Colour and Moisture Changes during the Manufacture of Iberian Dry-Cured Ham Caused by Some Biotic and Abiotic Factors

C. Sanabria, P. J. Martín-Alvarez and A. V. Carrascosa

Food Science and Technology International 2004; 10; 269
DOI: 10.1177/1082013204046094

Colour and Moisture Changes During the Manufacture of Iberian Dry-Cured Ham Caused by Some Biotic and Abiotic Factors

C. Sanabria,[1] P.J. Martín-Alvarez[2] and A.V. Carrascosa[2,*]

[1]*INTAEX Instituto de Tecnología Agroalimentaria, Dir. Gral. de Comercio e Industrias Agrarias, Consejería de Agricultura y Comercio, Junta de Extremadura, PO Box 22, 06080 Badajoz, Spain*
[2]*Instituto de Fermentaciones Industriales (CSIC), 28006 Madrid, Spain*

The effects of some biotic (pig-rearing system and muscle location) and abiotic factors (processing time and drying location) on colour (L^*, a^* and b^*) and moisture changes during the manufacture of Iberian ham were studied. The levels of L^* (from 27.14 to 44.44), a^* (from 6.10 to 19.84) and b^* (from 2.18 to 8.72) parameters, and moisture (from 31.71 to 75.04) decreased ($p < 0.05$) as processing time increased. L^*, a^* and b^* were strongly influenced by muscle location and their values were smaller ($p < 0.05$) in *semimembranosus* than in *biceps femoris*, as occurred with moisture. The rearing system produced differences ($p < 0.05$) in a^* at the first stage and in L^* and b^* at the final stage of processing. Drying location, probably in association with natural climatic conditions, caused differences ($p < 0.05$) at only the final stage of processing in a^* and b^* parameters. The variations in colour parameters were mainly affected by rearing system and muscle location.

Key words: Iberian ham, colour, moisture, rearing system, drying

INTRODUCTION

Colour is a very important characteristic of meat and meat products that serves to define their sensorial quality (Hoffmann, 1993). It has also been stated that colour is the most important characteristic for the selection of meat by consumers (MacDougall, 1982). The colour may be measured by determination of compounds that contribute to colour formation; however, reflectance spectrometry is usually used because it correlates well with visual estimation (Ansorena et al., 1997; Pribis and Svirzic, 1995; Perlo et al., 1995). Colour formation in meat products is a combined process influenced by several biotic and abiotic factors (Möhler, 1984; Bacus, 1984; Lücke and Hechelmann, 1987).

Recent studies of colour in muscle of Iberian pigs have evaluated the way that colour is affected by factors such as type of feeding and muscle location (Andrés et al., 2000; Cava et al., 2003; Estévez et al., 2003). Iberian ham is a traditional cured Mediterranean meat product with high commercial value because of its characteristic flavour, determined by marbling and by the diet of Iberian pigs, which consume mainly acorns. Colour of Iberian ham affected by vacuum packaging technology has been previously reported (Elías and Carrascosa, 2000) but there is not data about changes that have occurred in this important sensorial characteristic during its manufacture. There are studies of colour in cured white pig ham, a Spanish meat product with a lower commercial value (Forcen et al., 1993; Perez-Alvarez et al., 1999; García-Esteban et al., 2003) which pointed out the strong influence of muscle location and processing time on the colour and other sensorial parameters of ham.

The aim of this work was to describe colour changes during the manufacture of Iberian ham from the Extremadura region of Spain (protected by an Appellation of Origin) depending on the rearing system, drying location, processing time and muscle location.

MATERIALS AND METHODS

Rearing System

Castrated male Iberian pigs were free-range reared with acorns (AC) and pasture, or reared in confinement with mixed feeds (MF) during the last weeks before slaughter.

*To whom correspondence should be sent (e-mail: acarrascosa@ifi.csic.es).
Received 6 November 2003; revised 22 April 2004.

