Review: Achievements, needs and perspectives in dry-cured ham technology: the example of Parma ham

Revisión: Avances, necesidades y perspectivas de la tecnología del jamón curado: el ejemplo del jamón de Parma

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Palabras claves: jamón curado, jamón de Parma, control de calidad

Keywords: dry-cured ham, Parma ham, quality control

INTRODUCTION

Consumer acceptance for dry-cured ham relies on typical flavour properties imparted by complex biochemical phenomena occurring during lengthy processing and ageing. In the last decade significant advances in the knowledge of structural changes involving lipids and proteins and related effects on dried ham qualities have been due to chemical (Berdagué *et al.*, 1991; García *et al.*, 1991; Barbieri *et al.*, 1992) and sensory profile studies (Parolari, 1994a). Relation studies between distinctive sensory attributes and compositional data (Careri *et al.*, 1993; Buscailhon *et al.*, 1994) have shown that low-weight nitrogen compounds and a wide array of volatile compounds play a role in perception of those flavour traits that are unique to dry-cured ham. Most low-weight components have been linked to fragmentation patterns occurring in maturing pork as a result of endogenous enzyme activity.

The role of muscle enzymes as potential precursors of free amino acids and low-weight peptides has been mainly addressed by Spanish researchers who have also investigated the possible effects of curing adjuncts on enzymes extracted from selected muscles or from pigs of different weight and breeding (Toldrá *et al.*, 1993; Sárraga *et al.*, 1993; Toldrá *et al.*, 1995). Other authors (Virgili *et al.*, 1995) have demonstrated that abnormal proteolytic enzyme activity may be the cause for defective softness and white film discoloration, two major complaints from consumers and retailers. Additional benefits to the ham industry are expected from biochemical studies aimed at hog breeding and meat quality optimisation, or from studies relating animal feeding to meat lean and fat properties (Anon, 1993; Mitsumoto *et al.*, 1993).

In addition, efforts are needed to bridge the knowledge gap in processing technology, which still relies on empirical bases and closely resembles manufacturing techniques that have been adopted for centuries in the southern regions of Europe. Though most steps in manufacturing have been automated, helping to manage labour costs, overheads are still overwhelming because of high locking up of capital and, what is worse, significant amounts of defective or rejected produce.

To reduce costs, accelerated curing techniques have been suggested by American authors such as ham tumbling, the use of starter cultures, skinning or de-boning of legs prior to salting and drying at increased temperature (Marriott *et al.*, 1992). Further research is needed to establish if fast processed, less expensive hams would comply with consumer ex-

Received 26 September 1995; revised 27 December 1995.

pectations in those areas, such as southern Europe, where dry-cured ham consumption is a deep-rooted food habit.

Optimizing processing technology still preserving consumer acceptance is a prime objective for the modern ham industry. In view of this, efforts should be made to reduce costs by managing the problem of defective hams through improvement of current technologies.

The present paper describes the main advances in the last two decades in dry-cured ham technology as adopted in Italy. Parma ham was the item of choice because of the large amount of experimental data available from research studies, and the availability of professional assistance from several manufacturing units.

TECHNOLOGY OF PARMA HAM

To process pork legs into Parma hams, manufacturers have to comply with requirements established by the Parma Ham Consortium Regulation (DPR, 1978). Early statements were aimed at establishing criteria for fresh-leg supply and rejection of defective produce. A very recent issue, effective as of 1 January 1996, states that 12 months old Parma ham must not exceed the following composition values (measured on defatted biceps femoris muscle): moisture, 63.5%; salt, 6.7%; non-protein nitrogen (NPN) 31%. Further requirements must be met for fresh fat quality and pig feeding.

Though wide use of automation and remote control was made in time, the principles underlying manufacturing techniques do not differ from the original ones. Basic procedures for Parma ham preparation are as follows.

Fresh meat

Legs are cut from hot-sectioned carcasses just after slaughter, hung by hooks to facilitate bleeding, and allowed to chill for at least 24 h at 0–3 °C. The aitch bone is completely removed except for a small portion which is left on the cushion, to avoid a hollow-like shape. Foot-less legs are then trimmed of meat from 6 cm below the femur knob to ensure circular, regular shape. Typically, legs to be processed into Parma hams will weigh 11–13 kg on average to meet the requirement that dry-cured hams must weigh at least 7 kg after ageing.

Hams, grouped according to weight class, are placed on plastic or steel shelves and held for 24–36 h at low temperature (1–4 °C) in order to attain a uniform temperature. These should not vary by more than 2–3 °C between the outside and the core of the leg. Legs with inner temperature lower than 0.5 °C are generally regarded as unready for salting, since salt penetration, and consequently, water activity reduction, might be negatively affected.

