Iberian ham is a meat product mainly produced in the southwest of Spain. The meat characteristics of Iberian pigs (marbling, fat composition, antioxidant status) together with the prolonged curing process (about twice as long as in any other type of ham) produce a dry-cured ham with special features and a variety of flavour tones that make this the most valuable meat product in Spain, with excellent consumer acceptance. Increasingly hams are being ripened using shorter curing processes than traditionally used to reduce costs. However, hams having a shortened curing process possess a weaker flavour and odour than those from the traditional process (Ruiz, Ventanas, Cava, Timón, & García, in press-a), this being known as "lack of cellar".

Several studies in our laboratory dealing with Iberian hams ripened in the traditional manner have shown that changes in the proteins and lipids during processing are the main contributors to volatile and non-volatile flavour compounds formation (Antequera et al., 1992–1994; Córdoba et al., 1994a,b; Ventanas et al., 1992).

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Nevertheless, the effect of a shorter curing process on the production of Iberian ham volatiles has not been studied. Studies on other ham types are not necessarily applicable to Iberian hams because of the special characteristics of Iberian pigs (breed, high slaughtering weight, feeding system...) which produce a meat with particular quality traits (e.g. high intramuscular fat and myoglobin contents, and high anti-oxidative status) and because of the long processing times used to produce these hams, much longer than used for any other ham type.

The purpose of this study was to elucidate the effect of using a shorter curing process than the traditional one on the headspace volatile profile, and to assess the influence of changes in the volatile profile on Iberian ham flavour.

2. Materials and methods

2.1. Experimental design

Ten hams obtained from Iberian pigs (140–145 kg live weight), which had been fattened on the traditional extensive production system where acorn and pasture are the main food source, were processed into cured hams according to the traditional method (Córdoba et al., 1994b). During the first stages of processing all hams were treated the same, but in the last phase (the ripening of the hams in a cellar) one group was matured for 9 months (420 days of total processing time) and the other for 15 months, as in the traditional method, the total time of the curing process being 600 days. Hams were bone-in, 6.0 ± 0.4 kg weight. These times of processing correspond to the minimum and the maximum required for Iberian hams of this weight by the Specific Designation of Origin (SDO) "Dehesa de Extremadura" (Diario Oficial de Extremadura, 1990).

2.2. Sampling

Ham slices were taken from three different depths in the front and the back of each ham using anatomical references to sample exactly the same muscles in all hams. Slices from each location were used for volatile and sensory analysis. Samples for volatile analysis were frozen at −80°C until required, whereas sensory analysis was performed immediately on the fresh samples. Sensory analysis has been reported previously (Ruiz et al., in press-a).

2.3. Volatile analysis

About 20 g of frozen ham slices were ground in a domestic blender, and 9.00 g weighed into a dynamic headspace vial. The volatile compounds were isolated by the dynamic headspace technique and adsorbed on a capillary Tenax trap, using an automatised dynamic headspace apparatus (Chrompack, Middelburg, The Netherlands). The sample was thermostated at 40°C for 10 min, and subsequently, during 40 min the volatile substances were purged with purified Helium (grade He > 99.999%, flow rate 10 ml/min) and adsorbed on a capillary Tenax trap held at −120°C with liquid nitrogen. The compounds were thermally desorbed into the gas chromatograph (Hewlett Packard 5890 series II) by quickly heating at 250°C for 5 min. The separation was performed on a 5% Phenyl–Methyl Silicone (HP-5) bonded phase fused silica capillary column (Hewlett Packard, 50 m × 0.32 mm id, film thickness 1.05 μm), operating at 6 psi of column head pressure. Oven program was: 35°C, 15 min, 4°C min^{-1} to 200°C, 20°C min^{-1} to 250°C. The transfer line to the mass spectrometer (MS) was maintained at 280°C. The mass spectra were obtained using a mass selective detector (Hewlett Packard HP-5971 A) by electronic impact at 70 eV, a multiplier voltage of 1756 V and collecting data at a rate of 1 scan s^{-1} over the m/z range 30–300. Compounds were tentatively identified by comparing their mass spectra with those contained in the NIST/EPA/NIH and Wiley libraries and by comparison of Kovats indices with those reported in the literature by Kondjoyan and Berdagué (1996) and Acree and Arn (1997) and others.