Food Sci Tech Int 2004; 10(4):269–275

ISSN: 1082-0132
DOI: 10.1177/1082013204046094

Time of Processing and Drying Location

Samples were taken from three different hams, each time from fresh hams (FRESH), after post-salting (POSTSALT), after natural drying (NATDRY) and at the end of processing (FINAL). All those samples belonged to a lot of 100 hams. Samples of fresh hams were taken immediately after slaughter, so that the values of analysed parameters were identical at all locations. Hams from Valdesequera pigs (average weight 10.03 kg from free reared and 10.65 kg from confined pigs) were rubbed with a mixture of 1% sodium chloride (100 g) and a curing agent (0.25 g of KNO_3 + 0.05 g of $NaNO_2$) salted by covering in sea salt, and kept for 15 days in controlled atmosphere chambers (5 °C). After salting, hams were brushed to remove any salt left on the surface, and hung in chambers (5–15 °C, 80% relative humidity) for 60 days. After post-salting, hams were naturally dried for 100 days, in summertime environmental conditions in Olivenza (OL), Higuera la Real (HIG) and Montánchez (MON), three drying locations from the 'Dehesa de Extremadura' Appellation of Origin with different altitude and climatic conditions (Sanabria, 2001). After natural drying, hams were hung in underground cellars, in natural environmental conditions (20 ± 5 °C and 75 ± 10% relative humidity) for 500 days.

Muscle Location of Samples

Samples were taken from *biceps femoris* (BI) and *semimembranosus* (SM) muscles, which are respectively protected and unprotected by the subcutaneous fat cover. Three samples from three different hams belonging to an initial lot of 100 fresh hams were taken at every location and for every rearing system.

Methods

Determination of Colour

CIE surface colour parameters (L^*: lightness, a^*: redness, b^*: yellowness) were evaluated using a Minolta CR-3000 Colorimeter, following the method of Francis and Clydesdale (1975). Measurements were made on flesh, taking care not to measure on subcutaneous fatty tissues. The colorimeter was calibrated with a blank before each series of measurements.

Moisture Determination

Moisture was determined in duplicate following standard ISO-1442.

Statistical Analysis

The statistical methods used for data analysis were: cluster analysis (Ward's method from standardised variables); principal component analysis to examine the relationships among the variables; four-way analysis of variance (ANOVA) to test the effects of the four factors (rearing system, climatic conditions, time in process and muscle location of the sample) and Student–Newman–Keuls test for comparison of means (Martín-Alvarez, 2000). The STATISTICA program for Windows, release 5.1 (Statsoft Inc. 1998, Tulsa, OK 74104) was used for data processing. This program was run on a personal computer.

RESULTS AND DISCUSSION

In an attempt to obtain a preliminary view of the main causes of change in the variables studied, cluster analysis was carried out on the whole analytical data from all samples analysed. Figure 1 displays a dendrogram built from the mean values of the variables in the 48 groups of samples, taking into account the levels of the four target factors (three sites, four times, two rearing systems and two muscle locations). The squared Euclidean distance was taken as a measure of proximity between two samples and Ward's method was used as the linkage rule. The variables were standardised previously. As can be observed, there were two larger groups of samples, one mainly corresponding to samples taken from muscle 2, and time in process 3 and 4, and one mainly corresponding to samples taken from muscle 1 and times in process 1 and 2. Within this second group, there was a clear grouping determined by feeding, corresponding to samples taken at stage 1. This was the only case of samples grouping by feeding, and there were no groupings by processing site. The influence of feeding on colour has been demonstrated in recent studies on Iberian pork (Andrés et al., 2000; Cava et al., 2000).

Something similar is deduced from the plot of the samples on the plane defined by the first two principal components, which explained 88.4% of the total variation (Figure 2). The first component correlated strongly (loadings >0.84) with all four variables analysed. Again we found that the samples form groups, mainly by processing stage and muscle, and to a lesser extent by feeding and processing site. There were no references to the evolution of colour parameters and moisture during preparation of Iberian ham with which to compare these observations; however, in similar studies on the manufacture of cured white pig ham, these two factors have also been found to influence colour parameters (Forcen et al., 1993; Perez-Alvarez et al., 1999; García-Esteban et al., 2003). Existing studies on aspects of Iberian ham

