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Concerns about the high content of acrylamides in food: A comprehensive review

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Abstract. Acrylamide's presence in food has recently drawn considerable interest on a global scale. One of the antecedents of acrylamide is asparagine, an amino acid that is frequently present in both plant and animal proteins. Acrylamide is listed as a potential cause of cancer, abnormal birth outcomes, and nerve damage in people. It appears naturally in foods that have been heated to high degrees as a synthetic chemical. Acrylamide is generally associated to the Millard reaction, which is prevalent in foods that mostly contain asparagine and starch, and forms during high-temperature cooking such as frying, roasting, and baking. According to the FDA, although it's unclear exactly what risk acrylamide poses to humans, research investigations in animals' labs demonstrate that excessive quantities of the chemical caused cancer. Since acrylamide exposure is so high, it's important to recognize its hazardous effects, especially in nations where people are still mostly unaware of the danger's acrylamide poses to their health. This article gives a summary of relevant scientific data on the production of acrylamide, its potential health risks, and methods for reducing it in the food industry and at home. Depending on the producer, cooking time, temperature, and production process, different foods contain different amounts of acrylamide. To control the manufacture and use of acrylamide, some nations have put regulations and laws into place. For the purpose of regulating the manufacture and use of acrylamide, maximum amounts of acrylamide in foods have been established in the USA, Europe, Japan, and Canada, and which are expected to be updated in the coming year.

Keywords: Acrylamide, asparagine, food, hazardous effects, human health

1. Introduction

The recent years, the occurrence of acrylamide in various widely consumed foods presents a challenging issue and problematic for the food industry and its supply chain (Raffan S, 2019). Acrylamide (AA) - (C_3H_5NO) is an extremely reactive chemical molecule that can polymerize to create polyacrylamide (SFNA, 2002), a substance widely employed in many different sectors. The discovery of acrylamide in food, first noted by the Swedish Authority for Food Safety in 2002 (SFNA, 2002; Lofstedt, 2003), has since gained widespread awareness. Over the past two decades, there has been an increasing interest in study on AA because of its harmful effects on both humans and animals (Rifai, 2020; EFSA, 2015). Starchy foods are one of the primary sources of AA animals (Pruser KN et al, 2011; Nica-Badea, 2022).
In food processing the interaction between amino acids and reducing sugars do they exist. In this case acrylamide is visible in cooked food especially fried foods (Feng Zhu, 2022).
Well-known staples including coffee, bread, and potato goods, have high amounts of AA. According to EFSA (2015), when some foods are cooked at high temperatures (above 120ºC and in low moisture conditions) especially in foods containing asparagine and reducing sugars, including when baking, frying, or roasting, acrylamide can develop. It can be found in many different meals, such as coffee, breakfast cereals, french fries, and potato-based snack production (Gunduz, 2023).
Frenf Zhu in 2022 study found that vegetables, cereals, and potatoes were the primary contributors to acrylamide exposure, accounting for almost 90% of the total intake. Comparing frying, roasting, and baking potatoes, frying causes the highest acrylamide formation (FDA, 2022). Boiling and steaming do not typically form acrylamide.

Safe food advocacy Europe (safe), after a study conducted in 10 European countries, has found very high levels of acrylamide in about 500 food products analysed and according to the notification from the Rapid

Alert System on Food and Feed (RASFF) 2020- 21, AA contamination was 497 and 2690 µg/kg and exceeded the benchmark values in the EU by 4-5 times.

The European Commission's Regulation (EU) 2017/2158, addresses the control of AA in a variety of foodstuffs. This regulation, while not setting explicit legal thresholds, sets benchmark levels to motivate the food industry to implement measures for reducing AA content. Furthermore, in 2019 Food Drink Europe (FDE, 2019), developed a comprehensive Toolbox that outlines various strategies for managing AA levels, applicable at different points in the food processing chain. This paper gives a summary of relevant scientific data on the production of AA, its potential health risks, and the use of different strategies methods for reducing it in the food industry and home.

