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Perspectives in meat processing

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Abstract. Meat technology includes all steps from animal handling and slaughtering to production of different meat products. During animal handling, special attention is paid to animal welfare, not only to protect animals from suffering but also because of animal welfare's importance for meat quality. The oldest processing methods (chilling, freezing, salting, smoking and drying) are being readjusted with respect to equipment and consumer's health issues. Special attention is given to preservation of meat's nutritive value (milder heat treatment) and health promoting properties of the products (functional foods). Novel methods (irradiation, high pressure, pulsed electric field, pulsed light and cold plasma) struggle with some issues such as acceptance by consumers, expensive equipment and effects on food's sensory properties. Along with novel products, demand for traditional meat products is still increasing which requires the uniqueness and quality of these products to be preserved, along with increased production capacity.

1. Introduction

Meat and meat products are a very important source of nutrients in human diets. The whole process of obtaining meat reaches back to the farms and includes animal handling, transport to the slaughterhouse and slaughtering process, followed by preservation techniques aiming to extend the shelf life of fresh meat or to convert it into meat products [1]. From the oldest techniques to preserve meat such as salting, smoking and drying, the development of the meat industry led to new techniques that include contemporary equipment and machines on the one hand, and chemicals and non-meat ingredients on the other hand [2]. Along with preservation techniques, the concept of animal welfare has also flourished, not only to protect animals from suffering but also because of animal welfare's influence on meat quality [3]. The awareness of consumers about the influence of food on their health has led to the rise of the concept of functional food, which also inspired research in functional meat product development [4] as well as in preserving the nutritive value of products [5]. Apart from conventional meat processing techniques, there are novel approaches, including high pressure or irradiation, that have their advantages and disadvantages [6,7]. However, traditional meat product manufacture still retains its significance and certainly commands attention thanks to increasing demand for these products by consumers [8]. The aim of this paper is to discuss contemporary meat processing concepts and approaches and to review their current status and future perspectives.

2. Animal welfare and meat quality

Although *meat processing* is the "further processing of meat" [9], it would be negligent not to mention the quality issues of meat as a raw material. In the last two decades, awareness of the influence of



stress in animals intended for slaughter on meat quality has increased. The first meeting of the *Ad hoc* Group on the Humane Slaughter of Animals within the OIE (World Organisation for Animal Health) was held in 2003, which further resulted in defining guidelines for the slaughter of animals for human consumption [10]. This provoked further research into stressors and their indicators. Already during transport to the slaughterhouse, animals are exposed to stress [3], which continues in the lairage and during stunning [11]. Lairage duration and animal density influences meat quality, showing a positive correlation with the occurrence of PSE (pale soft exudative) and DFD (dark firm dry) meat [12]. The breeding system influences the occurrence of pathological lesions in slaughtered pigs [13]. Biochemical stress indicators such as lactate and acute phase proteins also show positive correlations both with stress and meat quality [14]. Improper animal stunning procedures point to the need for continuous staff training [12]. Additionally, slaughter of stressed animals leads not only to meat quality defects but also could lead to endogenous microbial contamination, endangering the safety of meat and, consequently, of meat products [15].

3. Conventional meat processing methods

3.1. Chilling and freezing

From meat chilling in natural caves followed by building cellars cooled by natural ice [16], technological development led to mechanical refrigeration and the emphasis on processes currently used, such as quick chilling and super fast chilling by cold air, as well as spray and immerse chilling by cold water [1,16,17]. A new approach, which is a variation of super fast chilling, is *stepwise chilling*. This process includes three steps: fast chilling, tempering and fast chilling again. This approach leads to 5% energy cost savings compared to super fast chilling, but it also results in meat tenderisation because of meat enzyme activation during the tempering phase [2]. A future perspective could be so-called *pad chilling*, based on the direct contact of the animal carcass on a cold surface, whereby the temperature is lowered through the conduction process and not evaporation like in conventional chilling. This process is 30% faster, chill loss is very low (0.1-0.2%), and the energy cost saving is about 50% compared to conventional chilling methods [2]. As a newer method that is between chilling and freezing, *superchilling* involves initial freezing of the surface, then meat is exposed to equalization of ice crystals at only 1-2°C below the freezing temperature. The shelf life of such meat could be up to four times longer than that of chilled meat. Furthermore, because there is no need for any thawing process, this method reduces costs in labour, energy and weight loss, as well as resulting in meat with better sensory characteristics than frozen meat has after thawing. However, this method requires more precise temperature control and monitoring systems because of the narrow range between superchilling and chilling temperatures [18]. Freezing of meat expanded at the end of 19th century, as a method that provided long shelf life of meat and long distance transport from one part of the world to another. Although meat storage below -18°C stops all microbial growth and cellular metabolism, lipid oxidation remains the main problem during storage. Adequate packaging films could help in lowering the oxidation processes and the incidence of freezer burns on meat surfaces [1,16,17]. A relatively newer method, *cryogenic freezing* is faster than air freezing and requires only tanks or sprays for cryogen application. However, it is suitable only for smaller and packed meat pieces, and the cost of the cryogenic liquid makes this method relatively limited in commercial use [18].

