Acrylamide in Processed Food and Reduction Strategies

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Objective: After determining that acrylamide (AA) occurred in carbohydrate-rich foods through frying and roasting as a result of heat treatment, protein-rich foods have also been found to occur in lower levels of acrylamide today. Acrylamide formation in studies of high-risk foods are French-fries and chips, biscuits, bread and cereals. Its formation is also identified in protein content rich food in Turkish cuisine such as döner, kebap, meat and poultry products. The International Agency for Research on Cancer has classified acrylamide in food as a 'Group 2 Possible Carcinogenic to Humans'. Due to the AA evaluated as potential carcinogens, numerous studies have been done to reduce AA formation in cooked products. This article aims to provide a better understanding of the chemistry and biology of acrylamide in food, and can lead to the development of food processes to decrease the acrylamide content in the diet.

Methods: Medline, Embase, Cochrane Central Register of Controlled Trials databases were used for searching acrylamide information.

Conclusions: Various heat treatments applied in food for preparation, processing and storage such as frying, baking, sterilization, roasting, grilling and even drying can lead to physical and chemical changes. Studies of AA have reported that it is important to determine the formation of AA in carbohydrate and protein-rich foods after heat application over 120ºC. It occurs at lower concentrations in protein rich foods (eg. döner, kebap, grilled meat and chicken) and is not formated in raw and boiled food.

Comment: The total amount of acrylamide in food can be reduced significantly by suitably processing as well as raw materials added to the product.

Keywords: Acrylamide in food; heat treatment; asparagine; maillard reaction

1. Introduction

Acrylamide may have a risk for public health. Acrylamide (AA, 2-propenamid was first found by Christian Moureau in Germany as a chemical compound in 1893 [1]. Acrylamide is the most active compound which has been researched among food contaminants, on which acrylamide heat effect has been applied [2]. Thereafter, many researchers have released publications stating that they found Acrylamide at different amounts in several food substances [1, 3]. The existence of chemical acrylamide in food was published in a press release in April 2002 by the Swedish National Food Administration (SNFA) and Stockholm University. According to that release, it is presented to the attention of the public that *"carbohydrate rich foods"* contain high degrees of acrylamide which is a chemical substance that has the potential to cause cancer in fried and baked foods [4, 5]. The International Cancer Research Center (IARC, 1994) classifies acrylamide in the "2A group", that is, "it is a potential carcinogen for people".

Product variables and process variables are two factors that influence the formation of AA. While the product variables are things such as asparagine, sugar type and concentration, pH, water content and the food matrix, the process variables are things such as the temperature and the time.

Acrylamide influences the genotoxic, carcinogenic, neurotoxic, reproduction and development toxicity [6]. According to the classification system of the European Union (EU), AA has toxic effects on the carcinogenic, mutagen and reproduction [7, 8, 9].

According to the WHO directive for drinking water quality, it is stated that 1 liter drinking water contains 0.5 µg acrylamide. This figure in the European Union is 0.1µ g/lt water [10]. Acrylamide has been found to be carcinogenic with a standard 2 years bioassay works in lab rats. It is known that it causes benign and malign tumors. AA has been included in the drinking water of lab rats at 2 mg/kg/day in two independent animal work groups and it has been approved that it is carcinogenic. At the same time, this result is valid for brain tumors, spinal cord and other tissues [10].

The objective of this article is to focus on the formation mechanism of the acrylamide found in some products and provide complied information or the strategies to decrease it in food.

Materials and Methods: Medline, Embase, Cochrane Central Register of Controlled Trials databases were used for searching acrylamide information.

2. Formation of Acrylamide in Foods

Acrylamide has two forms which are monomeric and polymeric [11]. Acrylamide is one of the elements that have a negative effect on human health and are formed as a result of heat treatment. Acrylamide is a water-soluble vinyl

monomer used in the synthesis of the polyacrylamides and involves polar functional groups in different physical and chemical characteristics and the monomer form is created in food [3, 12, and 13]. This monomer is an amide, involving unsaturated double bonds and it appears as a crystal while it is white and shows resolution at room temperature. It is odor free and has high solubility in water. It is polymerized immediately once it is dissolved or exposed to oxidative agents. The heat of the solution is 84.56^{o}C and the boiling temperature is 1256^{o}C. It is a unique compound since its polymeric form is a water proof gel [1].

It has been indicated that the monomeric form of acrylamide has a toxic effect on the nervous system and has an anemic effect as well and it is a carcinogen in lab animals [1, 11]. It is possible that the level of acrylamide in the diet can form higher than the other known carcinogens. Formation of acrylamide depends on the temperature and time and the ambient temperature needs to be in excess of 100^{o}C for acrylamide to form. It has been reported that acrylamide has been formed by a reaction of specific amino acid with reducing sugar (Maillard reaction) during the formation of browning around 120 ^{0}C. Furthermore, formation of AA is affected by the period of cooking, food source, and type of the food and cooking temperature. The World Health Organization (WHO) and Food and Agriculture Organization (FAO) state that foods which are processed or cooked at high temperatures can considerably contain AA and this can cause a risk for the health of the people [14]. When the ambient temperature increases to 180^{o}C, the formation of the acrylamide maximizes.

