PERSPECTIVES IN NEW MEAT PROCESSING TECHNOLOGIES

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Abstract

The aim of new meat processing technologies is primarily to reduce the manufacturing time, improve product quality or to achieve a better profitability in meat processing. The main processes used in meat manufacturing are curing, drying/ageing and preservation processes.

Accelerated curing has already benefitted from better equipment for injection of curing ingredients and for mechanical treatment. Newer technologies such as needleless brine jet injection, high pressure treatment or ultrasonic treatment could accelerate the curing process further.

Drying and ageing processes are accelerated by supplementing the traditional process with enzyme treatment for faster maturation or by using rapid drying processes such as freeze drying, vacuum drying or osmotic drying.

New *preservation methods* are often milder, minimal processing methods. Examples are methods using electromagnetic waves, ohmic heating, ultrasound and high pressure treatment. Pulsed electric fields and biopreservation are new methods, but a method which has been known for many years - radioactive irradiation - has been given renewed interest recently.

It is expected that the greatest future potential will be for methods combining new technologies with conventional methods. The possibilities are wide ranging, but successful application depends on economics, the competitive situation and not least consumer attitudes and statutory restrictions.

Introduction

The meat processing industry has increasingly had to focus on profitability in step with the increasing world trade and market liberalisation. The traditional markets are concentrating on quality, food safety and longer shelf-life and the competition is increasing. A more effective production system demands appreciation of new technologies for improved raw material utilisation, accelerated processes and more gentle thermal and non-thermal preservation methods. It is important, that these technologies have a positive influence on the operational economics in addition to ensuring product uniformity and quality. They must also provide a sound basis for innovative product development and product differentiation.

Development of new processes will often, but not always, require new research efforts. However, it is often the challenge to "translate" and adapt existing knowledge to useful meat processing technologies. The development of technologies and processes for meat manufacturing is rapid. The time taken to transfer basic technical research into useful and profitable industrial solutions is short.

The Danish Meat Research Institute has established a "bank of knowledge" based on a continuous surveillance of new quicker and more gentle technologies, which can reduce the manufacturing time, improve the product quality or improve the profitability of the Danish meat processing industry in other ways.

Main operations in modern meat processing

The main, and often the most time consuming tasks in any meat processing plant, are:

- curing
- drying and ageing
- thermal and non-thermal preservation.

I will in the following attempt to illustrate some of the technologies being developed both at research level and nearing application within these areas. These are technologies which are expected to be promising with respect to fulfilment of the requirements to financial results, food safety and sensoric attributes for the meat products of the future.

Accelerated curing

Acceleration of diffusion, colour formation and protein extraction

The objects of curing are colour formation, protein extraction, flavour modification and preservation. This involves a number of temperature dependent diffusion processes. They control the rate at which the curing can progress. Acceleration can theoretically be achieved by letting the process take place at a higher temperature than the normal 0-5ºC. Both the rate of diffusion and of colour formation are increased with increasing temperature.

However, extraction of salt soluble proteins, production hygiene and colour stability are better at the lower temperature. Protein extraction and functionality of the protein-exudate are at their optimum at 0ºC. A uniform distribution of the curing ingredients is an important condition for a good curing process.

The development of technologies for acceleration of the curing process is based on the above mentioned facts. The development of new curing equipment has more than halved the total process time for meat curing during the last 15-20 years.

The multi-needle injector has been developed to a near-ultimate performance with respect to the distribution of the injected brine. Today, it is the biological inhomogeneity of the raw materials, rather than the technology, which creates the limit for an ideal distribution of the curing ingredients during the injection process.

Mechanical tenderisation with needle or roller tenderisers contributes further to an acceleration of the curing time due to the increased surface area, the smaller "particle size" and the increased access to the myofibrillar proteins. The latter are the basic substance in the exudate which is all-important for the best possible utilisation of the ability to form emulsions, the gel formation, texture and not least product yield.

Addition of mechanical energy in the form of friction, pressure or shear forces improves the rate of the distribution and extraction processes and can thus to some extent compensate for the slow rate of diffusion at the low temperature.

