# EFFECTS OF CONSUMER FOOD PREPARATION ON ACRYLAMIDE FORMATION

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**Abstract:** Acrylamide is formed in high-carbohydrate foods during high temperature processes such as frying, baking, roasting and extrusion. Although acrylamide is known to form during industrial processing of food, high levels of the chemical have been found in home-cooked foods, mainly potato- and grain-based products. This chapter will focus on the effects of cooking conditions (e.g. time/temperature) on acrylamide formation in consumer-prepared foods, the use of surface color (browning) as an indicator of acrylamide levels in some foods, and methods for reducing acrylamide levels in home-prepared foods. As with commercially processed foods, acrylamide levels in home-prepared foods tend to increase with cooking time and temperature. In experiments conducted at the NCFST, we found that acrylamide levels in cooked food depended greatly on the cooking conditions and the degree of "doneness", as measured by the level of surface browning. For example, French fries fried at 150-190°C for up to 10 min had acrylamide levels of 55 to 2130 µg/kg (wet weight), with the highest levels in the most processed (highest frying times/temperatures) and the most highly browned fries. Similarly, more acrylamide was formed in "dark" toasted bread slices (43.7-610.7 µg/kg wet weight), than "light" (8.27-217.5 µg/kg) or "medium" (10.9-213.7 µg/kg) toasted slices. Analysis of the surface color by colorimetry indicated that some components of surface color ("a" and "L" values) correlated highly with acrylamide levels. This indicates that the degree of surface browning could be used as an indicator of acrylamide formation during cooking. Soaking raw potato slices in water before frying was effective at reducing acrylamide levels in French fries. Additional studies are needed to develop practical methods for reducing acrylamide formation in home-prepared foods without changing the acceptability of these foods.

Key words: Acrylamide; consumers; cooking; frying; toasting; bread; potato; browning

# 1. INTRODUCTION

In April 2002, researchers at the Swedish National Food Administration (NFA) and the University of Stockholm reported the presence of acrylamide in variety of heat-treated, carbohydrate-rich foods such as potato- and grain-based products. This report caused worldwide concern since acrylamide has been found to induce tumors in experimental animals (Johnson et al., 1986; Friedman et al., 1995), to be neurotoxic in humans and in laboratory animals (Bachmann et al, 1992; Callemen et al., 1994; Towell et al., 2000; LoPachin, 2004) and to be genotoxic in *in vivo* and *in vitro* toxicity tests (Dearfield et al., 1995). The International Agency on Research on Cancer (IARC) has classified acrylamide as a probable human carcinogen (IARC, 1994).

Acrylamide forms in foods that are subjected to high-temperature (>120 °C) processes such as frying, baking and extrusion. It is not present in raw food (i.e. before cooking or processing) or in foods that are processed at lower temperatures (e.g. boiled foods). In model systems and in foods, acrylamide content increases in the temperature range of 120-175°C, then decreases when the material is heated at higher temperatures (Mottram et al., 2002; Rydberg et al., 2003; Taubert et al., 2004). The mechanism(s) by which acrylamide degrades at temperatures >175°C is not known at this time, but there are reports that the compound decomposes and polymerizes at high temperatures (US EPA, 2004).

Research to-date suggests that acrylamide forms in foods mainly through Maillard reactions between reducing sugars and specific amino acids. Using model systems, four different laboratories (Becalski et al., 2003; Mottram et al., 2002; Stadler et al., 2002; and Zyzak et al., 2003) demonstrated that asparagine is the major amino acid precursor. These results explain the occurrence of acrylamide in cereals and potato-based foods which are particularly rich in free asparagine (Mottram et al., 2002). Similar to the Maillard reaction, acrylamide formation in model systems has been shown be at a maximum at about pH 8 (Rydberg et al., 2003).

The finding of acrylamide in food staples in Europe prompted surveys on acrylamide levels in foods consumed in the U.S. (U.S. FDA, 2004) and elsewhere (SNFA, 2002; Leung et al., 2003; Ono et al., 2003; Health Canada, 2003). According to such surveys, acrylamide may be present at concentrations exceeding 2000 μg/kg, especially in fried potato products (potato chips, French fries, hash browns). The surveys indicate that acrylamide levels can vary considerably between brands of a particular food category (i.e. potato chips) and also within lots of a single brand (U.S. FDA, 2004). It is likely that the wide variations of acrylamide concentration in foods are at least partially caused by different levels of acrylamide precursors in various batches of raw materials (Becalski et al., 2003; Roach et al., 2003). They also suggest that acrylamide levels in food are influenced by the method in which they are cooked or processed.