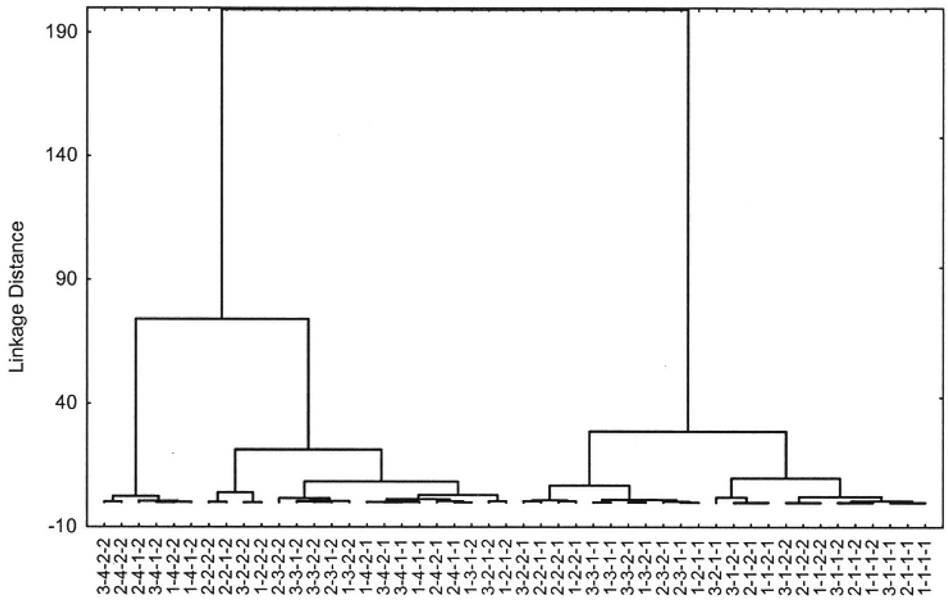

Figure 1. Dendrogram of the 48 mean samples of Iberian ham according to moisture and colour parameters. The labels are: Drying location (1 = Olivenza, 2 = Higuera, 3 = Montánchez). Processing time (1 = Fresh, 2 = Postsal, 3 = Natdry, 4 = Final). Rearing system (1 = ace, 2 = Mf). Muscle location (1 = BI, 2 = SM).

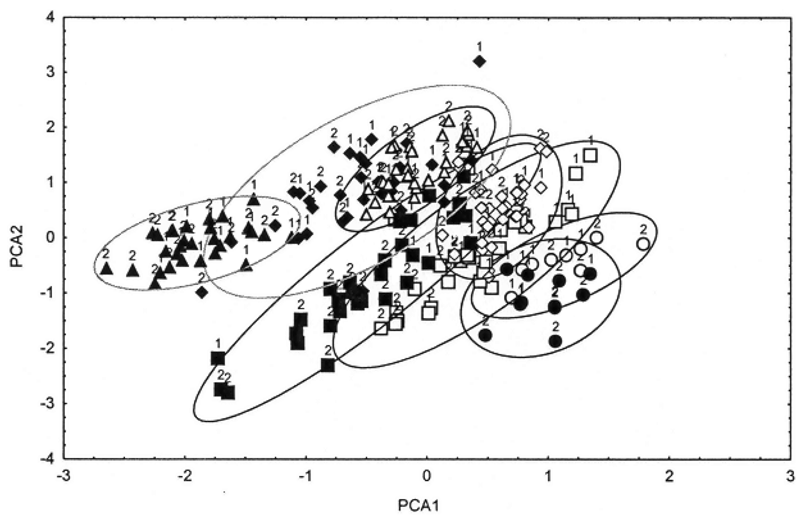

Figure 2. Plot of all samples on the plane defined by the first two principal components, and ellipses for the time in process and muscle location groups for 95% confidence. The labels of groups are: Pigs free reared (1), Pigs confined (2); Fresh hams/*Biceps femoris* group (○); Fresh hams/*Semimembranosus* group (●); Post-salting/*Biceps femoris* group(□); Post-salting/*Semimembranosus* group (■); Natural drying/*Biceps femoris* group (◇); Natural drying/*Semimembranosus* group (♦); Final of process/*Biceps femori*s group (△); Final of process/*Semimembranosus* group (▲).

quality in finished product (Cava et al., 2000) and the evolution of quality during storage of vacuum-packed slices (Elías and Carrascosa, 2000) also indicated that the muscle influences sensory aspects of colour or colour parameters. Muscle location and its influence on colour has also been discussed in relation to Iberian pork (Cava et al., 2003) but that influence had never before been investigated throughout the manufacturing process.