Salting

Salt is the only additive allowed since nitrate was banned in 1993. Medium-to-coarse grain sea salt is added to the hams just after they have been mechanically bled. This is an automated three-step procedure, where a steel belt first moves the hams through floating rollers enabling vein and artery purging. Then skins are rubbed with wet coarse salt containing 20% water. Finally the hams are sprinkled with hopper-supplied medium-grain dried salt. Typical amounts of added salt are in the range 2–3% of ham weight for dry salt and 1–2% for wet salt, respectively.

In recent years, increased usage of robotized loading and unloading devices has enabled further reduction of personnel at the salting stage, and this phase of processing is continuously surveyed by experts, to check for possible errors in salt addition.

Placed on shelves, the hams are located into a first salting (S1) cold room held at 1–4 °C. To ensure salt solution, relative humidity must be kept high (75–90%); accordingly, compressors in this phase will run for short periods, and attention should be paid to prevent meat from surface drying.

Salt is renewed after 5–6 days by using the previously described machinery, equipped with an additional unit for residual salt removal and massaging rollers. Salt used at this step is usually 1% less than the amount employed at first salting, and some additional salt is usually hand-sprinkled onto the knob region, which is generally recognized to be more prone to surface spoilage. Placed on clean shelves, the re-salted hams are held for an additional 3 weeks in a so-called second salting (S2) room, kept at 1–4 °C and 70–80% RH, (i.e. lower than in S1), to favour mild dehydration of abundant surface moisture. Typical running and stopping time for compressors in this phase is in a 2 to 1 ratio, but most processors assert that larger values are desirable to cope with increasingly wet meats. After completion of this stage, hams are passed through de-salting and massaging units and are trimmed of excess meat around the knob. The ends of the aitch bone are also mechanically cut, to yield a smoother, regular butt surface. Though lengthy and labour costly, trimming is accomplished by all manufacturers for purposes of appearance and more importantly to aid subsequent drying of more critical surface areas.

Resting

Hung by twines strung around the shank, the hams are kept cold for 2 to 3 months, to favour salt equalisation and a_w reduction by adequate shrinkage. This treatment is generally accomplished in two subsequent stages, called first and second resting (R1 and R2 respectively), differing essentially in RH values, with temperature encompassing the same range (1–4 °C). Intensive drying during R1 is obtained by powerful machines enabling RH to reach values as low as 50–60%. After 2 weeks, the hams are transferred into a cold room (R2), where RH is raised to 70-90%, in order to prevent crusting of outer muscles and consequent moisture pockets inside the ham.

Washing and drying

Salt streaks and traces of microbial slime are washed off the ham surface by high pressure injection of lukewarm water. A main advantage of this procedure over the old-fashioned washing by soaking and brushing is the prevention of possible microbial contamination through the hock.

Wet hams are placed in a drying room at 20 °C for 12 h, after which the temperature is decreased gradually to 15 °C over 6 days. Higher temperatures are no longer in use in this phase, as they might result in abnormal swelling or uncontrolled enzyme activation.

Maturing and ageing

Lengthy ripening at mild temperatures takes place up to completion of the required overall duration of 10 or 12 months (for end-weight lower or greater than 9 kg, respectively). Typically, maturation is carried out at lower temperature than ageing (15 *vs.* 18 °C) and higher RH (75% on average, vs. 65%). After 6 to 7 months of processing, the maturing hams are smeared with a spreadable mince made up of pork fat and rice flour, to prevent excessive drying of lean meat. An entirely manual treatment, this process is by far the most expensive in terms of labour cost; nevertheless some manufacturers use it twice, i.e. at 5 and 7 months, to favour moisture equalization between meat layers. The former fat application is often performed in a less accurate way by quick spraying. Depending on weather conditions and fat mince composition, the ageing hams may undergo mould and yeast contamination, which is more likely to occur in small units lacking air-conditioning systems.

MAIN PROBLEMS IN DRY-CURED HAM PROCESSING

Microbial defects

Problems of microbial origin have long affected the ham industry, and are still far from being completely wiped out. The onset of microbial spoilage is easily and cheaply assessed through the 'probe-and-sniff' technique, consisting of quick insertion and sniffing of a thin horse bone into selected ham areas where off-smells are more likely to develop (Figure 1). Most defects show dependence on season (Parolari, 1994b), with spoilage of deep shank muscles prevailing in cold months, while surface areas are mainly affected in summer (Figure 2).