3.2. Salting and Curing

Salting was recognised very early in human civilisation as a method of prolonging meat's shelf life without chilling [16]. Curing also arose long ago in history, when ancient civilisations incorporated nitrates in meat via contaminated salt, but it took a long time until the actual chemical processes in cured meat were completely understood [17,19]. At present, nitrite plays a very important role in the meat industry, in the first place because of its strong antimicrobial activity, especially against *Clostridium botulinum*, as well as it being a colouring agent. Recent studies, however, proved the carcinogenic potential of N-nitrosamines that can be formed in cured meat products, which provoked a series of investigation in order to find nitrite substitutes. Promising results were obtained with

essential oils, polyphenols, lactic acid bacteria and acid whey, etc. [4], but these single ingredient solutions could provide only one of the main functions of nitrite in meat products. As it is also known that endogenous production of nitric compounds in the human body occurs physiologically from other sources of nitrate and nitrosamines not from meat products, the exclusion of the use of nitrites is not yet in sight [19]. Additionally, although some traditional meat products are produced without the use of curing salts, many of these products contain nitrate and nitrite residues which are indirectly incorporated in the products via spices [20,21]. Such products are often labelled as “uncured” or “without preservatives” which could be misleading for consumers in terms of nitrite presence in the product [19] and in terms of product labelling [22]. As for the use of NaCl, some meat products are a significant source of high sodium intake in the human diet, which is recognized as cardiovascular disease promoting factor. Partial replacement of NaCl with K, Ca and Mg salts (chloride, lactate etc.) could reduce the sodium content in meat products without adverse effects on products’ properties or safety [4,23].

3.3. Smoking

Smoking of foods, including meat, originated thousands of years ago and is a preservation method based on chemical compounds from smoke that influence the sensory properties of meat products and have antimicrobial and antioxidative roles on the meat surface [17,24]. Recently, emphasis has been given to the investigation of harmful smoke compounds such as polycyclic aromatic hydrocarbons (PAHs), because of their carcinogenic potential. There are several approaches in order to produce smoked meat products with less or with no PAHs, which include measures to obtain smoke with less PAHs by the controlled process of wood pyrolysis, smoke purification, or even to reduce the content of smoke in meat products by means of starter cultures or some spices [4]. The other approach to obtain smoked meat products free of PAHs is to use smoke flavourings. As the toxic compounds are not soluble in the water phase of the liquid smoke, the compounds are easily removed, producing smoke flavourings with no detectable amounts of PAHs [24].

3.4. Drying

Along with salting and smoking, drying is one of the oldest meat processing methods. Until the industrial revolution, meat was dried under the influence of natural climate conditions, but during the last century, the use of climate chambers became irreplaceable in the meat industry. However, as climate chambers are significant energy consumers, this fact provoked investigations on shortening the drying process or introducing new air drying systems [25]. Some approaches to shorten the drying process are microwave vacuum drying, which is a process combining microwave heating and vacuum drying [26], and ultrasonic vacuum drying [27]. Drying in a vacuum chamber is more than three times faster than drying under usual conditions, and the meat’s sensory properties are not affected, while microbiological stability is achieved more rapidly [28]. As for air drying systems, a heat pump dryer is more efficient than hot air drying systems. Among heat pump drying systems, the best appear to be CO₂-heat pumps, followed by glycol heat pumps, while ammonia heat pumps were less effective [25].

3.5. Heat treatment

Although early humans used fire to prepare meat for consumption, the commercial thermal processing of meat started at the beginning of 19th century with Nicolas Appert and design of the first canned products [16]. Heat treatment provides safety, shelf life, sensory properties and better digestibility of meat, and, depending on the chosen temperature intensity, pasteurization, cooking or sterilization can result [5]. Hermetically sealed cans are a good environment for growth of anaerobic bacteria, with special attention paid to toxigenic *Clostridium botulinum*. Therefore, process control of canning gained its importance, which resulted in development of F₀-values. These precisely measure whether the canning process ensures meat safety with respect to *C. botulinum* (F₀≥3) [15,16,17]. Sterilized cans are usually overheated in practice (F₀>8) in order to ensure product safety, but such processing significantly affects the nutritive value of the canned products. Such unnecessarily strong heat treatment could be optimized by F₀-value and C₀-value (cooking value) determinations, in order to provide safety and preserve the nutritive value as much as possible [5]. Furthermore, it is possible to

produce *shelf stable meat products* by mild heat treatment and which can be stored at room temperature, by means of the hurdle technology concept based on the simultaneous action of several antimicrobial parameters (pH, water activity, redox potential, F_0 -value, temperature). This approach led to the development of the so-called *refrigerated processed foods of extended durability*, where the accent is on mild heat treatment and prolonged shelf life [15].