The apparently slight influence of the type of feeding as a factor in the grouping of samples is not consistent with reports published until now. It has been found that meat from Iberian pigs reared on a free-range basis had significantly different values for colour parameters (Andrés et al., 2000) and other related sensory characteristics (Cava et al., 2000) from that of pigs reared in confinement. The reason for those differences were based on the fact that free-range rearing causes the development of a higher proportion of oxidative muscle fibres (Andrés et al., 2000). The more intense and prolonged free-range rearing was, the clearer was the effect on the muscle fibres (Essen-Gustavsson et al., 1992). The muscle fibres determined the myoglobin content, which is higher in the case of oxidative fibres (Monin and Ouali, 1991) and, hence, the colour. The fact that the only group of samples differentiated by feeding regime is the one corresponding to the first stage of processing probably indicates that this difference in fibre content is not very pronounced and that the differences disappear as a result of processing events such as drying, reduction of myoglobin, etc.

The reason for the scant influence of the processing site on sample grouping trends could be that the climatic differences between the drying sites are not very pronounced for 50% of the processing time (Sanabria, 2001) which is understandable given that the sites belonged to the same Appellation of Origin, and also that changes occurring during processing masked any climatic effect. This effect has not been studied before in connection with the processing of Iberian or Serrano ham.

The results of four-way ANOVA to test the significant effects of the four factors and their two-interaction terms (the three-way interaction between factors and the error term were pooled) revealed that the main effects of the time in process and muscle location factors, effects and interactions significantly ($p < 0.0001$) influenced all four target variables (moisture and the three colour parameters). The results also revealed the following: that the processing site significantly influenced all the target variables ($p < 0.01$); that the rearing system significantly affected parameters L^* and a^* ($p < 0.01$); and that the effect of some of the two-way interaction terms was significant. Specifically, the processing site/time in process interaction term influenced all the target variables except for parameter L^* ($p < 0.01$) and the time in process/rearing system interaction term influenced all the colour parameters ($p < 0.01$).

The variation in the mean values of L^* (lightness) during the manufacture of Iberian ham (ranging from 27.14 to 44.44) was affected fundamentally by processing time, muscle location and rearing system (Figure 3). Taking into account the comparison of means (t-test) at the end of the processing, the mean values of L^* were lower ($p < 0.01$) in both muscles (*semimembranosus* and *biceps femoris*) for both types of feeding (pigs reared in freedom with acorns and pigs reared in confinement with mixed feeds). L^* values were also lower in the *semimembranosus* muscle irrespective of feeding conditions in the last three processing stages ($p < 0.01$). L^* values were lower in hams from intensively fed Iberian pigs than in hams from free-range reared pigs, particularly in the *biceps femoris*, except in

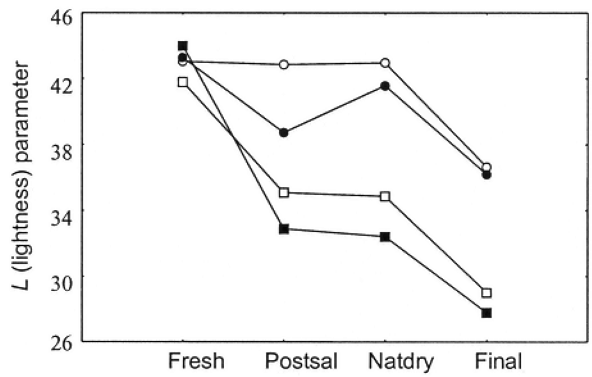

Figure 3. Plot of means of L^* (lightness) for interaction of time in process, muscle location and rearing system. The labels of groups are: Pigs free reared/*Biceps femoris* (○); Pigs confined/*Biceps femoris* (●); Pigs free reared/*Semimembranosus* (□); Pigs confined/*Semimembranosus* (■).

