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Review Article

Heat-Induced Food Toxicants: A Critical Review

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Abstract
Thermal processing improves the physio-chemical, functional, nutritional and sensory attributes, as well as increasing the consumer appeal or general acceptability of foods. However, hundreds of potentially harmful toxicants are also generated during the heating process. This paper talks a look at a few of the heat-induced food toxicants such as polyclic aromatic hydrocarbons (PAHs), hetrerolyclic amines (HCAs), acrylamide, acrolein, nitrosamines, lipid peroxides, benzene, hydroxyl-furfural and advanced glycation end-products (AGEs), with the hope of providing information on their presence in foods and creating awareness about their toxic effects which include carcinogenicity and organ damage. Possible ways of reducing their formation and hence the intake of such toxicants are also reviewed. The information provided here is based on evidence from epidomiological and toxicological studies and findings in both animal models and humans.

Keywords: Physio-chemical, Heat, Food, Toxicants, Processing

Introduction

Food processing is any physical, chemical or biological treatment to which a food substance is subjected from the point of harvest to the dining table (Okada *et al*., 2010). It involves basic convert raw materials into semi-finished or finished products that can be consumed or stored, or the transformation of a food substance into other forms (Ihekoronye and Ngoddy, 1985). Processing affects the physio-chemical, functional sensory and nutritional properties of any food that is processed. Processing can also totally eliminate or reduce some anti-nutritional factors in the food, some of which may be either toxic, antagonistic to digestive enzymes thereby reducing digestibility or may bind other important nutrients thus making them unavailable. It also increases the consumer appeal or general acceptability by improving the organoleptic and sensory attributes of the food substance (Fasoriyo *et al*., 2010). During thermal treatment of food many natural enzymes present in the food which are heat-labile because they are proteins, are denatured and hence deactivated, which leads to the extension of the shelf-life of the processed food. Similarly, some of the pathogenic microbes present in the food are destroyed. Other advantages of processing include food consistency, yearly availability, ease of transportation, offering of variety and alleviating food shortages. According to Reddy and Hayes (2001), the adverse effects of processing include partial or complete destruction or removal of nutrients, inferior or reduced digestibility and utilization of nutrients and generation of new potentially harmful substances called toxicants. This is as a result of molecular interactions between the food components or with other added ingredients or between the food components and the containers used for processing, packaging or storage (Friedman, 2003). A food toxicant can be defined as any substance (chemical) either natural or synthetic that has deleterious effects on living

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organisms including man and other animals. Processing induced food toxicants are chemicals added or formed during processing and may be either anti-nutritive (blocks, interferes with or destroys available nutrients), pro-toxicant or toxicants. A pro-toxicant is liable to undergo oxidation during digestion or through biotransformation, while a toxicant is subject to biotransformation, sequestration or elimination and it is dose dependent (Committee on Diet, Nutrition and Cancer, 2007). Generally, whether a substance poses harm depends on its concentration, amount of intake (dosage), health and nutritional status of the individual as the human body is capable of detoxifying low levels of several harmful substances. Thus, the toxicity of any toxicant depends on the individual, his/her susceptibility, metabolism and defense mechanisms available (Kabak *et al*., 2006).There are hundreds or even thousands of known food toxicants that are either formed as a result of thermal treatment of food either in the presence or absence of alkali or acid or as a result of additives added to food. Many others are known to migrate into food from the processing containers, packaging materials or during storage. In this paper only some important heat induced food toxicants will be reviewed, with the hope of creating awareness about their formation, harmful effects and the possible ways of reducing their presence in processed foods. This will help in improving the safety of heat processed food products which is of great concern especially in Africa where more than 91million people fall ill with about 137,000million resultant deaths occurring every year due to food-borne diseases (WHO, 2015). The burden of food-borne diseases is quantified by the WHO in terms of "Disability Adjusted Life Years" (DALYs), which is the number of healthy years lost due to illness or disease of food origin. Thus, from the 31 hazards on record in 2010, 33 million DALYs were lost (WHO, 2015).

