CHR HANSEN

Improving food & health

Bactoferm™ Meat Manual vol. 3

Dry-cured meat products with Chr. Hansen starter cultures

Contents

Production of dried cured meats

Introduction

The preservation of whole pieces of meat through salting, curing and potentially smoking is an ancient technique dating back to times when salting was the primary means of preservation, and it may be even older than the procedure for fermented sausages.

The products are often defined in national or even regional regulations or standards of identity. An example are the German basic principles (corresponds to GMP in Anglo-Saxon countries) which defines dried cured hams as raw meat products, which are stabilized by salting and drying.

The curing process uses ingredients like salt, nitrate and/or nitrite to obtain a preservation effect. Cured hams are smoked or non-smoked pieces of meat of stable color, typical flavor and of a consistency, which makes slicing possible.

In the European Union (EU) many of the cured meats are protected within the Protected Geographical Status (PGS) framework. Three regimes exist within this framework which came into force in 1992 (EU 2081/92, EU 501/2006): Protected Designation of Origin (PDO, most strict), Protected Geograical Indication (PGI, less strict) and Traditional Speciality Guaranteed (TSG, least strict). PDO and PGI apply to food and certain agricultural products, and the products must meet both origin and quality requirements, whereas TSG does not impose any geographical restrictions.

The use of meat cultures may not be defined in some of the PDO and PGI products.

Due to difference in animal species, meat cuts and applied technology, there is a multitude of commercial cured meat types. In Germany the name ham/Schinken always indicates that the meat is from the rear legs of a pig. For all other products, animal species or the part of muscle used must be mentioned.

Furthermore, particular aspects of the product types are expressed by the name of the product e.g. designation of origin (Prosciutto di Parma, Parma ham), special technology ("Katenschinken") or simply the name of the particular muscle used in the process (ham from muscle longissimus dorsi would be called "Lachsschinken").

General process

The industry uses different methods to introduce salt and curing agents into the core of a raw, compact piece of meat. The three most widespread methods are:

- Dry curing
- Pickle curing
- Injection curing

The next step in the process would be a "ripening in storage" or post salting step ("brennen" in German). This step is necessary to even out the difference in salt concentration between edge and centre zones of the ham. The ham obtains its typical flavor and appearance by the further maturation and drying steps. Depending on product type, a smoking process can follow. The finished ham is sold without further treatment or as a sliced and pre-packed ready-to-eat product.

Raw material

Sometimes very big differences in meat quality are found between hams. And the choice of meat and fat quality is key to an optimal end product. A few parameters should be applied as indicators of meat quality e.g. initial bacterial count, fast cooling of the carcass and of the meat.

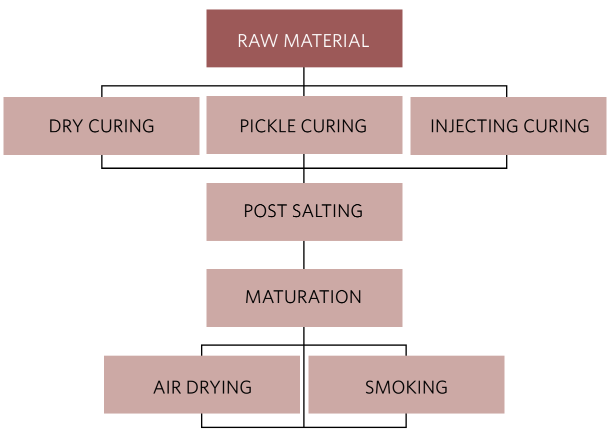


Figure 1. *Flow diagram of dry cured meat processing*

Initial bacterial count

The initial bacterial count of the meat must be low. This can be expected when the animals are rested before slaughtering and the slaughtering is done without any stress. In addition, the meat should be chilled as fast as possible.

An initial high bacterial count represents a high risk of presence of cold tolerant spoilage bacteria and pathogens. Undesired bacteria can penetrate the center of the meat by way of temperature and pH probes or during slaughtering when knives spike the meat in an unnecessary way. Furthermore, bacteria penetration is possible through the bleeding spot.

Temperature

To keep the bacterial count low the temperature in the core of the meat has to be brought **below +4°C (39.2°F)** as fast as possible. For pork this cooling has to be achieved within 24h.

The best temperature for inhibition of bacteria growth is a temperature near -1°C (30.2°F) (meat freezes at –1.6°C (34.9°F)!). Frozen meat may have a positive effect on water loss when drying, but it also releases bacteria when thawed. The resulting juice is an ideal substrate for proliferation of microorganisms. The thermometer should be checked regularly (simple method: put ice and water into a small vessel and allow for 1 minute waiting time and stir. The temperature is 0°C (32°F) until all ice has melted).

pH-value

The pH-value should be **below 5.8** in chilled meat (pH-value 24h post mortem). The pH-value is the most important hurdle (together with the chilling process) to impede the growth of micro-organisms. At pH-values above 5.8 the water binding capacity of the meat is higher and the water loss is slower throughout salting and post salting. The reason for this water binding effect at high pH is the swelling of muscle fibers at high pH-values. This "closed" structure of the meat slows down the penetration of salt and curing agents. Every piece of meat must be controlled. Therefore meat with a pH-value higher than 5.8 is unsuitable for dry cured ham and must be discarded. In practice, people often experience problems with determining the pH-value.

Therefore the following recommendations should be followed:

- Measure in muscle tissue, not in the fatty tissue or sinews
- Measure in several spots. It is not sufficient to measure only in the recommended measuring spot of the leg (muscle semimembranosus). Check as well the pH-value of the "thick flank" (nut) since this can be 1.0 units higher
- Measure for at least 15 seconds
- Calibrate the device with two buffer solutions daily and repeatedly if heavy duty is required (pH-values of 7.0 and 4.0, respectively at 25°C)
- Clean the electrode according to the manufacturer's recommendations. (e.g. the reading adapts only very slowly)
- Adjust pH-meter to meat temperature.
- The tip of the electrode must always be directed downwards. A horizontal handling of the probe leads to wrong results (air bubble in probe moves over the electrode)

Other aspects

Besides the three parameters for the meat quality the condition of the fatty tissue or the age of the animals play a decisive role. The texture of the fat mainly depends on the saturation of the fatty acids. The higher the quantity of unsaturated fatty acids, the more liquid and soft is the texture (low melting point). The soft texture of the pork fat can be explained mainly by the presence of oily acids. The proportion of unsaturated fatty acids in the fatty tissue can be influenced by feeding. Oil-seeds or their pulps make the fat softer. More solid fat is obtained by feeding of e.g. coconut oil.

The age of the animal is important as well. Meat of old animals has a high content of myoglobin. This is an advantage for the formation and stabilization of the curing color.

Furthermore, various residues can influence the raw ham production negatively, e.g. antibiotic residues are able to suppress the desired bacterial flora in the meat.

Ingredients

To produce an optimal ham it is also necessary to use the right ingredients. Common salt, nitrite salt, nitrate, spices, curing agents, sugars and starter cultures are the main components used.

Salt

Common salt (NaCl) is by far the most important ingredient for the cured ham production because the strongest microbiological stabilization is obtained by reducing the water activity, i.e. the a_w-value. This happens by addition of common salt and drying. Spoiled cured hams very often show a too low salt content. High salt content may give sensory problems. The art of salting cured ham consists of distributing salt as evenly as possible in the product. The finished ham should contain 4.5 – 6.0% of salt.

Nitrite

The addition of nitrite (NO_2^-) in the form of a mixture of nitrite with common salt is less important for the microbiological stabilization of cured ham than the addition of common salt. Whole, long maturing, cured hams, e.g. Parma hams, can be stabilized microbiologically without the addition of nitrite or nitrate (NO_3^-). Nitrite plays a role for the microbiological stabilization of short-maturing, cured hams e.g. smoked ham. The antibacterial effect of the nitrite depends on the pH-value as well. If the pH is low this effect will be big and vice versa. The nitrite is important for the curing color and the curing flavor of cured ham having a short or medium range maturing cycle. Long maturing products can beproduced without nitrite.

