

II Report and Conclusions

1 Foreword

The Senate Commission on Food Safety (SKLM) of the Deutsche Forschungsgemeinschaft (DFG) hosted a symposium entitled "Thermal Processing of Food: Potential Health Benefits and Risks" from 25th to 27th September 2005. Participants included experts from Germany and abroad. The main topics discussed were positive health effects and risk aspects of thermal food processing, also encompassing associated opportunities for innovative food technology. Following its mandate for evaluation and advice concerning human health the SKLM has elaborated conclusions and has highlighted areas that require further research.

2 General and Food Technological Aspects

Heating is one of the oldest and most reliable methods of food treatment that has substantially contributed to ensuring sustainable supply of food. Thermal treatment of foods, such as boiling, drying, roasting, baking, grilling and frying, affects food in many ways. For example, it can alter the taste, aroma and texture, and can also lengthen the shelf life. A large number of the processes taking place in foods during heating are based on non-enzymatic browning, i.e. the Maillard reaction.

Thermal processing of foods can often be combined with other conventional methods or novel technologies in order to ensure a product and energy saving process. The synergy effect resulting for example from combining high-pressure treatment and gentle heating can efficiently kill microorganisms or inactivate enzymes while desirable compounds, such as vitamins, colourants and flavourings, remain largely unaffected.

The application of novel technological treatment and processing methods in general presupposes that this does not lead to any additional microbial, toxicolog-

ical or allergenic risks. With respect to the use of such methods, the legislation has created an instrument to ensure the safety of correspondingly processed foods within the EU Directive 258/97 on novel foods and novel food ingredients.

3 Health Aspects of Thermal Food Processing

Evaluation of thermal processing of foods needs to take into account both, positive and negative aspects. These were discussed with examples during the symposium.

3.1 Advantageous Aspects

Nutritional aspects

Heating of foods often is a condition for intended consumption. In many cases, it is only the thermal process that produces an edible food, as is the case for bread or bakery products. Other foods, such as some raw vegetables, potatoes, rice and pasta, need to be cooked to render them palatable. The thermal treatment of foods is thus a process contributing to palatability, and ensures a sustainable and balanced diet. Heating of foods also plays an important role in the generation of aroma and taste thus improving palatability. Aroma, taste, colour, texture and appearance are greatly influenced by the heating process thus contributing decisively to acceptance of foods.

Microbial aspects

Heating of foods improves microbiological safety and shelf life. In addition to heat-induced inactivation of pathogenic organisms/microorganisms, toxins or enzymes, additional antimicrobial substances or enzyme inhibitors may be produced that also have a favourable effect on the shelf life.

Allergens

As a rule, thermal processes tend to inactivate food allergens rather than to increase the allergenic potential of food. A rapid decrease in the allergenicity of certain fruit allergens was observed after mild thermal processing. However,

sporadic studies, concerning the influence of roasting on peanut allergens, have reported an increase in allergenicity.

A change in the allergenicity after thermal processing is usually difficult to detect since e.g. the solubility of the proteins frequently decreases after such treatment. At present, there is little evidence for the formation of new epitopes during the thermal processing of foods. Although there are examples of the Maillard reaction being able to enhance the IgE antibody reactivity of food proteins in individual cases, there are as yet no structural data confirming the presence of "Maillard epitopes" that are not present in the raw state.

Other aspects

The elucidation of mechanisms or processes that promote the development of positive health effects during thermal food processing is within the focus of current scientific interest. For example, mechanistic aspects are important with respect to the formation of resistant starches and their influence on gastrointestinal health, the formation of substances with antioxidative or other chemopreventive properties or enhanced bioavailability of nutritional constituents, such as lycopene in tomatoes or tomato products. Intelligent selection of varieties and/or corresponding processing controls can also contribute to favour positive health effects or to reduce negative ones.

3.2 Disadvantageous Aspects

Thermal processing of foods may also have undesirable consequences, e.g. the loss of nutrients such as vitamins, essential amino acids and unsaturated fatty acids. Likewise, thermally induced formation of harmful substances is also possible. The latter constituted another main subject of the scientific discussions, addressing in greater detail acrylamide, heterocyclic aromatic amines, furan and 3-monochloro-1,2-propanediol.