Although acrylamide is known to form during industrial processing of food, high levels of the chemical have been found in home-cooked foods, including baked, fried and roasted potato- and grain-based foods (Biedermann-Brem et al., 2003; US FDA, 2004). One research gap that has been identified at several international meetings on acrylamide (Food and Agriculture Organization/World Health Organization, 2002; JIFSAN, 2002) is the needed to determine the effects of home food preparation on acrylamide formation and to assess the relative contribution of home-cooked foods to dietary exposure to acrylamide. Since acrylamide may have detrimental effects on public health, methods need to be identified for the consumer to reduce acrylamide formation during home preparation of food.

This chapter will focus on research conducted at the FDA-National Center for Food Safety and Technology (NCFST) and elsewhere on 1) the effects of cooking conditions (e.g. time/temperature) on acrylamide formation in consumer-prepared foods, 2) the use of surface color (browning) as an indicator of acrylamide levels in some foods, and 3) methods for reducing acrylamide levels in home-prepared foods.

## 2. EFFECTS OF COOKING CONDITIONS ON ACRYLAMIDE FORMATION

### 2.1 Introduction

Research-to-date has shown that the manner in which heat is transmitted to a food (e.g. frying, baking, roasting, grilling, etc.) appears to have a negligible impact on the rate of acrylamide formation (Taubert et al., 2004). However, processing and cooking conditions such as temperature and length of time of heat exposure are important factors affecting the formation and degradation of acrylamide in model systems and in foods (Mottram et al., 2002; Stadtler et al., 2002; Biedermann et al., 2002a,b; Becalski et al., 2003; Leung et al., 2003; Tareke et al., 2002; Taubert et al., 2004). This section will focus on cooking conditions and their effect on acrylamide formation in potato and cereal-based foods, two of the major dietary sources of acrylamide.

## 2.2 Potato products

### 2.2.1 Introduction

U.S. (DiNovi and Howard, 2004), Norwegian (NFCA, 2002), Dutch (Konings et al., 2003) and Swedish (Svennsson et al., 2003) authorities have estimated that over one-third of total dietary exposure to acrylamide in Western countries is due to fried, baked and roasted potato products. Cooked or processed potatoes are a significant source of intake of acrylamide since raw potato tubers contain substantial quantities of acrylamide precursors (free asparagine, fructose and glucose) (Amrein et al., 2003). Since the potato is a dietary staple in much of the world, research is needed to study the effects of cooking conditions on acrylamide formation in potato products and to identify conditions that reduce its generation.

### 2.2.2 Effects of cooking times and temperatures

Work at the NCFST focused on studying acrylamide formation in French fries as a function of cooking (frying, baking) conditions. In frying experiments, commercially available frozen French fries were deep-fried in corn oil at temperatures of 150-190°C for 0-10 min. For baking experiments, the fries were oven baked at 232°C for 16-24 min. These conditions were in the range of cooking conditions recommended by the manufacturer of this product. Acrylamide levels in the French fries were determined by LC-MS using the method of Zyzak et al. (2003).

As shown in Fig. 1, acrylamide content of the fries increased with frying time and temperature. The presence of acrylamide in this product before frying (55 μg/kg) indicates that they were pre-fried (par-fried) by the manufacturer before they were frozen and packaged. Acrylamide levels for deep-fried French fries ranged from 265 μg/kg for samples fried at 150°C for 6 min to 2130 μg/kg for French fries prepared at 190°C for 5 min. The acrylamide levels we report for this French fry product are within the range of levels reported by Becalski et al. (2003) and the US FDA (2004) for restaurant-prepared French fries. It is interesting to note that if this product was prepared according to the maximum frying times/temperatures recommended by the manufacturer (204°C for 5 min), acrylamide levels would have likely exceeded 3000 μg/kg.

Fig. 1 indicates that at higher frying temperatures (180-190 °C), acrylamide levels increased exponentially at the end of the frying process. Similar results were reported by Grob et al. (2003) for French fries prepared from fresh cut potatoes. This phenomenon is likely due to the fact that acrylamide formation occurs at the surface of food during cooking. At the end of the frying process, this surface becomes sufficiently dry as to allow the temperature to rise to >120°C, the temperature above which acrylamide is believed to form (Mottram et al., 2002, Tareke et al., 2002; Taubert et al., 2004).