Nitrate

Nitrate does not have any anti-bacterial effect as such and no or only a weak direct chemical effect. Micro-organisms use nitrate as an oxygen source and this chemical reaction leads to a reduction of nitrate to nitrite. Thus the nitrate-nitrite cycle is only working efficiently when nitrate reducing starter cultures are added. The active principle in this reaction, nitrate reductase, is primarily formed by strains of the *Staphylococcaceae* family.

Sodium ascorbate

Ascorbic acid and sodium ascorbate are known as antioxidants or more accurately as oxygen scavengers, and have a widespread use as curing agents throughout the industry. Ascorbic acid gives a very fast nitrite reduction. Hereby a lot of nitrite escapes as gas (nitric oxide, NO) and the result is a too low nitrite content for color development. For this reason only sodium ascorbate should be used in the curing process of ham. The sodium ascorbate works in two ways: it reduces nitrite to nitric oxide (NO) and reduces the trivalent iron of the metmyoglobin to the bivalent iron of the myoglobin. Furthermore, the ascorbate stabilizes the cured color-pigment by preventing its oxidation. Sodium erythorbate can also be used in place of ascorbate and is generally cheaper.

Spices

The use of spices is specific to regions or type of ham. It is important to use spices with a low bacterial count. A basic requirement is that they are stored under dry conditions and in sealed containers. Dominant spices, such as garlic or rosemary, should be used very carefully. In injection curing spice extracts have big advantages. Sometimes spices, such as red pepper, have a color effect. This can be useful or undesirable.

Starter cultures

To get an excellent flavor and to improve and stabilize the color, it is positive to use starter cultures in the curing process. In this case primarily coagulase negative *Staphylococci* are used. Furthermore, *Lactobacilli* can be used, depending on desired end product and raw materials available. The desired feature when using *Lactobacilli* is a slight drop in pH, ie increased acidity. The inoculation with mould cultures like *Penicillium* strains gives advantages for the surface treatment. Addition of sugar in combination with *Lactobacilli* must be handled carefully to avoid “sour ham”.

Sugars

Sugar serves primarily as an energy source for the starter cultures. Glucose, maltose, saccharose and starch hydrolysates are predominantly used. The bigger the carbohydrate molecules, the longer the time before the starter cultures can use these sugars for their metabolic activity. It is important that the sugar type is aligned with the starter culture needs in order to supply an energy source as early as possible. Some bacteria strains use only specific sugars for their metabolism.

Processing

Curing

Three different methods are used to distribute the salt and curing agents into the raw, compact piece of meat:

- Manual or mechanical application of dry curing agents to the meat (dry curing)
- Marinating the meat in brine (pickle curing)
- Injecting the brine into the meat (injection curing)

Dry curing

Dry curing is the oldest curing process. It starts with rubbing the mixture of curing agents (common salt, nitrate/nitrite, sugars, sodium ascorbate and starter cultures) onto the meat. For large pieces, salting by hand is recommended. In this case the meat is less damaged. For small pieces, a tumbler can be used because this has less effect on texture and helps to rationalize the process. Afterwards, the pieces of meat are packed side by side in curing containers. The pieces of meat should be packed in the curing containers in such a way that the desired shape of the product is already obtained at the beginning of the treatment. The meat is soft and easier to form than at a later stage of production. The use of stainless steel separators and sheets are well-proven means. The bottom of the curing container should allow drainage of the leaking liquid from the meat. This can be obtained by installing a grid approx. 20 cm above the bottom of the container.

Shortly after salting, meat juice starts to drip from the meat as a result of the high difference in salt concentration between the outside and the inside of the meat (osmotic pressure). This brine is drained and collected (or not) beneath a grid. It contains curing agents, salt soluble proteins, muscle pigment and other substances of meat origin. The diffusion of the curing salt ions into the core of the meat as well as the color development take places while the meat juice is running off. To ensure a better salt distribution and approximately the same pressure for all pieces of meat during the curing process, the meat should be repacked from time to time depending on their sizes. When repacked, the hams must be put into the curing container in reverse order. The upper layers of hams go down and vice versa.

The hams must be treated with the curing salt mixture once more when repacking takes place. For this reason the salt mixture must be divided into different batches with respect to the number of repacking steps. To avoid a loss of curing agents the salt mixture should always be freshly prepared. This is also advisable from a hygienic perspective. Spices should always be added during the last salting.

The curing process must take place at temperatures below 4°C (39.2°F). The a_w-value inside the meat is higher than 0.96 and therefore the product is not microbiologically stable at this stage. An a_w-value of 0.96 approximately corresponds to a salt content of about 4.5 %. The curing time depends on the size of the hams. A rule of thumb says that the curing time for fresh meat is 2 to 2.5 days/kg. This rule of thumb is confirmed by a mathematical approximation called the first law of diffusion developed by Fick:

dm = D * (dc * dA * dt) / dl
dm = quantity of curing salt
dA = cross-section of the ham
D = diffusion constant
dt = time
dc = gradient of ionic concentration
dl = diffusion distance

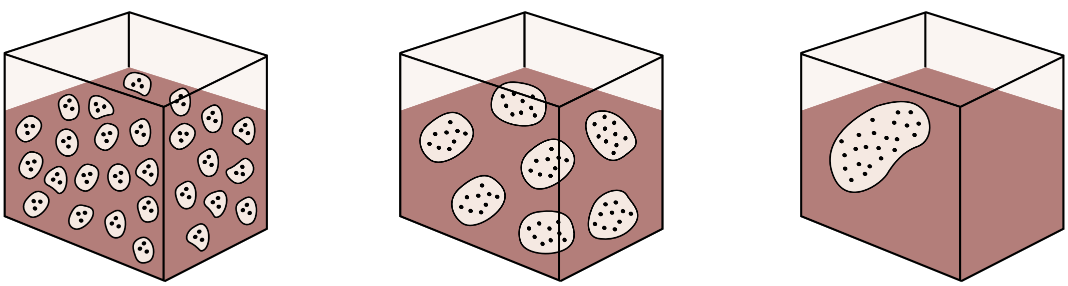
This equation explains that the amount of curing salt,which must diffuse into the piece of meat, is proportional to the gradient of ionic concentration, to the cross-sectional area, to the time and inversely proportional to the diffusion distance. The diffusion constant depends on several factors. One is surface structure of the meat and another is pH-value, the third is temperature. Sinews between single muscle groups slow down the diffusion and furthermore affect the evenness of the diffusion over the cross-section.

Pickle curing

In the pickle curing process the meat is marinated in brine, which can also contain curing agents and spices together with common salt. The salt concentration of the brine depends on the kind of desired ham product. It is often between 10% and 20%. Meat with a bigger diameter always requires higher concentrated brine. The diffusion of salt into the meat and the outflow of meat juice into the brine lead to a dilution of the brine. Due to the declining salt level and the high protein content the brine can spoil. The salt concentration of the brine can be determined by a density measurement with an "aräometer". The value is shown as a °B (degrees Baumé). The real amount of salt in the brine is 0.5 % lower than the determined °B. This knowledge makes it easy to prepare the brine with the required salt concentration. The required salt content of the brine for a given ham technology can be calculated as follows:

Cf = Cl * A / (Q * A + 1)
Cf = salt concentration in the meat
Cl = salt concentration in the brine
Q = meat brine relationship
A = amount of solution of the meat
A = (1 – fat % / 100) * 0,74

The factor 0.74 reflects the water content of pure meat (e.g. 74% water). During pickle curing a temperature below 4°C (39.2°F) is very important. The ratio of meat:brine is also very important. A meat:brine relationship of 1:1 to 2:1 is generally approved. In this context the density of the laminar layer (between meat and brine) is of importance (as a diffusion barrier).