the case of fresh samples ($p < 0.05$). This agreed with the findings of Estévez et al. (2003) in *longissimus dorsi* but not with the results of Andrés et al. (2000) in *biceps femoris*, in both cases dealing with fresh samples of Iberian ham. The initial L^* values in *biceps femoris* were similar to those reported by other authors (Andrés et al., 2000). However, the final values in both *semimembranosus* and *biceps femoris* were slightly lower than reported for Iberian hams from the Alentejo region of Portugal (Elías and Carrascosa, 2000). In the absence of any significant differences in L^* for different breeds of Iberian pig (Andrés et al., 2000) the differences mentioned might be due to the processing time, which is much shorter in the case of Iberian ham with respect to the Alentejo region.

The variation in the mean values of moisture during the manufacture of Iberian ham (ranging from 31.71 to 75.04) was fundamentally due to processing time, muscle location and rearing system (Figure 4). The general trends were the same as reported for lightness: general decrease by decreasing processing time and lower values in *semimembranosus* muscle. This coincidence is due to the high value of the correlation coefficient between the colour parameter L^* and moisture ($r = 0.80$, $p < 0.01$). Moisture loss was greatest in fresh and post-salting samples after 75 days of processing. More moisture was lost in the time up to the end of natural drying than in all the subsequent time (approx. 400 days). Dehydration, which affects meat colour (Möhler, 1984) could also partially explain the overall drop in colour parameters with increased processing time, in agreement with the concomitant decrease in moisture observed in this study and in other studies on Iberian hams (Rodriguez et al., 1994). The same high correlation between moisture and L^* has been observed during the manufacture of Spanish hams

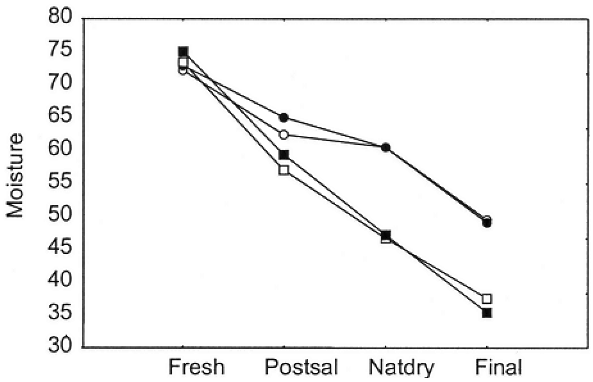

Figure 4. Plot of means of means of moisture for interaction of time in process, muscle location and rearing system. The labels of groups are: pigs free reared/*Biceps femoris* (○); pigs confined/*Biceps femoris* (●); pigs free reared/*Semimembranosus* (□); pigs confined/*Semimembranosus* (■).

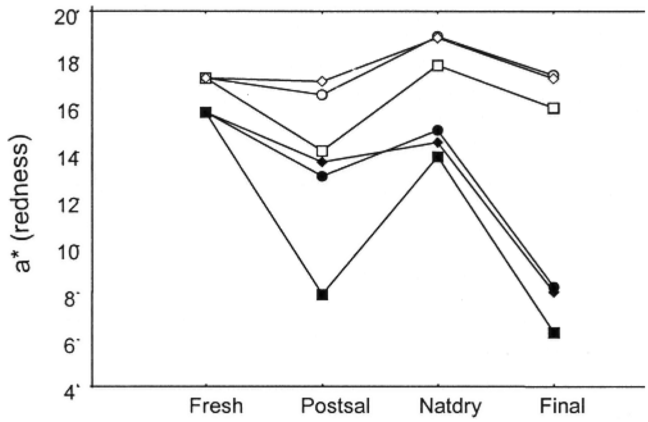

Figure 5. Plot of means of $a*$ (redness) for interaction of time in process, muscle location and rearing system. The labels of groups are: Olivenza/*Biceps femoris* (○); Higuera/*Biceps femoris* (□); Montánchez/*Biceps femoris* (◇); Olivenza/*Semimembranosus* (●); Higuera/*Semimembranosus* (■); Montánchez/ *Semimembranosus* (♦).

from white pigs (Fernández et al., 1991; Perez-Alvarez et al., 1999). Loss of moisture raises the concentration of pigments such as myoglobin, thus directly causing a reduction in the parameter $L*$, as reported by other authors in meats from various different sources (Estévez et al., 2003) which would explain the data recorded in this study.