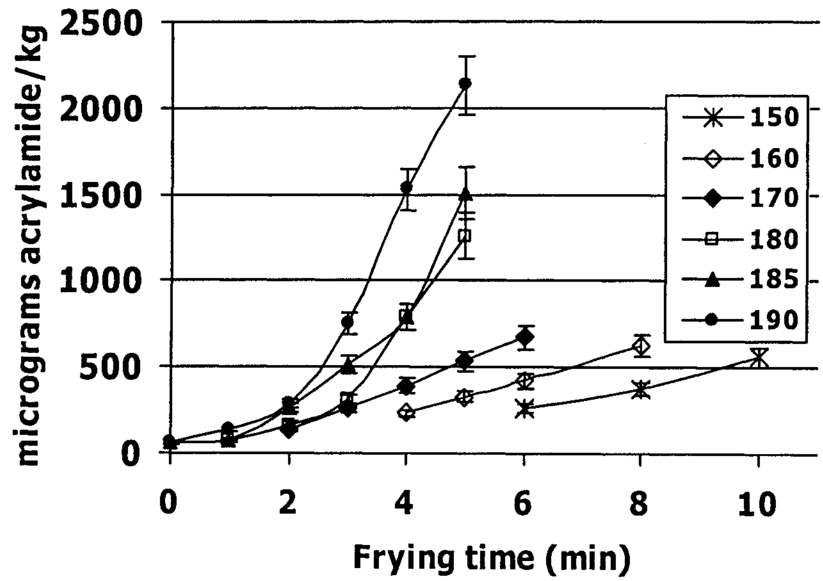


*Figure 1.* Effects of frying time and temperature on acrylamide formation in French fries that were fried in corn oil for 0-10 min at temperatures of 150-190°C. Acrylamide levels were measured by the LC-MS method of Zyzak et al. (2003). All frying trials were done in triplicate and acrylamide analyses were done four times. Error bars represent one standard deviation of the mean (Jackson et al., 2004).

We (Jackson et al., 2004) as well as others (Tareke et al., 2002; Biedermann et al., 2002a; Grob et al., 2003; Rydberg et al., 2003) studied the effects of baking on acrylamide formation in French fries. In our experiments, acrylamide levels in frozen French fries baked at 232°C increased with baking time and ranged from 198-725 μg/kg (Fig. 2). These values are within the range reported by Grob et al. (2003) for a similar product. Similar to the frying experiments, acrylamide levels increased exponentially during the baking run. This was likely due to a higher rate of acrylamide formation in the dry crust of the French fries.

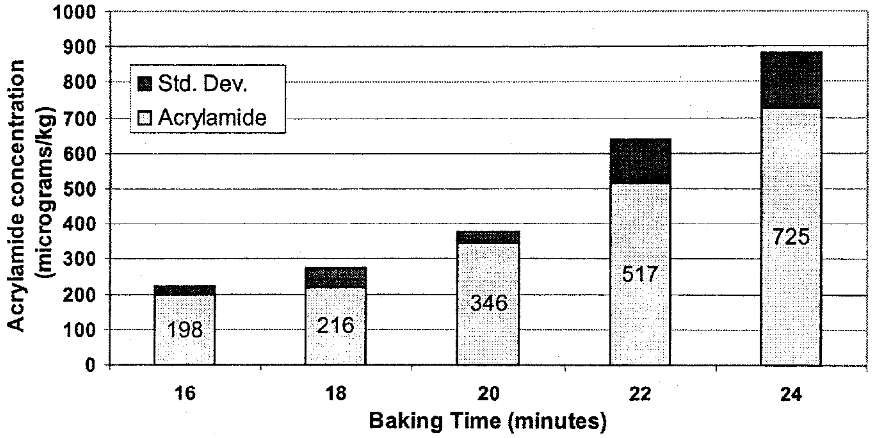


*Figure 2.* Effect of baking time on acrylamide formation in French fries (frozen) baked at 232°C for 16-24 min (as per manufacturer's cooking suggestions). Acrylamide levels were measured by the LC-MS method of Zyzak et al. (2003). All baking trials were done in triplicate and acrylamide analyses were done four times (Jackson et al., 2004).

### 2.2.3 Effects of other cooking conditions

Besides time and temperature, other cooking factors may alter acrylamide formation in fried potato products. Tauber et al. (2004) reported that the surface area of raw potato pieces influenced acrylamide formation during frying. In shapes with lower surface to volume ratios (SVRs), such as potato slices (potato chips), acrylamide levels increased with increasing frying times and temperatures. However, in shapes with high SVRs (i.e. shredded potato), acrylamide levels were greatest at 160-180°C, then decreased with higher frying temperatures and more prolonged frying times. These results suggest that the surface of potato pieces with large SVRs may reach 175°C, resulting in degradation of acrylamide. In contrast, the temperature at the surface of potato pieces with small SVR never approaches 175°C, even when frying oil temperatures reach 220°C (Taubert et al., 2004).

There is conflicting information on the effects of frying oil type and age on formation of acrylamide. Becalski et al. (2003) reported that potatoes pan-fried in olive oil had 60% more acrylamide than those fried in corn oil, while Gertz and Klostermann (2002) found higher acrylamide concentrations in potatoes fried in palm oil than other cooking oils. Roach et al. (2003) found more acrylamide in potato chips fried in thermally aged oil than those fried in fresh cooking oil. Possible explanations for these results include differences in the heat transfer characteristics for the oils (Grob et al., 2003) and the formation of carbonyls (Maillard browning precursors) in oils that are less thermally stable. In contrast to the above studies, we found that commonly used frying oils (peanut, canola, corn, safflower, olive and hydrogenated soybean) had no significant effect on acrylamide levels in French fries deep-fried at 180°C for 4 min (Jackson et al., 2004).