Acrylamide

Acrylamide may be formed by baking, roasting and frying of foods, particularly of potato products (e.g. chips, fried potatoes, crisps), cereal products (e.g. roasted cereals, bread, bakery products), coffee and cocoa. It is formed on heating of foods above 120°C by the Maillard reaction, preferentially by condensa-

tion of the amino acid asparagine with reducing sugars, such as fructose and glucose.

Acrylamide is considered a probable human carcinogen (IARC Group 2A, MAK Commission Carcinogen Category 2), implying that its metabolite epoxypropanamide (glycidamide) is the actual active genotoxic agent. In animal experiments with rodents, glycidamide-DNA adducts were found in all tissues investigated at high dosage. Furthermore, animal experiments have shown that acrylamide exhibits toxic effects to the nervous system and the reproductive organs.

There is a relatively small margin between the carcinogenic dose found in animal experiments and the highest estimated mean acrylamide intake in humans. However, hitherto quantitative estimates of the carcinogenic risk for humans by various scientific committees differ quite considerably. As yet, available epidemiological studies do not provide convincing evidence of a correlation between the acrylamide intake and tumour incidence; however, their ability to detect such an association is limited.

Heterocyclic aromatic amines

Heterocyclic aromatic amines (HAA) are formed in varying concentrations by frying or grilling or by comparable methods of heating meat and fish, depending on the type of protein, the temperature and the heating time. However, the formation of HAAs can be largely avoided by following certain precautions.

Two main types of HAAs are formed in varying amounts, depending on the temperature and precursor compounds: isoquinoline (so-called IQ compounds) and carboline derivatives.

Many HAAs show a mutagenic potential in bacterial and mammalian cell-based test systems and are carcinogenic in animal experiments. In humans, bioactivation of HAAs to carcinogenic metabolites varies greatly between individuals. There are also significant differences between species.

In addition to HAAs, thoroughly fried or overcooked red meat may contain other carcinogenic substances in comparable concentrations. It has not yet been unambiguously determined whether only HAAs or rather a complex mixture of thermally induced genotoxic compounds should be regarded as carcinogenic risk factors.

Furan

Furan is a volatile compound that has been detected in a number of heated foods, such as coffee, bread, vegetable and meat preserves, as well as in baby food. Its presence in widely different types of foods suggests that it is formed by different routes. There is only a limited database on its occurrence in differ-

ent food categories and most data has not been measured in food ready for consumption. It is therefore not possible as yet to provide a reliable estimate on exposure levels from this limited data.

Oral application of furan to rats and mice led to different tumour patterns. Rats exhibited dose-dependent hepatocellular carcinomas and a high percentage of cholangiocellular carcinomas and leukemias; mice exhibited hepatocellular adenomas and carcinomas. It is suspected that the carcinogenic activity, at least in part, is based on a genotoxic mechanism. In particular the metabolite cis-2-butene-1,4-dial is suspect to be the genotoxic mutagen. On the basis of the limited data available on toxicity, metabolism and exposure, an adequate risk assessment is not possible at present.

3-Monochloro-1,2-propanediol (3-MCPD)

3-Monochloro-1,2-propanediol (3-MCPD) is regarded as a reference substance for a series of undesirable compounds known as chloropropanols. 3-MCPD may be produced in the $\mu\text{g}/\text{kg}$ (ppb) range during manufacture of seasoning sauces from hydrolysed vegetable protein as well as by baking or toasting of bread, cereals and coffee beans. 3-MCPD is formed at temperatures significantly above 100°C ; various formation mechanisms are discussed. More recent studies show that certain foods may contain not only chloropropanols but also their esters in quantities that can be 50 to 150 times higher than those of 3-MCPD.

3-MCPD has caused tumours in animal experiments when applied at high dosage. However, based on the evaluation of all data a genotoxic mechanism is not considered likely. Both SCF¹ as well as JECFA² have therefore derived a tolerable daily intake of $2 \mu\text{g}/\text{kg}$ body weight for humans. The formation of 3-MCPD in seasonings can be controlled and minimised by varying the processing conditions. So far, the formation mechanism of 3-MCPD has only been investigated with acid-hydrolysed vegetable proteins.