Toxicant formed in heat-processed foods

The traditional or conventional heat processing of foods involves such operations like blanching, boiling, broiling, cooking, frying, roasting, smoking, toasting and extrusion which is a relatively new technology. During each of these processes, potentially toxic substances are formed or transferred to the processed foods and they include polycyclic aromatic hydrocarbons, hetroclylic amines, Maillard reaction products (non-enzymatic browning reaction products), acrylamide, acrolein, lysino-alanine, nitrosamines, amino acid hydrosylates, lipid peroxidation products and many others.

Polycylic aromatic hydrocarbons (PAHs) and Heterolyclic Amines (HCAs)

PAHs are fused aromatic compounds formed by the incomplete combustion (Pyrolysis) of proteineous foods during cooking, broiling roasting, grilling and frying of meat, fish or other foods containing proteins. HCAs are formed when mixtures of creatine, amino acids and sugars are heated together at high temperatures or for prolonged time. Like the PAHs, they are also formed during pyrolysis of proteins high temperatures mainly in roasted or grilled meat, fish or juice from roasted meat. The charred and black crusts on the surfaces of partially burnt meat or fish produced with naked flame contain high levels of these toxicants (Sugimura *et al*., 2004: Cross *et al*., 2010). HCAs are not found in significant amounts in foods other than meat (cooked fried, roasted, grilled, broiled, or boiled) at high temperatures but PAHs can be found in other smoked foods (Sabrina *et al*., 2005). The bad practice of grilling (roasting) meat using kerosene or old tyres is a potential source of high levels of PAHs and Okaka *et al*., (2005) have reported as high as 0.2g/kg of PAHs in charcoal broiled meat (*Suya*) and smoked fish. The research leading to the discovery of HCAs was inspired by the idea that smoke produced during thermal treatment of meat or fish might be carcinogenic, and so far, more than 10 different kinds have been isolated and characterized (Knize *et al*., 2005; Jagerstadand Skog, 2005).Factors influencing the formation of PAHs and HCAs include the type of food substance (meat and fish) method of heat treatment, degree of treatment (doneness), high temperature and duration of preparation (Cross and Sinha, 2004). PAHs and HCAs have been associated with cancers in animals in many studies (Sugimura *et al*., 2004). Diets supplemented with HCAs fed to redents have been associated with turmors of the breast, colon, lung, skin, prostate and other organs (Ito *et al*., 1991; Committee on Diet, Nutrition and

Cancer, 2010; Ward *et al*, 2001). Although doses used in the studies were 1000x higher than those obtainable from normal diets. Also, population studies are yet to establish definitive limit between PAHs and HCAs exposures from cooked meats and human cancers. However, epidemiological studies have revealed that high consumption of "well-done", fried or berbecued meat (*Suya*) could be associated with high risks of colorectal, pancreatic and prostate cancers (Cross *et al*., 2010; Chiavarini *et al*., 2017; Sinha, *et al.*, 2009). Drastic reduction in the intake of PAHs and HCAs can be achieved by avoiding direct exposure of meat to an open (naked) fire or hot metal plate and the turning of meat being roasted continuously instead of leaving it on fire without flipping. Other measures include avoiding prolonged heating especially at high temperature, removal of charred portions of the food substance (meat or fish) and refraining from consuming the gravy from meat drippings (Knize and Felton, 2005). Sugimura and Co-workers (2004) have also recommended the supplementation of diets with soyabeanisoflavones (or consumption of soybean) which suppresses the occurrence of HCA-induced breast cancer. The World Cancer Research Fund in collaboration with American Institute for Cancer Research (AICR, 2007) issued a report with dietary guidelines that recommends limiting the consumption red and processed (including smoked) meats, but there were no recommended intake levels of PAHs and HCAs.