Grob et al. (2003) reported that the ratio of the frying oil: potato may affect acrylamide formation during deep-frying. Acrylamide levels were minimized at oil: potato ratios of 1.5 L oil: 100 g potato since at this ratio, the oil temperature remained over 140°C throughout the frying process, resulting in decreased frying times.

### 2.2.4 Surface browning and acrylamide formation

Since acrylamide formation increases exponentially towards the end of the frying or baking process, an important factor for minimizing acrylamide formation is to determine the proper cooking end-point. This may involve the use of visual clues such as surface browning as an indicator of product "doneness". Since acrylamide and the brown color of cooked foods are formed in similar reactions and from similar precursors, it is likely that acrylamide formed in parallel with browning (Amrein et al., 2003).

We studied surface browning of the French fries as a function of frying conditions and acrylamide formation. Not unexpectedly, the surface of fries became visibly browner as frying times and temperatures increased. A colorimeter (Hunterlab Labscan XE, Reston, VA) was used to obtain a more objective assessment of surface color as a function of frying conditions. As the fries were fried for longer periods of time and at higher temperatures, the "L" component of color (a measure of the white/black component of color) decreased while the "a" values (degree of redness) increased. Statistical analysis (regression analysis) indicated that the "a" and "L" components of color correlated highly ($r^2$=0.8558 and $r^2$=0.8551, respectively) with the log of acrylamide levels in the French fries (Fig. 3). In contrast, the "b" color values (a measure of the yellow/blue component of color) for the samples correlated poorly with acrylamide levels ($r^2$ = 0.089; data not shown). Visual examination of the fries indicated that acrylamide levels tended to be lower in fries that were golden in color with light browning at the edges. More extensive browning of the surface resulted in acrylamide levels of >1000 μg/kg.

We also studied surface browning as a function of acrylamide levels in baked French fries (Jackson et al., 2004). Visual inspection of the fries indicated more extensive surface browning as baking time increased. However, the degree of surface browning between replicate baked samples was much more variable than between replicate fried samples. Similarly colorimeter measurements of surface color for baked samples were more variable than for fried samples. Colorimeter determination of surface color for baked fries indicated a weak positive correlation of "L" and "a" values with acrylamide ($r^2$=0.3425 and $r^2$=0.3502; data not shown). As with fried samples, the "b" color values correlated poorly with acrylamide levels ($r^2$ = 0.039). The greater variability in the results for baked samples than fried samples is not unexpected since deep frying produces more even heating of the food surface than baking.

A high degree of correlation between the brown color of the fries and acrylamide levels is not unexpected since acrylamide is formed in similar reactions responsible for the development of flavor and brown color in cooked foods. Taubert et al. (2004) studied the impact of browning level on acrylamide formation in potato slices of different surface areas. They found a close linear correlation between browning levels and acrylamide concentration for fried potato slices that had lower surface-to-volume ratios (e.g shapes that approximated potato chips). However, color did not correlate well with acrylamide levels in potato pieces with high surface area (shredded potatoes). These authors suggested that the lack of correlation in shredded potatoes is due to degradation of acrylamide at the end of the frying process.

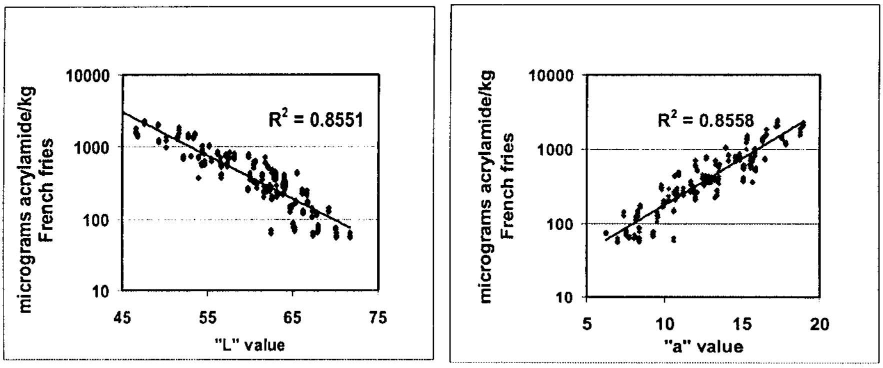


*Figure 3.* Correlation between "L" and "a" color values and acrylamide levels in deep-fried French fries cooked for 0-10 min in corn oil at 150-190°C (Jackson et al., 2004).