2.4. Statistical analyses

The effect of processing time (420 and 600 days) on the identified volatiles was carried out by analysis of variance, using the GLM procedure (SAS). Principal component analysis (PCA) was performed using results from the identified volatile compounds as variables in the Unscrambler (CAMO A/S, 1996). Correlation coefficients between the volatiles and the sensory traits were determined using the CORR procedure (SAS).

3. Results and discussion

3.1. Extracted compounds

More than 130 peaks were detected when analysing dry-cured Iberian ham samples by purge and trap coupled to gas chromatography–mass spectrometry, 83 of which were tentatively identified. These compounds and the reliability of the identification are shown in Table 1.

Aldehydes were the major group representing 65.4% of the total chromatographic area, 3-methyl butanal being the most abundant (26.3%). The other chemical groups identified were aliphatic hydrocarbons (22.3%), ketones (4.5%), aromatic hydrocarbons (3.5%), furans (1.5%), alcohols (1.1%), chloride compounds (0.46%),

Table 1
Volatile compounds identified in dry-cured Iberian ham headspace[a]

Peak no.[b]	Volatile compounds	Reliability[c]	420 days	600 days	Pooled SEM	*p*
1	Branched alkane	c	0.044	0.059	0.003	0.0741
2	Methylcyclopentane	a	0.372	0.047	0.052	0.0001
3	Branched alkane	c	0.065		0.011	
4	2-methyl-1-propanol	a	0.305	0.296	0.033	0.8972
5	Trichloroethane	a	0.067	0.233	0.065	0.2201
6	3-methyl butanal	a	23.511	29.277	0.837	0.0003
7	Tetrachloromethane + benzene + alkane	b, a, c	1.015	0.604	0.097	0.0306
8	2-methyl butanal	a	11.176	14.421	0.400	0.0001
9	3-methylhexane	a	0.117	0.038	0.015	0.0598
10	1-penten-3-ol	a	0.148	0.112	0.012	0.1566
11	2-pentanone	a	2.643	2.301	0.145	0.2223
12	Pentanal + heptane	a, a	14.146	12.212	0.421	0.0225
13	2-ethylfuran	a	0.607	0.601	0.045	0.9390
14	Alkene	c	0.027	0.018	0.002	0.0414
15	Branched alkane	c	0.098	0.031	0.017	0.0222
16	*n*-methylene ethaneamine	a	0.062	0.080	0.009	0.3607
17	Methyl butanoate	a	0.011	0.013	0.001	0.6036
18	3-methyl-3-buten-2-ol	a	0.120	0.131	0.023	0.8136
19	Ethylcyclopentane	a	0.030	0.029	0.003	0.8732
20	3-methylbutan-1-ol	a	0.454	0.290	0.045	0.0744
21	2-methylbutan-1-ol + 3-methyl-2-pentanone	a, a	0.214	0.160	0.016	0.0817
22	2-methylbutenal	b	0.041	0.036	0.002	0.3754
23	Dimethyl disulfide	a	0.064	0.029	0.008	0.0204
24	3-methylheptane	a	0.045	0.103	0.025	0.1834
25	Branched alkene	c	0.040	0.026	0.010	0.4830
26	Toluene	a	2.743	1.336	0.168	0.0001
27	3,5-dimethylisoxazole	b	0.194	0.316	0.109	0.6679
28	2-methylpropyl acetate	b	0.018	0.015	0.003	0.6011
29	Branched alkane	c	0.069	0.015	0.023	0.2057
30	2-hexanone + 1-octene	a, a	0.509	0.486	0.017	0.4869
31	Octane	a	11.739	10.783	0.534	0.3774
32	Hexanal	a	21.633	19.286	0.860	0.1799
33	4-octene	a	0.229	0.193	0.024	0.4330
34	2-octene (e)	a	0.082	0.061	0.008	0.1822
35	Tetrachloroethane	a	0.032	0.023	0.002	0.0326
36	Butyl acetate	a	0.068	0.050	0.004	0.0384
37	1,3-octadiene	b	0.081	0.039	0.012	0.0780
38	3-methylphenol	c	0.018	0.027	0.003	0.0713
39	Branched alkane	c	0.027	0.022	0.007	0.4333
40	Ethyl 2-methylbutanoate	a	0.042	0.046	0.005	0.6405
41	Ethyl 3-methylbutanoate	a	0.112	0.110	0.013	0.9236
42	1,4-dimethylbenzene (m-xylene)	a	0.223	0.239	0.036	0.8196
43	1-hexanol	a	0.024	0.016	0.003	0.1798
44	1,4-dimethylbenzene (p-xylene) + 2-heptanone	a	0.769	0.799	0.110	0.8891
45	3-methylbutyl acetate	a	0.026	0.016	0.003	0.0648
46	1,3,6-octatriene + hexanonitrile	a, a	0.123	0.141	0.010	0.3758
47	4-propyl 2-methylfuran	b	0.032	0.046	0.002	0.0044
48	2-heptanone	a	1.085	1.143	0.054	0.6185
49	2-butylfuran	a	0.060	0.081	0.008	0.1718
50	Ethenylbenzene	a	0.245	0.109	0.042	0.1338
51	1,2-dimethylbenzene (o-xylene) + nonane	a, a	0.231	0.263	0.017	0.3699
52	Heptanal	a	1.833	1.638	0.100	0.5720
53	3-ethylphenol	a	0.094	0.146	0.019	0.1681
54	Methyl hexanoate	a	0.028	0.025	0.005	0.6856
55	1-ethyl-2-methylbenzene	c	–	0.025	0.010	–
56	Branched alkane + propylcyclohexane	c, a	0.116	0.103	0.009	0.4768
57	α-pinene	a	0.591	0.204	0.107	0.0547
58	Methane, 1,1-(bis) methylthio	c	0.036	0.051	0.009	0.5716
59	2-heptenal	a	0.131	0.071	0.015	0.0365
60	Propylbenzene	a	0.025	0.015	0.004	0.0337
61	1-ethyl, 4-methyl-benzene + benzaldehyde	a, a	0.078	0.073	0.008	0.7458
62	1,3,5-trimethylbenzene	a	0.013	0.015	0.001	0.6469