Meat/Brine = 9/1
14 g salt/kg = too little salt

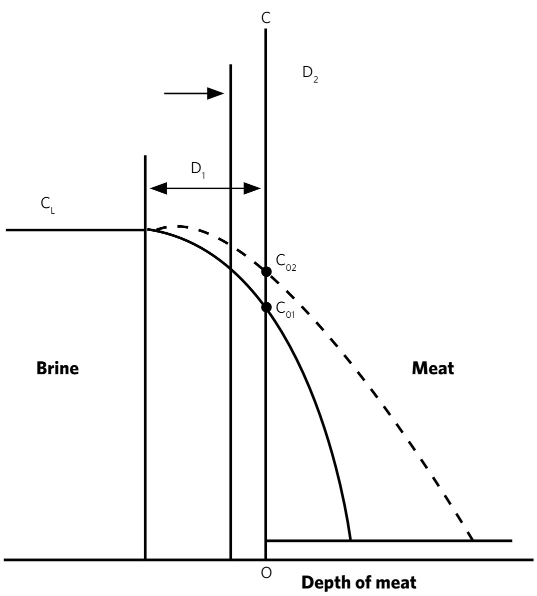
Meat/Brine = 3/1
35 g salt/kg = salting OK

Meat/Brine = 3/7
98 g salt/kg = too much salt

Fig. 2. *Relation between meat and brine to achieve optimal salt diffusion.*

Close to the meat surface the brine is diluted by the diffusion of salt into the meat and by the outflow of meat liquids into the brine. The factor of density of the laminar layer (as a diffusion barrier) indicates that the salt concentration decreases proportionally with the distance to the meat surface. The low concentration is closer to the meat and the high concentration is closer to the brine within the laminar layer.

The wider the laminar layer, the slower the salt diffusion and vice versa. This barrier can be reduced by creating turbulences in the brine (pumping) or by moving the meat (stir/overhaul). Even when applying those measures the curing time is approx. 2 days/kg of meat. Consequently, a process shortening is generally not possible as opposed to the dry curing method. However, a bigger disadvantage of pickle curing is the inability to shape the product in the very beginning of the curing process.



C = salt concentration
C_L = salt concentration of brine
C_{O1} = salt concentration by distance D1
C_{O2} = salt concentration by distance D2
D_1 = distance of laminar layer (1)
D_2 = distance of laminar layer (2)

***Fig. 3** Influence of the laminar layer on the diffusion of salt from brine into meat (Oskar Prändl et al, 1988)*

Injection curing

In the dry and pickle curing methods the salt and the curing agents move from the outside of the meat to the inside by diffusion. With injection curing the salt and the curing agents penetrate the meat by injection. The injection can be done directly into the muscle tissue (injection at random with a multi–needle injector) or indirectly into the blood vessels (artery injection) and the diffusion distance of the curing agents becomes fundamentally shorter and therefore the curing process is sped up considerably. The injection curing has a positive effect on the microbiological stability because the curing agents are very quickly present in the core of the product and can impede the bacteria in the core. On the other hand spoilage micro-organisms can be injected accidentally into the meat. In this ase the a_w-value is very high and therefore a curing temperature below 4°C (39.2°F) is necessary. Meticulous hygiene of the injectors is very important. The needles have to be regularly checked for corrosion as well, because corroding needles can lead to discoloration in the injection spots.

Post salting (ripening in storage)

The post salting step aims at leveling the difference in salt concentrations throughout the meat, which fundamentally contributes to the microbiological stability of the hams. At the beginning of the post salting step the salt distribution is still uneven and to avoid microbiological growth the temperature should be below 4°C (39.2°F). This processing step also contributes to an intensification of the curing flavor, an improved tenderness and a stabilization of the color. In parallel the product loses water. At the beginning the hams must be picked from the curing container, and superficial salt must be removed. Afterwards, the hams are hung, stacked on racks or shaped in special ham presses. If the hams are hung or stacked the relative humidity has to be chosen in such a way that the surface of the product is dry but no dry rim is formed.

The speed of air should be moderate. To avoid rancidity this process should be carried out in darkness. Relative humidity and air speed are of little importance if the hams are pressed. The advantage of pressing is to get a better sales quality via a square shape. Furthermore, the formation of a dry rim can be prevented in this ase. The post salting should take approx. 2/3 of the curing time. After this phase an optimal salt distribution should be obtained and the salt content must be at least 4.5% in all areas. This ensures an a_w-value below 0.96.

Maturation (ripening)

After post salting the microbiologically stable hams are treated in many different ways. This leads to a great variety of products. It is not possible to give a general statement about all types of ham and the characteristic differences in technology.

But some of the differences should be outlined. The maturation may be carried out at high temperatures if the hams are microbiologically stable. Long matured ham should predominantly be ripened at 15°C – 18°C (59°F – 64.4°F). Shortly matured hams should be ripened below 24°C (75.2°F). These temperatures ensure a good development of flavor. For big compact hams it is recommended to increase the temperature in the first week of maturation. These hams are stable due to sufficient salting and a corresponding post salting step (a_w-value < 0.96).

Therefore the temperature of 4°C(39,2°F) during post salting must be increased to approx. 30°C (86°F) and afterwards decreased to 13–14°C (55,4–57,3°F). This increased temperature has several advantages: Spoilage of the hams, which may arise during the salting and post salting steps, can more easily be recognized (spoilage bacteria often produce gas in the inside of the ham. This gas expands and the ham blows up) and micro-organisms and enzymes become more active at these temperatures, which is important for the development of flavor.

To obtain the desired water loss the relative humidity is lowered slowly from 85% to 70% during this maturation phase. The air speed should be approx. 0.5 m/sec at the beginning of the maturation. The air speed has to be lowered as the weight of the ham decreases. Water loss increases at the same humidity level when increasing air speed. The risk of developing a dry rim is highest close to the air entry openings in the climate chamber.

If the product is smoked the surface of the hams must be dry. Short ripened hams can be smoked at temperatures up to 25°C (77°F). Hams with long ripening time should be smoked at temperatures from 15–18°C (59–64.4°F). To suppress growth of mould a short smoking is recommended at the beginning of the ripening step. However, a too long or too intensive smoke results in a smoking rim.

Procedures of raw ham production

Microbiological stabilization

The primary aim of the cured ham production is to make fresh meat non-perishable, while the objectives of the processing steps are to protect the product from spoilage by micro-organisms. In contrast to canned products, which are made stable by heat treatment, cured hams become stable by preventing growth of spoilage bacteria by influencing their growth conditions in specific ways. Collectively, this is obtained by applying the hurdle principle; i.e. several hurdles/technologies that impede growth: At the beginning of the curing process the pHvalue and the temperature of the meat are the first hurdles/barriers for growth while the reduction of the a_w-value is the predominant hurdle at the end of the process. To inhibit growth of spoilage bacteria (Gram negative bacteria of the family *Enterobacteriaceae*) and pathogenic bacteria (*Clostridium botulinum*) an a_w- value below 0.96 is very important and the temperature must be below 4°C until this a_w-value is reached.

Color formation

Color development in dry cured meats is predominantly a result of the conversion of the unstable red myoglobin to the typical dark and stable red color of nitrosomyoglobin by means of the curing agent - nitrite.

