A Systematic Literature Review of Acrylamide Levels, Adverse Health Effects, and Reduction of Formation in Fried and Baked Potato Products

by

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Abstract

Acrylamide is a processing contaminant produced by the Maillard reaction at high temperatures, such as baking or frying. The Maillard reaction is also what creates the brown or caramelized color on the outside of food when going through these processes. Fried and baked potato products are one of the highest acrylamide producers in the food industry. Food researchers have proven the presence of acrylamide in this everyday food through studies which will get higher as the temperature gets higher and the length of time frying or baking gets longer. There are links between dietary acrylamide accumulation in the body and various cancers, reproductive issues, and neurological damage. Some discoveries and developments may help reduce acrylamide in potatoes, starting from pre-harvesting to post-processing. Given the high levels of acrylamide in potato products, research suggests additional monitoring of acrylamide in food products and their consumption.

Introduction

Acrylamide is a food contaminant and neurotoxin present in a variety of widely consumed carbohydrate foods via high-temperature processing. It was discovered in 2002 by Swedish scientists who believed it to be a substance that causes cancer in staple foods such as bread, rice, and potatoes (Giese 2002). At the time, this news was a big development and thus had numerous food agencies respond with statements regarding the work done by the original scientists. The World Health Organization (WHO) stated they recognized that acrylamide in foods is of major concern because of its carcinogenic nature but they did not believe low levels of acrylamide would pose a cancer risk to humans (Giese 2002).

The original research done in 2002 suggested that acrylamide was present in foods cooked at high temperatures. Once the food containing acrylamide is eaten and it is absorbed, acrylamide spreads throughout the body and metabolizes, which subsequently produces glycidamide. This glycidamide production may cause toxic effects, because it forms adducts within the DNA of humans and animals (Raffan and Halford 2019). Food scientists have linked acrylamide formation to the Maillard reaction and the presence of free asparagine as the main precursor (Bachir et al. 2023). Acrylamide found in potato products forms specifically from asparagine, glucose, and fructose. There are a few complex routes of acrylamide formation that can take place in potatoes. In 2013, Bethke and Bussan suggest a framework for acrylamide formation in the American Journal of Potato Research:

> “a reducing sugar reacts with an amino acid to generate a Schiff base. This rearranges to form an Amadori compound and these compounds dehydrate and fragment, releasing the amino acid and producing a suite of highly reactive intermediates, including deoxyosuloses, dicarbonyls, and hydroxycarbonyls. These intermediates react with amino acids to produce the Maillard reaction compounds that add flavor and color to fried or cooked potato products" (Bethke and Bussan 2013).

When these intermediates react with asparagine, they start other reactions that also produce acrylamide. So, the biggest feature of this reaction is that acrylamide and browning color, from the Maillard reaction, form from very similar pathways. The downside to this similarity is that if actions are taken to reduce acrylamide, this will likely affect the color of the product and it will not be as golden or brown, thus compromising crucial visual and flavor sensory profiles.