Overall, occurrence of off-odours has decreased systematically during recent decades (Figure 3),

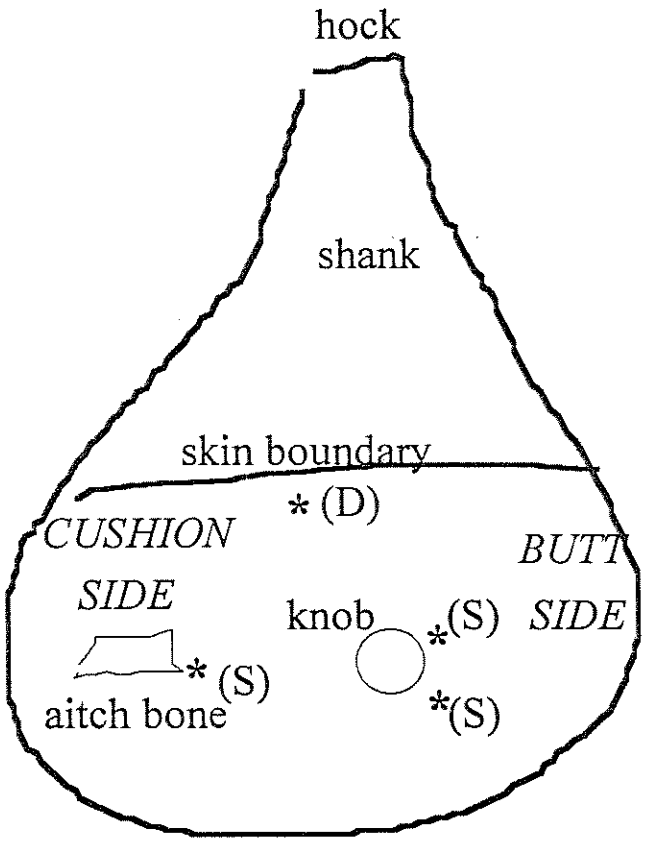

Figure 1. Quality control of dry-cured ham by 'probing and sniffing'. An asterisk shows where the probe is to be inserted for the search of surface (S) and deep (D) off-odours.

Figura 1. Control de calidad del jamón curado mediante la prueba de 'cala y ofateo'. El asterisco indica donde debe introducirse la sonda para el estudio de los "olores extraños" superficiales e internos.

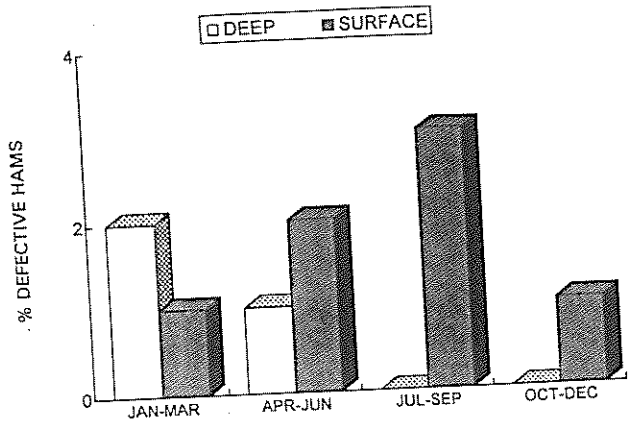

Figure 2. Occurrence of off-odours in Parma ham. Frequency distribution by manufacturing quarter.

Figura 2. Frecuencia de aparición de olores extraños en el jamón de Parma. Distribución por trimestres segun la elaboración.

due to the following two reasons: (i) microbiological studies have identified the limiting NaCl and a_w values for the inhibition of spoilage bacteria (Campanini *et al.*, 1985; Manganelli *et al.*, 1993), and (ii) since the early 1970s most factories have been equipped with coolers to enable manufacturing all throughout the year. Controlling the temperatures has resulted in more effective prevention of internal spoilage in hams that were otherwise kept at uncontrolled ambient temperature when their a_w was still too high to prevent spoilage.

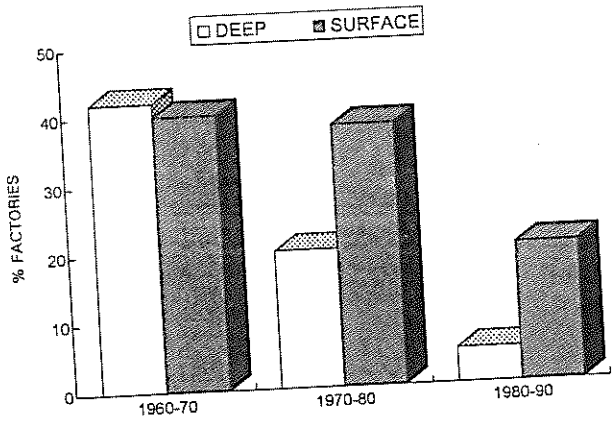

Figure 3. Trend in occurrence of spoilage defects in Parma ham. Estimated percent of factories affected by surface and deep off-odours (Parolari, 1994b).

Figura 3. Tendencia en la aparición de causas de deterioro del jamón de Parma. Porcentaje de fábricas afectadas por la aparición de olores extraños superficiales e internos (Parolari, 1994).

Unlike deep spoilage, surface odours appeared to be only slightly affected by temperature conditioning. Instead, their prevention required intensive cold drying in the early resting phase (R1), which has only been achieved by some manufacturers since the mid 1980s, resulting in a late decrease of surface off-odours (Figure 3). Today, the persistence of surface defects in summer (Figure 2) indicates that more rapid a_w drop would be required to manage heavier contamination of fresh meat that is customary in hot season.