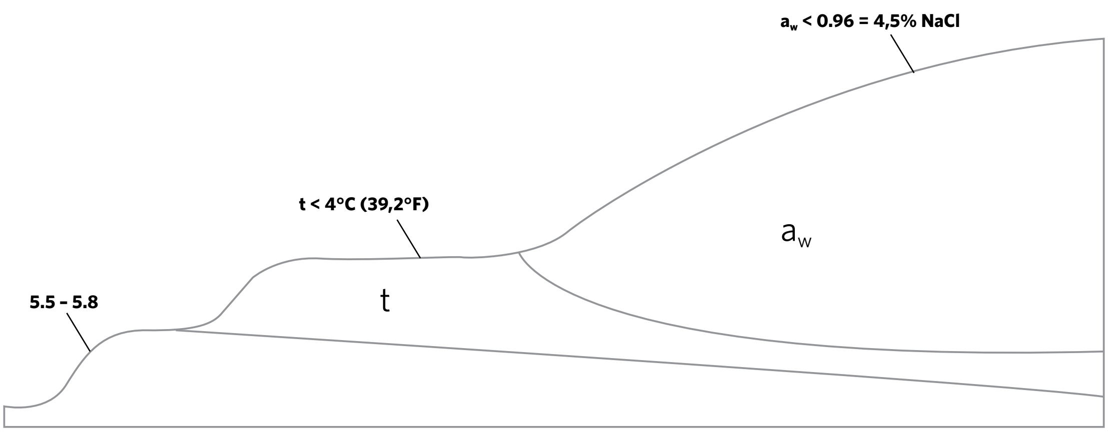


Fig. 4. *Hurdle effects during the manufacturing of dry cured ham (Leistner, 1986)*

KNO_3	→ KNO_2	catalyzed by nitrate reductase
KNO_2 + H2O	→ HNO_2 $^{+K+ + OH-}$	in slightly acidic conditions
3 HNO_2	→ 2 NO + HNO_3 + H_2O	catalyzed by reducing agents in slightly acidic conditions

Fig. 5. *Reactions during the color formation*

The nitrite, which is added as a mixture of sodium nitrite and common salt or is formed from the enzymatic reduction of nitrate by the action of *Staphylococci*, is decomposed in several steps. The nitrite changes to nitric acid in the presence of hydrogen ions. The further breakdown of the nitric acid to nitric oxide can be made by acid catalyzed decomposition of NO_2. This reaction takes place at a pH-value of 5.0 to 5.5.

But this is probably not the only way of obtaining a stable red color because there are often high pH-values in the cured ham production with good color results. Besides the acid catalysed decomposition, nitrite can also be decomposed by reduction or reducing agents to nitric oxide. A reduction can be made by the meat's inherent reduction systems like a cystein-cystein reduction system or any other enzyme reduction system.

Ascorbic acid or sodium ascorbate are used as reduction additives. With reduction by sodium ascorbate nitrate is formed as well. This nitrate can then be decomposed by *Staphylococci* to nitrite, which again can be used in color formation. The real color formation is the association of the formed nitric oxide to the central iron ion of the muscle pigment myoglobin. This complex is called nitrosylmyoglobin and it has a deep red stable color. During further maturation the protein part of the nitrosylmyoglobin is denatured to the more stable nitrosylmyochromogen. However, the brownish metmyoglobin may also stem from reaction of the myoglobins with oxygen. Metmyoglobin is formed in the presence of low amounts of oxygen from myoglobin. The central iron atom of the myoglobin is oxidized and the bivalent Fe++ becomes the trivalent Fe+++. At a high oxygen level, the unstable brightly red oxymyoglobin forms by further reactions with oxygen also the brownish metmyoglobin. The metmyoglobin cannot become nitrosylmyoglobin. Therefore it must be reduced to myoglobin first. In this case the ascorbic acid or the sodium ascorbate has a different function. They can reduce the metmyoglobin to myoglobin. There is predominantly unchanged myoglobin inside cured ham. On the surface of large hams the color development mainly follows the metmyoglobin chain. As all chemical reactions, the color development reactions always aim at a balance.

This means that the described pathways always imply two reactions. The color development in the meat stops when the balance is reached. A complete myoglobin change into nitrosylmyoglobin is therefore not possible.

It is possible to obtain an appetizing ham color without nitrite and nitrate, but it requires a very long ripening process. The color development is probably due to denaturation of the myoglobin to myochromogen inside the ham. The inside of the ham is protected from oxygen during the maturation. The myochromogen is stable against oxygen and light.

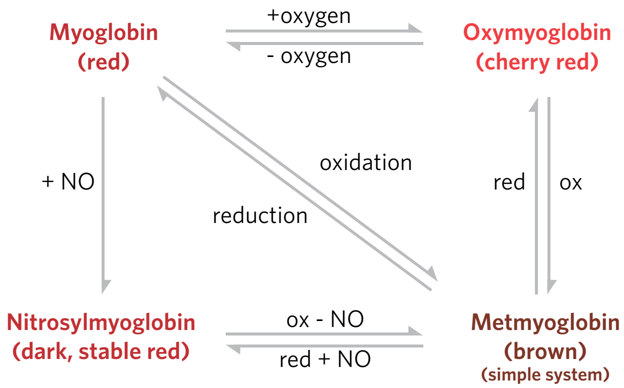


Fig. 6. *Possible reactions with myoglobin*

Flavor formation

The development of the product specific flavor profile is another important target of the process. Many components are responsible for the specific, well-rounded smell and taste of matured dry cured hams. Some are salt, spice and/or smoke and microorganisms. Others arise without a direct participation of microorganisms (e.g. oxidation of fat) or from the inherent meat enzymes.

However, the most important flavor components come from the microbial enzymatic breakdown of carbohydrates, fats and proteins.

Primarily *Staphylococci* form proteases and lipases. Lipases are able to release fatty acids from fats. Free fatty acids can react with oxygen. In the first step hydroperoxides are formed, then aldehydes, ketones and volatile fat acids arise. These components have a very intensive flavor and can be found especially in long matured cured hams. Proteases degrade soluble meat proteins. Therefore the content of free amino acids increases during maturation. Yeasts and molds also influence the flavor, especially on the ham surface. The ammonia formation by molds is important in this context.

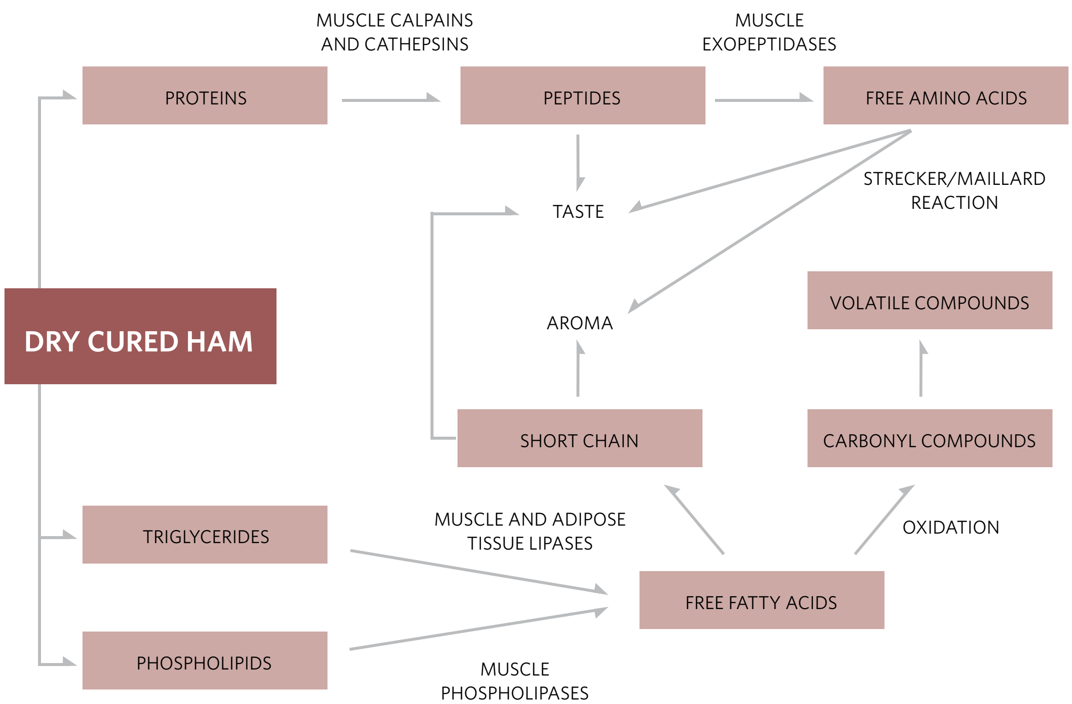


Fig. 7. *General scheme showing flavor generation during the processing of dry-cured ham (Fidel Toldrá 2002)*