Acrylamide

Acrylamide which is also known as 2-propenamide was first identified by Swedish scientist between 2000 and 2002 in fried and baked products such as potato, bread, coffee and corn products. It is formed by reduction reaction between asparagine and glucose or fructose during Maillad reaction/non-enzymatic browning (Kabat *et al*., 2009). The discovery of acrylamide caused a lot of concern that led to the formation of the Heat-generated Food Toxicants (HEATOX) project, a multi-disciplinary research project involving 24 partners in 14 countries and sponsored by the Lund University, Sweden which lasted for 40 months (HEATOX, 2007). The study has shown that formation of hemoglobin adducts increases linearly with increase in acrylamide intake in humans. Other research results have also linked acrylamide with cancer in redents and it is also as a neurotoxin (EFSA, 2011). Levels of acrylamide in foods depends on cooking temperature, time, nature of food matrix and frying oil. The allowable daily intake (ADI) of acrylamide by the FAO/WHO is 0.3-0.8µg/kg body weight per day, while the reference dose 12µg/kgbw/day causes problem (EFSA, 2011). To reduce intakes of acrylamide, it is necessary to avoid over cooking food rich in carbohydrates either for prolonged time or at high temperature, and limit the consumption of foods with high levels of asparagine and sugars.

Acrolein

Acrolein or 2-propanal is the simplest α-β unsaturated carbonyl formed in foods when carbohydrates, fats and amino acids are heated. It is formed from the glycerol and glycerides in fat, thermal decomposition of amino acids such as methionine, threonine and heating of carbohydrate rich foods at high temperature (EFSA, 2011; Watzek *et al*., 2012). It is present in bread, heat-processed meat, fish and cheese but occurs in highest levels of deep-fried products such as potato chips between 0.2 – 1.4mg/kg (Watzek *et al*., 2012). The formation of acrolein during heating of oils and fats depends on the fatty acid composition and temperature. Thus, heating or frying at 140^0C for 24 hours can lead to acrolein levels of up to 240mg/kg in lin seed oil, 160mg/kg for canola, 15mg/kg/olive oil), 70mg/kg for deep-frying fat and 7mg/kg for coconut oil (Ewert *et al*., 2011). Like acrylamide, acrolein has also been linked with many cancers and organ damage and the control measures are similar to those of acrylamide (Wu, 2006).

N-Nitrosamines

Nitrates and nitrites used in curing meat can react with 2^0 and 3^0 amines at high temperatures to form stable nitrosamines. The high temperature of processing leads to the degradation of amino acids of the meat proteins to 2^0 and 3^0 amines. N-nitrosamines have been linked to pancreatic cancer and liver DNA damage (Ward *et al*., 2007; Wu, 2006). Estimates by several investigators have suggested an average daily intake of approximately 1µg/person. Type of food components and heating methods play a major role in nitrosamine formation in foods. Ascorbic acid and Sulphur dioxide can be used to inhibit nitrosamine formation in foods

Nitrosodimethylamine has been reported to be formed in foods as a result of direct-fire drying process. Foods which have been shown to contain volatile nitrosamines include meat, fish, cheese, non-fat dry milk, beer and cooked bacon (Scalan, 1983). Nitrosamines have been shown in animal experiments to be the most broadly acting and the most potent group of carcinogens (Lihjinsky, 1999).

Lipid Peroxides

The polyunsaturated fatty acids in oils and fats can undergo 3 basic changes during heat treatment and these includes auto-oxidation, thermal polymerization and oxidation. The two oxidative processes generate free reactive peroxide radicals which are responsible for the rancidity in oils and harmful to human health (Reddy *et al*., 2001). Hydrogenation may also occur leading to the formation of trans-fatty acids (the so-called bad fats) which is one of the predisposing risk factors of cardio-vascular diseases (CVDs). Polyunsaturated fatty acids such as omega 3 and omega-6 fatty acids have been believed for many years to be more heart-friendly but are actually more susceptible to oxidation and also promote the damaging effects of other toxic substances such as HCAs (Sies *et al*., 2005; Raloff, 1985).