Late to develop during ageing, a phenol or potato like off-smell may sometimes affect the lean tissue close to the aitch bone. Unlike the other surface defects, this off-odour has been related to specific types of moulds or bacteria growing inside the aitch bone and imparting the surrounding meat either off smell or both, depending on the strains being involved (Spotti *et al.*, 1988; Blanco *et al.*, 1994).

Non-microbial defects

The increasing sales of sliced and vacuum-packaged sectioned hams has raised problems related to their appearance. Hams displaying poor colour or texture qualities have less chance of meeting the consumer expectations. Visual rating of ham cuts may be severely impaired by the following recurring blemishes mainly affecting the lean portions.

Colour

As a rule, stable homogeneous red colour of tissue is accepted. Colour fading due to small brown spots on the lean surface is a rather frequent occurrence and a major cause of rejection from retail. Poor colour rating is also related to wide bright shadows or quick discoloration which sometimes affect the freshly cut ham surface.

Normally, the above-mentioned defects do not originate from microbial spoilage, as confirmed by regular microbial loadings usually found in coloured hams. Rather, electrical and, to a lesser extent, CO_2 stunning of pigs is a prime cause of dark brown blood spots spreading within the leg muscles, in particular, in those of the cushion. Also affected is the cushion portion just after sectioning is bright-to-grey fading, which usually involves the semitendinosus (ST) muscle. An ascertained cause of the latter is abnormal protein breakdown induced by endogenous muscle enzymes. Uncontrolled proteolytic cleavage is believed to impair the integrity of myofibrin, which is of paramount importance in a binder-free meat product such as Parma ham. Primary causes of brown fading are moisture retention

muscle core, often enhanced by abundant marbling peculiar to the ST muscle, and crusting of surface lean tissue resulting from delayed fat mince application.

The meat close to the shank bone may sometimes display a brown discoloration also termed 'shank burn', resembling 'cold burns' of badly processed frozen meats. Burnt meat blemish may originate from too early drying of shank skin yielding stiff skin and incomplete salting of the inside. Hardened rind does not stick to shrinking muscle and internal air pockets are generated; oxidation of the meat will eventually result in myoglobin discoloration.

White crystals

A major disadvantage to ham packers is the formation of white crystals as a powder film or coarse chalks on the cut surface as result of insoluble peptide and free amino acid (mostly tyrosine) precipitation. An entirely biochemical, non-microbial phenomenon, tyrosine crystals (as they are often referred to by manufacturers) have been related to proteolytic activity of endogenous enzymes, mainly cathepsin B. The process is strongly activated by high drying temperatures and enhanced by low-salt treatment. The packaging technique has less influence on this aspect, and the available plastic films play a minor role in the prevention or delaying of white crystal discoloration. In contrast, the combined use of low-cathepsin meat and/or suitable salt levels looks promising in controlling the problem of white film development and, in general, of defects resulting from excessive proteolysis (Virgili, 1994; Figure 4).

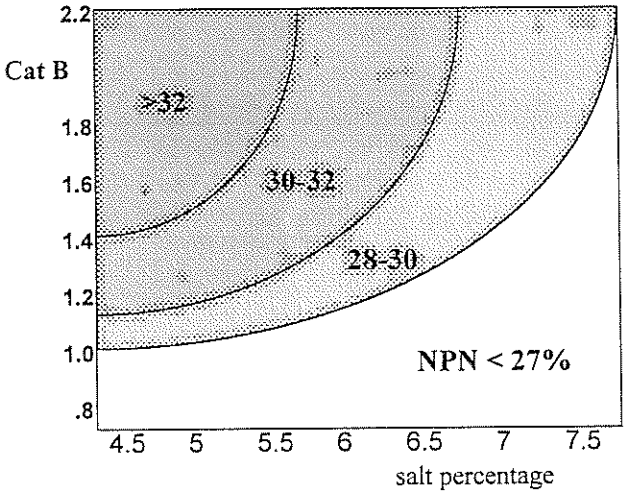

Figure 4. Non-protein nitrogen (NPN) in dried ham as a function of salt concentration and cathepsin B (Cat B) activity in fresh meat. Areas differing in shading correspond to ham classes with different NPN values. The Parma ham regulation rules out hams with NPN>31%. Figure adapted from Virgili (1994) with permission of the author.

Figura 4. Nitrógeno no proteico (NPN) en el jamón curado en función de la concentración y la actividad de la catepsina B (Cat B) en la carne fresca. Las diferentes áreas sombreadas corresponden a jamones con distintos valores de NPN. La regulación del jamón de Parma exige un contenido de NPN>31%. Figura tomada de Virgili (1994) con permiso del autor.

