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Review

Process-induced undesirable compounds: Chances of non-thermal approaches

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ABSTRACT

During the processing of meat and meat products the generation of undesirable compounds can occur. Known examples are the generation of substances that can lead to a negative effect on the texture, flavour or colour of products after processing or during storage. Furthermore, thermal processing and smoking have been associated with the generation of or contamination with toxic substances, *e.g.* polycyclic aromatic hydrocarbons or heterocyclic amines. The introduction of new processing technologies may result in the formation of different undesirable compounds compared to traditional technologies. Some of these changes may be without relevant nutritional or health impact, while others may raise concern. To begin with, an overview on the formation of undesirable process-induced compounds by the traditional processing of meat and the proposed strategies for their reduction is presented. Hereby attention is mainly paid to those compounds which present human health concerns. Later the focus lays on the process-induced modifications occurring in meat as a result of high hydrostatic pressure treatments.

1. Introduction

Food processing and food preparation present both beneficial and undesirable aspects. The inactivation of food-borne pathogens, the inactivation of natural toxins and enzymes, the prolongation of shelf life, the enhancement of the digestibility and the bioavailability of nutrients and the improvement of sensory attributes (*e.g.* flavour, texture) of products count among the most important beneficial aspects of food processing and preparation. The large availability and diversity of final (ready-to-eat) and semi-finished food products are further beneficial aspects of industrial processing (van Boekel et al., 2010). However, nutrients can be destroyed and undesirable process-induced compounds can be formed as a consequence of processing. Undesirable process-induced compounds can be substances which negatively affect texture, flavour or colour of the products after processing or during storage, or even have the potential to raise human health concerns. This later group of substances is often called toxicants or contaminants.

The term toxicant encompasses not only undesirable process-induced compounds, but a quite larger group of substances. Meat toxicants can originate from soil or environmental pollutants (*e.g.* arsenic, lead, dioxins and dioxin-linked polychlorinated biphenyls, organochlorine pesticide residues), from microbial metabolites (*e. g.* mycotoxins), from endogenous plant or animal toxicants, veterinary drug residues and finally from compounds generated during processing and storage of meat. Two recent comprehensive reviews, Andrée, Jira, Schwind, Wagner, and Schwägele (2010) and Püssa (2013), are recommended for more detailed information concerning meat toxicants in general.

The formation of undesirable process-induced compounds often cannot be avoided. However, if the respective mechanisms for their formation have been investigated and understood completely, it is possible to optimise food formulations, processing technologies and preparation methods, towards reducing or even preventing their formation. Based on the scientific knowledge currently available on the chemical changes occurring during traditional food processing it is possible, to a large extent, to reduce the formation of many known toxicants. However, the availability of analytical methods with increasing sensitivity and of new toxicological research outcome makes process optimisation towards the prevention of toxicant formation a permanently challenging task.

Novel, or as usually called, emerging food processing technologies have been proposed to overcome some of the known limitations or negative aspects of traditional processing. However, the introduction of new processing technologies may result in the formation of different undesirable compounds as compared to traditional technologies. Some of these changes may have no relevant nutritional or health impact, while others may raise concern.

This paper presents an overview concerning the generation of undesirable compounds during processing, storage and/or preparation of

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meat and meat products by means of traditional and emerging processing technologies. For the purpose of this paper, the term meat is used mainly for beef and pork. With few exceptions, only articles published during the last 10 years were reviewed. The major sources consulted were Web of Knowledge (Web of Science, FSTA, CAB Abstracts, Biological Abstracts) and SCOPUS. To begin with, the present knowledge on the formation of undesirable process-induced compounds resulting from traditional meat processing procedures and some of the proposed strategies for their reduction are reviewed. Hereby attention is paid mainly to those compounds which present human health concerns. Later the focus lays on the process-induced modifications occurring in meat as a result of high hydrostatic pressure treatments.

2. Toxicants generated by traditional meat processing procedures

Meat and offal are an important source not only for high biological value proteins but also for some micronutrients, *e.g.* iron, selenium, vitamins A, B12 and folic acid, which do not occur or show low bioavailability in plant derived food (Biesalski, 2005; Pereira & Vicente, 2013). However, meat and meat products have also been associated with a variety of toxicants generated during traditional processing, storage and/or preparation.

Curing and smoking have been used for meat preservation for centuries. Curing, due to the action of nitrite, inactivates pathogenic microorganisms and has antioxidant properties. Furthermore, it forms the desirable flavour and colour typical for cured meat and meat products. However, the addition of nitrite is also associated with the generation of N-nitrosamines; some of them are considered as carcinogenic. Smoking is applied to a considerable part of processed meats. This procedure is used for several reasons: product safety is increased due to antimicrobial and antioxidant properties, and product quality is improved because smoke adds value to sensory and technological parameters of the products. Nowadays, not only natural smoke, which is generated by smouldering (smouldering smoke), by treating wood chips with overheated steam (steam smoke) or, by friction of a log (friction smoke), but also liquid smoke and smoke aroma, respectively, are used. Depending on the type of smoke generator, smoke contains different amounts of phenolic compounds with antioxidant traits and polycyclic aromatic hydrocarbons, which may raise health concerns (Pöhlmann et al., 2013a); according to Jira (2010b) smoked meat products also contain 3-monochloropropane-1,2-diol, a substance belonging to undesired chloropropanols. Its formation is not correlated with the benzo[a]pyrene concentrations.

