Hazard Analysis or "Hurdle Technology"? The past and present view of the safety of dry fermented sausages

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Abstract

The introduction of air-conditioned chambers has become an important factor in the area of quality control ensuring product standardisation and safety in the production of dry fermented sausages. The widespread use of starter cultures in the 1990s also made a contribution in this area. Critical control points alone cannot be relied on when the HACCP system is applied in production practice. Their determination is ambiguous in the production of dry fermented sausages. Manufacturers must also place emphasis on control points.

Air-conditioned drying chambers, curing, fermentation, HACCP, starter cultures

Introduction

The modern production of dry fermented sausages in the Czech Republic dates back to the end of the 1970s when the General Directorate of the Meat Industry in Prague decided to purchase air-conditioned drying chambers for the plant in Police nad Metují, soon to be followed by the Studená, Kroměříž and Ostrava – Martinov plants (Steinhauser 2010). Chamber technology was produced by the German company Autotherm and supplied by the company Laska Wien which had a contract and a de facto monopoly on the sale of equipment of this kind to the Czech Republic at that time. No other brand of air-conditioned chambers could be found in meat industry plants until the year 1990, with the exception of simpler Nagema technology from East Germany in which only type of sausages with a small diameter (< 40 mm) could be produced. These products are characterised by a more favourable volume-to-surface ratio and are not so sensitive to the precise management of the microclimate. Salami with a bigger diameter, however, demand more advanced, effective and reliable chambers that ensure an even flow of air at the selected temperature and the desired relative air humidity. Only this way, it is possible to dry the batter of these products and obtain a sausage with longer shelf life.

Fermentation and ripening

The even and gradual loss of water is fundamental to the shelf life, safety and sensory properties of dry fermented meat products. Drying is a part of the process known as ripening. In addition to drying, ripening also includes biochemical processes induced by the action of microorganisms, i.e. fermentation. This results in the microbial stability of the product and its characteristic sensory properties. Two conditions must be fulfilled in order for the entire ripening process to proceed successfully. The first is the raw material for production – a sausage batter of the correct composition and structure filled in a casing. The second are the microclimatic conditions in which this raw material becomes the final product. The air-conditioned chambers mentioned above serve to manage the microclimate, specifically by the targeted adjustment of temperature, relative humidity and airflow. These parameters can effect both fermentation and the drying process.

The introduction of air-conditioned chambers thus became an important factor in quality control ensuring standardisation and safety in the production of dry fermented sausages.

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Management of the microclimate makes it possible to control the following parameters in the production process:

- The air temperature can support the development of lactic acid bacteria and gram-positive coagulase-negative cocci whose enzymes metabolise some compounds of the batter and contribute to the conversion into the final product. The usual fermentation temperature begins at 24 to 25 °C and falls gradually to 15 – 16 °C at the end of the ripening process.
- A managed temperature prevents the growth of undesirable bacteria (e.g. of the genus *Salmonella*, the species *Staphylococcus aureus* or strains of STEC) that might occur at the beginning of the ripening if the temperature exceeds 25 – 28 °C or even 30 °C. It is because those microorganisms are mesophilic bacteria which thrive at temperatures above 30 °C. Nevertheless, the use of rapid and effective starter cultures today makes it possible to set such high temperatures on the first day with the aim of shortening the ripening process. There is a direct correlation here – the higher the temperature, the more rapidly fermentation occurs. In the 1980s, however, starter cultures were practically unused in the Czech Republic (with the exception of the Herkules salami), and they did not begin to be used on a massive scale until the 1990s. Initial fermentation temperatures in excess of 25 °C cannot be recommended without the use of starter cultures.
- The relative air humidity allows water to be lost (by evaporation) from the surface of the sausage, i.e. their drying. It is generally recommended to maintain a difference of no more than 5 between the value of one hundred times the water activity (mathematically 100 x a_w) and the relative air humidity in the chamber. In practice, this means that at an a_w of 0.98 in the sausage batter, the relative humidity should be no greater than 93%; sometimes a difference of just 3 is recommended which, in this case, would mean 95%. This also depends, however, on the speed of the airflow – the higher the performance of the ventilators, the higher the relative air humidity should be. There is a risk of two problems occurring if this is not observed – the drying out of the casing accompanied by a loss of its ability to shrink around the batter during drying, and (even worse) by the so-called case hardening. These are both fairly familiar problems. Problems may, however, also arise in the opposite situation. If the relative air humidity is too high and only a little water is removed from the sausage, then the drying process becomes slow. A high a_w value in the batter also supports the growth and metabolism of microorganisms other than homofermentative lactic acid bacteria (LAB). If the manufacturer uses cheap starter cultures with low activity, uses cheap raw material of lower quality (meat and pork lard), then it runs the risk of failing to produce high-quality and safe stable sausages. We have had the opportunity to analyze products altered in this way several times in the past. The results have been described in the literature (Kameník et al. 2013), and for the sake of clarity values for the content of lactic acid and acetic acid in samples of fermented sausages with