Poor texture

Abnormal softness may affect either surface meat or inside muscles, impairing sliceability and mouth-feel quality of aged hams. Surface softening is a consequence of improper fat mince application, where early treatment or too heavy coating may result in moisture retention by outer meat layer. Softness of inside muscles such as semitendinosus and biceps femoris is more likely to be found in heavy hams or those containing little salt, as a consequence of incomplete water equalization or limited fibre swelling. Less frequently, abnormal softness is due to a loss of skeletal properties of muscle bundles resulting from uncontrolled protein cleavage. Proteolysis-linked poor texture has been shown to depend on the same mechanism described for white crystal precipitation. Hams exhibiting defective texture are much more prone to tyrosine crystals or white film discoloration. In order to prevent defective texture and related problems, the Consortium for Parma ham has established upper limits for moisture content and proteolysis values (63.5% and 31%, respectively) for hams to be certified as Parma hams.

CONTROL OF PROCESSING

Empirical quality control has long been based on the visual and odour properties of hams at several stages of manufacturing. Efforts to make the task more reliable and quantitative have included training personnel in the collection of processing data and the use of basic statistics for selection of relevant descriptors to be used in routine quality control. Packages have been developed which enable multi-purpose scoresheets to be easily adapted to the specified needs of the ham factory. Moreover, continuous recording of temperature, relative humidity and weight shrinkage has become available, making remote control of curing and maturing rooms an easily affordable task.

Table 1 reports a medium-size scoresheet used by 10% of Parma ham factories that adopted quality control procedures in the last decade. More complex data bases are rarely encountered (1–2% of

Table 1. Sensory[a] and instrumental descriptors of Parma ham technology.

Tabla 1. Descriptores sensoriales[a] e instrumentales del proceso tecnológico del jamón de Parma.

N	Descriptor/stage	Comment	Reference values
Fresh meat			
1	External temperature of fresh ham	Measurement at 1cm-depth, butt region, close to the knob. Average of 5 samples per batch	0–4 °C
2	pH	Measurement on the semimembranosus muscle (SM). Average of 10 samples per batch	5.6–6.1
3	Intramuscular fat (sensory)	Visual assessment of SM muscle after removal of a thin (2–4mm) meat layer	0 = no visible white; 9 = white exceeding 50% of meat surface
4	Brown spots (sensory)	Use the same samples prepared for assessment of intramuscular fat	0 = devoid; 9 = 3 spots or more
5	Dryness (sensory)	Tactile perception of dryness by skin and meat touching	9 = no wet left to the hand after touching
6	Cold storage time	Days elapsed prior to salting	
	End of 1st salting		
7	Internal temperature of ham before salting	Insert needle thermometer close to the knee, cushion side. Average of 5 samples per batch	1–3 °C
8	Salt added	As % original batch weight	
9	Weight loss after 1st salting	As % original batch weight	
10	Meat colour (sensory)	Visual assessment of salt-induced meat browning	0 = red; 9 = completely brown surface meat
11	Average RH during 1st salting	Calculated from RH values recorded in the 1st salting room	
	End of 2nd salting		
12	Salt added	As % original batch weight	
13	Weight loss after 2nd salting	As % original batch weight	
14	Average RH during 2nd salting	Calculated from RH values recorded in the 2nd salting room	
15	Meat conductivity after 2nd salting	Needle conductometer insertion at 5cm depth, SM muscle	
16	Meat colour (sensory)	Visual assessment of surface colour	0 = red; 9 = brown surface meat
17	Meat texture (sensory)	Hand compression of lean meat, SM muscle	0 = soft, plastic (like unsalty raw meat); 9 = very hard, elastic
18	Meat trimming performance (sensory)	Visual assessment of hams after trimming	9 = well trimmed meat around the knob
End of 1st resting			
19	Weight loss after 1st resting	As % original batch weight	
20	Average RH during 1st resting	Calculated from RH values recorded in the 1st resting room	
21	Minimum RH during 1st resting		
22	Maximum RH during 1st resting		
23	Surface dryness (sensory)	Visual/tactile assessment of surface meat and skin dryness	0 = extremely wet; 9 = no surface wetness
24	Holes or fissures (sensory)	Checking for muscle disjunction	0 = devoid; 9 = 3 holes or more
25	Meat texture (sensory)	Hand compression of lean meat, SM muscle	0 = soft, plastic (like unsalty raw meat); 9 = very hard, elastic
End of 2nd resting			
26	Weight loss at the end of resting	As % original batch weight	
27	Average RH during 2nd resting	Calculated from RH values recorded in the 1st resting room	
28	Minimum RH during 2nd resting		
29	Maximum RH during 2nd resting		
30	Surface dryness (sensory)	Visual/tactile assessment of surface meat and skin dryness	0 = wet; 9 = extremely dry
31	Holes or fissures (sensory)	Checking for muscle disjunction	0 = devoid; 9 = 3 holes or more
32	Meat texture (sensory)	Hand compression of lean meat, SM muscle	0 = soft; 9 = hard, elastic
33	Surface moulds/yeasts (sensory)	Visual assessment of moulds/yeasts spreading	9 = more than 50% surface spreading
	Half maturing (fat application)		
34	Weight loss	As % original batch weight	
35	Surface meat hardness (sensory)	Hand compression of lean meat, SM muscle	0 = soft; 9 = extremely hard
36	Cover fat oxidation (sensory)	Visual assessment of rancidity	0 = white; 9 = orange to brown
37	Mould/yeast spreading (sensory)	Visual assessment of surface moulds/yeasts	9 = more than 50% surface spreading
38	Mite spreading (sensory)	Visual assessment of mites on the ham surface	9 = more than 30% surface spreading
	End product		
39	Spoiled odour (deep)[b]	Per cent defective hams in the batch. By probe-and-sniff technique	0 = no spots, homogeneous colour; 9 = 3 brown spots or more; severe browning
40	Spoiled odour (surface)[b]	Per cent defective hams in the batch. By probe-and-sniff technique	
41	Defective colour (sensory)	Visual assessment of cut surface	
42	Defective texture (sensory)	Hand compression on cut ham, semitendinosus muscle	0 = extremely soft, mushy; 9 = extremely hard on compression