Fermentation and drying – separately or in combination – of raw meat or meat products have a very long tradition. In general, a food is fermented, if microorganisms or enzymes have significantly modified a food by causing desired biochemical changes. This applies to most types of raw sausages and raw hams (Campbell-Platt, 1987). According to Lücke (1994) “fermented sausages are defined as ground meat mixed with salt and curing agents, stuffed into casings and subjected to a fermentation process, in which microorganisms play a crucial role. Most fermented sausages are dried and they can be stored with little or no refrigeration.” Fermented and dry-cured sausages are characterised by their typical sensory traits, their dietary and nutritional aspects, the effective technological way of production and the energy saving storage conditions required.

Quality traits such as smell and taste, both of them closely related to the formation of volatile and non-volatile compounds, respectively, benefit only partly from the addition of starter cultures, because the maturation, *i.e.* the development of the aroma of fermented meat products, is a slow process, which can hardly be accelerated by microbial activities. Furthermore, Verplaetse, Gerard, Buys, and Demeyer (1992, 1994) found that the breakdown of polypeptides to smaller peptides and free amino acids is to a lower extent (40%) of microbial origin and to about 60% of endogenous origin.

Thermal processing and preparation procedures generate toxicants, including polycyclic aromatic hydrocarbons *via* combustion and heterocyclic aromatic amines through reactions involving creatin(in)e, sugar and amino acids in meat (Sugimura, 2002). Cooking methods such as boiling, conventional roasting and grilling, (superheated) steam roasting/baking, steam grilling, convection grilling and deep frying are known to be sources of human exposure to polycyclic aromatic hydrocarbons, cholesterol oxidation products, furans and others. Furthermore, according to Alina et al. (2012), the cooking process can lead to the formation of cholesterol oxidation products which can give negative biological effects to humans.

Some examples of process-induced undesirable compounds generated by traditional processing and preparation of meat and meat products are given in Table 1. Subsequently, recent studies towards the generation of toxicants by traditional meat processing and preparation procedures and the proposed strategies for limiting their generation are presented.

2.1. Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds containing two or more aromatic rings, mainly generated from free radicals during incomplete combustion or pyrolysis of organic matter and during various industrial processes. PAHs are environmental pollutants resulting from human activity (traffic, incineration), and can also contaminate food during smoking and/or roasting over an open flame due to the presence of PAHs in the smoke. Furthermore, during grilling PAHs can be generated from melting fats dripping onto the charcoal, getting pyrolysed to volatile PAHs which then contaminate the food surface (Hotchkiss & Parker, 1990; Park & Penning, 2009).

Benzo[a]pyrene, one of the carcinogenic PAHs, has been used as an indicator of PAHs in food for many years. However, recently the Panel on Contaminants in the Food Chain of the European Food Safety Authority (EFSA) reviewed the available data on occurrence and toxicity of PAHs, concluding that benzo[a]pyrene is not a good indicator of PAHs in food and recommending the use of PAH4, (sum of benzo[a]pyrene, chrysene, benzo[a]anthracene and benzo[b]fluoranthene contents), and PAH8 as the most suitable indicators of PAHs in food, with PAH8 not providing much added value compared to PAH4 (EFSA, 2008).

PAHs have been also detected in liquid smoke flavourings, though the concentration of carcinogenic PAHs present was very low (Guillén, Sopena, & Partearroyo, 2000a, 2000b). The EFSA evaluated the safety assessment of eleven smoke flavouring primary products, including animal testing and proposed dietary exposures. It was stated among the conclusions of the study that the manufacturing process and the wood used as a starting material are determinants for the chemical composition and thus the toxicological properties of these products. Only three of the analysed primary products would not be a safety concern for humans, but the additional purification of these materials was proposed as a possibility to obtain safer products. It was also suggested that as the content of two of the PAH4 is very low as a consequence of legal requirements, the use of primary products could be preferable to the traditional smoking (Theobald et al., 2012). Since January 1st 2014 a new EU regulation authorises only ten commercial smoke flavouring primary products for the use in/on foods and for the production of derived smoked flavourings. The maximum levels authorised in/on meat and meat products range from 0.06 to 5.0 g kg^{-1} depending on the flavouring product (EC, 2013).

Onyango, Lalah, and Wandiga (2012) analysed the concentrations of the PAHs in raw beef, goat meat, and pork, and investigated the effect of direct-heat charcoal roasting, electric-oven grilling, and shallow-pan frying on these concentrations. They found that roasting and shallow-pan frying introduced new PAHs and increased the concentrations of those existing in raw meat. Apart from this, direct-heat charcoal roast beef had five new PAHs and a total mean PAH content of 17.88 μg kg^{-1},