Cystein-cystin redoxsystem:

$$2\,HNO_2 + R1\text{-}SH + HS\text{-}R2 \xrightarrow{-2H_2O} 2\,NO + R1 - S - S - R2$$

Enzyme redoxsystems:

$$NO^-_2 + \text{Cyt. -c (red.)} \longrightarrow \text{NO-Cyt. - c (ox.)} \xrightarrow{NADH2 \quad NAD+} NO + \text{Cyt. -c (red.)}$$

Reducing additive (e.g. sodium ascorbate):

$$C_6H_8O_6 + 2\,HNO_2 \xrightarrow{-2H_2O} 2\,NO + C_6H_6O_6$$

Fig. 8. *Further reactions during the color formation*

Benefits of starter cultures

The described technology steps show that microorganisms play a decisive role almost in all processes of the cured ham production. The *Staphylococci* have a key role. They improve the color of the hams by reducing nitrate to nitrite. This is a significant feature even if only nitrite is applied. The explanation is the formation of nitrate during the decomposition of nitrous acid to nitric oxide (see ***Color formation*** p. 11). This nitrate can be reduced/decomposed enzymatically to nitrite by nitrate reductase from the *Staphylococci.* This nitrite is in turn available for the color development. Furthermore, *Staphylococci* have the ability to produce catalase enzyme. Catalase is able to decompose generated hydrogen peroxide.

Hydrogen peroxide and other peroxides are strong oxidants, which react with the red and brown myoglobin complex. This leads to discoloration and green and yellow colors appear. These colors together with the red and brown curing color look grey to the human eye. Besides this reaction, peroxides are also responsible for rancidity. Consequently, *Staphylococci* have not only an effect on the color formation and stabilization, but they also prevent rancidity. Furthermore, *Staphylococci* have a very positive effect on the formation of nice taste and flavor. *Staphylococci* are able to produce enzymes like lipases, proteases and peptidases. These enzymes break down fats and proteins to small molecules. These molecules have a very positive influence on the cured ham flavor (see ***Flavor formation*** p. 13). All these positive effects can be obtained by using the starter culture Bactoferm® C-P-77.

Another starter culture is Bactoferm® SM-75, a mix of *Staphylococcos* carnosus and *Staphylococcos xylosus*, which gives a more intensive flavor during ripening. The more proteolytic strain of *Staphylococcos xylosus* leads to a more “Mediterranean“ aroma.

In BactoFlavor® BFL-C08 the *Staphylococcos xylosus* is replaced by *Debaromyces hansenii*. This leads to more yeasty flavor compounds during ripening.

The Chr. Hansen starter cultures for cured meat products are specifically developed to work at lower temperatures than normal fermentation cultures.

Culture name	Strains included	Characteristics
C-P-77	*Staphylococcos carnosus*	Color formation and stability, tenderizing, improving flavor
SM-75	*Staphylococcos carnosus* *Staphylococcos xylosus*	As C-P-77, but more flavor
BFL-C08	*Staphylococcos carnosus* *Debaromyces hansenii*	As C-P-77, but more Mediterranean flavor

Table 1. *Selection of Chr. Hansen cultures for dry cured meat products*

Product examples

Parma ham

The true Parma ham/prosciutto di Parma or prosciutto di San Daniele are from northern Italy's province of Parma. The special diet of chestnuts and "whey" (from the cheese-making process) that Parma pigs enjoy results in an excellent quality of meat. The pigs have to be a weight of 140 kg at least and older than 10 month. Parma hams are seasoned, salt-cured and air-dried but not smoked. The real Parma cured ham goes through at least 14/18 months of maturing. This long treatment results in the special mild, nutty taste. Most Parma hams have PDO status.

Process	Temperature	Relative humidity	Duration
1. Salting with coarse salt	0 – 4°C	80 – 90%	7 days
2. Salting with fine salt **Addition of starter cultures**	0 – 4°C	80 – 90%	21 days
3. Salting	0 – 4°C	70 – 80%	28 days
Removing of the superficial salt by brushing			
1. Post-salting "burning" 2. Post-salting "burning" 1. Ripening	2 – 4°C 2 – 4°C 25 – 30°C	50 – 60% 70 – 80% 80 – 85%	14 days 70 days 5 days
Removal of spoiled hams			
2. Ripening	15 – 18°C	75 – 85%	until a water loss of 25 %
Sealing of the meat surface with a special lard mixture			
3. Ripening	10 – 12°C	65 – 75%	180 – 330 days

Serrano ham

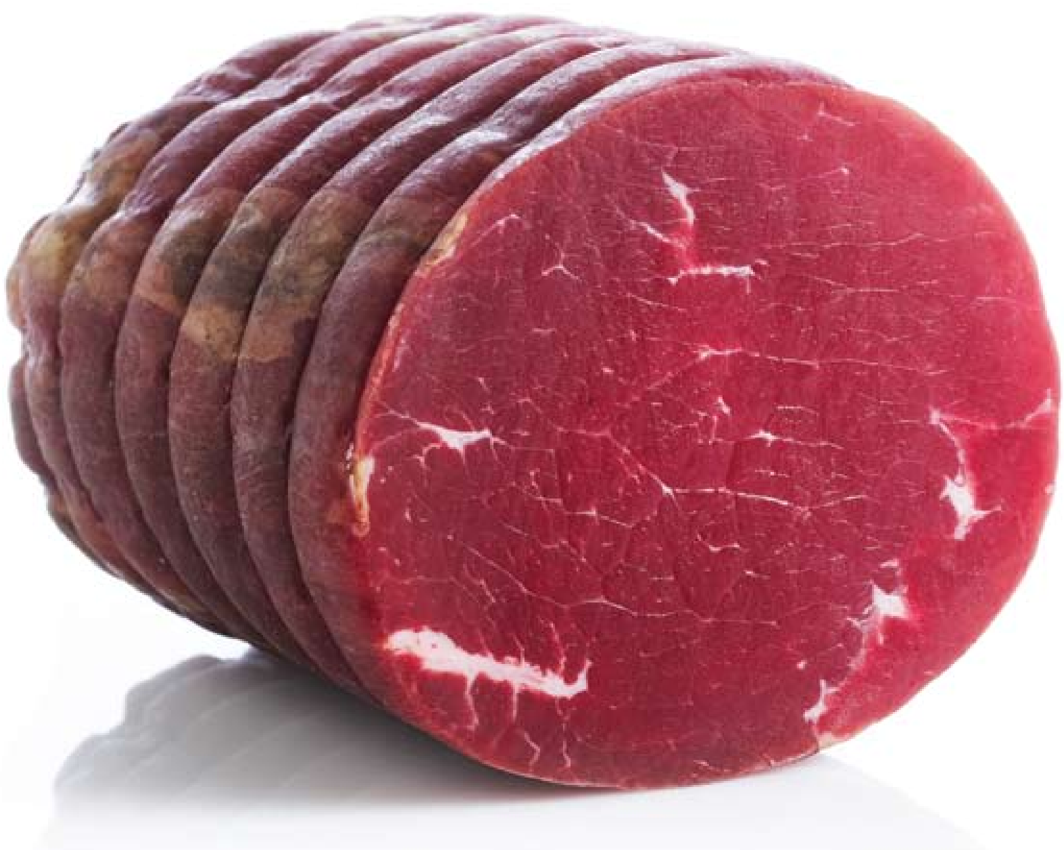
Serrano means "from the mountains", as the cool dry mountain air offers the perfect condition for the curing process. Serrano ham has TSG status i.e. it must be traditional and different from other similar products. The production process involves three distinct phases:

1. The fresh hams are first trimmed and cleaned, then stacked like cordwood and covered with salt. This serves to draw off excess moisture and to preserve the meat from spoiling. This typically lasts 2 weeks.

