ACRYLAMIDE: A CHEMICAL TOXIC GENERATED DURING HEAT PROCESSING OF STARCHY FOODS

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Acrylamide

Acrylamide is an odorless and colorless crystalline solid with a melting point of 84.5 °C that is formed from the hydration of acrylonitrile. Such a small compound is soluble in water, acetone, and ethanol, has a high mobility in soil and groundwater and is biodegradable. Before its discovery in foods, acrylamide was known as an industrial chemical and a component of cigarette smoke. Acrylamide, a potential genetic and reproductive toxin with mutagenic and carcinogenic properties in experimental mammalians in both in vitro and in vivo study, has been found in a large range of carbohydrate-rich foods processed at high temperatures, which has attracted worldwide concern. On the other hand, acrylamide is considered as probably carcinogenic to humans (Casado et al., 2010). It has been claimed that dietary acrylamide does not constitute any risk to human health (Jung et al. 2003; Carrieri et al. 2009). However, considering the potential health hazard of this molecule and its wide distribution in the Western diet, numerous studies have been undertaken to provide reliable mitigation strategies to minimize its levels in processed products (Jung et al. 2003; Carrieri et al. 2009). Besides, acrylamide can penetrate into breast milk and the human placenta. Based on their results, Sörgel et al. (2002) advised that pregnant and breast-feeding mothers omit acrylamide-containing food until the individual sensitivity to acrylamide is known.

Acrylamide is formed during thermal processing in carbohydrate-rich and protein-low plant foods at high temperatures and low moisture conditions associated with frying, baking, and roasting (Tareke et al., 2000). There are many reports about how to reduce acrylamide formation in foods, including selecting foodstuffs, removing acrylamide precursors, adapting processing conditions, and adding food ingredients (Ou et al., 2010). In April 2002, Swedish researchers shocked the food safety world when they presented preliminary findings of acrylamide in some fried and baked foods, most notably potato chips and French fries, at levels of 30-2300 µm/kg. As acrylamide has not been detected in unheated or boiled foods, it was considered to be formed during heating at high temperatures. Research up to date shows that acrylamide formation in starch-based foods (such as potato chips, French fries, bread and breakfast cereals, cookies and crackers) takes place via
Maillard reaction upon heating above 120 °C (Friedman 2003; Mottram and others 2002; Stadler et al., 2002). They attributed this fact to the higher temperatures reached in Maillard nonenzymatic browning reactions required for desirable color, flavor and aroma production. The data published so far indicate that a temperature >120°C is required for acrylamide formation.

An interesting example of how the exposure of acrylamide from coffee is found to contribute substantially to the total dietary acrylamide exposure in Norway is shown. Dybing and Sanner (2003) estimated that the daily mean intake of acrylamide from foods and coffee was to be 0.49 and 0.46 μg kg⁻¹ body weight in Norwegian males and females, respectively. These authors estimated the Norwegian daily intake level of acrylamide from foods for 70 years in males to correspond to a lifetime cancer risk of 0.6 × 10⁻³, implying that 6 out of 10000 individuals may develop cancer due to acrylamide. Finally, a Swiss total diet study of acrylamide in the diet of 14 men and 13 women showed that coffee contributed 36% of the total acrylamide intake. Recently, the US Food and Drugs Administration (FDA) reported levels of acrylamide in brewed coffee from 6 to 16 μg l⁻¹ (Andrzejewski et al. 2004).

**Importance of acrylamide in heated processed foods**

Currently, a substantial body of research has been carried out world-wide to build greater understanding of how acrylamide is formed in high-temperature processed, what the risks are for consumers and how to reduce occurrence levels. For instance, Maillard reaction has been identified as the major mechanism of acrylamide formation in fried potatoes and at the same time is responsible of the desirable flavour, odour, colour, texture and taste attributes of the fried potatoes. So, producing French fries or potato chips with low levels of acrylamide without affecting the sensorial properties of the final product is a major challenge for fried potato manufacturers.