The current state-of-the-art for multi-needle injection, needle and roller tenderisation, massaging and tumbling technologies has typically reduced the total curing time e.g. for cooked hams to 24 hours. One could therefore rightly ask whether there are advantages by accelerating a process which today is based on a 1-2 shift operation and uses the "free" part of the day to achieve optimum curing uniformity and colour formation.

A further useful acceleration is on this background a process where curing, filling and smoking/heat treatment/chilling can be completed within seven hours or one shift. In order to fulfil this target, it is not sufficient to accelerate the curing process. The subsequent cooking and chilling processes must also be accelerated. I will return to accelerated heat processing methods later in my talk. The potential for a continuous curing process which also integrates the subsequent process steps is obviously considerable.

The basic research related to curing particularly deals with diffusion, molecular transport, colour formation and oxidation. Ultra high pressure and ultrasound are likely to offer perspectives for more rapid diffusion, distribution of curing agents, colour formation and protein extraction. However, a considerable amount of basic research is still required in these areas, before they become tools in processing technology.

Pre-massaging

The application of pre-massaging of meat at low to medium pressure has shown promising results. The process uses pressure impacts of 60-100 kp/cm^2 sequentially to the meat. This softens the muscles by causing a stretching and separation of cells as well as increasing the interfibrillar free spaces resulting in faster brine absorption and distribution and in a reduction of the total massaging time.

Needleless injection

Increasing focus on quality, safety and hygiene issues may become the commercial break-through for the needleless brine injection developed and described in many patents during this decade. The technology uses high-pressure liquid generators and straight water jet-flow nozzles for injection of the dynamically pressurised brine. In combination with in-line tenderising and massaging, the technology holds potential for making curing a continuous operation.

High pressure

High pressure technology, which will be dealt with further later in this talk, is currently in an interesting phase of its development. The prospect for its practical use in processes, and thus the interest from the food industry, is increasing steadily.

At the present very little research has been carried out into the effect of high pressure treatment on curing processes. Under high pressure the water holding capacity of meat is increased as result of a simple expansion of the molecular cavities and a freeing of the polar areas. The ability of high pressure to increase the water holding capacity, and thus the yield and tenderness of meat, has been patented by the *Nestlé* company. They have described a high pressure treatment of cuts from pork hind legs at 2,000 atmospheres pressure prior to multi-needle injection, tumbling and filling. At the subsequent heat treatment, the yield is said to increase by 0.7-1.2% compared to products which are not pressure treated.

Ultrasound

Knowledge about the effect of ultrasound on meat is generally limited to bacterial lethality and tenderness of uncured meat. However, some recent publications deal with investigations into interesting applications of ultrasound for meat processing. The reports contain information about ultrasound as a supplement to tumbling for protein extraction and accelerated drying using air-borne ultrasound. The pressure variations in the food caused by the sound waves contributes allegedly to an acceleration of the water transport and thus transport of water solutes. In the case of drying by ultrasound, the sound waves remove water from the outermost layer of the meat very fast, thereby accelerating water transport from the core to the surface. Careful control of this process is necessary to avoid drying rings.

One of the effects connected with ultrasound is the so-called *damping*, i.e. a transfer of sound energy to heat. This is obviously unwanted. However, small temperature increases can, as mentioned earlier, increase the rate of curing.

Interesting equipment

I will now give some examples of development of curing equipment with perspectives for process improvement.

Cure-in-bag (Grace)

One of the important developments in integrated curing and packaging was pioneered by the Grace packaging company and developed further by the *Fomaco* company as the *QCP* process or the *Quality Curing Process*. It uses continuous curing of bacon cuts (gammons, backs, collars, streaks etc.) followed by vacuum packaging in shrink bags. The "cure-in-bag" process line consists of multi-needle injection, dry salting, tumbling in an open drum and packaging line. The total process time from start of curing to palletising of the packed products is approx. 10 minutes. The required distribution of the curing agents takes place during the transport from the producer to the customer. In addition to the capacity advantage, the process is said to achieve an improved aroma development and half the drip loss of the conventional process.