Color measurements (both visual and instrumental) indicate that regardless of frying conditions, it is the degree of surface browning that determines final acrylamide content of French fries. A lower frying temperature combined with a prolonged frying time did not result in lower acrylamide content if the product had similar amounts of surface browning. Therefore, determining the degree of surface browning appears to be a good method for estimating acrylamide formation during cooking (Tareke et al., 2002). All studies point to the need to control the cooking process to achieve the desired food qualities such as proper flavor and texture development, yet prevent excessive browning. They also stress the importance of using surface browning rather than cooking times and temperatures to determine the degree of doneness of potato products.

## 2.3 Bread products

According to several estimates (US FDA, 2004; Svensson et al., 2003; Konings et al., 2003), bread, crackers, cookies, breakfast cereals and other grain-based products are major dietary sources of acrylamide. At present, little has been published on the effects of cooking conditions on acrylamide formation in grain-based foods, especially those prepared at home. Surdyk et al. (2004) examined baking conditions on acrylamide content of yeast-leavened wheat bread. In experiments with wheat flour naturally deficient in asparagine as well as asparagine supplemented flour, over 99% of acrylamide in bread was found in the crust (Surdyk et al., 2004). They also reported that temperature, but also time, increased acrylamide levels in the bread crust. When baked with the same recipe but with different baking temperatures and times, Surdyk et al. (2004) found a strong correlation between bread crust color and acrylamide content. These results indicate that color could be used as a gauge of acrylamide formation during bread-making. They also indicate that if at all possible, baking conditions should allow proper crumb formation, but yet prevent excessive browning in the crust.

Since bread is frequently toasted before it is consumed, work at the NCFST focused on studying the effects of toasting conditions on acrylamide formation in six different types of store-bought bread. "Light", "medium", and "dark" degrees of doneness were achieved by toasting the bread slices for 10, 13 and 15 min, respectively at the broil/bake setting in a toaster oven. Infrared (IR) thermometry measured the surface temperature of bread slices during toasting.

In general, acrylamide levels increased with toasting time (Fig. 4). However, in most cases, toasting to a "light" degree of doneness resulted in a negligible increase in acrylamide levels as compared to the untoasted bread. Similarly, Tareke et al. (2002) reported only slight increases in acrylamide levels as white bread was toasted (unspecified degree of doneness). As measured by IR thermometry, average surface temperatures of the bread slices at the end of the toasting runs were 120-143°C, 139-178°C, and 143-223°C for "light", "medium", and "dark" toasted bread, respectively. These findings are in accordance with previous studies (Tareke et al., 2002; Taubert et al., 2004; Becalski et al., 2003) that formation of acrylamide requires the food surface to reach temperatures >120°C. The data indicate that for most types of bread, toasting to a "medium" degree of doneness results in small to moderate acrylamide levels (<200 μg/kg). However, "dark" toast made from potato bread may have substantial (>600 μg/kg) acrylamide levels. Overall, potato bread tended to form more acrylamide during toasting than other bread types. This is likely due to higher concentrations of asparagine in breads containing potato flour than those without.

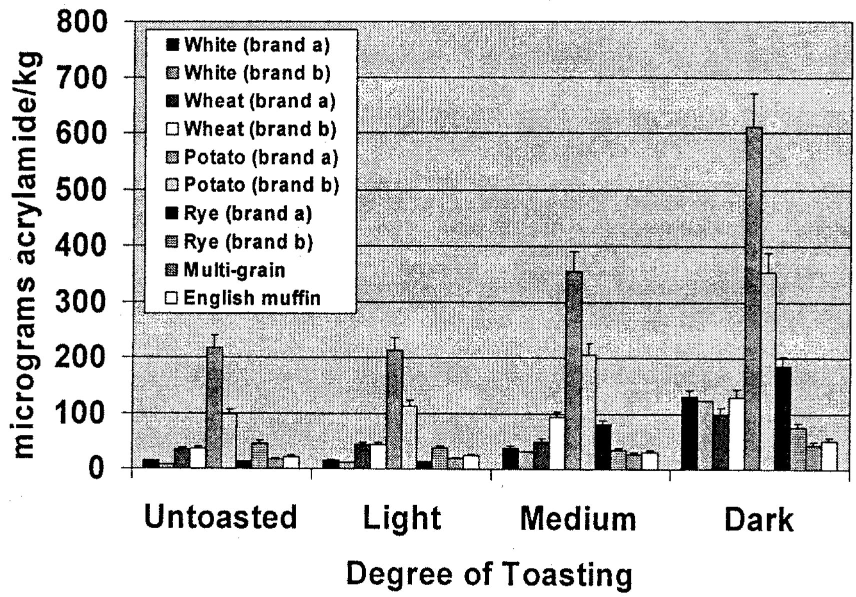


*Figure 4.* Degree of toasting affects acrylamide levels in bread. Six different varieties of bread (up to two brands of each variety) were toasted to light, medium and dark degrees of doneness. Three toasting trials were done for each type of bread and toasting condition. Acrylamide levels were measured as described previously. Error bars represent one standard deviation of the mean (Jackson et al., 2004).