Control measures for reducing the formation of peroxides and oxidized unsaturated oils include avoiding over frying or heating of oils and oily foods. This is particularly important to local “Akara” (bean cake) processors who use the same oil for frying repeatedly far long periods of time and only top it up when the volume runs down, as such over-heated oils could contain high level of lipid peroxides.

Hydroxymetyl Furfural

5-hydroxymethylfurfural was one of the toxicants investigated during the HEATOX study and it is formed in heat processed foods when carbohydrates are heated especially at high temperatures. It was discovered that human sulfotransferase enzyme can convert 5-hyroxymethylfurfural (HMF) into 5-sulphoxymethylfurfural (SMF) which is a mutagenic substance that is capable of forming DNA adducts. It was also found to be strongly neutrotoxic in mice (HEATOX, 2007).

Advanced Glycation End-products (AGEs)

These are glycosylated proteins formed during heating and cooking of food. AGEs can cause intracellular damage and cell apoptosis through the process of cross-linkage. They have been reported to be associated with series of disorders ranging from allergies to Alzheimer’s disease, rheumatoid arthritis and urinogenital disorders. Diabetic patients in particular are known to have high levels of AGEs in their blood serum due to their condition of hyperglycemia (Bernheinm *et al*, 2001).

Benzene

Benzene is a cyclic aromatic hydrocarbon (C_6H_6) which can be generated during heating or cooking of food as a result of thermal decomposition of food components, additives, preservatives (e.g benzoates) and during irradiation of food (Vanda, 2015).Smoking and roasting of food substances can also produce benzene, thus, as high as 21-121 ppb levels have been reported in smoked fish and meat (Wittkowski *et al*., 1990; Ahn, 2002). Breakdown of phenylalanine by ionization also leads to the formation of benzene in heat-processed foods (Sammers *et al*., 2012). Lachenmeier and his co-workers (2008) have also reported that β-carotene and terpenes can decompose to form benzene. According toVania *et al*., (2015), non-alcoholic beverages have the highest concentrations of benzene, hence more attention should be paid to its reduction in soft drinks. The oral lethal dose of benzene for humans is 125mg/kg (Sammers *et al*, 2012). It is however difficult to assess accurately the human dietary exposure to benzene because its levels in various foods greatly vary, but the Human Exposure Characterization of Chemical Substances (HEXPOSC) estimated that human dietary exposure to benzene is between 3-50mg/kgbw/day (Vania *et al*., 2015. Presently, there is no specific limit for benzene in food/beverage hence the reference value for drinking water (1-10ppb that is 1-10μg/l) is adopted and used. Benzene is genotoxic, carcinogenic and can cause damage to the hematopoietic system and may also cause leukemia (Vania *et al*., 2015).

Conclusion

A lot of toxic substances are produced during heat processing of foods and only a few have been reviewed in this paper. Though most of these toxicants are generated in low and imperceptible levels during food processing, they tend to accumulate with time and thus elicit their toxic effects later in life especially at the old age. Therefore, their intakes through the diets should be reduced as low as possible because they cannot be completely avoided as they will inevitably be present in processed foods.

Food safety is a concern and responsibility of everybody including government, food manufacturers, local food processors/vendors and individuals. Control or safety measures including extensive awareness campaigns on the formation, dangers and ways of reducing these toxicants are important. There should be more funding for toxicological and analytical research activities and regular monitoring/evaluation of manufactured food products by agencies such as NAFDAC. Good manufacturing practices by large scale food producers is very important and should include use of approved and safe techniques, additives and safety measures. Steaming of food is always better and should be preferred to other forms of heat-processing. At personal level, consumption of foods with high levels of antioxidants such as sesame seeds on daily basis is highly recommended and above all, personal hygiene and eating balanced diets are very important. Finally, consumption of lots of assorted fresh fruits and vegetables with very little or no processing has been shown to positively correlate with long life span.