CMM (Wolfking-Belam)

CMM is an abbreviation of *Continuous Meat Massaging*, developed by the equipment company Wolfking-Belam. With the CMM concept it is, according to the manufacturer, possible to avoid the time consuming tumbling procedure and let the product proceed straight to filling and cooking. However, it has proven difficult completely to avoid normal massaging, but up to a 50% reduction im tumbling time has been possible. The CMM concept is based on a passage of the meat between several rollers with pyramid-shaped protrusions. Not only can the roller pressure of both top and bottom rollers be varied. They can also move from side to side and turn forward and backward. The result is an acceleration of the salt distribution and protein extraction with retension of the muscle fibre structure. The CMM treatment does not deteriorate the visual impression of the finished product as can be seen with roller tenderisers. Uniform muscle sizes are important for optimum massaging.

Myac

German *Myac*-concept is based on the theory, that the curing process should be carried out at as low a temperature as possible, in order to facilitate extraction and optimum activation of the salt-soluble proteins. Best at 0-2°C and with advantage under vacuum. Cold meat, cold brine, massaging in a roller-based contraption similar to CMM and tumbling under chilling contribute to an accelerated extraction of salt-soluble proteins and distribution of the curing agents.

SCANMAG (Scanio)

SCANMAG made by the *Scanio* company, is a massaging equipment using pulsing pressure/vacuum to reduce tumbling time; temperature control at 2-20°C for acceleration of diffusion, colour formation and protein extraction; addition of CO_2 and N_2 to promote colour formation, colour stability and exudate extraction. The process is used by several manufacturers, e.g. at TULIP INTERNATIONAL, the biggest Danish manufacturer of cooked hams. TULIP has also attempted a combination of this curing line with high frequency cooking and continuous packaging.

Accelerated drying and ageing

Fermentation, drying and ageing of traditional products typically last from four weeks for salami to several months for dry cured hams. These long time periods are necessary due to the drying speed, which is limited by the diffusion speed and the wish to avoid quality defects such as drying rings.

Technologies which can accelerate the manufacturing process without loss of sensoric properties will be important for capacity and thus for the financial result.

The development within starter cultures and drying technology using computer controlled climate cabinets has in some cases halved the original process time for salami sausages. However, it is still 3-6 weeks depending on product type, calibre, composition etc.

The current research and development in drying and ageing has moved in two directions:

- traditional process technology combined with biotechnology tools such as enzymes for accelerated ageing

- alternative drying processes for acceleration of traditional drying or for pre-drying of raw materials.

Enzymatic ageing

Use of proteolytic enzymes for acceleration of the maturation process in cheese has given promising results. The separation of the milk protein into smaller peptide fragments and amino acids has promoted the growth and activity of the added cultures and thus resulted in accelerated souring and subsequent formation of aroma compounds.

It is therefore obvious to try to accelerate the maturation process in salami products by adding enzymes. The well known proteases papain and bromelain which are found naturally in papaya fruit and pineapples have both been tested without apparent results. The use of purified, commercial proteases from molds was not successful either.

In investigations carried out at MATFORSK in Norway they used a protease of their own manufacture and purification - a so called serin-protease originating from a genetically modified cultivar of the lactic acid bacterium *Lactobacillus paracasei*. This resulted in acceleration of the drying as well as the maturation process. Salami sausages with serin-protease added, dried faster than the control batch, which required another week to reach the same values. The sensoric assessments confirmed the presence of a finished mature aroma in the batches with serin-protease approx. one week before the control batch.

The normal ageing period for the examined salami type is three weeks. The saved ageing time is thus 30%, which provides an interesting financial perspective. The future challenge is to scale the protease production up to a commercial level.

The effect of a couple of commercial proteases on the maturation of pepperoni has been evaluated in a preliminary test at the Danish Meat Research Institute. Both enzymes increased the transformation of protein to peptides and free amino acids. Analysis of aroma compounds showed a tendency to increased aroma formation in the batches with enzymes after two weeks drying. With an increased drying rate, it is therefore theoretically possible to produce pepperoni quicker.

The choice of protease is thus a deciding factor. For practical application it is necessary to have an industrial production of the pure protease or a starter culture which is "tailored" to produce the required proteases, and of course a statutory approval of protease and starter culture.