In a separate experiment, we determined that scraping the surface of darkly toasted potato bread to remove the browned portions reduced acrylamide levels from 483 μg/kg to 181 μg/kg. These findings support data that indicate that over 99% of acrylamide in bread is found in the crust (Surdyk et al., 2004). Overall these results indicate that consumers should avoid toasting bread to a "dark" degree of doneness to reduce their exposure to acrylamide. In addition, scraping the toast surface to remove excessively browned portions could further reduce acrylamide levels.

The only other publication that describes cooking conditions and their effects on acrylamide formation in cereal-based foods besides bread is by Amrein et al. (2004). In their study, the effects on baking times and temperature on acrylamide formation in gingerbread were investigated. Both at 180°C and 200°C, acrylamide formation increased linearly over the 20 min baking period. This contrasts with acrylamide formation in potato products where acrylamide formation increased exponentially with time in this temperature range. Similar to our work with French fries, Amrein et al. (2004) reported that the degree of browning in baked gingerbread was an excellent predictor of acrylamide levels. The overall message from this work is that prolonged baking or excessive browning should be avoided to minimize acrylamide formation in gingerbread or other baked goods.

# 3. METHODS FOR REDUCING ACRYLAMIDE LEVELS IN FOOD

## 3.1 Raw ingredient selection and storage

Current research indicates that some simple measures may reduce acrylamide formation during home-preparation of foods. One method is to use raw ingredients such as potatoes or grain products that contain lower levels of acrylamide precursors. For example, an active area of research has been to identify potato cultivars that have reduced amounts of asparagine and reducing sugars. Amrein et al. (2003) and Becalski et al (2004) found that reducing sugar levels varied by a factor of 32 among potato cultivars, while free asparagine contents varied only within a narrow range. Both reported a linear relationship between sugar content of the raw tuber and the potential for acrylamide formation. Amrein et al. (2002) reported that neither the farming system (organic vs. conventional) nor extent of nitrogen fertilization influenced precursor levels and acrylamide forming potential in potatoes. These authors concluded that acrylamide content in cooked/ processed potato products can be substantially reduced by selecting cultivars with low levels of reducing sugars.

A high degree of variation in reducing sugar content among potatoes of the same cultivar suggest that other factors such as storage conditions may have an even stronger influence on sugar content than cultivar. We studied acrylamide formation in French fries prepared from two different varieties of fresh potatoes (Russet and Klondike Rose) stored at room temperature (22-26 °C) or under refrigeration conditions (6-8 °C) for up to 28 days (Jackson et al.., 2004). These conditions were an attempt to mimic conditions used by consumer to store fresh potatoes. After storage for 0, 1, 7, 14, 21, and 28 days, the potatoes were sliced into strips, soaked in water for 15 min, and then fried in corn oil (180°C, 3 min). The French fries were analyzed for acrylamide content using methods described earlier.

French fries prepared from Klondike Rose potatoes before storage contained more acrylamide (1132 μg/kg) than those made with Russet potatoes (677 μg/kg) (Fig. 5). The acrylamide forming potential of both potato cultivars did not significantly change during the 28 days of storage under refrigeration conditions. In contrast, acrylamide levels in fries made from potatoes stored at room temperature decreased during the 28 day study (Fig. 5). Fries made from Klondike Rose potatoes showed approximately a 73% decrease in acrylamide concentration while those from Russet potatoes had about a 50% decrease in acrylamide levels. Noti et al. (2003) and Biedermann et al. (2002b) reported that even short-term storage of potatoes at 4°C markedly increases the potential for acrylamide formation. Collectively, these data suggest that the potatoes used in our study were stored at refrigeration temperatures in the supermarket from which they were purchased.

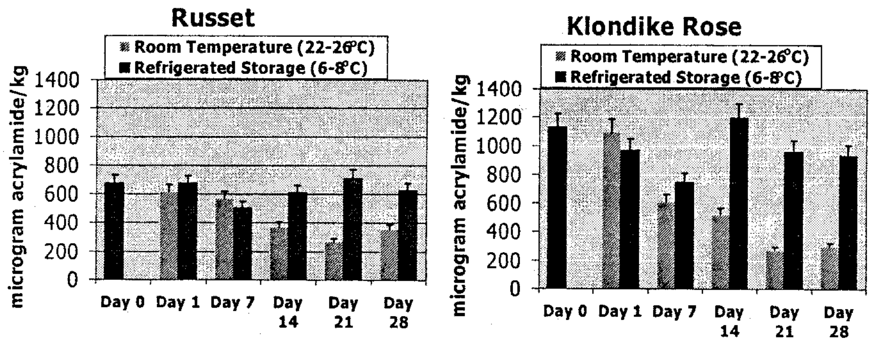


*Figure 5.* Acrylamide forming potential in potatoes stored at room temperature and under refrigeration conditions. Russet and Klondike Rose potatoes were stored at 6-8°C or 22-26°C for up to 28 days. French fries were prepared by frying (180 °C; 3 min) slices of stored potato in corn oil (Jackson et al., 2004).