Table 1 *(continued)*

Peak no.[b]	Volatile compounds	Reliability[c]	420 days	600 days	Pooled SEM	*p*
63	2,3-octanedione	a	0.136	0.064	0.011	0.0006
64	Dimethyl trisulfide	a	0.047	0.028	0.004	0.0081
65	3-octanone	a	0.041	0.036	0.003	0.2814
66	β-pinene	a	0.142	0.052	0.031	0.1460
67	2-octanone	a	0.144	0.096	0.025	0.0730
68	2-pentylfuran	a	0.859	0.891	0.013	0.9057
69	Ethyl hexanoate + decane	a, a	0.235	0.223	0.137	0.8162
70	1,2,4-trimethylbenzene + octanal	a, a	0.307	0.256	0.022	0.2512
71	Limonene	a	0.058	0.076	0.019	0.7058

[a] Results are expressed as mean area percentage of the five hams analysed at six different slice locations.

[b] Order of appearance of the peak within the identified peaks.

[c] Reliability of identification: a, mass spectrum and KI in agreement with the literature; b, mass spectrum consistent with spectrum in NS and Wiley libraries; c, tentative identification by mass spectrum.

esters (0.4%), terpenes (0.4%), nitrogen compounds (0.3%) and sulfur compounds (0.18%). The major chemical classes found agree with those reported in the literature for Iberian ham (García et al., 1991; López et al., 1992) and other dry-cured ham types (Berdagué et al., 1991, 1993; Bolzoni et al., 1996; Buscailhon et al., 1993; Flores et al., 1997; Hinrichsen & Pedersen, 1995). There were variations in the quantities reported that may be due to the analytical method, but more likely due to differences in raw meat composition and processing, especially when compared to Parma hams, in which the ester content is much higher.