[a] Sensory evaluations scored on a 0–9 scale (0 = devoid, 9 = maximum perception of the attribute). Average score of at least 5 hams per batch.
[b] By 'probe-and-sniff' technique.

cases), while oversimplified ones are more popular among beginners. Though apparently huge and time consuming, a medium-size processing card is rather simple to fill in by personnel acquainted with principles of quality control and sampling routines. For training and maintenance, standard references or standard concepts may be provided, such as those given in Table 1 to anchor either or both extremes of the rating scale. Typically, 6 to 12 months will be needed for a skilled technician to become familiar with data collection and its subsequent usage within a quality control project.

EXAMPLE

The following case study describes basic steps towards implementation of a quality control system in a ham factory. Data were collected in a 2-year survey and were statistically handled to select critical processing variables or variables relevant to the factory under examination. The chosen variables were eventually used in the building of general-purpose control charts.

Statistical data analysis

Statistical analysis followed data collection, which encompassed two years of production and was based on measurements reported in Table 1. Preliminary work was aimed at acquainting two skilled workmen with descriptor usage and data arrangement by an electronic spreadsheet program. Data collection, consisting in the follow up of two ham batches per week, generated a data table of 42 processing variables 208 ham batch records. Extra wages to personnel in charge of data collection raised overall labour costs by 0.5%.

No processing variable was found to be related to any defective ham property in a preliminary univariate approach to data analysis based on one-way ANOVA and linear regression. Therefore a multivariate technique such as principal components analysis (SIMCA-R, 1992) was used to search for possible linkage between variables and for selection of more relevant descriptors of processing. The basics of this technique and the main features of pattern recognition procedures in the handling of large data tables commonly dealt with in food science