4 Conclusions

Thermal processing of foods is necessary to make food digestible and palatable, to ensure microbiological safety and to produce a distinct taste, aroma and texture. This may lead to extensive changes in the foods. The processes occurring during thermal treatment of foods are by far not completely understood and a multitude of compounds formed by thermal reactions are not characterised.

¹ Scientific Committee on Food (2001): Opinion on 3-Monochloro-Propane-1,2-Diol.

² Joint Expert Committee on Food Additives (2002): 3-Chloro-1,2-Propanediol, WHO Food Add. Ser. 48.

Elucidating the influence of composition of raw materials (e.g. choice of variety, growth and storage conditions) is of prime importance. This applies even more to the mechanisms that lead to the formation of colour, taste and flavourings, and to constituents with positive or adverse biological effects. Knowledge of these factors allows to specifically influence the formation and concentrations of such compounds in foods, for example, by appropriate choice of raw materials, control of the processing conditions or by combining thermal processing with other methods. A case-by-case evaluation is needed for each individual thermal process taking into account the associated benefits and the risks.

5 Research Needs

The SKLM sees a need for further research on both the positive and negative effects of thermal food processing in general, as well as on details of individual toxic substances/groups of substances.

Positive health effects of thermal food processing

The relevance for humans of positive health effects from thermal food processing observed in experimental systems *in vitro* (cells) or *in vivo* (animal) have to be proven. At the same time, wholesomeness of thermally treated foods must be guaranteed. The SKLM recommends further research to be carried out on mechanisms and processing aspects that enhance the positive effects of thermal food treatment. This applies primarily to the elucidation of effects on matrix materials and constituents and how they affect digestibility, nutritional value and gastrointestinal health. Particular attention should be paid to the following:

- to study effects on bioavailability of nutritional constituents
- to increase the formation of substances with antioxidative or other chemopreventative properties
- to develop sensitive biomarkers for exposure and effect
- to reduce the bioavailability of substances with adverse health effects, e.g. by binding to the matrix.

Adverse effects on human health of thermal food processing

The formation of harmful substances as a consequence of the treatment of food is generally undesirable and should be minimised by appropriate methods. The

SKLM sees a need for further research on the impact of such minimisation measures on other food constituents. Further research is needed, in particular, on the following:

- more data on exposure to thermally generated substances with adverse health effects
- development of sensitive biomarkers for exposure and effect
- more data on toxicologically relevant effects comparing animals and humans (as far as ethically justifiable) and including, as far as possible, kinetics, metabolism, bioavailability and molecular mechanisms
- continued development of improved methods in molecular epidemiology to investigate individual sensitivities or to identify risk groups
- improved methods to determine allergenicity after thermal treatment in individual cases (where this appears necessary).

Further research needs, relating to specific substances discussed during the symposium

Acrylamide:

- Development/optimization of biomarkers of exposure and effect, particularly improved methods to measure DNA damage, adduct formation, mutations and repair of adducts, and investigations on a correlation of glutathione/mercapturic acid/haemoglobin adducts. Quantitative comparisons of these processes in animals and humans are of particular interest
- improved understanding of mechanism of tumour formation: Possible influence of acrylamide on the hormonal system

HAAs:

- more in depth studies on defined risk groups carrying enzyme polymorphisms and determination of relationships between exposure and incidence of cancer
- clarification of possible endogenous formation of HAAs in conjunction with a high creatinine intake

Furan:

- more data on the formation and occurrence of furan in foods
- improvement of the toxicological database, including developmental and reproductive toxicology
- investigation on substituted furans in comparative studies, to elucidate the toxicological relevance of these compounds

3-MCPD:

- more data on the formation and occurrence of 3-MCPD and other monochloropropane diols and dichloropropanols in foods. The contribution of esterified chloropropanols to the total content has not been studied adequately so far. More data are required on the bioavailability, toxicokinetics and toxicity of chloropropanols and their esters.