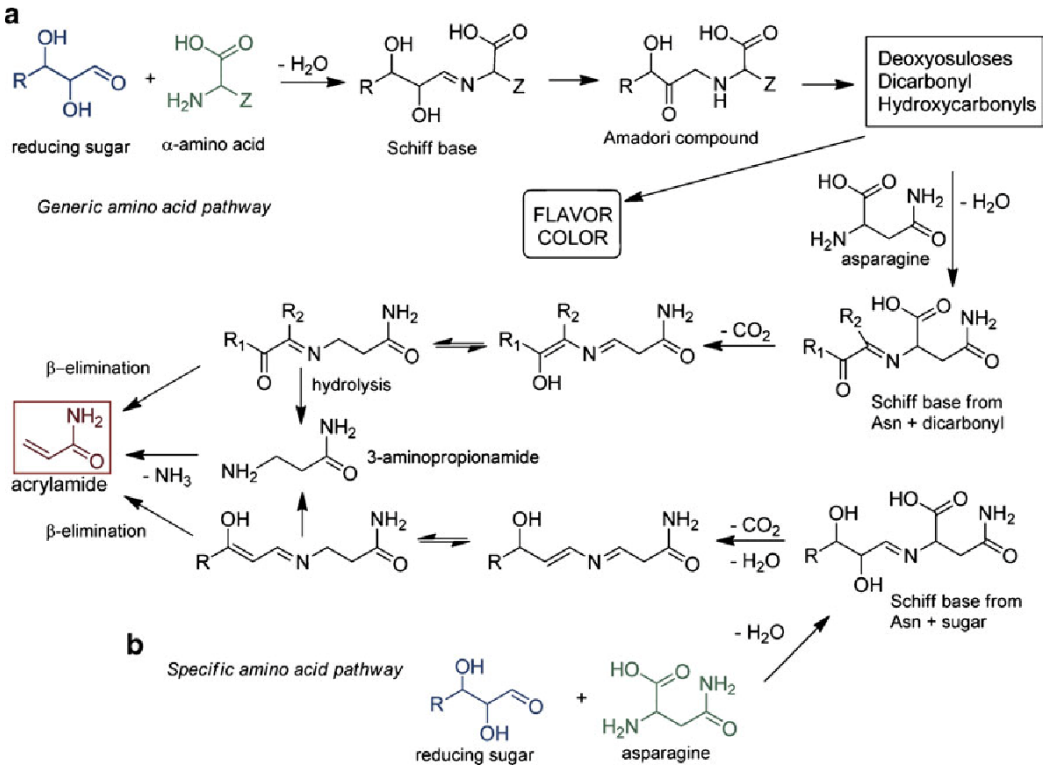

Figure 1. Chemical reactions which could lead to the formation of acrylamide during frying, baking, or heating (Bethke and Bussan 2013).

Some foods containing the most acrylamide are wheat, corn, rye, and potato products. Studies have shown there is no acrylamide production in raw material foods, as the formation of acrylamide results from processing contamination, such as heating, frying, and roasting. The risks posed by acrylamide accumulation include cancer, neurotoxic effects, human reproductive issues, and genotoxicity. Although we do not fully understand all mechanisms and pathways of formation about acrylamide in potatoes, researchers have been working on ways to develop new potato varieties that allow for pre- and post-processing treatments, which will reduce the production of acrylamide, such as “soaking blanching, the addition of salts, organic acids, amino acids other than asparagine, hydrocolloids, and antioxidants…” (Kumari et al. 2022).

Key Questions

This systematic review evaluates studies that prove that acrylamide levels are high in fried and baked potato products, and how an excess of acrylamide can be harmful to the body. This review also emphasizes how consistent monitoring of acrylamide levels would be beneficial. I aim to help cover and address the following questions:

1. What acrylamide levels have been seen in fried and baked potato products?
2. What are the risks related to high dietary acrylamide exposure?
3. What are some possible approaches to reduce acrylamide formation in potato products?

I answer these questions by doing a systematic review of academic literature that has conducted global studies on acrylamide. In the research approach section, I describe what techniques and verbiage I used to gather information from studies to conduct a thorough review. I review three literature studies that show data regarding increased acrylamide levels in fried and baked potato products and their processes on collecting this data. In the adverse health effects of dietary acrylamide section, I analyze another three studies that prove there have been negative effects seen from an accumulation of acrylamide in the body. In the reduction of acrylamide in the potato products section, I suggest many effective ways the food industry is trying to reduce acrylamide in potatoes, from pre-harvesting to post-processing. Lastly, the discussion and conclusion section discusses what the food industry suggests as a safe amount of acrylamide to consume, and also summarizes details from the systematic review.

Research Approach

I carried most of the research out through Google Scholar, using the entry terms “acrylamide in potatoes”, “acrylamide pathways”, and “acrylamide health implications and the reduction”. After assessing the search results, I chose journals that gave a clear definition and

understanding of how acrylamide forms within potatoes, because that is something I wanted to address in the introduction. Next, I chose a few studies, out of many, that were done to prove the health risks of exposure to acrylamide in fried and baked potato products. If these journals referenced other studies, I went down to their citation list and found the referenced study. Lastly, it was essential to obtain journals that show how to reduce acrylamide in these potato products to help mitigate the problems they can cause. I did not exclude journals reporting acrylamide in other foods—wheat, rye, and corn — from my research, but I used them as educational support to show how dietary acrylamide can affect the body.

Acrylamide Levels in Potato Products

Through past studies, baked and fried potato products have shown increased acrylamide production. In a study done at the Lebanese American University School of Medicine, the cancer risk from acrylamide exposure to potato chips appears significant. Before acrylamide analysis of the chips, university researchers set the temperature and an injection of methanol was used to wash the gas chromatography machine (Biedermann et al. 2002; Hariri et al. 2015). This is an important step to calibrate the machine. Once the chips were ground, researchers mixed them with water, heated the mixture, added it to the machine, and the concentration of acrylamide was determined by comparing the experimental results with a calibrated curve made from acrylamide solutions (Hariri et al. 2015). The potato-based chip had about 1939 g/kg of acrylamide content, which is around 3500-fold higher than the federal limit for acrylamide (0.5 g/kg body weight/day) at the time of treatment water (Hariri et al. 2015). During this experiment, the researchers exposed the population studied to about 1.29 g/kg of acrylamide a day (Hariri et al. 2015). This study proves that the population was over-consuming their share of acrylamide which can ultimately be dangerous.