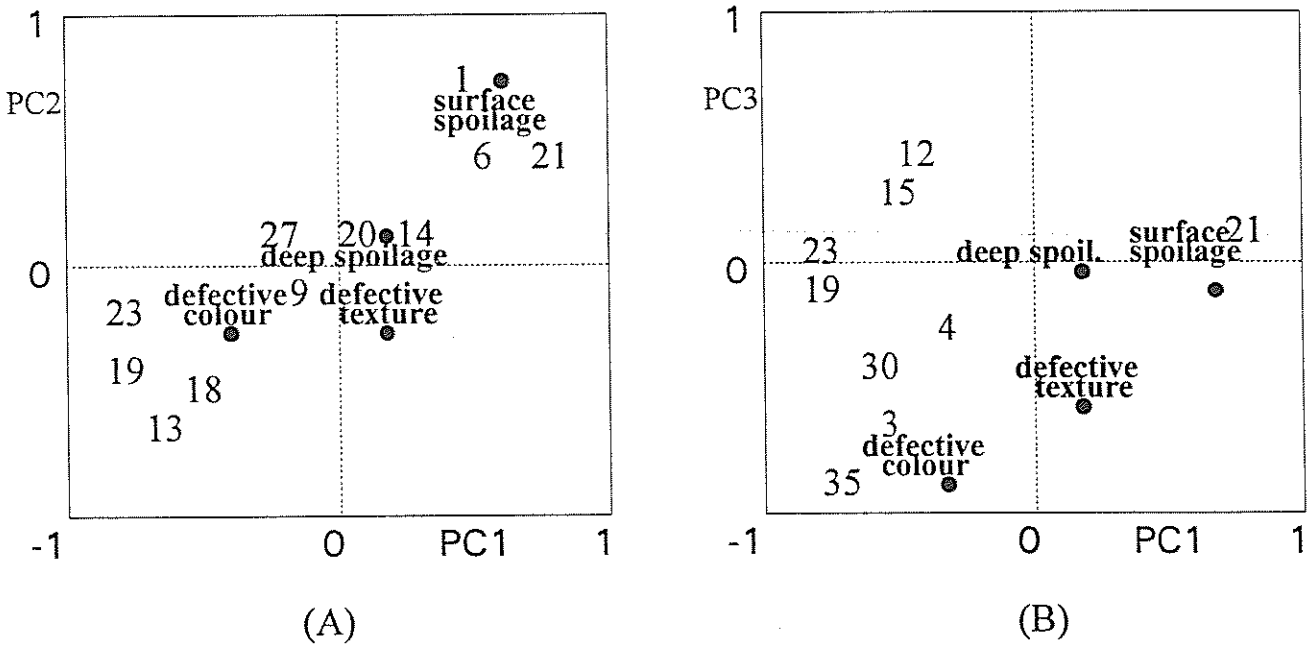

Figure 5. Selection of relevant descriptors of processing by Principal Components Analysis. Projection of processing and sensory variables on the plane of the first two components (A) and on the plane of the third vs. first component (B). Processing descriptors are denoted by their numbers in Table 1. PC1 is related maintly to surface spoilage, and PC2 and PC3 are essentially related to defective colour.

Figura 5. Selección de los descriptores relevantes en la elaboracióm del jamón mediante el análisis de componentes principales. Representación de las variables de proceso y sensoriales sobre el plano de las dos primeras componentes y sobre el plano de la tercera frente a la primera (B). Para la notación de los descriptores de proceso ver Tabla 1.

have been discussed (Wold *et al.*, 1983; Virgili and Parolari, 1991).

Three significant principal components (PC1–3) explained 50% of the original variance. Their plots (Figure 5) were used to achieve a better understanding of the role of processing variables and their possible relationships to defective traits in the end product.

The first component (PC1) was related mainly to surface spoilage, which occurred at 2% in the summer production of both surveyed years. As clearly shown by their location in Figures 5A and 5B the onset of surface spoilage was linked to higher fresh meat temperature, longer cold storage of legs prior to salting and limited shrinkage after the second salting and the first resting. The latter was clearly due to less intensive drying, as suggested by raised mean RH in first resting. It is noteworthy that RH values and weight losses measured at other stages of cold processing played no role in this respect, as evidenced by negligible loadings along the first principal component. The second and, to a greater extent, third component were essentially related to defective colour, which was the second cause for ham rejection in the factory under examination. Figure 5B indicates that spotted or brown fading occurred in heavily dried hams, with more abundant intramuscular fat acting as a favouring factor. The same figure shows that poor texture, a less frequent occurrence in this study, accompanied lower salt addition which resulted in reduced in-depth conductivity.

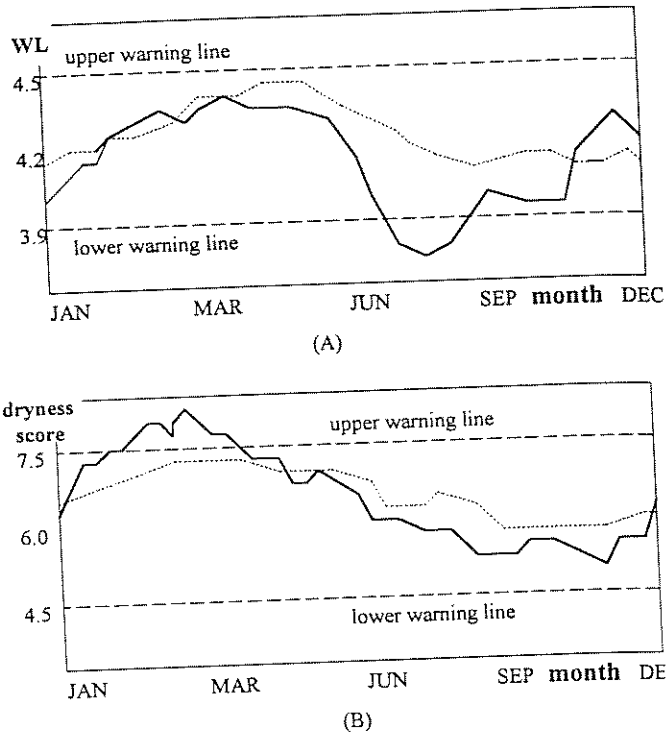

Figure 6. Control charts for weight-loss (WL) after first resting (A) and visual dryness at half maturing (B). Data from a preliminary 2-year survey (continuous line) are compared with data collected successively (dotted line), showing that the latter were under control.

Figura 6. Evolución de la pérdida de peso (WL) después del primer curado (A) y aspecto del secado a la mitad de la maduración (B). Datos obtenidos de una investigación preliminar de dos años (línea continua) frente a los obtenidos posteriormente (línea de puntos), donde se muestra que los últimos estaban bajo control

Selection of critical processing variables to be used with control charts

Two requirements were stated for descriptors to enter the pool of selected critical variables for use with control charts: (i) they had to be significantly related to the above-described PC model (based on a modelling power approach not described here), or (ii) their coefficient of variation had to exceed 10%, meaning that a variable exhibiting negligible variation was regarded as a constant of the process and dropped.