2. The salt is washed off and the hams hung to dry and start the first curing phase. This phase serves to initiate the curing process, here (among other things) the fat begins to breakdown.

3. Air drying - it is during this phase that the hams are hung in a cool, dry place, and where the distinct, subtle flavors and aromas develop. This lasts from 6 to 18 months, depending on the climate and the size and type of ham. The drying sheds ("Secaderos") are usually built at higher elevations, thus the name "Serrano".

Process	Temperature	Relative humidity	Duration
Salting with coarse salt **Addition of starter cultures**	0 – 4°C	75 – 95%	10 – 18 days 1 day/kg ham
Washing with water	(Water temp.) 30 – 40°C		
Post-salting "burning"	4 – 6°C	70 – 90%	40 – 60 days
1. Ripening	6 – 16°C	80 – 90%	> 45 days
2. Ripening	16 – 24°C	50 – 85%	> 35 days
3. Ripening	24 – 34°C	70 – 80%	> 35 days
4. Ripening	12 – 20°C	70 – 80%	> 35 days until a water loss of 34 %



Bündnerfleisch and Bresaola

Bündnerfleisch (Bündner meat) is a special product from Switzerland. This natural product is made from selected lean parts of the leg of beef. The beef meat is salted with a mixture of salt, nitrate, pepper, garlic and bay leafs. After salting, the product is dried in the clear air of the mountain valleys of "Graubünden" (the Grisons) for 6 month. Bündner meat is very lean and has a very strong flavor. Usually this special product is eaten in very thin slices.

Bresaola is the protected (PGI) Italian version produced in Northern Italy. It originates from the Valtellina valley in the mountainous Lombardy region. Products produced outside Valtellina may have generic names like "beef prosciutto". Bresaola is produced from carefully trimmed top inside round cured with salt and spices like juniper, cinnamon and nutmeg for 1–2 weeks and dried for 2–3 months.

Process (Bündnerfleisch)	Temperature	Relative humidity	Duration
Salting with a salt/spice blend into containers **Addition of starter cultures**	0 – 4°C		21 days
Collection of brine and overflow the meat.			Every day
Repacking			Every third day
Washing in salt-water			
Drying Three pressing phases for 1 – 2 days during drying step (faster equilibration of water).	8 – 12°C	70 – 75%	until a water loss of 40 – 50%
Removal of mold by brushing			

Coppa

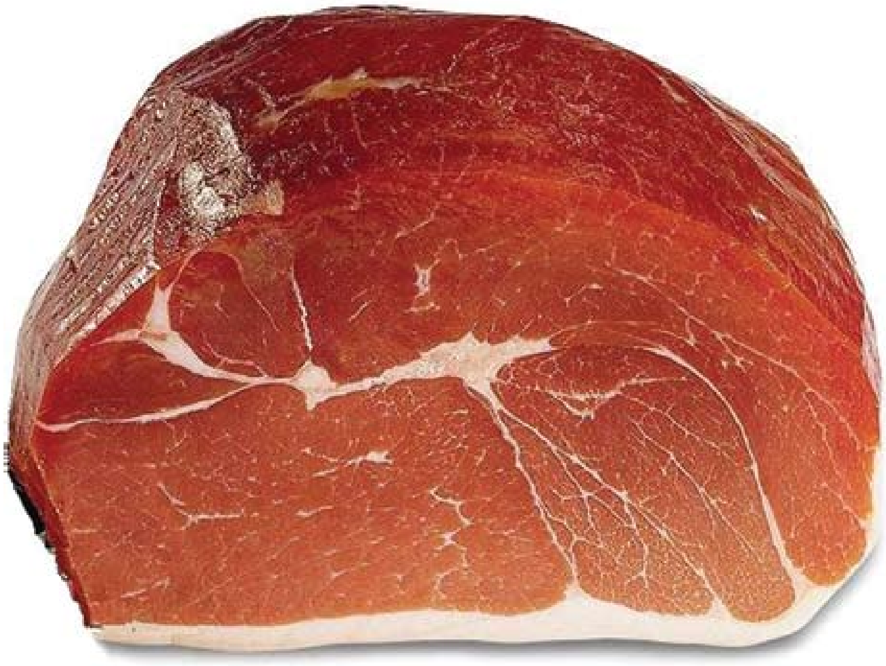
Coppa is a special type of ham. It is made from pork neck, salted, aged naturally and stored raw. The finished product is cylindrical in shape and when sliced open displays a homogenous interior of red meat flecked with pinkish-white areas.

Process	Temperature	Relative humidity	Duration
Salting **Addition of starter culture**	2 – 4°C		7 days
Drying and ripening	24°C 20°C 18°C	94% 90% 86%	24 hours 24 hours 24 hours
Post ripening			until a water loss of 25%

Westphalian ham

Westphalian ham comes from the Western region of Germany and has a very long tradition. This kind of ham is made from pork leg including bones. After the dry salting and post salting stages the ham is air dried or smoked over beech wood dust. Depending on the quality there is a 3–8 month ripening phase. The final weight is usually 4–5 kg. The bones remain in the ham until the end of maturation.

Process	Temperature	Relative humidity	Duration
1. Salting (3,5 % nitrite salt, dextrose, ascorbate and starter culture)	0 – 2°C		5 days
2. Salting (3,5 % nitrite salt, dextrose, ascorbate and starter culture)	4 – 6°C		8 days
3. Salting (0,2 % nitrite salt)	4 – 6°C		5 days
4. Salting (0,2 % nitrite salt)	6 – 8°C		5 days
Post-salting (burning)	18°C	85%	3 – 5 days
Smoking (if desired)	24°C	85%	
Ripening (with pressing phases to obtain the desired form)	14°C	82%	9 – 12 weeks



Coburg ham

Originally this protected ham type was established by pigs from the Fränkisch area. The Coburg ham is a raw ham which is cut from the main item of the ham (topside and subshell). It depends on the curing whether the ham will be used for a smoked ham or an air-dried Coburg ham. Before the ham is sold, it must mature for at least six months. It then weighs approx. 2.5 to 3.0 kg and the taste is mild and soft.

Process	Temperature	Relative humidity	Duration
1. Salting with a salt mixture **Addition of starter cultures**	0 – 4°C		7 days
2. Salting (addition of brine)	0 – 4°C		7 days
Post-salting	4 – 6°C	80%	7 days
Drying (rolling before)	24°C	70%	2 hours
Smoking (if desired)	20°C	75%	desired color
Ripening	15°C	80%	5 – 6 months

Schwarzwälder ham

Black Forest ham, or Schwarzwälder Schinken in German, is a smoked ham from pork leg, produced in the Black Forest region of Germany. The production of Black Forest ham can take up to three months. The raw meat is salted and seasoned with garlic, coriander, pepper, juniper berries and other spices. After curing, the salt is removed and the ham cures for another one to two weeks.