1.1 Formation and presence of AA in foods.

The formation of AA in foods is a complex process that involves various factors beyond the basic Maillard reaction between asparagine and reducing sugars. Factors like the type of food, its moisture content, and the cooking method (such as frying, baking, or roasting) significantly influence acrylamide production especially fried foods (Feng Zhu, 2022). Foods with higher carbohydrate content and low in proteins, like potatoes, grains and cereals, tend to produce more AA when cooked at temperatures above 120°C (Feng Zhu, 2022). Various factors influence AA production, including the type of food, cooking temperature, duration, moisture content, pH levels, and the presence of certain minerals. The conditions of cooking, especially higher temperatures, significantly enhance the generation of AA, a compound associated with potential health risks (Schuten, Slotboom, & Gijssel, 2004). Understanding these factors is essential for devising strategies to mitigate acrylamide levels in foods, risks contributing to safer consumption.
Common foods: where acrylamide can be found include Potato-based products, like french fries and potato chips fig.1. Baked goods such as bread, toast, crackers, and biscuits. Coffee and coffee substitutes that undergo roasting processes. Cereal products, including breakfast cereals. Snack foods that are fried or oven-baked. It's important to note that acrylamide formation is more likely in these foods when cooked at temperatures above 120°C (248°F).

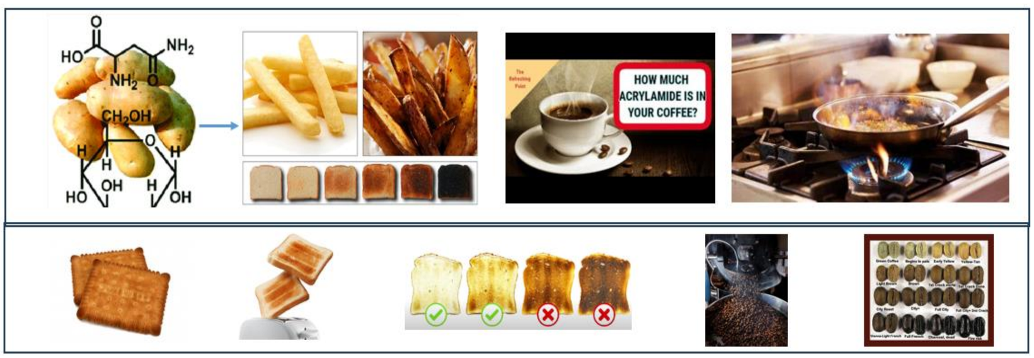

Fig. Acrylamide formation in some foods

Many studies have been done to reduce AA in foods and according to Raffan (Raffan S, 2019) reducing the levels of acrylamide in bread would have much more impact on AA intake than reducing the levels in breakfast cereals or potato crisps.

1.2 Levels of AA in popular foods

Information regarding the occurrence of acrylamide in food products in Europe has been gathered since 2003 from different sources like ECJR and EFSA. The collected data has been scrutinized and presented in a series of published reports (CONTAM Panel, 2015; EFSA, 2009, 2010, 2011, 2012, 2015). In the study report (CONTAM Panel, 2015) shows that, selected foods (vegetable crisps, coffee substitute, coffee/dry, potato crisps & snakes, potatoes fries, biscuits, crackers & crisp bread, breakfast cereals, roasted nuts & seeds processed cereal-based baby food, cakes and pastas, soft, bread and non-cereal baby foods). The higher AA levels were found in vegetable crisps and coffee substituents. According to same source, reducing the levels of acrylamide in bread would have much more impact on AA intake than reducing the levels in breakfast cereals or potato crisps.