3. Probable Mechanisms

Even if all of the formation mechanisms of acrylamide are not known, there are positive results as to the formation mechanism. Alternatively, it can react to form the "Schiff base", which expresses the Maillard reaction with free sugar and free amino acids. It has been put forward that during the formation mechanism of the acrylamide, the Schiff base is formed, which is an indecisive by-product, from the reaction of asparagines with carbonyl after the decarboxylation in the Strecker type reaction. Acrylamide is formed with 3- aminopropanamid with hydrolysis of the decarboxlate Schiff base and thereafter the dissolution of ammoniac.

Besides, the high degree lipids that are generated due to reducing lipids (blown oil acid or glycerol) pave the way for the formation of AA. Acrolein is a three carbon aldehyde and resembles the structure of acrylamide. Acrolein enters into the oxidation reaction and generates an acrylic radical by-product. AA is generated upon the existence of the two type nitrogen resources but acrolein is not required in the alternative formation mechanism of the AA [15]. For this reason, acrolein is accepted as the beginning of acrylamide. Acrolein can turn into acrylamide with basic chemical transformations [16]. Acrylamide is not constituted in fat, which are used in deep frying in the food production industry [17].

Sugar alcohols or polyols (sorbitol, xylitol) do not react to Maillard reactions. This means that when baked products are sweetened with sorbitol, the color does not or rarely changes during baking. The reaction of large sugar is slower with amino acids. Pentose sugars (5 carbon atom), such as ribose, react faster than the hexose sugars (glucose, fructose) and disaccharide (sugar, lactose). With its two amino groups, lysine from the amino acids, reacts faster and causes the formation of a brown color. The formation of the Maillard reaction is avoided since some flavor compounds are formed in some circumstances such as sterilized dairy products. An excessive heat application may result in the loss of quality since it changes the structure and flavor as well as odor compounds. The loss of essential amino acids such as lysine due to the Maillard reaction significantly affects the biological values of the proteins in foods [18].

It has been observed that the asparagine rate in the asparagus is at a high level (11000-94000 mg/kg) and AA may be formed at high rates in asparagus under the proper circumstances in the resources which state that asparagine is the major pioneer of acrylamide in foods [19, 20].

No acrylamide is formed when glucose, glycine and cystine or methionine amino acids are heated to 185°C [21]. They only form acrylamide at trace amounts when glutamine and aspartic acid are exposed to heat (0.5–1 mg mol-1) [21].

This work has been undertaken by the Marmara Research Center (MAM), affiliated with the Scientific and Technological Research Council of Turkey (TUBITAK). It has been observed that acrylamide is found in the crust, which is largely consumed by the Turkish people and no acrylamide formation is available in the bread [22]. TUBITAK observed that rice, tahini halva, kebab, doner kebab, grills, rye bread have AA at lower than the measurable amount and French fries and several bakery products have the highest rates in Turkey. According to the recent research, meat and poultry products such as döner, grills and kebab, which have an important place in Turkish cuisine, have been examined in terms of the acrylamide content and the level of acrylamide has been observed between the ranges of 25-250µg/kg [23].

4. Factors Affecting the Formation of Acrylamide in Foods

The existence and concentration of molecules such as asparagines and reducing sugars have influence on the formation of AA. The heat, heat density and water activity, which are used in the processing technologies and relative

concentration of these molecules, have effects on the formation of AA. Asparagine concentrations and reducing sugars for each of the three products have been affected by the cultivation conditions (season, watering and fertilization) harvest season and storing conditions. Redundancy of the reducing sugars and asparagine concentration for cereal affects the formation of AA. On the contrary, asparagines are seen more in potatoes and reducing sugar concentration affect the formation of AA [24].

AA formation in green beans of coffee is not affected by reducing the sugar content and shows a weak correlation with the asparagine concentration. During coffee roasting, AA is not accumulated and its formation and degradation (deformation) happen concurrently. While free asparagine seems to be a limiting factor for the formation of the acrylamide, the concentration of the reduced sugar is affected less. 20% of the AA which has been formed in the beginning, is formed during roasting. Roasted and ground coffee contains 170–351 μg/kg AA. The subsequent degradation is observed during storing. It is reported that acrylamide mainly occurs for the affiliation with the coffee ground compounds and roasted coffee matrix. It is required to take more notice of such degradation since the amount changes depending on the period of the storing to guess the exposure rate. For that reason, it is recommended to have a moderate coffee consumption [21]. No relation has been observed between the amount of sugar and AA formation during the baking or roasting process [25].