3.6 Packaging

The main purpose of packaging was firstly just to mechanically protect products from contamination, over-drying, oxidation, weight and nutrient losses, adsorbing strange odours from the environment etc., simply by overwrapping with packaging material. With the development of polymer materials with low gas permeability and the technology to remove air from the packaging, vacuum packaging emerged, which additionally provides reduced oxidative changes and limited growth of aerobic bacteria. This led further to the development of modified atmosphere packaging, which provides antimicrobial effects due to the high CO_2 concentration in the packs. Another novel method is active packaging, where active components are purposefully incorporated into the packaging material. There are several variations of active packaging: *antimicrobial packaging* which releases antimicrobial substances during storage (silver ions, bacteriocins, essential oils, nisin etc.), *antioxidative packaging* containing oxygen scavengers, and finally, *intelligent packaging* which contains sensors and indicators for detection of gas, temperature abuse, package integrity etc., and which utilise colour changes to inform the consumer about the state of the products [18,29]. As active packaging is mostly based on nanotechnology, there are still issues concerning the lack of knowledge about the impact of nanomaterials on human health and their occurrence and destiny in the environment, which should be further studied [30].

4. Novel meat processing methods

4.1. Irradiation

Food irradiation was developed during the second half of the 20th century [31] and involves exposure of food to ionizing irradiation (Gamma rays, Electron beams) in order to promote safety and prolong the food's shelf life, but also refers to product quality examination using computer tomography (CT) based on X rays. Gamma rays are obtained from radioactive isotopes Co^{60} or Cs^{137} with relatively short half lives (5.27 and 30.19 years respectively), with electron beams produced in an electron accelerator and X-rays produced by slamming electrons into metal (tantalum or platinum). Irradiation dose refers to the amount of absorbed energy in Greys (Gy) [31,32]. Irradiation is a highly effective, cold, penetrative and relatively easy to control process, which does not affect the sensory or nutritive properties of food if properly used. One problem can be lipid oxidation in high fat foods, but simultaneous use of antioxidants can prevent this [31]. Although food irradiation has been approved since 1989 by the USDA and FDA, nowadays, about 30 % of countries worldwide have adopted it as a commercial method of food preservation, led by the USA, China, The Netherlands, Belgium, Brazil, Thailand and Australia. The types of foods irradiated are mostly spices, crops, vegetables, fruits etc. and to a smaller extent, meat, mostly ground beef, poultry, fish and seafood. The main obstacle for wider use is acceptance by consumers but this could be overcome by their education and proper labelling of irradiated food [33].

4.2. High pressure

The idea of high pressure implemented as a food preservation method started at the end of the 19th century with the first studies, but it gained importance only during recent decades because of the rising demand for food with preserved nutritive properties [34]. High pressure processing (HPP) includes the use of a pressure chamber at 100-600 MPa, transmitted via water as the pressure transfer medium, and conducted at room temperature. The preservative effect is based on the destruction of microorganisms as well enzyme inactivation, while nutritive value is not affected. In fresh meat, pressure above 150 MPa starts to change the colour by affecting myoglobin, so PHH is more appropriate for cured meat products such as cooked and dry cured ham. Because of the differences in bacterial resistances to high

pressure, hurdle technology using a combination of other antimicrobial parameters could provide a stronger preservation effect at low pressure [35]. HPP could have special importance as a post-packaging processing step in the control of *Listeria monocytogenes* in ready-to-eat products. Furthermore, the fact that this technology is environmentally friendly and waste free could contribute to its greater importance in the future [34]. However, it is considered that the possibilities of HPP are still underestimated because of the lack of activity from large companies, and limited commercial research as well as consumer awareness of its benefits [36].

4.3. Pulsed electric field

Pulsed electric field (PEF) is based on the discharge of high voltage short electric pulses that leads to permeabilization of cell membranes of microorganisms without negative impact on the nutritive value of food. It is mainly used for liquid foods and has no wide use in the meat industry [37], but some studies indicate some interesting approaches concerning the use of PEF (1-3 kV/cm in 100 pulses) as a support for drying, marinating and salting of meat. Specifically, PEF could increase both the speed of salt diffusion and drying during production of dry cured ham, provide faster fermentation in fermented sausages and improve brine distribution in cooked ham production [38].