1.3 Toxicity of AA and health implications

AA in certain foods cooked at high temperatures, has emerged as a significant public health concern. AAy the International Agency for Research on Cancer (IARC) as possibly carcinogenic to humans in 1994. Classified as a 'probable human carcinogen' by IARC, AA has been linked to an increased risk of cancer in laboratory animal studies. Beyond its carcinogenic potential, studies suggest that AA exposure may also pose neurological risks and impact reproductive health (Rifai & Saleh, 2020). Furthermore, AA has demonstrated genotoxic, group 2a carcinogenic, hepatotoxicity, immunotoxicity. reproductive toxicity and neurotoxic effects described for each category by some authors (Rifai & Saleh, 2020; Carere, 2006; IARC, 1994). The effects of this toxicity are described by scientific article (Başaran et al, 2023).
According to findings of the (IARC) by the Joint FAO/WHO, average human intake of AA is valued to be 0.4 μg/kg bw/day from two years of age, though consumption may vary generally from 0.3 μg/kg bw/day to 5 μg/kg bw/day. The estimate of average daily human intake was 1 μg/kg bw/day, and it can be 4 μg/kg bw/day for high consumers. Several toxic effects of AA are summarized and described by Dilini N. Perera with collaborators (2021) Previous results of epidemiological studies on dietary acrylamide intake and cancers of the urinary tract, cancers of the gastro-intestinal tract, cancers of reproductive organs, and cancers of the respiratory tract, are presented by (CONTAM Panel, 2015). Many investigations have demonstrated that AA significantly affects a variety of physiological processes, such as the transmission of signals in peripheral nerves, the regulation of enzymatic and hormonal processes, muscular function, reproduction, and so forth. Given its presence in commonly consumed foods, understanding and mitigating the health risks associated with dietary acrylamide exposure is crucial in food safety and public health research.

1.4 Effect of Processing Conditions and food property in AA formation

Many studies on AA formation in some foods have shown that the major factors contributing to the AA production are frying temperatures & time, different frying oils, pH, Water Activity, soaking, Blanching etc. (A. Torang, 2016; Khalaf H.H.A., 2015).

1.4.1 Effect of pH, Water Activity, and Fermentation

pH levels
Were pH levels influence the formation of AA, lower pH indicates with lower AA formation. Effect of pH, Water Activity, and Fermentation on AA formation are mentioned and demonstrated by many authors (Rifai & Saleh, 2020). Were pH levels influence the formation of AA, lower pH indicates with lower AA formation. Decreasing the pH of the soaking solution has been demonstrated to prevent the formation of the Schiff base, where the nucleophilic amine group (NH2) is converted into the non-nucleophilic protonated-NH3þ, which is a precursor to AA formation.

Water Content
The quantity of water within food significantly impacts the level of acrylamide (AA) in the food. Studies indicates that AA formation in foods occurs when the water activity (aw) ranges from 0.4 to 0.8. However, when water activity falls below 0.4, there is a decrease in acrylamide production (Rifai&Saleh 2020; Rydberget al.2005; Vleeschouwer et al., 2006) activity and moisture content are interconnected parameters, meaning that foods containing less than 5% moisture content are more prone to engage in the Maillard reaction and produce AA. In the Ciesarove study (Ciesarova, 2023), it was noted that the lowest formation of AA occurred when the water content was between 25 and 40%; outside this range, there was an increase in AA concentration.

Fermentation
The generation of AA in food is also influenced by fermentation. For example, lactic acid fermentation has been noted as effective in decreasing AA formation in potato products, particularly when employed in conjunction with blanching.

Colour

Also, it has been found that AA is formed during the browning process, which is a result of the Maillard reaction between reducing sugars and asparagine at temperatures over 120 °C. Colored products are also formed in foods during heating because of Maillard reaction. Given that color is a measurable attribute, it can serve as an indicator for other products of the Maillard reaction, such as AA. The CIE a* color value is correlated with the AA content in coffee or colour changes in fried potato (Vural, 2006; Pedreschi, 2005).

1.4.2 Effect of Processing Conditions

Frying Time and Temperature

In general, the temperature and duration of frying have been proven to have a substantial impact on the quantity of acrylamide (AA) generated and are regarded as the most crucial factors influencing its presence in fried potato products. Some studies (Israilides, 2015) reported that, when potato chips frying at temperatures 180-190°C, AA concentrations showed a rapid, exponential rise as the frying period concluded. Elevated temperatures and lengthier cooking times are correlated with increased AA levels. (Gökmen, 2008). Numerous research studies on bakery items have shown that the formation of AA is slower at lower temperatures, while at higher temperatures, its maximum level is attained quickly. The formation of AA is also affected by the method of heat transfer (Qingqing Jiao et al., 2022; Mogol & Gökmen, 2014; Ahrné et al., 2007). It seems that, formation of acrylamide can be decreased in fried food by lowering frying temperature below 175 °C (GERTZ et al., 2003).