New drying methods

It is obvious to consider the use of PSE raw materials for meat manufacturing, as they often have a low ultimate pH and thus a reduced water holding capacity. This method is not without problems. PSE meat will result in an increased tendency to rancidity and a loose texture in the finished products. The extent of these quality defects obviously depends on the ratio between PSE and normal raw materials. A partial use of lean raw materials with reduced water holding capacity is today a common practice in salami production.

Freeze-drying (vapour pressure below the triple point of water)

Another strategy is to remove some of the water before the manufacturing process. This could be done by freeze-drying the uncured raw materials, which subsequently are added to a modified recipe. The interest in this method culminated during the 1970s when several investigations showed that a substitution of fresh raw materials with freeze-dried could shorten the drying period without quality loss, as long as the substituted quantity was not too great.

German investigations from 1995 showed that up to 2% substitution with freeze dried raw material could lead to a 20% reduction in drying time without impairing the sensoric properties.
They also compared the economics and found that the cost (exclusive of labour cost and depreciation) for the batch with freeze-dried meat was approx. 1.5% higher than for the control batch. However, if the capacity improvement achieved is utilised, this will compensate for the increased cost.

The report emphasised the following advantages by using freeze-dried raw materials:

- a lower water activity (a_w) both at the start of the process and during the majority of the drying and ageing period
- improved product safety and reduced risk of faulty production
- shorter drying time = increased production capacity
- a moderate pH-drop (particularly important for fat reduced products)
- a faster achievement of the desired firm texture (bite resistance and hardness).

Vacuum drying (vapour pressure above the triple point of water)

Vacuum drying at temperatures above 0ºC can theoretically be done on the stuffed sausages, as well as on the uncured raw materials as with the freeze drying concept. In a US investigation in 1995 it was found that vacuum drying of pepperoni led to a 30% or higher reduction in drying time. The actual level depended on process parameters and product composition. The challenge in this concept is the vacuum chamber technology and the capital costs related to this. All tests carried out hitherto have been made in the laboratory. Several costly difficulties can be anticipated in the scaling up of the concept. The influence of a full scale operation on drying performance and finished product quality is currently unknown.

The possibility of vacuum drying the raw materials is rather interesting, as this method is simpler and require less energy than freeze-drying. A combination of freeze-drying and vacuum drying might be the most promising method.

Osmotic drying (DIS)
Osmotic drying is also called DIS - **D**ewatering and **I**mpregnation **S**oaking. It is carried out by dipping the material in concentrated salt, sugar, glycerol or sorbitol solutions. This drying method is receiving increasing popularity in the food industry, not least in the growing market for dried fruit and semimoist foods. Osmotic drying is energy saving compared to air drying or freeze-drying because the water does not have to alter its state when it leaves the product. DIS, which is a similar process to tank curing, is not yet widely used for the drying of meat products. This might be due to the fact that a possible saving in traditional drying time is compensated by a similar time consumption for osmotic dehydration. It is basically old fashioned curing, and is therefore dependent on diffusion rates etc. as related earlier, when dealing with the curing process.

High pressure and ultrasound
High pressure for accelerated ageing and mild preservation of a ham product is used commercially in Japan by Fujichiku Company. This company has been marketing a "raw ham" product. Vacuum packed slices of cured ham is exposed to a pressure of 2,500 atmospheres for three hours at 20ºC. The level of maturation reached in this process would traditionally take two weeks. The product is said to be very tender and juicy with a gentle cooked flavour. The pressure treatment is also alleged to reduce the bacterial count in the product.

Air borne ultrasound can, as mentioned earlier, contribute to accelerated drying.

Summing up
To sum up, the most promising technologies for accelerated drying and ageing/maturation are considered to be enzyme application combined with one or more of the methods for accelerated drying mentioned earlier. However, application oriented development is still missing. Thorough cost/benefit analyses would be natural tools to evaluate the potentials and to decide levels of priority for the technological development efforts.