4.4. Pulsed light

Pulsed light (PL) is based on short time light pulses which are capable of inactivating microorganisms on food surfaces. The antimicrobial effect is provided through the UV spectra of the light, which damages the microbial DNA. PL treatment includes 1-20 light flashes per second, applying energy from 0.01 to 50 J/cm² [39]. There are several possible uses in the meat industry, such as decontamination of carcasses (skin and meat) [40], improved safety of fresh food products such as beef and tuna *carpaccio* [41], decontamination of equipment (knives) after being in contact with meat and meat products [42] and sliced fermented sausages [43]. As too intensively pulsed light could lead to changes in sensory properties of meat, especially colour and aroma, there are some limitations concerning the intensity of the treatment which should be optimised according to the number of flashes, voltage, spectral range and the distance between the product and the light source. Another concern is the economic aspect because of the need for specific equipment [39].

4.5. Cold plasma

Cold plasma (CP) consists of an ionized gas that contains ions (+ and -), electrons, free radicals and photons. Such accumulated charged particles act destructively on microorganisms, providing the antimicrobial effect. CP could serve for decontamination of surfaces of equipment and meat and meat products [37], but as some adverse effects on fresh meat colour were observed, and as lipid oxidation and a certain degree of off-flavour developed, a balance must be found between the antimicrobial effect and sensory qualities of the product [44]. An interesting approach could be application of plasma-treated water (PTW) as a curing agent in emulsion type sausages, because plasma treatment of water generates NO₂⁻ ions which could give colour to the sausages as if they were treated with nitrite [45].

5. Functional meat products

The concept of functional food has gained interest with consumers' awareness of the influence of nutrition on their health and includes the approach of food modification to reduce the amount of potential harmful components and enrich food with health promoting components. As meat products are often described as potentially harmful because of their saturated fat and salt contents, as well as the moieties formed through smoking and curing, most research in this area deals with these issues [4]. Saturated fat reduction is based on the replacement of animal fat with prebiotics, with promising results obtained with inulin [46,47] and with emulsion systems containing oils rich in polyunsaturated fatty acids (PUFAs) [48,49]. The possibilities of the reduction of N-nitrosamines, PAHs and sodium were discussed in other sections of this paper. As for enrichment of meat products with functional ingredients, probiotics could be successfully implemented in fermented sausages, prebiotics both in fermented and heat treated products simultaneously serving as animal fat replacers, minerals such as

salts of Ca, Mg or K could be used as partial NaCl replacers and at the same time, would serve as functional ingredients [23, 47]. The main problems concerning functional meat products enriched with PUFAs are their proneness to lipid oxidation as well as the adverse influence of the oils on sensory properties, but novel techniques in oil emulsification such as organogelation, oil bulking, structured emulsions and microencapsulation could help to overcome these issues [50].

6. Traditional meat products

The production of traditional meat products leans heavily on the oldest processing techniques, including salting, smoking, fermentation and drying. These products are highly appreciated by consumers and have a special value on the market. Although traditional production is, in general, considered as “safe”, there can be some safety issues concerning some parasites (*Trichinella* spp.), bacteria (*C. botulinum*), moulds and PAHs etc. Therefore, there is a need for food safety management systems for small producers, based on good hygiene practice and good manufacturing practice or some sort of generic hazard analysis and critical control points plan [9]. Small producers are not often capable of increasing production in order to meet growing market demands, whereas industrial companies try to take advantage of market desires. Industrial production, though, often leads to changes including lower quality of raw materials, use of starters, additives, artificial casings etc. Because of that, traditional principles should be implemented in industrial production of such products in order to achieve the expected product quality demanded by consumers [51].

7. Conclusions

Meat processing techniques continuously change following contemporary scientific and technological achievements. The oldest processing methods such as chilling, freezing, salting, smoking and drying still remain irreplaceable but have, nowadays, been modified with respect to equipment and consumers' demands about health issues. Novel methods, such as irradiation, high pressure, pulsed electric field, pulsed light and cold plasma still present some obstacles, including consumer acceptance, equipment costs and preservation of sensory properties of the meats. The functional food concept in meat processing struggles with oxidation issues and maintaining the required sensory properties of PUFA-enriched products, with promising results obtained by improving emulsification processes or utilising microencapsulation. Traditional meat products are evergreen in the area of meat processing, with growing demand for these products from consumers requiring introduction of flexible safety management principles, although the production principles and quality should be unchanged.

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