Use of Additives

Some studies examined the effect of some additives as a mitigation strategy to reduce the levels of AA. Amino acids as glycine, alanine, lysine, glutamate and glutamic acid have been found to reduce acrylamide formation in heated potatoes (Rydberg et al., 2003), the herbs Rosmarinus, ascorbic acid or citric acid. This is probably since AA information is minimized at low pH values (<pH5) (Theodoros, 2015).

Enzymes, as biological catalysts, may play a significant role in mitigating AA formation during cooking processes in various food products. Some results suggest that enzymes, such as asparaginase, proteases, amylases, and lipases, hold promise in reducing acrylamide levels in foods (Covino et al., 2023; Paper, T., 2019; A. El-Sayed et al, 2023). The degree of reduction varies depending on the type and concentration of the enzyme used. Their potential to catalyse reactions that interfere with AA formation pathways highlights their suitability as natural agents for AA mitigation. Enzymes like asparaginase are frequently used in food products to inhibit the formation of AA. For these enzymes to be most effective, it's essential to maintain a balance in the availability of substrate, the moisture content, and the extent of mixing (PAPER, 2019). Importantly, the preservation of food quality attributes underscores the feasibility of using enzymes in culinary applications.

Research suggests that specific vitamins such as vitamin C (ascorbic acid), vitamin E (tocopherol), and vitamin B3 (niacin) hold the potential to effectively lower acrylamide concentrations in food products, if they applied to the food either through direct infusion or as part of a marinade (Wang& Xu, 2014; Zeng et al, 2009; Daniels, 2009; Rifai&Saleh. 2020).

Soaking/ Brining

The effect of pre-treatments like food soaking have been proven to have a substantial impact on the quantity of AA generated on AA concentration of in potato chips. Soaking or blanching prior to frying can reduce AA formation (Grob et al., 2003; Tomás, 2017; Torang& Alemzadeh, 2016; Khalaf et al. 2015; Bunger et al. 2003. In a study (Khalaf H.H.A., 2015), with soaking potato chips in $CaCl_2$ 1-2% and acid citric 0.5-1%, concludes that soaking of potatoes before fraying in calcium chloride 2% and citric acid 1% for 60 min can reduce the formation of AA up to 83 %. Jung et al., 2003 reported that soaking in an acidified solution, using vinegar (mixed in a 1:3 ratio with water) or 2% citric acid, can lead to a reduction of acrylamide levels by up to 75%.(Israilides, 2015). This process works by lowering the pH of the solution due to the action of the acids, as reported by Jung et al., 2003. It's important to note that the effectiveness of salt in reducing AA formation depends on several factors, including the type of food, the cooking method, and the concentration of salt used.

Another study has shown that soaking blanched potato strips in an asparaginase solution at 40°C for 20 minutes reduces AA by 60% compared to blanched strips without enzyme treatment (Pedreschi, The effect of asparaginase on acrylamide formation in French fries, 2008)The creation of AA experienced a reduction exceeding 80% when potato slices were immersed in a 3% solution of either lysine or glycine before the frying process (Heong et al, 2005). In the study of (Andrea Bunger, 2003) found that potatoes immersed in a $CaCl_2$ solution exhibited a 95% decrease in acrylamide formation during frying, without adversely impacting the sensory qualities of the potato strips.

Blanching

Blanching is conducted to decrease the concentration of reducing sugars in raw potatoes, as these sugars could lead to elevated acrylamide (AA) levels. (Gunilla et al, 2010). Additionally, blanching in hot or warm water has been found to decrease the acrylamide content in French fries. With higher blanching temperatures and longer durations, an increased amount of glucose and asparagine are extracted, resulting in French fries containing reduced acrylamide (AA) levels. (Zhang, 2018).