Minimal processing: Thermal and non-thermal preservation technologies

The main purpose of thermal processing is to ensure the microbial and biochemical shelf-life of the product. In addition to the preserving effect, positive changes are taking place in texture, colour, flavour and odour. Traditional heat treatment in the meat industry employs hot air, steam or water as heat transfer media. It is a characteristic of these methods that the heat energy is created outside the products and subsequently transferred to the product surface and its interior. From the surface towards the interior, the heat transfer takes place via conduction, with the risk that the surface is excessively heated and the core underheated.

Volumetric heating
Some of the "new" thermal processes are based on so-called volumetric heating. The heat is first created inside the meat and the heating is rapid and uniform in the total product. As a result of the quicker heating, the sensoric properties are influenced less, or in different directions. The rapid heat processes thus produce products with a different - possibly better - flavour, appearance and smell compared to conventional heat treatment.

Electromagnetic energy
Most of the volumetric heat treatment methods are based on electromagnetic radiation. With falling wavelengths (increasing frequencies and thus energy content) they are:

Radio waves **RF/HF**	13.56 or 27.12 Mhz	Wave length 30 or 10 m
Microwaves **MW**	915 or 2450 Mhz	Wave length 30 or 10 cm
Infrared waves **IR**	10^8 Mhz	Wave length 1-1000 µm

A common factor for these methods is, that ordinary alternating current is used to produce the desired wave length via a suitable generator. Only inside the meat is the energy transformed to heat energy. The electrodes emitting the waves do not need to be in direct contact with the meat.

Radio waves
The *APV company* has developed a commercial RF cooking installation for extremely rapid heat treatment of meat products. The wave length for radio waves are as shown above longer than for microwaves. Penetration is greater, which should create a basis for a rapid and uniform temperature distribution in the meat. Radio frequency cooking reduces the cooking time of e.g. hams from several

hours to a few minutes. The investigations carried out to date, mainly in Denmark, have shown some difficulties, particularly with heat distribution. The future for this interesting technology is currently uncertain, as APV has decided to stop further development and sell the rights to the technology to another company.

Microwaves
The application of microwaves for heating is commonly known. When the technology has not found extensive industrial use, it is mainly due to three factors. Firstly it is extremely difficult to achieve a uniform wave distribution in the microwave chamber and thus in the product. Secondly, the geometry of the product and its contents of fat, water and salts are very important for the heat distribution. Thirdly, the depth of penetration for microwaves is rather shallow - approx. 1.5 cm at 2,450 Mhz. Intense research is taking place in several centres in order to improve these aspects of the microwave technology. The microwave technology is currently used in combination with other heat treatment techniques for the production of finished meals, thawing of frozen meat raw materials and pre-frying of bacon rashers.

Infrared waves
Infrared radiation is very rich in energy, but the depth of penetration is only a few mm. This technique can therefore not be used alone for heat treatment of whole muscle products, but it can be used for surface decontamination or crisping of the surface. The technology can of course be combined with other heat treatment methods for depth heating.

In the meat industry infrared heating could be used in combination with traditional or micro- wave/radio wave heating when producing a range of surface fried products: roast beef, fried meat balls, sliced bacon etc. The *Unilever* company has for example patented a continuous process using a combination of hot air and infrared irradiation.

Ohmic heating
Ohmic heating or **D**irect **R**esistance **H**eating (DRH) was used commercially more than twenty years ago for heat treatment of skinless frankfurter sausages in the Tender-Frank Method developed by *Swift & Co* in the USA. Today, ohmic heating is mainly used commercially for continuous heating of liquids or particles suspended in an electrically conductive and pumpable matrix (e.g. meat pieces in gravy). The particle size is limited in order to obtain pumpability past the electrodes. In such pumpable products a considerable reduction in cooking time can be achieved combined with a more even temperature distribution compared to traditional heat treatment.

The *Unilever* company has patented an application for ohmic heating of whole muscle products. The process is carried out batch-wise by positioning the meat between the electrodes, film packaging, injection of a conductive liquid (salt solution), ohmic heating, evacuation of film and liquid followed by sealing of the film. The patent does not state heating times, the resulting product quality etc., but demonstrates that ohmic heating of solid objects is not impossible.