Based on these criteria for eligibility, twenty descriptors were selected for routine control of processing at the plant under survey. They were monitored on a regular basis and continuously reported by means of control charts, which allowed the critical factors to be easily followed and restored when necessary. As shown by Figure 6, two major processing variables could be successfully controlled one year after selection of critical points. As a result, surface defect occurrence was reduced by 40%. Moreover, focusing on a limited number of selected variables resulted in reduced labour costs for the personnel in charge, with a 30% saving in quality control expenditure.

CONCLUDING REMARKS

Although lengthy to achieve and initially time consuming, control of processing in the ham industry is a feasible task and a means capable of improving profitability by controlling defective traits in the finished product. An additional benefit is that by describing the process in quantitative terms each manufacturing step will become an understandable knowledge-based stage of the production process. This will rapidly result in greater reliability and will eventually make the implementation of the control methodology cost effective.

Table 2. Major problems in Parma ham production and solutions available from research studies.

Tabla 2. Principales problemas de la fabricación del jamón de Parma y sus posibles soluciones resultado de diferentes trabajos de investigación.

Problem	Main known cause(s)	Available solution	Reference
Off-odours			
Deep muscles	Spoilage from Enterobacteria strains	Control internal a_w at the end of resting. Use reduced room temperature on drying	Campanini *et al.* (1985)
Surface muscles	As above	Increase cold drying during 1st resting. Perform better meat trimming	Campanini *et al.* (1985)
Aitch bone	Growth of selected mould strains	Accelerate a_w decrease of ham surface	Spotti *et al.* (1988)
Skin-tight, shank-butt boundary	Growth of moulds/ bacteria	Prevent pouch formation during washing	Blanco *et al.* (1994)
Discoloration			
Brown spots, all muscles	Capillary haemorrhage on stunning	Reject fresh legs with surface blood spots	
Brown fading, Semitendinosus (ST) muscle	Excessive moisture retention, abnormal proteolysis. Further study needed on ST muscle biochemistry	Allow internal muscle moisture and proteolysis values to be lower than 63% and 30%, respectively	Parolari (1994b)
Black layer, external muscles	Surface muscle crusting	Improve fat mince application	
Shank burns	Skin detachment, air pouches	Improve skin salting	
White film/white chalks	Abnormal FAA[a] formation	Control muscle proteolysis. Refer to values reported in Figure 6	Virgili (1995)
Rancid, yellow, outer cover fat	Undesired fat oxidation	Reject fresh legs with iodine test value >68. Avoid light exposure and high drying temperature. Check wash water for chlorine levels	
Brown discoloration, inner fat	Unknown	Waiting for solution	
Texture			
Undesired softness, cushion muscles	Moisture retention	Enable a_w reduction to 0.91 or lower	
Undesired softness, cushion muscles	Abnormal proteolysis	Refer to composition values in Figure 6. If reduced-salt hams are to be made, use low cathepsin meat	Virgili (1995)
Flavour			
Too salty	High salt content; low pH; high moisture concentration	Comply with CPP's regulation for aged muscle moisture <63.5% and salt < 6.7% and proteolysis[c] <31%	
Bitter	Abnormal protein breakdown	Refer to values reported in Figure 6	Careri *et al.* (1993)
Process-related drawbacks			
Too high weight loss	Excessive drying; low-pH fresh meat		
Mite growth	Uncontrolled RH or temperature during maturing/ageing	Recommended range for RH and temperature during ageing: 65–70 and 15–18, respectively	
Abnormal amount of phosphates released to wash water	Improper management of resting rooms	Avoid surface crusting during resting	Grischott *et al.* (pers. comm.)

[a] Free amino acids, of which tyrosine is most abundant.
[b] Consortium for Parma ham. Regulation to begin on 1 January 1996.
[c] Non-protein nitrogen (trichloroacetic method) as percentage of total nitrogen.

As suggested by the previous case study, there is not a single quality control routine, but rather a series of procedures typical of manufacturing processes. One procedure might prove redundant for a factory or be lacking essential information for another. In the search for, and implementation of critical control factors, a factory may be greatly aided by institutional or professional scientists in order to obtain the sensory and statistical information that the small processing units usually lack.

Meat researchers are also urged to deal with and eliminate several problems still affecting the ham industry and to make results easily available to manufacturers in a usable form. As shown by Table 2, which reports a trouble-shooting guide to Parma ham manufacturers, helpful results have become available in the last few years from the research side; however, new matters have arisen at the same time, ranging from the acceleration of processing and related economic issues to environmental aspects. Most of these problems are shared by the swarm of small dry-cured ham units in Southern Europe. To help them survive, an effort is needed from meat scientists in the forthcoming years.

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