The very high proportion of 2- and 3-methylbutanal found (13 and 26.3%, respectively), higher than reported in any other type of dry-cured ham, is remarkable. These compounds have been associated with nutty, cheesy and salty notes in Parma ham (Hinrichsen & Pedersen, 1995) and correlate with the aged flavour of hams (Careri et al., 1993). The importance of these compounds to the overall flavour has been described not only in hams but in other meat products, such as sausages (Montel, Reitz, Talon, Berdagué, & Rousset Akrim, 1996; Stanhke, 1995b) and bacon (Hinrichsen & Andersen, 1994). The high percentage found in the dry-cured Iberian ham could be one of the reasons for the high degree of acceptance of this type of ham. Ventanas et al. (1992) have proposed Strecker degradation reactions of amino acids as the origin of these branched aldehydes, since the water activity, pH, temperature and the time of processing should allow such reactions to develop, and the carbonyl content is high enough for Maillard condensation reaction to occur (Labuza & Saltmarch, 1981). On the other hand, Hinrichsen and Andersen (1994) have shown an increase in the concentration of methyl branched aldehydes due to microbial activity in cured bacon; however, the ripening conditions undergone by the two meat products (ham and bacon) are very different. The results from our study support both formation routes, since there was an increase in branched aldehydes content (Table 1) and a decrease in most α-amino acids, including leucine and isoleucine (respective precursors of 3- and 2-methylbutanal) (data not shown), in the 600-day compared to the 420-day hams. Further research on the role of microorganisms in the production of methyl branched aldehydes in Iberian ham is presently being carried out in our laboratory.

Some other molecules may also derive from amino acids, such as the methyl alcohols, 2-methylpropanol and 2- and 3-methylbutanol, and the sulfide compounds, dimethyl disulfide and trisulfide.

Straight chain aliphatic aldehydes are typical products of lipid oxidation. Hexanal, a carbonyl that arises from the oxidation of n-6 fatty acids, was the major such compound (20.4%), similar percentages to those obtained by García et al. (1991) in Iberian ham. Other compounds from lipid oxidation were also detected, i.e. aliphatic alkanes and alkenes, unbranched alcohols, ketones and furans. The number of methyl branched alkanes detected is greater than that found by other workers investigating ham volatiles. These compounds may arise from the oxidation of methyl branched fatty acids, naturally present in very low quantities in animal tissues (Berdagué et al., 1991). It is well known that high energy-grain diets produce soft and oily fats in sheep (Busboom et al., 1981; Miller, Field, & Agboola, 1986) and rabbits (López-Bote, Rey, Isabel, & Sanz, 1997) because the increased propionate and methylmalonate concentrations in the rumen (sheep) or large intestine (rabbits), lead to increased concentrations of odd and branched-chain fatty acids (BCFA) in the storage fats (Garton, Hovell, & Duncan, 1972), when these volatile fatty acids replace acetate in fatty acid synthesis (Horning, Martin, Karmen, & Vagelos, 1961). In pigs starch in the diet is believed to be completely absorbed in the small intestine; however, when studying the large intestine

contents of Iberian pigs fed on acorns and grass, González (1997) observed a significant content of undigested acorn pieces. Since acorn has a high starch content (Cava et al., 1997; Rey, López-Bote, & Sanz Arias, 1997; Ruiz et al., 1998), the presence of undigested acorns could increase propionate and methylmalonate formation in the caecum. We found an increase in odd-chain fatty acids in lard when feeding pigs on acorn and grass (Ruiz et al., 1996); the techniques used in the current study were unable to detect BCFA. However we propose that there is a parallel increase in these compounds that would explain the high quantities of methyl compounds derived from the BCFA oxidation in hams from pigs raised on this feeding regime.

It is generally accepted that alkanes do not contribute significantly to meat flavour (Shahidi, Rubin, & D'Souza, 1986), but little is known about the influence of methyl-branched alkanes on flavour. However, changes in the structure of a molecule can influence both its flavour and its threshold value (Belitz & Grosch, 1986), i.e. some branched-chain fatty acids have a much lower odour threshold than their corresponding straight-chain counterparts (Baldwin & Cloninger, 1973; Boelens, Haring, & de Reijke, 1983). In fact, some authors have related higher scores in some flavour descriptors with small increases of BCFA in sheep (Locker, 1980; Wong, Nixon, & Johnson, 1975).