According to gender, age and ethnic group, the suggestion is to consume between 0.3 and 0.8 μg/kg. According to the 2002 evaluation by WHO and FAO, AA exposure per day is 0.3-0.8 μg/kg body weight [26]. There is a requirement to drastically decrease exposure since there is no threshold value of the effect for genotoxic carcinogens. According to WHO, cancer risk is 1/100.000 when we are exposed to AA 1μg/day throughout our life. Risk assessment of these compounds, containing the toxicological and exposure status has to be conducted [26].

5. Precautions to Decrease the Formation of Acrylamide in Food

Well baked products contribute to the total AA intake due to containing AA concentrations. Decreasing the cooking period or heat in formation of Acrylamide effectively diminishes the formation of AA [27, 28]. The studies about decreasing the formation of acrylamide cover the characteristics of the raw material. For example, the effect of conditions such as the harvest year, variety, storage conditions in potato products on the level of the acrylamide has become a subject for many studies. Furthermore, there are many findings that antioxidants decrease the formation of acrylamide in food which has heat treatment at high temperatures applied [29].

To sum up, refined cereal products increase cereal consumption. Well baked products contribute to the total AA intake due to them containing AA concentrations. Decreasing the cooking period or heat in formation of Acrylamide effectively diminishes the formation of AA. Gertz and Klostermann reported that the formation of AA accelerates over 175^{o}C. It is stated that the formation of AA decreases by 50% when the temperature of the frying oil is decreased from 185^{o}C to 165°C in French fries; and when it is decreased from 190^{o}C to170^{o}C, it decreases by 68% and from 190^{o}C to 150^{o}C, formation of AA decreases by 88% [26, 30].

To sum up, it has been stated that elements such as potato type, the agriculture system, vaccination, damp, heat density, enzyme and the addition of some minerals and amino acids, carbonyl (R-CHO), the concentration of the compounds, harvest time (seasonal changes), asparagine amount, pH, cooking rules, additives, storing period and the degree and vaccination have a significant effect on the formation of AA concentration [26, 31].

6. Discussion

According to the evaluation by the World Health Organization (WHO) and FAO in 2002, exposure to acrylamide is 0.3-0.8 μg/kg/day body weight. Neither value measurement over the predictions nor biological process is understood well. A mechanism has yet to be found to stop the formation of acrylamide. It is known that AA is constituted in some foods which are cooked or processed at high temperatures and it increases with the waiting period at a high temperature.

In brief, acrylamide can be formed through different mechanisms, which contain the reactions of carbohydrates, protein and amino acids, lipids or other micro food elements in food treated with heat. As it is observed in the studies, to control the level of acrylamide is to start from the selection of the raw material of which the product will be manufactured. There can be a significant decrease in the amount of acrylamide with the optimization of the processing conditions and suitable raw material. Cooking conditions to be carried out on food should be systematic and common analysis methods should be developed.

It is recommended for individuals to take adequate and balanced nutrition, to increase their food and vegetable consumption, decrease total fat intake and fried food consumptions. It goes without saying that people who are living in Turkey are very lucky to have a culture of braising in the cooking pot.

References

[1] Boettcher MI, Schettgen T, Kütting B, Pischetsrieder M, Angerer J. Mercapturic acids of acrylamide and glycidamide as biomarkers of the internal exposure to acrylamide in the general population Mutation Research 2005;580:167–176.

[2] Zhang Y, Zhang G, Zhang Y. Occurrence and analytical methods of acrylamide in heat-treated foods. Review and recent developments. Journal of Chromatography A. 2005; 1075:1–21.

[3] EFSA. Food standards agency study of acrylamide in food background information and research findings press briefing. What is acrylamide? 2002.

[4] Dearfield KL, Abernathy CO, Ottley, MS, et al. Acrylamide. Its metabolism, developmental and reproductive effects, genotoxicity and carcinogenicity. Mutation Research/Reviews in Genetic Toxicology. 1988;19581:45-77.

[5] Vattem DA, Shetty K. Acrylamide in food: a model for mechanism of formation and its reduction. Innovative Food Science and Emerging Technologies. 2003;4:331-338.

[6] Abramsson-Zetterberg L, Vikstrom AC, Törnquist M, Hellenas KE. Differences in the frequency of micronucleated erythrocytes in humans in relation to consumption of fried carbohydrate-rich food. Mutation Research 2008;653:50–56.

[7] Friedman M, Mottram D. Chemistry and Safety of Acrylamide in Food. Volume 561, Advances in Experimental Medicine and Biology. 2005; p161-163.

[8] Ruden C. Acrylamide and cancer risk-expert risk assessments and the public debate. Food and Chemical Toxicology. 2004;42:335-349.