Blanching potato strips in sunflower oil at 150°C for 43 seconds exhibited a more substantial reduction in acrylamide (AA) precursor levels, specifically asparagine and reducing sugars, resulting in a lower final AA content compared to soaking them in water.

Utilizing lower temperatures for frying (around 120 °C) and pre-frying blanching in hot water significantly reduces the acrylamide levels in potato chips (Pedreschi et al., 2004) showed that Blanching effectively removes glucose and asparagine extracts from potato slices, resulting in reduced acrylamide formation during frying. Blanching treatment reduced the acrylamide content in potato chips in 68%, 75% and 49% at the frying temperatures of 120, 150 and 180 °C, respectively.

Effects of Different Frying Oils

Many studies examined the effect of different types of oil on AA formation (Klostermann, 2002; Daniali et al., 2016; Başaran& Turk, 2021; Research, 2009; Daniali2016; Ahmad, 2021). In Ahmed's study 2021, it was found that the choice of oil had a significant impact on the acrylamide levels in beef nuggets, whereas the number of frying cycles did not influence it. In the 2002 research conducted by (Gertz&Klostermann, 2002), where six varieties of oil were examined, it was indicated that palm oil had a significantly greater tendency to form acrylamide during deep-frying compared to the other oils studied. But this study didn't observe a significant correlation between oil qualities attributes and acrylamide content. Another study by Varzakas (Varzakas et al, 2016) analyzed and reported that while the average acrylamide levels in olive oil and soybean oil were higher than in corn oil, the differences were not statistically significant ($p<0.05$), owing to the considerable variation in the estimated acrylamide content among these oils.

1.5 Regulatory situation

Acrylamide legislation varies globally, with different countries implementing various regulations to address the presence of acrylamide in food products. In the European Union, for instance, the European Commission issued Regulation 2017/2158 in 2017, establishing mitigation measures and benchmark levels for reducing the presence of acrylamide in food. This regulation recommends practices to limit acrylamide formation and defines benchmark levels for at-risk food categories. while 2019, the Commission Recommendation (EU) 2019/1888 on the monitoring of the presence of acrylamide in certain foods, recommends to competent authorities and food business operators to monitor the presence of acrylamide in such food in view of the adoption of possible risk management measures, which should complement those already provided by Regulation 2158/2017. In other parts of the world, including the US, Canada, and Asia, acrylamide content in food products is carefully monitored by health bodies and regulatory agencies, especially in products targeting children, due to concerns about acrylamide's neurotoxicity and potential cancer risk.

The EU Acrylamide Regulation (EU_2017/2158) establishes maximum levels of acrylamide in specific food categories as well as guidelines (EU_2019/1888) for reporting and monitoring acrylamide levels in food. In order to lessen the development of acrylamide in food, it also establishes standards for food production process monitoring.

Table1. Benchmark levels for acrylamide in food that have been set in EU regulation No. 2017/2158 are as follows:

Food Category	Benchmark Levels (µg/kg)
French fries (ready-to-eat)	**500**

Potato crisps from fresh potatoes and from potato dough, Potato-based crackers Other potato products from potato dough	**750**
Fried potatoes	**500**
Sweet pastries	**500**
French fries (cooked and ready to eat)	**200**
Soft bread	
Wheat based bread	**50**
Soft bread other than wheat-based bread	**100**
Breakfast cereals (excl. porridge)	
bran products and whole grain cereals, gun puffed grain	**300**
wheat and rye-based products	**300**
maize, oat, spelt, barley and rice-based products	**150**
Biscuits and cookies / wafers	**350**
Crackers with the exception of potato-based crackers	**400**
Crispbread	**350**
Ginger bread	**800**
Products similar to the other products in this category	**300**
Coffee and substitutes	
Roast coffee	**400**
coffee substitutes exclusively from cereals	**500**
Instant (soluble) coffee	**850**
coffee substitutes exclusively from chicory	**4000**
Baby foods, processed cereal based foods for infants and young children excluding biscuits and rusks.	**40**
Biscuits and rusks for infants and young children	**150**

The benchmark levels also are described by (Rifai & Saleh, 2020) for max. and min. benchmark levels of AA in foods. The mitigation measures to be applied by food business operators are set in annex II. referred to I article 2 of Regulation (EU) 2017/2158. Alo, they have been shown/ instructed in CODE OF PRACTICE FOR THE REDUCTION OF ACRYLAMIDE IN FOODS_ CAC/RCP 67-2009. The European Union's regulations on the presence of acrylamide in food have been guided by a series of EFSA reports arising from analyses of these data.