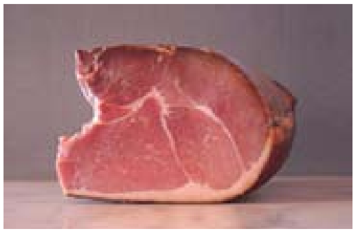
Then the ham is cold smoked for several weeks. The smoke is created by smoldering pine wood pieces and sawdust. This special smoking treatment gives the ham its typical flavor and dark surface. Finally the ham is ripened for another couple of weeks in order to get its tender structure.

Process	Temperature	Relative humidity	Duration
1. Salting (5 % salt mixture) **Addition of starter culture**	0 – 4°C		7 days
2. Salting (3 % salt mixture) **Addition of starter culture**	0 – 4°C		7 days
3. Salting (2 % salt mixture) **Addition of starter culture**	0 – 4°C		7 days
Post-salting (burning)	6 – 8°C	75 – 80%	7 days
Drying	30 – 35°C	70 – 75%	2 hours
Ripening	15 – 18°C	70 – 75%	7 days
Smoking (pine wood and pine needles)	15 – 18°C	75 – 80%	4 – 6 weeks

Holsteiner Katen ham

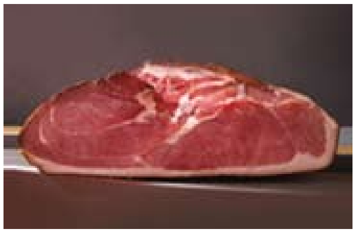
With a weight of up to 17kg the "Holsteiner Katen" is the biggest ham type. By rubbing, the ham is dry salted for a couple of weeks. After this it hangs for several weeks in the smoke house (cold) where it is smoked slowly by using beech wood flour.

After smoking, the ham must mature 2–3 months. This traditional method gives the ham a deep brown color, delicate and juicy meat and a mild taste with a sweet note. Due to the extreme size the "Katen" ham is frequently offered in 3 partial cuts:



The "Pape" is the item part of the ham.

The "Blume" is the lean part of the ham.



The "Kappe" is the "rump" of the ham with a little bit more fat.

Process	Temperature	Relative humidity	Duration
1. Salting with coarse salt	0 – 4°C	80 – 90%	7 days
2. Salting with fine salt **Addition of starter cultures**	0 – 4°C	80 – 90%	21 days
3. Salting	0 – 4°C	70 – 80%	21 days
4. Salting	0 – 4°C	70 – 80%	21 days
Washing			
Drying	20 – 24°C	70 – 75%	1 – 2 days
Smoking	12 – 14°C	70 – 75%	30 – 120 days
Ripening	14°C	80%	1 – 6 months

Bacon ("Gelderländer")

Bacon comes from the side of the pig. The meat is cured and usually smoked. It is the fat in the bacon that provides most of the flavor and allows it to cook up crispy, yet tender. A high ratio of fat to meat is essential to good bacon, usually one-half to two-thirds fat to meat. The flavor of regular bacon can vary widely depending on the breed of the pig, its feed, how it is cut, processing and curing methods.

Process	Temperature	Relative humidity	Duration
Salting with a salt mixture **Addition of starter cultures**	0 – 4°C		7 days
Repacking in a reversed order	0 – 4°C		7 days
Washing			
Drying	22 – 24°C	70%	8 hours
Smoking	22 – 24°C	75%	until desired color

Pancetta

Pancetta is Italian bacon that is cured with salt, pepper, and other spices and dried for about 3 months, but it is not smoked. Pancetta is only from the belly and is often rolled up like a large sausage.

It is usually used as a flavoring for dishes, added to sauces, stuffings, etc. In Italy, there are numerous recipes called “all’amatriciana,” meaning “with pancetta.” It is often found as an ingredient in pastas, on pizzas, etc.

Process	Temperature	Relative humidity	Duration
1. Salting on pallet (salt, spice and culture)	2 – 4°C		5 days
2. salting on pallet	2 – 4 °C		5 days
Washing and hanging			
1. Fermentation cycle	25°C (40°C)	80% moderate ventilation	24 hours (4 – 6 hours)
Spices (pepper) + culture/rolling + netting			
2. Fermentation cycle	25°C	65 - 75% strong ventilation	24 – 48 hours
Drying cycle	12 – 13°C	appr. 80% moderate ventilation	appr. 3 weeks

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Troubleshooting

TEXTURE	
TOO SOFT	
Raw material	Use of meat with high pH-value, badly chilled meat
Ingredients	Amount of salt is too low
Technology	Injection of too much brine when injection curing Unfortunate ratio of brine to meat when pickle curing The temperature during the curing process has been too high The relative humidity during "burning" step has been too high
Ripening	The temperature during smoking has been too high
Storage	The temperature during storage has been to high The relative humidity during storage has been too high
Packing	Packing of ham with a too high pH-value Packing of insufficiently matured ham (too fresh)
TOO FIRM, RIM TOO FIRM	
Technology	Too strong dehydration during "burning" step
Ripening	The temperature has been too high and the relative humidity has been too low
Storage	The relative humidity has been too low => formation of dry rim
TOO DRY	
Raw material	Use of PSE meat
Technology	The relative humidity during "burning" step has been too low
Ripening	During ripening the temperature has been too high and the relative humidity has been too low
Storage	The relative humidity has been too low => formation of dry rim
DRY FIBROUS TEXTURE	
Raw material	Use of PSE meat
Ingredients	Amount of salt has been too high
Ripening	During ripening and smoking the temperature has been too high and the relative humidity has been too low
Storage	The relative humidity has been too low => formation of dry rim

APPEARANCE AND COLOR

ROUGH SURFACE WITH LOTS OF OPENINGS	
Raw material	Bad cutting of the fresh meat
PALE COLOR (BAD COLOR FORMATION)	
Raw material	Use of PSE meat
Ingredients	Amount of nitrite and/or nitrate has been too low The storage of the nitrite or nitrate was unfavorable Addition of ascorbic acid to the nitrite salt brine resulting in decomposition of nitrite
Technology	The temperature during the curing process has been too low, thus delaying the color formation reactions The ratio of brine : meat is unfavorable (pickle curing) Curing time has been too short
Ripening	During ripening and smoking the temperature has been too high and the relative humidity has been too low
Storage	The relative humidity has been too low => formation of dry rim
COLOR UNSTABLE	
Raw material	Use of PSE or DFD meat
Ingredients	Too low amount of nitrite and/or nitrate has been added Addition of ascorbic acid to the nitrite salt brine (i.e. decomposition of nitrite)
Technology	Bad hygiene when curing, the amount of drying has been insufficient
Ripening	The temperature and relative humidity during ripening and smoking has been too high, with these conditions unwanted bacteria can grow (they are often responsible for discoloration primarily at the rim)
Storage	The temperature and relative humidity during storage has been too high Too much light during storage leads to decomposition of the color
Packing	Unhygienic packing conditions Unwanted condensation on product Deficiencies of the film; e.g. storage of the films under strong effect of light
UNEVEN COLOR OF SLICE	
Raw material	Use of PSE meat
Ingredients	Too low amount of nitrite salt and/or nitrate has been added
Technology	Time for curing has been too short

APPEARANCE AND COLOR

GREY RIM

Raw material	Meat with a high amount of unwanted bacteria
Ingredients	Too low amount of nitrite salt and/or nitrate has been added
Technology	Unfortunate ratio of brine:meat (too much brine) when pickle curing
	The meat is not full covered with brine (oxygen)
	Watering of the hams after the salting step (diffusion of color substances from the rim)
	The temperature and relative humidity during “burning” has been too high (steaming up and growth of unwanted mold at surface can damage the color)
Ripening	The temperature and relative humidity during smoking have been too high (damage of color at the rim)
Storage	The temperature and relative humidity during storage have been too high (damage of color at the rim)
	Too much light during storage leads to decomposition of the color
	The temperature during storage has been too low (pale surface)
Packaging	Unhygienic packing conditions
	Deficiencies of the film (oxygen)
	Storage under strong light