Table 1. The acetic acid and lactic acid content in samples of dry fermented sausages

Sample		Acetic acid	Lactic acid
		µmol·g^{-1} of dry matter	
Standard product	Herkules salami Day 0 (batter)	3.65	81.77
	Herkules salami Day 21	18.92	236.31
Non-standard product (Day 21)	Sample A	49.58	45.58
	Sample B	57.80	35.55
	Sample C	48.45	30.07
	Sample D	67.41	57.89

a heterofermentative process are shown in Table 1 in comparison with standard products (characterised by predominantly homofermentative fermentation).

A "Hurdle concept" in the production of dry fermented sausages

The production of dry fermented sausages is a simple process characterised by specific requirements. The absence of heat treatment and the relatively long production process provide opportunities for microbial activity known as fermentation (Kim and Gadd 2013). These microbial processes are important in two respects. Firstly, desirable ("useful") bacteria (lactic acid bacteria – LAB, in particular) create metabolites (primarily lactic acid) that influence the sensory and technological properties of the batter (taste, pH value and, thereby, texture and diffusion – water loss). By doing so, they can curb undesirable bacteria that are capable of causing spoilage and alimentary illnesses (the second aspect). Conditions suitable for the growth of LAB in particular are created in the sausage batter. The presence of salt and nitrite, a relatively low temperature, the absence of air in the batter, a low value of pH and, later, also a_w – this all acts to positively select specific LAB (lactobacilli with a homofermentative metabolism such as *L. sakei* and *L. curvatus*) while repressing gram-negative bacteria. Those are in particular representatives of the family *Enterobacteriaceae* and aerobic microbes capable of rapidly spoiling meat (in particular the genus *Pseudomonas*). A theoretical explanation and graphic presentation of this is given by the "hurdle concept" described by Leistner (1985). The author of this concept postulated that certain steps in food processing (e.g. heat treatment, the use of antimicrobial additives, etc.) act as hurdles to bacterial growth. Microorganisms are weakened by their efforts to overcome these hurdles, and if sufficiently strong (high) hurdles are used, the microbes cannot "hurdle" them with the result being a stable product. The succession of barriers to undesirable bacteria during the production of dry fermented sausages is shown in Fig. 1. From the viewpoint of today's food microbiology, we can see them as selective pressure that provides certain bacterial groups (species) with advantages, while suppressing others.

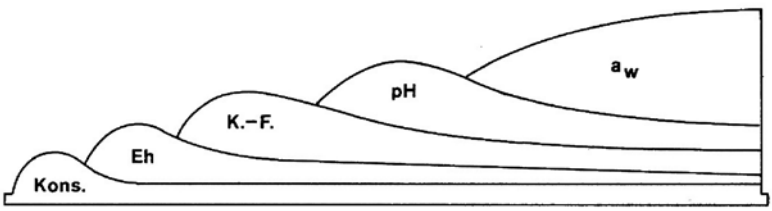

Fig. 1. The succession of hurdles to the growth of undesirable bacteria in the production of dry fermented sausages (Kons. = additives, Eh = redox potential, K.–F. = competitive microflora) (Leistner 1985)