Work by Noti et al. (2003), Biedermann et al., (2002b), as well as data generated in our laboratory, indicate that cooling potatoes to temperatures <10°C causes an increase in reducing sugars and thus, an increase in the potential for acrylamide formation. The phenomenon by which potatoes accumulate sugars during storage at low temperatures is known as "cold sweetening" and is believed to be a response by the potato plant to protect the tuber from freezing (Amrein et al., 2003). Biedermann et al. (2002b) stored potatoes of the cultivar Erntestolz for 15 days at 4°C and showed an increase in reducing sugars and the acrylamide forming potential by a factor of 28. Our work (Jackson et al., 2004) as well as reports by Amrein et al. (2003) and Biedermann et al. (2002b), show a high degree of correlation ($r^2$ >0.89) between reducing sugar content (glucose + fructose) and the acrylamide forming potential in potatoes Biedermann-Brem et al. (2003) determined that potatoes used for roasting and frying should contain less than 1 g/kg fresh weight of reducing sugar to minimize acrylamide formation during cooking.

To minimize acrylamide formation in potatoes cooked at high temperatures (fried, baked, roasted), it is imperative that raw potatoes not be stored at temperatures <10°C. This may be difficult especially during the late spring months when the majority of potatoes sold are from the previous year's harvest. During this time period, low temperature storage is needed to inhibit sprout formation and to prevent softening of the potato tissue and spoilage. More work is needed to identify or develop potato cultivars that are resistant to the "cold sweetening" phenomenon.

In baked grain-based products, there are several ingredients that may enhance acrylamide formation during baking. Amrein et al. (2004) found that use of ammonium hydrogen carbonate (ammonium bicarbonate) rather than sodium hydrogen carbonate (sodium bicarbonate) as a leavening agent in gingerbread augmented levels by three-fold. The promoting effect of ammonium hydrogen carbonate on the formation of acrylamide might be indirect by providing more reactive carbonyls originating from the reaction of ammonia with reducing sugars (Amrein et al., 2004). Amrein et al. (2004) also reported that using sucrose instead of honey or inverted sugar syrup in a gingerbread recipe reduced acrylamide content by a factor of 20. These results are explained by the fact both honey and inverted sugar syrup are a rich source of reducing sugars, precursors of acrylamide. Clearly more work is needed to identify ingredient or recipe changes that result in reduced acrylamide levels in home-prepared foods and to determine the effects of the changes on the sensory properties and acceptability of these foods.

## 3.2 Cooking conditions

Several investigators have made attempts at identifying cooking conditions that result in reduced acrylamide formation in home-prepared foods (Biedermann et al., 2002b; Grob et al., 2003; Taubert et al., 2004). Conditions that minimize acrylamide in French fries involve frying or baking potato pieces only as long as necessary to get the surface golden in color and the texture crispy (Grob et al., 2003). In fried potato products, Grob et al. (2003) found that keeping the oil temperature at 170°C or lower was effective at minimizing acrylamide formation if the cooking process was terminated once the potatoes were golden in color. Using raw potatoes with low amounts of reducing sugars, a 15 min soak to remove surface precursors, frying temperatures of 165-170°C, and a oil: potato ratio 1L: 100 g, Grob et al. (2003) was able to consistently produce French fries with 40-70 μg acrylamide/kg. Suggestions made by Grob et al. (2003) to limit acrylamide formation in baked or roasted potatoes included the use of fresh potatoes with reduced amounts of reducing sugars and lower cooking temperatures <250°C. In grain-based foods such as breads and cookies, baking should proceed until the proper moisture levels are obtained and minimum browning in the crust or surface occurs. More work is needed to determine the flavor, texture and acceptability of products cooked at conditions that reduce acrylamide formation.

## 3.3 Additives

Some work has been published on additives that modulate acrylamide formation in food. In experiments aimed at finding conditions that might reduce or prevent the formation of acrylamide, Tareke et al. (2002) found that addition of oils, antioxidants, or argon gas during frying of beef had minor or nonsignificant acrylamide-reducing effects. Vattem and Shetty (2003) and Rydberg et al. (2003) found that the presence of sodium ascorbate, ascorbyl palmitate, or the phenolic antioxidants from cranberry and oregano extract had no effect or slightly enhanced acrylamide formation in potatoes. In contrast, Becalski et al. (2003) found that adding ground rosemary to olive oil resulted in a 25% reduction in acrylamide formation in fried potato slices.