In a 2011 study published in the international journal, Plant Foods for Human Nutrition, researchers explored the effect of domestic preparation of some potato products on acrylamide content, including baking and frying. The products used were commercially available frozen French fries with three size variants and four other frozen potato products other than French fries. The products were pan-fried at 180 degrees Celsius for three minutes, deep-fried at 180 degrees Celsius for three minutes, roasted in the oven for 10 minutes at 220 degrees Celsius, and microwaved for 10 minutes at 220 degrees Celsius (Michalak et al. 2011). To start the process of acrylamide extraction, the products were blended separately and homogenized. In this experiment, reversed-phase high-performance liquid chromatography determined acrylamide levels (Gökmen et al. 2005; Michalak et al. 2011; Zhang et al. 2005). Acrylamide increased in these potato products as time and temperature increased. The conditions' processing temperature of 180 degrees for three minutes produced acrylamide levels of 469 g/kg for pan-frying and 495 g/kg for deep-frying, using the statistical analysis results from all products (Michalak et al. 2011). The conditions' processing temperature of 220 degrees Celsius for 10 minutes produced acrylamide levels of 630 g/kg for roasting and 725 g/kg for microwaving (Michalak et al. 2011). This research suggests that all domestic preparations of the potato led to an increased level of acrylamide in the final French fry product.

Finally, there are manufacturers' data on acrylamide in potato crisps in Europe, which were analyzed from 2002 to 2016. Researchers completed the analysis using liquid chromatography-tandem mass spectrometry or gas chromatography-mass spectrometry (Ono et. al 2003; Powers et al. 2017). The European Snacks Association gave the authors of the journal the data for the acrylamide levels in the samples of potato crisps. In 2002, the mean acrylamide level produced for 42 observations was 763 g/kg (Powers et al. 2017). In 2009, the mean

acrylamide level produced for 6493 observations was 500 g/kg (Powers et al. 2017). In 2016, the mean acrylamide level produced for 7264 observations was 412 g/kg (Powers et al. 2017). These results suggest that the acrylamide levels have gone down over the years in Europe. These factors include switching to a lower sugar variety of potatoes for crisp making, sugar content of the potato at time of harvest and storage, improved control of cooking temperature and duration, etc.

Adverse Health Effects of Dietary Acrylamide

There is a link relating carcinogenicity, neurotoxicity, and reproductive toxicity to high dietary acrylamide accumulation. It can be dangerous when a person consumes too much acrylamide. Research done for the journal Cancer Epidemiology Biomarkers & Prevention aimed to study the positive association between acrylamide and endometrial and ovarian cancer (Hogervorst et al. 2007; Michels et al. 2005; Zhang et al. 2002). The study used 62,573 Dutch women between 55 and 69. Their assessment took 11.3 years, and the researchers had to exclude cases if doctors ever diagnosed the women with non-epithelial tumors, borderline invasive tumors, or if their dietary habits were incomplete or inconsistent during that period (Hogervorst et al. 2007). To assess acrylamide in food, there was a focus on the foods containing a lot of acrylamide from various European countries, and mean values of these were obtained. The women had an acrylamide intake of 21.0 g/kg per day based on their food diaries, which included a high amount of French fries and potato crisps (Hogervorst et al. 2007). The results found statistical significance associated with these specific cancers and dietary acrylamide for the women.

Concerning neurotoxicity, acrylamide has proven to have negative effects on humans. In 2015, the research explored the changes in human neuroblastoma and glioblastoma after

acrylamide exposure (Chen and Chou 2015). For this, cell lines were obtained, treated, and transferred into a specialized medium for proliferation and statistical analysis. The researchers quantified cells and viewed after stimulation from acrylamide exposure. As a result, there was suggestion that "cellular differentiation in human neuroblastoma and glioblastoma cells was inhibited after acrylamide exposure...these effects were associated with the down regulation of MAP expression and JAK-STAT signaling" (Chen and Chou 2015; Harrison 2012). This suggests that acrylamide is a neurotoxin, which can cause eventual muscle weakness and other neuropathy issues when exposed to daily or for longer periods.

We also have research that helps us understand how acrylamide negatively affects the human reproductive system. Researchers in the Islamic Azad University Department of Biology conducted a laboratory study to measure the effect of different concentrations of acrylamide on human sperm, and also its impact on the mitochondrial membrane and glutathione levels of the sperm (Omidi et al. 2020). University researchers did the study using 30 samples from fertile men treated with three different concentrations of acrylamide. Using the WHO standards for human sperm parameters, the enzyme-linked immunosorbent assay analyzed these results (Omidi et al. 2020). Results concluded that acrylamide destroys sperm membrane integrity. Also, there was an observation that mitochondrial function and glutathione content of the sperm had negative impacts once exposed to different levels of acrylamide (Omidi et al. 2020; Treulen et al. 2015). These results suggest that there is reduced quantity and quality of sperm because of high acrylamide consumption in this population.