Dry fermented sausages are characterised by two principal factors that guarantee their microbial stability and safety. These are their low pH value and, more importantly, their low a_w value. Their influence may, however, only be seen after a certain time (generally a number of days) has passed during the phase of fermentation and ripening. What actually goes on in the first few days? Meat is a perishable foodstuff. During the production of dry fermented sausages, it is, therefore, necessary to stabilise the batter with other "hurdles" until the low pH and, most importantly, the low water activity value can take effect.

A nitrite curing salt is added to the batter during mixing. This is the first hurdle facing undesirable bacteria. Its effect is weak, though sufficient to block the growth of rapidly growing gram-negative microbes (the genus *Pseudomonas* in particular) that are capable of

causing meat spoilage relatively quickly. Nitrite, as part of a nitrite curing salt, has multiple functions in meat production. In the batter, it is changed by a chemical reaction into nitric oxide (NO). NO reacts with iron ions (Fe^{2+}) in bacterial cells and thereby interferes with their energy metabolism whose biochemical reactions require the presence of Fe ions (Lücke 2008). Clostridia are sensitive to nitrite, for which reason we can anticipate that Fe ions serve as electron carriers in their energy metabolism. An inhibitory effect on salmonella has also been seen. The results of the study published by Kabisch et al. (2008) have shown that the addition of 100 $mg \cdot kg^{-1}$ of sodium nitrite is quite enough to prevent the growth of *Listeria monocytogenes, Escherichia coli* and *Salmonella* spp. The reaction of NO with iron also influences the aroma of meat products. Iron bound to NO cannot cause oxidative changes to fat or other undesirable oxidation processes.

Today, the sausage batter is generally filled into casings by vacuum fillers. Air is pumped out to create an anaerobic environment, which leads to a fall in the redox potential value. This is again disadvantageous to the growth of many gram-negative bacteria (*Pseudomonas*) which are aerobic microbes. This is followed by the growth of starter cultures, largely LAB. This group of microorganisms are considered obligate anaerobes (Kim and Gadd 2013) and are not troubled by a low redox potential level. They get their name from the main fermentation product they create – lactic acid. An environment conducive to LAB that promotes their growth exists in the batter of fermented sausages in practically the first few hours. This has two positive effects. On one hand, LAB create a population that competes with undesirable microbes that might cause alimentary illness or spoilage of the sausage batter, while on the other hand LAB ferment saccharides added to the batter (generally dextrose – glucose at a dose of around 0.3 – 0.5%) to produce the lactic acid. LAB in starter cultures ferment saccharides in a homofermentative manner. Lactic acid lends fermented sausages a pleasant aroma which creates the taste of these products along with smoke, seasonings, meat and fat. Lactic acid also lowers the pH value in the batter from an original value of around 5.8 to 5.0 and less. A lower pH supports the growth of LAB and the drying of the sausages. This completes the processes that lead to stable (durable) and safe products.

The theory (and practice) of hurdles leads reliably to standard production in the case of dry fermented sausages. It is, however, essential to remember all four basic pillars of good manufacturing practice for dry fermented sausages:

- The selection and handling of raw materials, the composition of the recipe
- Preparation of the batter (comminution & mixing)
- Filling the batter into casings
- Fermentation and ripening

The attitude of the competent authority towards the dry fermented sausage production has been changed in the Czech Republic over the last 35 years. We can follow three stages of that development.