The variation in the mean values of the colour parameter $a*$ (redness) (ranging from 6.10 to 19.84) as affected fundamentally by muscle location, time in process and climatic conditions, are presented in Figure 5. Unlike the case of parameter $L*$, values of $a*$ were lower at the end of processing only in the samples taken from the *semimembranosus* muscle. The fall in $a*$ values in this muscle was greatest during the time from natural drying until the end of processing. The pattern of variation in *biceps femoris* muscle was different: in most cases, values fell from the outset up to the post-salting stage; thereafter they increased up to the end of the natural drying stage, then decreased again up to the end of processing. We know that visual perception of redness in Iberian ham varies according to the muscle concerned (Cava et al., 2000). One of the reasons why the parameter $a*$ decreases in the course of processing could be an increase in the concentration of metamyoglobin, as explained by Estévez et al. (2003) for a similar phenomenon observed during storage of fresh *longissimus dorsi* muscle from Iberian pigs. The $a*$ values recorded were generally lower in *semimembranosus* than in *biceps femoris* muscle. This could be due in part to a greater concentration of nitrifiers in the *semimembranosus* muscle (Rodríguez et al., 1994) and has also been reported in cured white pig ham (García Esteban et al., 2003).

The values of the colour parameter $a*$ were smaller in the hams from Iberian pigs reared in confinement, if not always to a statistically significant extent ($p < 0.05$). Differences due to the rearing system were smallest at the end of processing ($p > 0.05$), which could indicate that changes occurring in the course of curing influence $a*$ more than feeding does. Free-range rearing increases the myoglobin content in the musculature (Weiler et al., 1995; Lindahl et al., 2001) and the proportion of oxidative red fibres (Andrés et al., 2000) and that is one of the reasons why $a*$ values were higher, as reported in fresh *longissimus dorsi* muscles of Iberian pig (Cava et al., 2003). The decrease in $a*$ was greatest between natural drying and the end of processing in the *semimembranosus* muscle. The $a*$ values recorded in fresh muscle were lower than reported by other authors, also in Spanish Iberian ham (Andrés et al., 2000). However, the $a*$ values recorded for the finished product in the present study were higher than those reported in Alentejo Iberian ham (Elías and Carrascosa, 2000).

The variation in the mean values of the colour parameter $b*$ (yellowness) ranged from 2.18 to 8.72 and was affected fundamentally by processing time, muscle location and climatic conditions without taking into account the rearing system (Figure 6). In general, $b*$ values decreased as the time in process increased, and the decrease was more pronounced in *semimembranosus* muscle. A similar phenomenon has been reported in the curing of white pig ham (Fernández et al., 1991). The recorded values were lower in hams from intensively-reared pigs, except in the sample from the start of processing, where the opposite was true ($p < 0.05$). The same downward trend in values in hams from intensively-reared pigs has been reported by other authors in fresh Iberian ham muscle (Andrés et