Amrein et al. (2003) measured the ability of different amino acids to reduce acrylamide formation in gingerbread. The amino acids, glycine and L-glutamine, did not affect acrylamide levels, but addition of L-cysteine reduced the acrylamide content of gingerbread. Similarly, Biedermann et al. (2002b) reported that addition of cysteine to potato reduced acrylamide levels by 95%. Unfortunately, cysteine addition is not a practical method for affecting acrylamide formation since the amino acid imparts an unpleasant odor and flavor to food (Amrein et al., 2004). Other amino acids that have been found to reduce acrylamide formation in heated potato include glycine, alanine, lysine, glutamine and glutamic acid (Rydberg et al., 2003). However, it is not clear whether amino acid treatments can be used with any practicality to prevent or reduce acrylamide formation in cooked food.

Several papers discuss the effects of pH reducing treatments on acrylamide formation. Citric acid added at levels of 0.5 and 1.0 g/100 g to gingerbread reduced acrylamide formation by factors of 4 and 40, respectively (Amrein et al., 2004). These results support those by Jung et al. (2003) and Rydberg et al. (2003) who found that citric acid treatments prevented acrylamide formation in fried French fries, baked tortilla chips and an oven-heated potato homogenate. Rydberg et al. (2003) found major reductions (>90%) in acrylamide formation when ascorbic acid was added to homogenized potato and then microwave heated (3 min, 750 W). Acid treatments are effective at preventing acrylamide formation since they lowered pH into the range where acrylamide formation is minimized (<pH 5) (Jung et al., 2003).

Zyzak et al. (2003) reported that treating potato with asparaginase, an enzyme converts asparagine into aspartic acid, reduced acrylamide levels by 99%. There has been some interest in using the enzyme to reduce acrylamide formation in some commercial fried potato snack products (JIFAN, 2004; Zyzak et al., 2004).

Work-to-date suggests that, in general, additives have little to no effect on acrylamide formation. With treatments such as citric acid and asparaginase, where significant acrylamide reductions are possible, more work is needed to determine if they can be used for reducing acrylamide formation in home-prepared foods. In addition, more research is needed to determine if these treatments affect the acceptability (flavor, color, texture, etc.) of food.

## 3.4 Washing treatments and acid dips

Rinsing and soaking treatments have been effective at reducing acrylamide formation in French fries prepared from fresh-cut potatoes. We found that soaking potato slices in room temperature water for at least 15 min before frying resulted in 63% reduction in acrylamide (Jackson et al., 2004). Similarly, Grob et al. (2003) found that soaking potato pieces for 10 min in cold or warm water resulted in desirable flavor and texture when fried, yet had only half the acrylamide content of the comparable untreated slices. Soaking treatments reduce acrylamide formation by leaching out sugars and asparagine from the surface of the potato slice.

Using acid solutions rather than water to soak potatoes had enhanced ability to reduce acrylamide levels. We found that soaking the potatoes in 1:3 vinegar:water reduced the acrylamide forming potential by 75%. No greater effect was seen when the wash solution contained higher vinegar levels (1:1 vinegar:water). Jung et al. (2003) showed that dipping potato cuts in 1% and 2% citric acid solutions for one hour before frying inhibited acrylamide formation in French fries by 73.1% and 79.7%. Use of acid washes for preventing acrylamide formation likely is due to the drop in pH at the surface of the potato slice as well as to leaching losses of asparagine and reducing sugars.

## 4. CONCLUSIONS

Although current research indicates that some simple measures can be used by consumers to reduce acrylamide formation during home-preparation of foods, no method has been successful at totally preventing formation of acrylamide. One of the most practical and most efficacious methods for reducing acrylamide formation is to avoid frying, baking, broiling and grilling foods at excessively high temperatures and for long times. Since formation of acrylamide increases exponentially toward the end of the cooking process, an important factor for minimizing its formation is to determine the proper cooking endpoint. Research-to-date points to the need to control the cooking process to achieve the desired qualities, such as flavor and texture, yet prevent excessive browning. Degree of surface browning rather than cooking times and temperatures appears to be a good method of estimating the "degree of doneness" of some foods.

Several approaches have been identified for reducing acrylamide formation in home-prepared foods made from potato. They include proper storage of the raw potato tubers (i.e. >10°C) and soaking potato slices in water or acid solutions for at least 15 min before cooking (baking, frying or roasting). Acrylamide formation in bakery products can be minimized by using sodium hydrogen carbonate rather than ammonium hydrogen carbonate as a leavening agent and sucrose rather than sweetening agents high in reducing sugars. More work is needed to identify methods for consumers to reduce acrylamide formation in home-prepared foods. In addition, the consumer acceptability of foods cooked under conditions that prevent or reduce acrylamide levels needs to be determined.

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