HACCP and the production of dry fermented sausages

The first of these periods can be said to have been in 1978 – 1995, i.e. from the beginning of the industrial production of dry fermented sausages to the privatisation of the large state-owned companies. The competent authority looked at fermented sausages extremely critically during this period. A simple equation applied: the absence of heat treatment = the risk. Nothing was known of hurdle concept. Starter cultures were not used (with the exception of the Herkules salami) which certainly indicated a certain level of risk. The author of this paper remembers one case at the turn of the 1980s and 90s in which an entire drying chamber of salami (around five tons!) at his previous workplace was condemned as

the result of continual findings of salmonella in final products even after extended ripening. At that time, first-class raw materials, by today's standards, were used in the production of fermented sausages – beef and pork meat of category H1 and S1 (formerly referred to as specially processed lean pork or beef rump) with only pork back fat. The absence of starter cultures extended ripening which was five to six weeks for sausage Poličan. Samples of semi-processed products were taken for microbiological tests on a regular basis (salmonella was a real fear). Concerns about parasitic zoonoses led to the processing of only frozen raw materials, and this requirement was even stipulated in the legislation.

The second period can be defined by the years 1996 and 2004, i.e. up until the country's accession to the EU. The mass introduction of starter cultures began, and recipes were altered, with the proportion of lean beef being heavily reduced and replaced with pork. Leg of pork was ousted by cheaper boned shoulder. Imported meat and, in particular, pork fat was used to a large extent, and producers began to lose trace of the origin of the raw materials they used (traceability was guaranteed, but only to a limited extent). Finished products began to be packed in a barrier films or sliced and packed. Sausages ceased to be sold merely wrapped in paper and cardboard. Thermoforming packaging machines for vacuum-packing and "flow-pack" equipment for modified atmospheres appeared. The "optimisation" of recipes at the end of the 1990s caused great fluctuations in quality among individual manufacturers. Decree No. 326/2001, which defined the standard of traditional products, came into force. The HACCP system was introduced in production plants in the Czech Republic at this time. The Decree No. 147/1998 talked of a "method of determining critical points", though this is not always unambiguous in the production of dry fermented sausages. If we base our understanding on the definition of a critical control point – CCP (a step in which process management may be applied and which is essential to limiting or eliminating a risk to food safety or reducing it to an acceptable level (ISO 22 000 2006), what can meaningfully be called a technological step meeting this definition when, e.g., a "succession of hurdles" shares in the elimination of a biological threat (e.g. *Salmonella* or *Listeria monocytogenes*)? In this case, is it the addition of glucose, which can reduce the pH following fermentation, or the use of the starter cultures that induce this fermentation? We should pay due consideration to both of these features. And what about drying? Is it the relative air humidity, the temperature or the airflow that is important to water loss? Undoubtedly, all the three parameters. But if you produce a poor batter and the fat is "smeared", then the sausage will be difficult to dry even if you take to sleeping in the drying chamber. It is not possible to stipulate unambiguous critical control points in the production of dry fermented sausages. A thorough hazard analysis and consistent monitoring of control points is essential for an HACCP system for this commodity. A control point as defined in the IFS standard is a point "identified in hazard analysis as fundamental for controlling the likelihood of the introduction or multiplication of a hazard in the product and/or environment (IFS 2007). In the case of production of dry fermented sausages, emphasising control points is more effective than relying on CCP alone.

The final period, which continues to this day, is characterised by a continuing search for production efficiency. Vacuum fillers with a sausage grinder ensuring a higher standard of batter structure (as long as the producer respects the demands of this technology) have been introduced. Lean whole-muscle meat is being replaced in recipes by lean trimmings (a cheaper raw material, but one prone to greater bacterial contamination). Many producers are using animal proteins to increase the protein content and make production even cheaper. The ripening period of traditional salami (Poličan, Paprikáš) is approaching that of Herkules (21 days). Rapid starter cultures are being used to shorten fermentation and drying. Fermentation is often begun at a temperature of around 30 °C. The competent authority now looks on dry fermented sausages just like any other smoked meat product.

What does the future hold for us? It will probably take two paths, as has become usual

in the meat processing business in recent years. One path will lead to high quality based on the careful selection of raw materials, modern air-conditioned chamber technology and carefully chosen starter cultures. The second route will be based on the demands of low production costs in terms of both, the raw materials used and the total drying time (as short as possible). In both cases, however, production safety must be assured, representing the basic prerequisite and property of all foodstuffs.

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