SURFACE SLIMY, MOLDY, GREYISH/WHITISH SURFACE

Technology	Unhygienic conditions at the “burning” rooms
	High amount of bacteria at the air
	The temperature and relative humidity at the “burning” rooms have been too high
Ripening	The relative humidity during ripening has been too high
Storage	The relative humidity during storage has been too high
	Too high amount of unwanted bacteria in the air
	Unhygienic conditions in the storage rooms
Packaging	Deficiency of the film (oxygen)
	Condensation on product
	Hams have been too wet when packing
	Unhygienic packing conditions
	Temperature of storage has been too high

DRY RIM

Technology	The relative humidity at the “burning” room has been too high
Ripening	The temperature and relative humidity during ripening and smoking have been too high
Storage	The relative humidity during storage has been too low

DARK RIM, SMOKING RIM

Technology	The relative humidity at the “burning” room has been too high
Ripening	The temperature during smoking has been too high
	The relative humidity during smoking has been too high
	Strong development of carbon black during smoking

FLAVOR

SPOILED, STICKY/MOIST AND SOFT SURFACE	
Raw material	Use of meat with high pH-value Use of DFD meat Use of bad chilled meat or meat with too high temperature
Ingredients	Too low amount of nitrite salt and/or nitrate has been added
Technology	Temperature at the curing room has been too high Unfortunate ratio of brine:meat; e.g. not enough brine (pickle curing) Unhygienic handling (e.g. workers with open wounds) Temperature and relative humidity during "burning" have been too high
Ripening	The relative humidity has been too low, leading to development of dry rim which results in a "stuffy" centre of the ham Temperature during ripening and smoking has been too high (especially bone-in hams)
Storage	Temperature during storage has been too high (especially if pH-value is high)
Packaging	Hams have been too fresh when packing
RANCIDITY	
Raw material	Use of old/non-fresh meat
Technology	Temperature during curing has been too high, strong effect of light during curing and "burning"
Ripening	Temperature during ripening and smoking has been too high Strong light
Storage	Temperature during storage has been too high Strong light
FATTY	
Raw material	Fat of the meat has been too soft
Ingredients	Amount of salt has been too low
Technology	Temperature during curing has been too high
Ripening	Temperature during ripening and smoking has been too high
Storage	Temperature during storage has been too high
Packaging	Temperature of the hams have been too high
MOLDY, SMELLY	
Raw material	Use of old/non-fresh meat
Technology	Temperature and relative humidity during "burning" have been too high (excessive relative humidity and hence growth of unwanted mold and bacteria at the surface can lead to flavor changing)
Ripening	Temperature during smoking has been too high Usage of smoking material, which was stored under wet conditions Usage of molded smoking material (strong deviance of flavor)
Storage	Relative humidity during storage (development of unwanted mold which leads to unwanted flavor)
Packaging	Barrier deficiency of the film (oxygen) Film is too thin Condensation on product Unhygienic packing conditions

FLAVOR	
SALTY	
Ingredients	Amount of salt has been too high Incorrect addition of salt
Technology	Injection of too much brine (injection curing) Unfortunate ratio of meat:brine (pickle curing) Relative humidity during "burning" has been too low, which leads to strong drying
Ripening	Relative humidity has been too low
Storage	Relative humidity during storage has been too low, which leads to strong drying
SMOKY / ACRID (TONGUE) FEELING	
Ingredients	Dosage of sugar has been too high
Technology	Temperature and relative humidity during "burning" has been too high
Ripening	Temperature and relative humidity during smoking have been too high Use of timber which produce a lot of carbon black when the timber is smoldering

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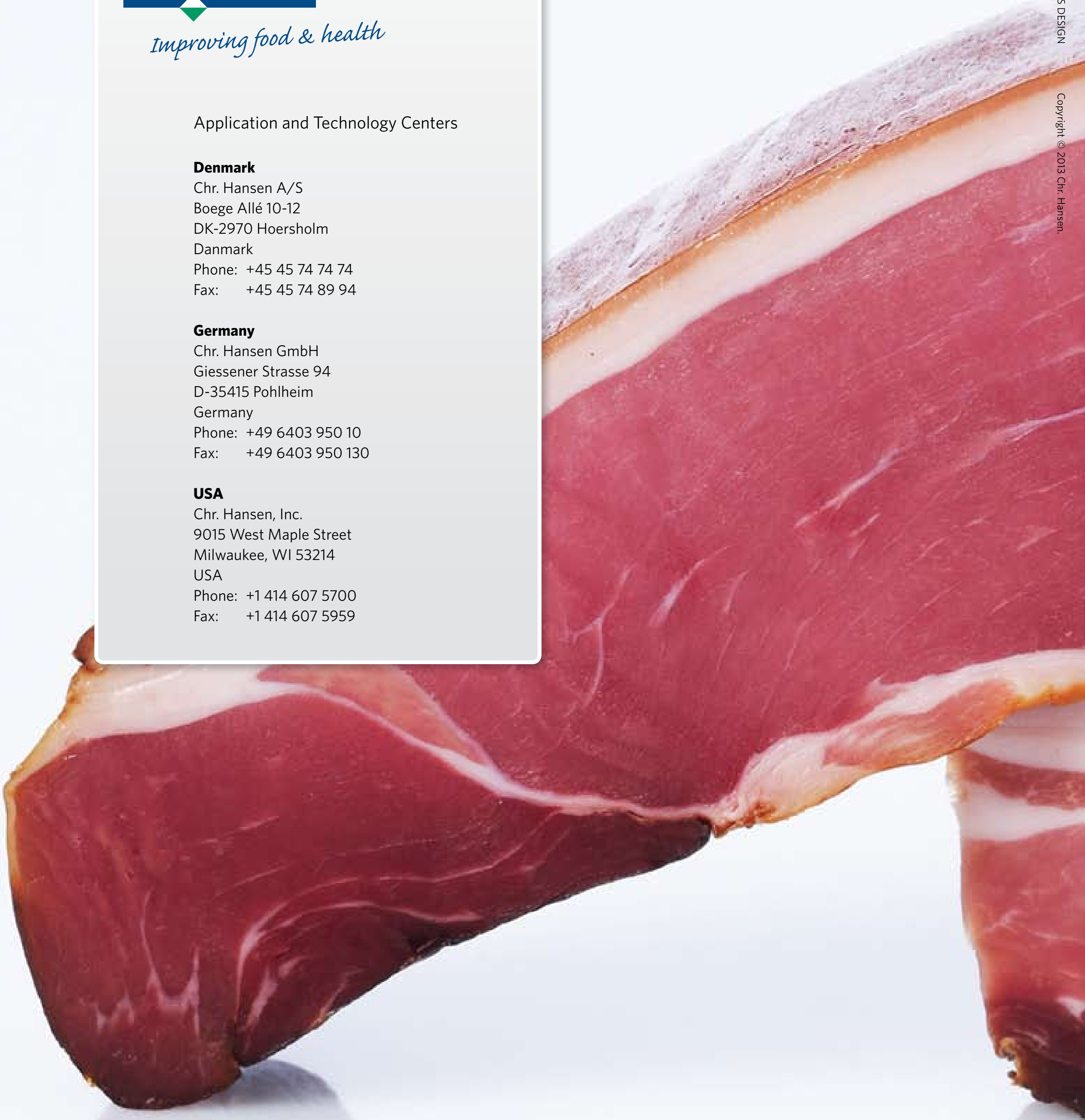

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