References

Ahn, D. U. (2002) Production of Volatiles from Amino Acid Homopolyzms by Irradiation. *Journal of Food Science*,67(7),2565-2570

Bernheim, J.,Rashid, G., Gavrieli, R., Korzeta, Z. and Wolach, B. (2001). In vitro Effect of Advanced Glycation End-products on Human PolymorphonuclearSuperioxide Production. *Euro. Journal of Clinical Investigation*, 3l,(1), 1064-1069.

Chiavarini, M.,Bertarelli, G.,Minneli, L. and Fabicani, R. (2017).Dietary Intake of meat cooking-related Mutagens (HCAs) and Risky of colorectal adenoma and cancer: A systematic Review and Metal-analysis.Nutrition, 9(5*)*, 514

Committee on Diet, Nutrition and Cancer (2007), Assembly of Life Sciences, *National Research Council. Diet, Nutation and Cancer National Academy Press, Washington D.C*268

Cross, A. J. and Sinha, R. (2004).Meat-related Mutagens/Carcilnogens in the Etiology of Colorectal Cancer.*Environmental and Molecular Mutagenesis, 44(1),* 44-55

Cross, A. J. Ferruce, L. M.,Risch, A.,Graubard, B. I., Ward, M. H., Park, Y. A.,Holanbeck, A. R.,Schatzkin, A. and Sinha, R. (2010). A Large Perspective study of meat consumption and Colorectal Cancer Risk: An Investigation of Potential Mechanism Underlying their Association. *Cancer Research, 70(6),* 206-2414

European Food Safety Authority, EFSA (2011).Scientific Report of EFSA.*Results on Acrylamide levels of food from mentoring years 2007-2009 and exposure assessment. EFSA Journal, 9(4),* 21-33

Ewert, A.,Granvogi, M. andScheberle, P. (2011).Development of two stable Isotope Dilution Assays for the Quantification of Acrolein in Heat-processed fats.*Journal of Agriculture and Food Chemistry* 59, 3882-35889

Fasoriyo, S. B.,Akande, S. R.,Sadeko, O. O.,Sulaiman, P. O.,Olapade, C. O. and Ochi, C. E. (2010). Physio-chemical and Sensory Properties of Pigeon Pea (CanjaousCarja).*Journal of Agricultural Information* II, 35-364

Freidman, M. (1992). Nutritional value of proteins from different food sources: *A Review Journal of Agriculture and Food Chemistry* 44, 6-21

HEATOX (2007).Heat-generated food toxicants project. Final report available at www.heatox.org

Ihekoronye, A. I. and Ngodedy, P. O. (1985) Integrated Food Science and Technology for the Tropics – Macmillan Publishers Ltd, London, p284

Ito, N. Hasegawa, R. Sano, M., Tamano, S., Esumi, H. Takayama, S. and Sugimu, T. (1991). *A New Colon and Mammary Carcinogen in Cooked Food*: 2-amino-1-methyl-6 henylimidazole [4,5,bj] pyridine (Phip). Carcinogenesis 12(8), 1503-1506

Jagorstad, M. and Skog, K. (2005) *Genotoxicity of Heat-processed Foods*. Mutation Res, 574

(1-2), 156-172

Kabak, B., Dobson, A. D. andVor, I. (2006).*Strategies to Prevent Mycotoxin Contamination of food and Animal Feed*: A Review. Crit Rev. Food Sci. Nutr., 46(8), 593-619

Kabat, G. C., Cross, A. J., Park, Y.,Schalzkin, A., Hollenbeck, A. R.,Rohan, T. E. and Sinha, R. (2009).*Meat Intake and Meat Preparation in Relation to Risk of Postmenopausal Breast Cancer in the NIH-AARP Diet and Health Study*. International journal of Cancer 124(10), 2430-2435

Knize, M. G. and Felton, J. S. (2005).*Formation and Human Risk of Carcinogenic Hetrocylic Amines formed from Natural precursors in Meat.* Nutrition Review 63(5), 158-165

Lachenmier, D. W.,Reusch, H.,Sproll, C.,Schoberl, K. and Kuballa, T. (2008). Occurrence of Benzene as Heat-induced Contaminant of Carrot Juice for Babies in a Genreal Survey of Beverages “Food additives and Contaminants – *Part A Chemistry, Analysis, Control, Exposure and Risk Assessment, 25*(10), 12-16.