[9] Zhi-Rong L, Zou HC, Park SJ, Park D, Shi L, Oh SH, Park YD. The effects of acrylamide on brain creatine kinase: Inhibition kinetics and computational docking simulation. International Journal of Biological Macromolecules. 2009; 44:128–132.

[10] Joint FAO/WHO Consultation on Health Implications of Acrylamide in Food (2002: Geneva, Switzerland). Health implications of acrylamide in food: Report of a joint FAO/WHO consultation, WHO Headquarters, Geneva, Switzerland, 25-27 June 2002.

[11] Lopachin RM, Schwarcz AI, Gaughan CL. In vivo and in vitro effects of acrylamide on synaptosomal neurotransmitter uptake and release. NeuroToxicology. 2004; 25:349-363.

[12] LoPachin RM. The Changing View of Acrylamide Neurotoxicity. NeuroToxicology. 2004; 25:617–630.

[13] Zhang Y, Zhang Y. Formation and Reduction of Acrylamide in Maillard Reaction: A Review Based on the Current State of Knowledge. Critical Reviews in Food Science and Nutrition. 2007; 47:521–542.

[14] Gokmen V, Senyuva H. A simplified approach for the kinetic characterization formation in fructose-asparagine model system. Food Additives and Contaminants. April, 2006; 23(4): 348–354.

[15] Taeymans D, Wood J. A Review of Acrylamide: An Industry Perspective on Research, Analysis, Formation, and Control. Critical Reviews in Food Science and Nutrition. 2004; 44:323–347.

[16] Lingnert H. Acrylamide in food–mechanisms of formation and influencing factors during heating of foods. The Swedish Institute For Food and Biotechnology Chairman of Expert Committee. 2002.

[17] Totani N, Yawata M, Takada M, Moriya M. Acrylamide Content Of Commercial Frying Oil. Journal of Oleo Science. 2007; 56(2) :303-306.

[18] Skog K. The HEATOX Project. Heat-generated food toxicants: identification, characterisation and risk minimisation. Final report. Lund University; 12 April 2007.

[19] Kamal-Eldin A. Lipid Oxidation Pathways (Ed.), AOCS Press, Illinois. 2003.

[20] Mottram DS, Low MY, Elmore JS. The Maillard reaction and its role in the formation of acrylamide and other potentially hazardous compounds in foods, in: K. Skog, J. Alexander (Eds.), Acrylamide and Other Hazardous Compounds in Heat-Treated Foods,Woodhead Publishing Limited, Cambridge. 2006.

[21] Becalski A, Lau BPY, Lewis D, Seaman SW. Acrylamide in foods: Occurrence, Sources and Modelling. Journal of Agriculture and Food Chemistry. 2003; 51(3):802-808.

[22] CIAA. Confederation of the food and drink industries of the EU. The CIAA acrylamide toolbox. Rev 9. 2006.

[23] Kaplan O, Kaya G, Özcan C, İnce M, Yaman M. Acrylamide concentrations in grilled foodstuffs of Turkish kitchen by high performance liquid chromatography-mass spectrometry. Microchemical Journal. 2006; 93:173–179.

[24] Klaunig JE. Acrylamide Carcinogenicity. J. Agric. Food Chem. 2008;56:6162–6166.

[25] Seal C J, De Mul A, Eisenbrand G, Haverkort A, Franke Knut J, Lalljie Sam PD, et. al. Risk-benefit considerations of Mitigation Measures on Acrylamide Content of Foods- A Case study on Potatoes, Cereals and Coffee. British Journal of Nutrition. 2008; Ap. Vol 99: Supp 2.

[26] Dybing E, Saner, T. Risk Assessment of Acrylamide in Foods. Toxicological Sciences. 2003; 75:7– 15.

[27] Pelucchi C, Galeone C, Levi F, Negri E, Franceschi S, Talamini R, et al. Dietary acrylamide and human cancer. Int. J. Cancer. 2006; 118:467–471.

[28] Ou S, Lın Q, Zhang Y, Huang C, Sun X, Fu L. Reduction of acrylamide formation by selected agents in fried potato crips on industrial scale. Innovative Food Science and Emerging Technologies. 2008; 9: 116-121.

[29] Gertz C, Klostermann S. Analysis of acrylamide and mechanisms of its formation in deep-fried products. Eur. J. Lipid Sci. Technol. 2002;104:762–771.

[30] Haase NU, Matthaeus B, Vosmann K. Acrylamide formation in foodstuffs - minimizing trategies for potato crisps. Dtsch. Lebensm. Rundsch. 2003; 99:87–90.

[31] Saldamlı İ. [Food Chemistry] Gıda Kimyası. Hacettepe Üniversitesi Yayınları. 2007.