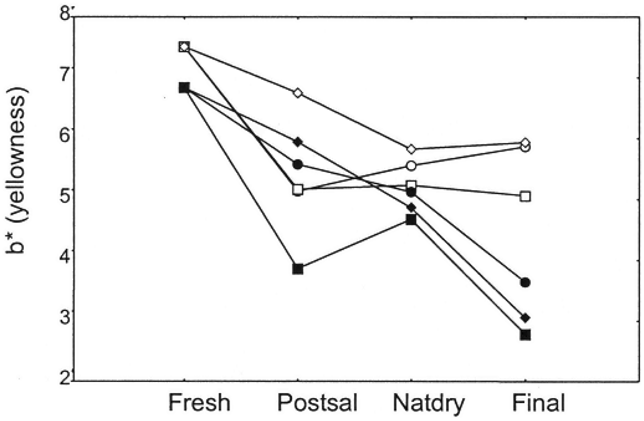

Figure 6. Plot of means of *b** (yellowness) for interaction of time in process, muscle location and climiatic conditions. The labels of groups are: Olivenza/*Biceps femoris* (○); Higuera/*Biceps femoris* (□); Montánchez/*Biceps femoris* (◇); Olivenza/*Semimembranosus* (●); Higuera/*Semimembranosus* (■); Montánchez/ *Semimembranosus* (♦).

al., 2000). The reason could be that confined animals have a higher percentage of infiltrated fat (Cava et al., 2000). The *b** values were different ($p < 0.05$) in the Higuera la Real samples, as were the values of colour parameters *L** and *a**. In the Olivenza and Montánchez samples, the differences between initial and final values of *b** were not statistically significant ($p > 0.05$).

The variations in colour parameters (*L**, *a** and *b**) were affected by all the factors addressed in this work, and by some of the interactions, but the most influential factors were the time in process and the muscle location. The influence of these two factors has also been observed during the manufacture of Spanish dry-cured hams from white pigs (Forcen et al., 1993; Perez-Alvarez et al., 1999).

In summary, the main effects of the four target factors, considering the results of the S-N-K test, were as follows.

In the first stage of processing (fresh samples): (*i*) neither the type of muscle nor the type of feed produced differences in the values of the parameter *L**; (*ii*) both the type of muscle (SM < BI) and the type of feed (MF < AC) produced differences in the values of the parameter *a**; (*iii*) the type of feed (AC < MF) produced differences in the values of the parameter *b**, which were more pronounced in samples of BI muscle; (*iv*) moisture values varied depending on the muscle analysed (BI < SM).

In the final stage of processing (final samples): (*i*) values of the parameter *L** differed according to the muscle analysed (SM < BI) and the type of feed (MF < AC); (*ii*) values of the parameter *a** differed according to the muscle analysed (SM < BI) and the drying location (2 < 1 or 3); (*iii*) values of the parameter b* differed according to the muscle analysed (SM < BI), the type of feed (MF < AC) and the drying location (2 < 1 or 3); (*iv*) moisture values differed according to the muscle analysed (BI < SM) and the drying location (2 < 1 or 3); (*v*) all values of the target parameters were lower at the end than at the beginning of processing, irrespective of the type of feed, the muscle analysed and the drying location.

ACKNOWLEDGEMENTS

This work has been partially supported by a Research Project from the Spanish Comisión Interministerial de Ciencia y Tecnología (CICYT, ALI97-0588).

REFERENCES

Andrés A.I., Ruiz J., Mayoral A.I., Tejeda J.F. and Cava R. (2000). Influence of rearing conditions and crossbreeding on muscle color in Iberian pigs. *Food Science and Technology International* **6**(4): 315–321.

Ansorena D., de Peña M.P., Astiasarán I. and Bello J. (1997). Colour evaluation of chorizo de Pamplona, a Spanish dry fermented sausage: comparison between the CIE *L*a*b** and the Hunter Lab Systems with Illuminants D65 and C. *Meat Science* **46**: 313–318.

Bacus J. (1984). *Utilization of Microorganisms in Meat Processing. A Handbook for Meat Plant Operators.* Letchworth: Research Studies Press Ltd.

Cava R., Estévez M., Ruiz J. and Morcuende D. (2003). Physicochemical characteristics of three muscles from free-range reared Iberian pigs slaughtered at 90 kg live weight. *Meat Science* **63**: 533–541.

Cava R., Ventanas J., Ruiz J., Andrés A.I. and Antequera T. (2000). Sensory characteristics of Iberian ham: influence of rearing system and muscle location. *Food Science and Technology International* **6**(3): 235–242.

Elías M. and Carrascosa A.V. (2000). Effect of processing and slicing methods on the microbiological and physicochemical aspects of vacuum-packed Iberian ham. *Fleischwirtschaft* **2**: 36–41.