Reduction of Acrylamide in Potato Products

A large part of the ongoing acrylamide research includes how to reduce it within our everyday food items. For potatoes specifically, there are several ways to accomplish this.

Reduction strategies can start from pre-harvesting of the potato to post-processing. Farmers grow certain potato varieties to help reduce the amount of reducing sugars in the potato, which would lead to acrylamide formation during processing. Although doing this can lead to minor problems within the food industry, because only certain potato varieties can be for products like chips, other potatoes should only use others for French fries because their sugar content is too high. Differing the reductions of sugar in the varieties too much would lead to switching potato types for different products. Despite this, soil composition and fertilizer used to grow the potato also play a role in the amount of acrylamide produced at the end. Minerals such as zinc may increase the amount of reducing sugars in the potato, and others like potassium, which decreases the reducing sugars. In a study done for the American Journal of Potato Research, they found that the addition of nitrogen fertilizer, which reduces the reducing sugars in the potato variety, could positively affect fried potato products (Sun et al. 2018). However, this addition of nitrogen possibly increases asparagine, an amino acid that is a precursor for acrylamide and accumulates in the raw potato.

Some other harvesting and processing strategies for the potato to help reduce sugars and thus acrylamide, can include storage, blanching, and processing temperature and time. Once harvested in a commercial setting, it is important to keep the potato at a room temperature of around 10 to 12 degrees Celsius for a long time to reduce the production of reducing sugars in the potato (Kumari et al. 2022). This temperature works to maintain an environment that is not cold enough to have a cold-induced sweetening of the potato occur. Although this mitigation strategy works for reducing sugars, this temperature can lead to the sprouting of the potato, which diminishes quality faster. The pre-treatment of the potato before processing, like frying or baking, involves blanching them for a short time to remove acrylamide precursors, and will also

inactivate browning enzymes (Kumari et al. 2022). This would cause the leaching of the reducing sugars and asparagine from the potato into the boiling water. When fried, there would be less frying oil being absorbed into the product, resulting in less acrylamide content in the end product. Researchers know that acrylamide content increases when there is an increase in temperature and time of the processing period. Results from a study on frying potatoes suggest that when kept at a constant temperature, there is a linear relationship between increasing acrylamide concentration and frying time (Matthäus et al. 2004). While these mitigation techniques can work, it often compromises the value of the end potato product.

Technologies are currently being heavily researched on how to mitigate acrylamide in potatoes products without compromising the sensory values of the final product. Vacuum baking is a promising technique that has been used for certain food products to reduce thermal load and achieve proper moisture content while keeping ideal sensory properties. Research done on the vacuum baking of potato chips saw a reduction in acrylamide content from 72 percent to 98 percent when compared to a conventionally baked potato chip (Akkurt et al. 2021). The vacuum baked samples were more appreciated than the conventional oven baked potato chip in texture and also overall acceptability (Belkova et al. 2018). Another technology that shows promise in reducing acrylamide in potato products is vacuum pre-drying and pulsed electric field treatment. There was significant reduction of oil uptake during the frying process and decreased the acrylamide levels around 86 percent after these treatments on the potato chips (Liu et al. 2022). The vacuum baking technology and pulsed electric field treatment may be a way to process a safer potato chip product, but more research needs to be done to definitively say how these processes would do in an industrial manufacturing setting.

Conclusion

In this review, there was evidence of high levels of acrylamide in fried and baked potato products from different studies, and dietary acrylamide potential effects. The Food and Drug Administration suggests that an adult should consume between 0.4 and 0.6 g/kg body weight/day safely (Center for Food Safety and Applied Nutrition 2006). So, if a person were about 70 kilograms in body weight, they could safely consume between 28 g/kg and 42 g/kg per day. Compared to the levels of acrylamide in the fried and baked potato chips, people would be consuming way over the limit considered safe for their health.

Notably, another factor is the location of people eating these acrylamide-filled products. Although people eat potatoes in most places around the world, there are some locations more exposed to acrylamide than others because of availability or cultural reasons. Children are even more exposed to acrylamide in potatoes than adults, because children are more likely to eat foods like French fries or potato chips. Since fried and baked potatoes have high levels of acrylamide and are one of the most commonly eaten foods internationally, there should be a big concern about the dietary risks of this accumulation. Exposure to dietary acrylamide for a long time can pose significant problems to the body and mind.

There is growing evidence that acrylamide levels in potatoes are being reduced over the years. In the cited European study from 2002 to 2016, results suggested that acrylamide levels came down to around 100 g/kg after every six years. This could be from new and updated use of varieties of potatoes, environment changes, better storage conditions, or new processing applications. These can help reduce the precursors that lead to acrylamide formation. More thorough research needs to be done to monitor acrylamide and its effects, to keep everyone informed of what is in their food and how to keep themselves safe.

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