The presence of four furans representing 1.5% of the total chromatographic area is surprising, since they are normally described as compounds generated during heating; nevertheless, they have been found in dry-cured hams by other authors (Buscailhon et al., 1993; Flores et al., 1997; López et al., 1992), and formation of furans has been observed in model systems leading to linoleic acid oxidation at 20°C (Grosch, 1987). These compounds could contribute to the unique Iberian ham flavour, since they are present in higher contents than found in other studies on hams, and they may contribute to the overall odour of cooked meat (Shahidi et al., 1986) and roasted flavour (Ames & MacLeod, 1985).

Some of the other compounds detected might be accumulated in pig fat from feeding, such as the terpenes α- and β-pinene and limonene, and most of the benzene compounds (Buscailhon et al., 1993).

Eight esters, including acetates, butanoates and hexanoates, were also found in the headspace of the hams. García et al. (1991) and López et al. (1992) have described several esters in Iberian hams, but with the exception of 2-methyl ethyl butanoate and ethyl hexanoate, the other six esters are reported in Iberian ham for the first time. Flores et al. (1997) have discarded a microbial origin for these compounds due to the low microbial counts found (Baldini et al., 1992; Molina and Toldrá, 1993). However, when studying microbial populations in Iberian ham, Núñez, Rodriguez, Ḿrmudez, Córdoba, and Asensio (1996a,b) and Rodríguez et al. (1994), found high counts of yeasts, moulds and bacteria of the Micrococcaceae family in the surface of the hams during ripening. Thus, we believe microorganisms cannot be discarded as a possible origin for ester formation during the ripening.

Three nitrogen containing compounds (3,5-dimethyl-isoxazole, hexanenitrile and *n*-methylene ethanamine), not reported previously in dry-cured hams, were found. The presence of an oxazole in ham is surprising, considering they are normally only found in heated meat (Shahidi et al., 1986). Their occurrence in ham supports the Strecker formation of 2- and 3-methylbutanal, since oxazoles may arise by Strecker degradation of aminoketones resulting from the condensation of α-dicarbonyl compounds with amino acids (Ohloff & Flament, 1978). Several oxazoles have been described as nutty, sweet, green, woody, musty and vegetable-like (MacLeod & Seyyedain-Ardebii, 1981).

Nitrile compounds have been detected in sausages (Stanhke, 1995a) and nitrite-cured cooked pork (Mottram, Croft, & Patterson, 1984). The latter proposed their formation at the expense of the corresponding aldehydes during lipid oxidation involving nitrite. In respect of the volatile amines found, these are frequently cited as being of microbial origin in meat sausages (Dainty & Blom, 1995). However, amines can also originate from decarboxylation of amino acids at low pH, as occurs in cheese (Belitz & Grosch, 1986). They can also be formed during pyrolysis of aminoacids (MacLeod & Seyyedain-Ardebii, 1981), but the temperatures reached during processing are not high enough to allow such reactions. An increase in volatile basic nitrogen during ripening of Iberian hams has been described previously (Ventanas et al., 1992), and López et al. (1992) have detected an amine in Iberian ham volatiles.

1,1(bis) methylthiomethane has been found in canned beef, being associated, with other carbonyl and sulfur compounds, with the off-flavor of this heated product (Persson & von Sydow, 1973). Its origin might involve reactions between hydrogen sulfide and such compounds as ribonucleotides, but these type of reactions have only been described in heated model systems (MacLeod & Seyyedain-Ardebii, 1981).

The chloride compounds found, have been related to pesticide residues in the feed (Flores et al., 1997), but we agree with Berdagué et al. (1991) who attributed them to laboratory contamination.

3.2. *Influence of processing time*

Differences in the areas of identified peaks are shown in Table 1. Processing time significantly affected 14 peaks, however 3-methyl-ethyl-butanoate was the only compound that showed significant differences between

slice locations (data not shown). The changes observed can be summarised as an increase in 2- and 3-methyl butanal and 4-propyl-2-methyl furan and a decrease in some hydrocarbons, both straight chain and branched, in dimethyl and trimethyl disulfide, toluene, butyl acetate, 2,3-octanedione and 2-heptenal from 420 to 600 days.