The presence of acrylamide in nearly all fried, baked, and roasted carbohydrate rich foods has been confirmed in many studies performed all over the world. Browned crispy crusts in foods like French fries, potato chips, crackers, pretzel-like snacks, cereals, and browned breads tend to have the highest levels of acrylamide. Concentrations of acrylamide present in heated foods are the result of simultaneously occurring formation and elimination mechanisms (Gökmen & Senyuva, 2006a). Finally, this significant variability of acrylamide levels in foods becomes important when considering dietary exposure to acrylamide.

**Acrylamide mitigation in heated processed foods**

For heat processed food industry it is not only important to know the principal mechanism(s) of acrylamide formation but also several acrylamide mitigation procedures reported in the literature that could be very useful for heated food manufacturers in order in reduce to reasonable levels the acrylamide generation in their processing lines. Maillard reaction is believed to be the main route for acrylamide formation between reducing sugars (glucose and fructose), sucrose, and the amino acid asparagine, and, consequently, a variety of
technologies have been developed to reduce acrylamide concentration in thermally processed foods based either on: (i) Changing process parameters (e.g. time and temperature of cooking) which inhibits Maillard Reaction; (ii) Reducing acrylamide precursor levels in raw materials to be cooked at high temperatures (e.g. by using microorganisms, asparaginase, amino acids and saccharides, blanching, etc.). At the same time, food heating has many advantages since it adds taste, color, texture and minimizes harmful germs, among others. Flavor and aroma compounds are produced via the Maillard reaction, where various hazardous compounds may form as well, such as acrylamide (Mottram et al., 2002). Most of recent research for acrylamide reduction in foods processed at high temperatures will be mentioned and in order to develop new mitigation techniques for acrylamide in different food matrixes.

The reduction of acrylamide precursor levels in raw materials is another strategy used to reduce acrylamide formation in heat-processed foods and various pre-treatments have been developed such as: (i) By using food grade microorganisms; (ii) By using the enzyme asparaginase; (iii) By using amino acids; (iv) By using non reducing sugars; (v) By using genetic modification. On the other hand, it is also possible to mitigate acrylamide formation in high temperature processed foods by changing the processing parameters. In this way, cooking, methods and equipment, food material, and pre-treatment unit operations that modify process parameters can significantly diminish the acrylamide amount in heat processed foods (up to 90%), maintaining intact their sensorial attributes (Mariotti et al., 2011). For instance, some results have shown that vacuum frying may be a mitigation alternative process for producing fried products with lower amounts of acrylamide (Lindsay et al., 2005).

By changing some parameters of food processing such as time, temperature, pressure and pH; it would be possible to diminish the acrylamide content of high-temperature processed foods. In this sense, some authors have developed acrylamide mitigation technologies based on lowering the pH of the food products. They have studied the effect of pH on acrylamide formation concluding that the dependency of acrylamide formation exhibited a maximum around at pH value of 8. Lower pH values enhanced acrylamide elimination and decelerated its formation (Low et al., 2006; Mestdagh et al., 2008). Another acrylamide mitigation approach has been the use of cations, in this respect different studies have shown that the addition or divalent or trivalent cations effectively reduce the amount of acrylamide thermally processed food (reduction up to 90 %) while minimally affecting its sensorial desirable attributes (Lindsay et al., 2005).

Finally, acrylamide mitigation in high temperature processed foods could be reached by combining several techniques previously mentioned. Some authors have considered that the combination of several methods could be the best option for reducing acrylamide formation in heat processed foods. The main strength of this approach appears to be that the final products could preserve better their original and desirable sensorial attributes because of it is possible to decrease the intensity and duration of each treatment alone.
CONCLUSIONS

Acrylamide is a toxic compound with mutagenic and carcinogenic properties in experimental mammalians which has been found in several carbohydrate foods processed at high temperatures. Nowadays, most available information regarding to acrylamide formation in foods is attributed to the Maillard reaction in which the reducing sugars react with asparagine when the food is heated. There is an urgent need to reduce the content of dietary acrylamide in order to prevent adverse in vivo effects in human beings. On the other hand, attempts to determine a possible involvement of dietary acrylamide in human cancers have not been conclusive. Recently published data have suggested that there are associations between dietary acrylamide exposure and risk of cancer but only at certain places. These issues have prompted scientists to develop a wide range of methods for acrylamide mitigation. These technologies have been also effective not only as an alternative for reducing acrylamide but also for maintaining the desirable sensorial attributes of foods.

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