2. Materials and methods

Numerous scientific studies AA, methods of detection, and ways to lower acrylamide have been conducted on the synthesis of AA levels in the food industry as well as through legislative enforcement and restriction. Some techniques for measuring AA

- High-Performance Liquid Chromatography (HPLC): One of the most used techniques for determining the amount of acrylamide in food is HPLC (Elbashir, 2014). With its excellent sensitivity, this approach can identify acrylamide at incredibly low quantities.
- Gas Chromatography (GC): Another popular technique for determining the amount of acrylamide in food is GC. Additionally exceedingly sensitive, this approach can identify very low acrylamide levels.
- Mass Spectrometry (MS): MS is an extremely sensitive technique for determining the amount of acrylamide in food. This technique, which frequently works in tandem with HPLC or GC, can identify very low concentrations of acrylamide.
- Immunoassay: This technique uses antibodies to determine the amount of acrylamide in food. With its excellent sensitivity, this approach can identify acrylamide at incredibly low quantities.
- Enzyme-Linked Immunosorbent Assay (ELISA): ELISA uses antibodies to determine the amount of acrylamide in food. Because of its high sensitivity, this approach can identify even very low acrylamide levels.

3. Conclusion and recommendations

The challenge of AA in widely consumed foods is a significant concern for the food industry. In food, acrylamide can form from the reaction of naturally occurring sugars and the amino acid asparagine when heated to high temperatures. This reaction, called the Maillard reaction, is responsible for the characteristic golden-brown color and flavor of many cooked foods, which results also harmful by-products, including the infamous toxicant acrylamide. Knowledge of both recipe and processing factors in acrylamide generation and mitigation is the key on acrylamide reduction. We recommend using the following steps as a strategy to cut down acrylamide in foods:

Increase consumer awareness about the risks of acrylamide.

- Choose low-sugar and whole-grain goods for healthier options.
- Cook meals at lower temperatures and for shorter durations to reduce acrylamide formation.
- Instead of frying or roasting, choose alternative cooking methods like boiling or steaming
- Avoid burning and overcooking meals to prevent excessive acrylamide production.
- Steer clear of very brown areas in food, as they tend to contain the highest levels of acrylamide.
- Be aware that acrylamide forms in coffee during the roasting of beans, not during the brewing process at home or in restaurants.
- Bake and toast bread and other baked goods to a light brown color, rather than dark brown, to minimize AA.
- Cook cut potato products, like frozen French fries or potato slices, to a golden yellow rather than brown to reduce AA.
- Aim for a light golden colour when cooking, especially to avoid browning fries.
- Soak potatoes in water before cooking to help prevent acrylamide formation.
- Store potato tubers at temperatures between 8-12 C and never in the fridge to reduce acrylamide formation.
- Industries should work to reduce acrylamide levels in baked goods and ensure compliance with regulatory standards.
- Combine regulatory measures with scientific advancements and industry collaboration to ensure our favourite foods are both delicious and safe.

Future research should focus on developing new cooking techniques and exploring the role of diet diversity in further minimizing acrylamide exposure. As consumers become more aware of these issues, it is crucial that the food industry and regulatory bodies continue to provide clear guidelines and support healthier cooking practices. Together, these efforts represent a comprehensive approach to reducing the risks associated with acrylamide, thereby contributing to a healthier society.

Since, Chemical composition of foods plays an important role in the formation of AA and the quality of foods. Then, the Knowledge of both recipe and processing factors in acrylamide generation and mitigation is the key on acrylamide reduction.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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