Thus, there was a decrease in most of the compounds derived from oxidation, such as aliphatic aldehydes and hydrocarbons, whereas few compounds showed an increase, except for the methyl aldehydes cited above. The loading plot of the variables and the score plot of the samples in PCA (Fig. 1) confirm that hams cured for the shorter time had higher values in axis 1, and were in the same region where compounds derived from oxidation (hexanal, octane, pentanal + heptane), while the long ripened hams were primarily in the negative part of the axis, close to the loadings of 2- and 3-methyl butanal. Similar results were found by Hinrichsen & Pedersen (1995) in Parma ham, but in their case, the differences were found between half, fully matured and overmatured hams (485 days), and by Flores et al. (1997) in "serrano" hams matured for a long and shorter time. However, in our study the hams cured for the shorter time still had a ripening time longer than the fully matured Parma and serrano hams. In a previous study on oxidative changes during ripening of Iberian ham, Antequera et al. (1992) observed two increases in the concentration of carbonyls from oxidation during the ripening of the hams, the first in the post-salting phase (120 days of ripening), and the second and smaller increase, at half the final "cellar" phase (360 days). These results are in agreement with the present work, where after 420 days, higher levels of compounds derived from lipid oxidation were found. In the longer ripened hams lower concentration of these compounds were found.

In a previous work carried out on the same samples (Ruiz et al., in press-a), hams ripened traditionally had a more marked odour intensity, "acorn ham" odour, flavour intensity, aftertaste and cured flavour (Fig. 2). However, differences in rancidity between the processing

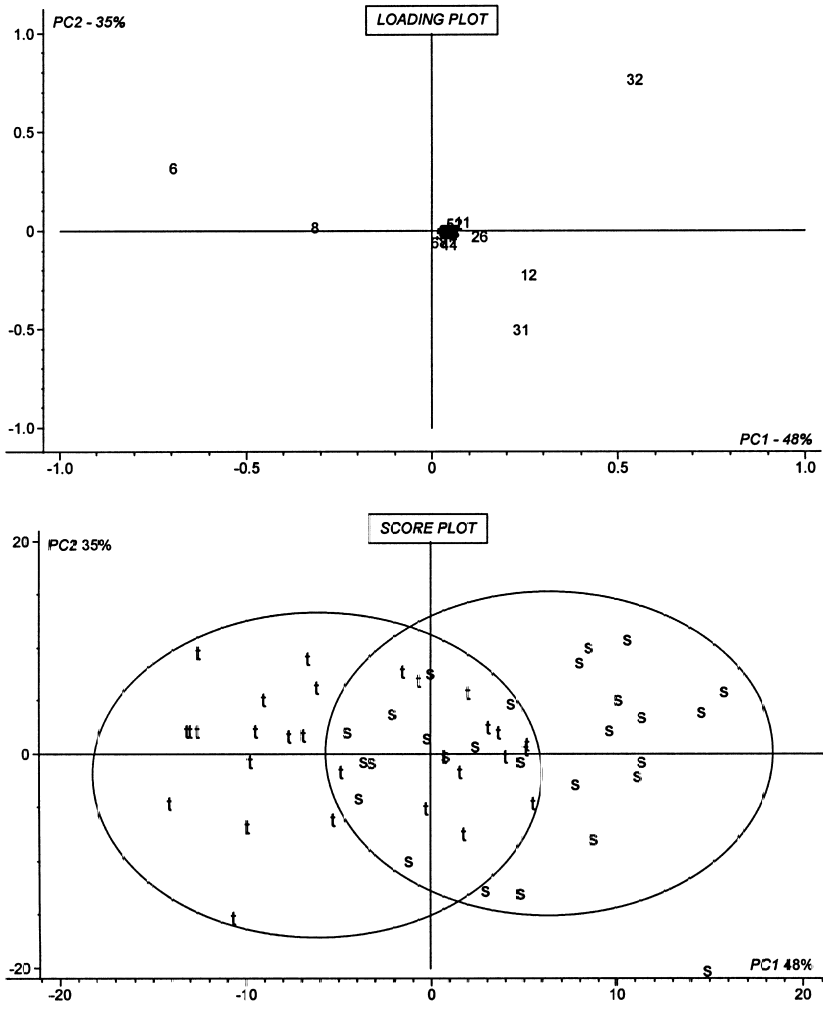

Fig. 1. Loading plot and score plot, after principal component analysis of dry-cured Iberian ham volatiles. In the loading plot the numbers correspond to those in the first column of Table 1. In the score plot (t) are the hams processed by the traditional method and (s) are the 420-day hams.