Essen-Gustavsson B., Karlsson A., Lundström, K. and Enfält, A.C. (1992). Intramuscular fat content and lipid in muscle fibres of pigs fed high and low protein and relation to meat quality. In: *Proceedings of 38th International Congress of Meat Science and Technology.* 3–28 August, Clermont-Ferrand, France, pp. 41–44.

Estévez M., Morcuende D. and Cava R. (2003). Oxidative and colour changes in meat from three lines of free-range reared Iberian pigs slaughtered at 90 kg live weight and from industrial pig during refrigerated storage. *Meat Science* **65**(3): 1139–1146.

Fernández A.D., Pérez J.A., Sayas M.E. and Aranda V. (1991). Caracterización física y físico química del jamón curado: influencias sobre el color en la etapa de maduración. *Anales de Investigación del Master en Ciencia e Ingeniería de los Alimentos* **1**: 921–937.

Forcen R., Perez J.A., Gago M.A. and Aranda V. (1993). Evolución del color en los períodos de salado y postsalado en la elaboración de jamón curado. *Anales de Investigación del Master en Ciencia e Ingeniería de los Alimentos* **Vol III:** 545–562.

Francis F.J. and Clydesdale F.M. (1975). *Food Colorimetry Theory. An Application*. Westport: Avi Publishing Company.

García-Esteban M., Ansorena D., Gimeno O. and Astiasarán I. (2003). Optimization of instrumental colour analysis in dry-cured ham. *Meat Science* **63**: 287–292.

Hoffmann K. (1993). Quality concepts for meat and meat products. *Fleischwirtschaft* **73**: 1014–1019.

Lindahl G., Lundström K. and Tornberg E. (2001). Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and from pure breed pigs. *Meat Science* 59: 141–151.

Lücke F.K. and Hechelmann H. (1987). Starter cultures for dry-sausage and raw ham. Composition and effect. *Fleischwirtschaft* **67**: 307–314.

Monin G. and Ouali A. (1991). Muscle differentiation and meat quality. In: Lawrie R. (ed.), *Developments in Meat Science*. Vol. 5, Essex: Elsevier Applied Science, pp. 89–157.

MacDougall D.B. (1982). Changes in the colour and opacity of meat. *Food Chemistry* **9**: 75–88.

Martín-Alvarez P.J. (2000). *Quimiometría Alimentaria*. Madrid: UAM Ediciones.

Möhler K. (1984). *El curado*. Zaragoza: Editorial Acribia S.A.

Perlo F., Gago-Gago A., Rosmini M., Cervera-Pérez R., Perez-Alvarez J., Pagán-Moreno M., López-Santovera F. and Aranda-Catalá V. (1995). Modification of physico-chemical and colour parameters during the marketing of paté. *Meat Science* **41**: 325–333.

Perez-Alvarez J.A., Sayas-Barbera M.E., Fernandez-Lopez J., Gago-Gago M.A., Pagan-Moreno M.J. and Aranda-Catala V. (1999). Chemical and color characteristics of Spanish dry-cured ham at the end of the aging process. *Journal of Muscle Foods* **10**(2): 195–201.

Pribis V. and Svirzic G. (1995). Application of modern colour systems in investigation of colour changes in dry fermented sausages during production. *Fleischwirtschaft* **75**: 819–821.

Rodríguez M., Núñez F., Córdoba J.J., Sanabria C., Bermúdez E. and Asensio M.A. (1994). Characterization of *Staphylococcus* spp and *Micrococcus* spp isolated from Iberian ham throughout the ripening process. *International Journal of Food Microbiology* **24**: 329–335.

Sanabria C. (2001). *Aspectos de la calidad del jamón ibérico extremeño: putrefacción profunda*. Doctoral Thesis, Universidad Extremadura Badajoz.

Weiler U., Appell H.J., Kremser M., Hofacker S. and Claus R. (1995). Consequences of selection on muscle composition. A comparative study on gracilis muscle in wild domestic pigs. *Journal of Veterinary Medicine (Series C)* **24**: 77–80.