Lijinsky, W. (1999). N-Nitro Compounds in Diet Mutat. Res. 443 (1-2) 129-138

Okaka, J. C.,Akobundu, N. T. and Okaka, C. C. (2014).*Human Nutrition*: An Integrated Approach (2nd edition) University Press, Ibadan; Nigeria, 342

Reddy, C. S. and Hayes, A. W. (2001) *Food-borne Toxcants in: Principles and Methods of Toxicology* (4th edition) Taylor and Francis, Philadephia.

Raloff, J. (1985). *Oxidized Lipids: A key to Heart Disease?* Science News, 127, (18), 278

Sabrina, M., Giogia, P. andLafranco, S. C. (2005) Polycylic Aromatic Hyrocarbons in Vegetable Oils from Canned Foods. *European Journal of Lipid Science and Technology*, 107, 7-8

Scalan, R. A. (1983) *Formation and Occurrence of Nitrosamines in Foods*. Cancer Research 43(5 supple) 24353-24405.

Sies, H., Stahl, W. and Svanant, A. (2005).Nutritional, Deitary and Post-prandial oxidative stress. *Journal of Nutr.*135, 5, 969-972.

Sammers, C. H., Delincee, H., Smith, J. S. and Marchionic, E. (2012).*Toxicological Safety of Irradiated Food in Food Irradition and Research and Technology*, Sammers C.H and Fan, X eds Wiley-Blackwell Windmoor, Pa, USA 2nd edition, 53-74

Sinha, R., Park, Y., Graubard, B. I., Leitzman, M. F., Hollenbeck, A., Schatzkin, A. and Cross, A. J. (2009).Meat and meat-related Compounds and Risk of Prostate Cancer in large Prospective Cohort Study in the US. *American Journal of Epidemiology*, 1, 170(19), 1165-1177.

Sugimura, T., Wakabayashi, K.,Wakagama, H. and Nagao, M. (2011).*Heterocyclic Amines: Mutagans/Carcinogens produced during Cooking of Meat and Fish*. Cancer science, 95(4) 290-299.

Vania, P.S.S., Andrea, M.S.,Alexandre, G. T. and Karen, S. P.(2015).Benzene as a Chemical Hazard in Processed Foods. *International Journal of Food Science.*2015, Article ID545640; http;//dx.doi.org/01.1155/2015/54560

Ward, M. H., Cross, A. J., Divan, H.,Kelldorff, M., Nowell-kadlubar, S., Kadlubar, F. F., and Sinha, R. (2007). Processed Meat Intake, Cyp2A6 Activity and Risk of Colorectal Adenoma.*Carcinogenesis* 28,(6), 1210

Watszek, N., Scherbi, D., Feld, J. and Berger, F. (2012).Profiling of Mercuric Acid of Acrolain and Crylamide in Human Urine after Consumption of Potato Crisps. Molecular Nutrition and Food Science Research, 56, 1825-1837

Wittkowski R. Bulters, W. and Jennings, W. G. (1990).*Analysis of Liquid Smoke and Smoked Meat Volatiles by Headspace Gas Chromatography Food Chem* 37,(2) 135-144.

World Cancer Research Fund/American Institute for Cancer Research AIRC (2007). Expert Report on; Nutrition, Physical Activity and Prevention of Cancer: A Global Perspective, 7–30

Worth Health organization WHO (2015).*News Release*.https://www.who.int/news-room

Wu, K. (2006). *Meat Mutagens and Risk of Distal Colon Adenoma in a Cohort of US*. Men Cancer Epidemology Biomarkers,15(6), 120-1125