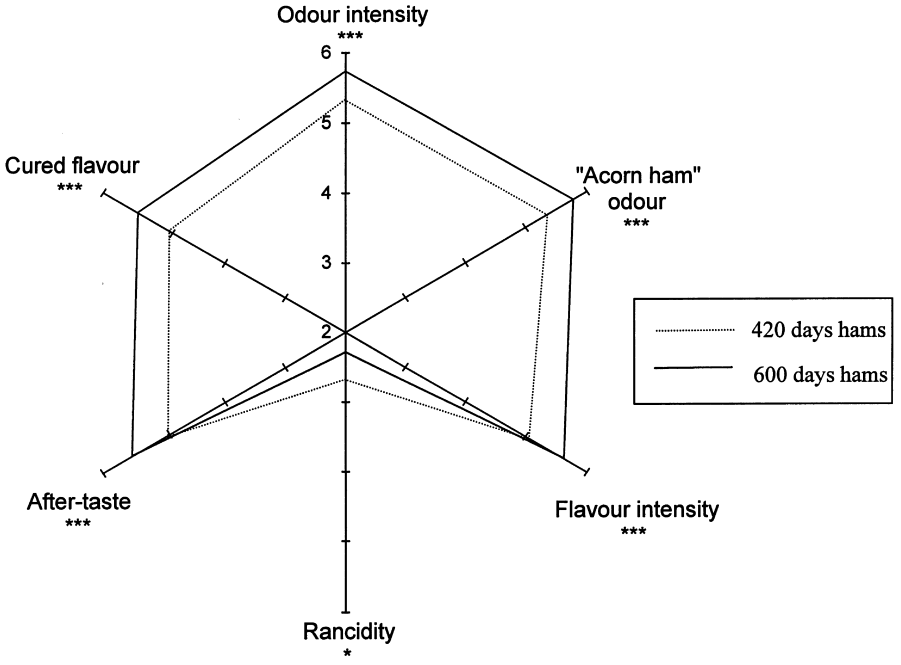

Fig. 2. Mean of odour and flavour traits for dry-cured Iberian hams processed in a shortened and a traditional method (time effect: *, significant at $p < 0.05$; ***, significant at $p < 0.001$) (taken from Ruiz et al., in press-a).

regimes were not statistically significant, although the results suggested that the 420-day hams were more rancid. If two judges because of their inconsistency were excluded, then rancidity was higher ($p < 0.0066$) in the 420d hams. These results might explain the lower acceptability of hams cured in a shorter time, since the traits that showed higher values in the 600-day hams are considered positive (Careri et al., 1993), while rancidity is usually referred to as a negative attribute in meat products (Konopka, Guth, & Grosch, 1995; Shu-Mei, Gray, Booren, Crackel, & Gill, 1995). The increase in positive flavour traits and decrease in rancidity parallel the increased levels of 2- and 3-methylbutanal and the reduced levels of hexanal and other oxidation products. A positive correlation (0.36, $p < 0.005$) was found between cured flavour and 2-methyl butanal. This is in agreement with previous works showing 2- and 3-methyl butanal are associated with aged ham flavour in Parma ham (Careri et al., 1993; Hinrichsen & Pedersen, 1995). As well as the methyl branched aldehydes themselves, thiolane and thiazine from reactions between such aldehydes and ammonium sulfide at low temperature, give an intense cured flavour (Shu, Mookherjee, Bondarovich, & Hagedorn, 1985). In respect of hexanal, there is a well established relationship between its content and rancid flavour (Lai, Gray, Booren, Crackel, & Gill, 1995)

Further research into the relationship between the acceptability of the ham as assessed by consumers and flavour volatile content is needed to determine which compounds could be used as markers of ham quality, and hence, determine optimum ripening conditions to produce high quality hams.

4. Conclusion

Flavour depends upon a great variety of volatile compounds. Although some compounds might be primarily responsible for the dry-cured Iberian ham aroma, the increase in flavour intensity with processing time seems to be related to quantitative rather than qualitative changes.

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