Ultrasound
Heat exposure is, as stated earlier, one of the effects when using ultrasound on meat and meat products. Investigations have demonstrated, that it is possible to reduce the heat treatment to half, when high energy ultrasound is used. At the same time the meat becomes more tender, mainly as a result of an increased myofibrillar denaturing compared to traditional heat treatment.

Campden & Chorleywood Food Research Association has in 1994 carried out a project entitled: "Thermosonication for Food Processing". It was concluded that an increased kill-effect on microorganisms could be achieved in different food test systems by using a combination of ultrasound and mild heating.

The ultrasound technology is likely to be widely applied for processing in the food industry. Preliminary calculations indicate, that capital and running costs are low enough to justify the use of ultrasound for food preservation. However, it is expected that industrial application of ultrasound for meat processing lies some years ahead.

High pressure
Application of high pressure solely with the purpose of accelerating preservation of conventional, cooked meat products does not offer major advantages compared to traditional heat treatment. The process can only be carried out batch-wise and time is consumed in building up the high pressure. The technique can on the other hand be used as a gentle preservation method to create new meat product types. High pressure can of course also be combined with traditional heat treatment.

Professor Dietrich Knorr from *Berlin University of Technology* speaks about high pressure as the "third dimension" in heat preservation because it is now possible to vary not only time and temperature but also the pressure. High pressure is expected to be introduced when developing completely new meat product types with high levels of quality and food safety, better flavour, better texture, increased nutritional value and use of fewer additives. The Swedish company *ABB Pressure System* is developing a new equipment concept consisting of an external pressure amplifier and two pressure chambers made from a new steel alloy. This should improve the capacity and thus the costs per kg treated product.

Ultra high temperature, short time (UHTST)
Laboratory based techniques have been developed to perform surface preservation of meat products with ultra high temperature, short time (UHTST). One technique employs vacuum before and after the heat treatment, which goes to 145°C for a few milliseconds.

Another uses a far higher temperature - 800ºC - in a conventional oven. The methods provide a longer shelf-life due to the reduction in surface microbial flora, but they must be combined with other heat treatment methods to give a complete preservative effect

Pulsed Light/ Pulsed Electric Fields (PL/PEF)

Pulsed Light (PL) and Pulsed Electric Fields (PEF) are relative new preservation technologies. Pulsed Light is a technique reducing the surface microbial contamination of food products. The technique is based on a light exposure of the surfaces in flashes of a few hundred microseconds duration with light which is more than 20,000 times more powerful than sunlight. In laboratory substrates a total kill have been achieved of both spores and vegetative cells. On meat surfaces the microorganisms are protected and the reduction is only 1-3 logarithmic units. Pulsed light does not appear to influence the chemical stability of the products.

Pulsed light is not yet applied in production scale in the food sector, but equipment is available from the US company *PurePulse Technologies (PureBright®)*. The perspectives for using pulsed light for preservation of meat products are considered to be limited.

PEF is only suitable for liquid foods and is considered to have a bright future particularly in the juice and dairy industries.

Radioactive irradiation

The FDA approved the use of low dosage radioactive irradiation of fresh meat and poultry in the USA in 1997. Market tests have shown that the negative consumer attitude in the USA is turning. Due to the risk of pathogens, the majority of the consumers in a USA research said they would choose irradiated meat. They would also be willing to pay a premium for it.

Development of new irradiation equipment using another source of irradiation than the one used hitherto (Caesium 137 instead of Cobalt 60), for example from the company *Grey Star,* has led to a reduction in irradiation cost.

Minilac® is another US irradiation equipment. It is designed for in-line irradiation of chilled or frozen burgers. The installation consists of a 10kW electron accelerator and has a capacity of ten tons per hour at an irradiation of two kGy. That should be sufficient to eliminate possible Salmonella or *E. coli* organisms.

It will be interesting to follow the first commercial launches of irradiated meat in the USA.

Active packaging

Active packaging comprise a number of technologies: Oxygen absorbers, moisture absorbers, odour absorbers, carbon dioxide absorbers, emitters containing anti-oxidants and anti-microbial substances, indicators for time/temperature, freshness, oxygen and carbon dioxide. Best known are the oxygen and moisture absorbers placed in the packs and the time/temperature indicators, which are stuck onto the packs to control the cool-chain.

Incorporation of the active components in the packaging, and systems which can do more than just absorbing oxygen, carbon dioxide and water, are on the way. Examples are organic acids against microorganisms and specific anti-oxidants to prevent rancidity and discolouration.

Active packaging will certainly have an increasing role due to the increasing requirement for freshness and safety. In Europe we are behind Japan, where e.g. oxygen scavengers have been an integrated part of food packaging for more than 20 years. The required development in Europe is a change in the food regulations. Active packaging goes against the current requirement for food packages, which must be inactive and non-migratory.

Biopreservation

Biopreservation is currently one of the most promising newer preservation techniques.

In biopreservation, a bacterial culture of harmless, desired bacteria, which can eliminate or inhibit the growth of unwanted, often pathogenic, microorganisms in meat products is used. This results in improved safety of the finished products.

Biopreservation is mainly based on the use of starter cultures producing special peptides - the so-called bacteriocins. An effective application of biopreservation presumes a knowledge of the conditions for the starter culture's production of the preservative bacteriocins. Current investigations indicate, that a large proportion of the bacteria already occurring naturally in meat products when in a sufficiently high concentration can inhibit growth of *Listeria monocytogenes.*

Bacteriocins exert their effect by making holes in the bacterial cell walls, thus causing a loss of nutrients and death. The currently most applied bacteriocin is *nisin,* which is used mainly in the dairy industry. There are also examples of bacteriocin-producing starter cultures being used for production of fermented sausages.

It is widely agreed, that the concept of biopreservation is promising. At this stage, most investigations have been carried in model systems only. Product tests in larger scale will in the time to come show the level of benefit of the biopreservation concept. Some of the many challenges to overcome will be verification of the risk of resistance development and achievement of statutory consent.

On-line optimisation in manufacturing

Fat standardisation is presumably the most widespread application of industrial measuring technology in meat processing. To a large extent different types of at-line batch oriented methods have been replaced by continuous measuring equipment for example integrated in processing equipment such as mixers. Near infrared light and microwave systems are some of the most applied technologies.

X-ray systems - comparable to luggage scanners in airports - may be a future technology for on-line determination of fat content. The technology has the potential to measure continuously on meat being transported in plastic boxes or on conveyor belts. This means that fat standardisation could be performed more accurately on trimmings and other product types already at the supply source, the boning departments.

Fat quality is important for products like dry cured hams, raw sausages and bacon. Soft fat and too high content of certain fatty acids can cause problems with shelf-life, rancidity and poor sliceability. Today, the industry is mainly left with slow and expensive laboratory methods. However, a new NIR-based on-line instrument for measuring fat quality parameters has recently been introduced. The instrument can be used either on a pig slaughterline or for inspection of raw materials received by a meat processing company.

The industry is still awaiting sufficiently rapid and economical methods for determination of the microbiological status of raw materials and finished meat products. Today, reliable methods for detecting for example *E. coli* and Salmonella still takes 12 hours or more. However, a lot of development is currently carried out in this area, and a major break through may be expected in the coming years. One of the promising technologies is conductivity measurements in combination with advanced spectral analysis and data interpretation.

Conclusions

The way ahead for future meat manufacturing processes is to use intelligent technology combinations!

Developments in basic research and applied technologies within meat processing is currently moving along rapidly, as this talk indicates. It is expected that the greatest potential will be for methods combining new technologies with conventional methods as for example:

- Ultrasound and high pressure for accelerated curing, ageing and preservation in combination with traditional methods
- Vacuum and enzyme technology for accelerated drying and maturation
- High pressure and mild heat treatment for gentle processing
- Radio waves combined with ultrasound or microwaves for optimum energy and temperature distribution
- Biopreservation combined with traditional "hurdles" such as salt, nitrite, pH, controlled water activity (a_w) etc.
- More extensive use of bacteriocin producing starter cultures
- On-line measuring and analysis equipment for optimum raw material utilisation when producing emulsion products.

The possibilities are wide ranging, but a successful application depends on economics, the competitive situation and not least consumer attitudes and statutory restrictions.

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