

# Acrylamide formation is prevented by divalent cations during the Maillard reaction

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## Abstract

The effects of mono- and divalent cations on the formation of acrylamide were studied in a fructose-asparagine model system at 150 and 180 °C. At amounts equivalent to those of asparagine and fructose, added divalent cations, such as Ca<sup>2+</sup>, were found to prevent acrylamide formation completely, whereas monovalent cations, such as Na<sup>+</sup>, almost halved the acrylamide formed in the model system. It was confirmed by mass spectrometric analyses of pyrolyzates that the formation of the Schiff base of asparagines, which is the key intermediate leading to acrylamide, was prevented by the cations. Meanwhile, the reaction proceeded to form brown coloured products. Dipping potatoes into calcium chloride solution inhibited the formation of acrylamide by up to 95% during frying. The sensory quality of fried potato strips, in terms of golden yellow colour and crispy texture, was not adversely affected by this treatment.

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**Keywords:** Acrylamide; Divalent cations; Calcium; Inhibition of formation; Fried potatoes

## 1. Introduction

Detection of high concentrations of acrylamide in common heated foodstuffs in April 2002 (Swedish NFA, 2002) caused considerable public concern, since acrylamide was found to be carcinogenic in rodents (Johnson et al., 1986) and is classified as a probable human carcinogen (IARC, 1993). These findings caused the European Community (EC, 2002), and the WHO (FAO/WHO, 2002) to initiate projects for the minimization of acrylamide content in commercial as well as in homemade foods.

A number of theoretical mechanisms have been proposed for the formation of acrylamide in heated food. Most probably, acrylamide in food results largely from the Maillard reaction between asparagine and a reactive carbonyl, proceeding through intermediates that include a

Schiff's base (Mottram, Wedzicha, & Dodson, 2002; Stadler et al., 2002; Zyzak et al., 2003). Several factors, such as the initial concentration of reactants and their ratio, temperature and time of processing, pH and water activity, have been shown to influence the formation levels of acrylamide in heat-processed foods (Friedman, 2003). The influence of temperature on the formation of acrylamide has been repeatedly demonstrated (Becalski, Lau, Lewis, & Seaman, 2003; Biedermann & Grob, 2003; Rydberg et al., 2003; Stadler et al., 2002; Tareke, Rydberg, Karlsson, Eriksson, & Törnqvist, 2002).

Recent studies have indicated that polyvalent cations reduce acrylamide formation in thermally processed snack foods and bakery products (Elder, Fulcher, Leung, & Topor, 2005; Lindsay & Jang, 2005). In this study, model Maillard and real food systems were employed to investigate the potential formation and degradation of acrylamide during heating in the presence of mono- and divalent cations.

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## 2. Materials and methods

### 2.1. Chemicals and consumables

Acrylamide (99+%) and  $^{13}\text{C}_3$ -labelled acrylamide (99% isotopic purity) were obtained from Sigma (Diesenhofen, Germany) and Cambridge Isotope Laboratories (Andover, MA, USA), respectively. Fructose and asparagine were obtained from Sigma. Acetic acid, formic acid, sodium chloride, potassium chloride, calcium chloride and magnesium chloride were all reagent grade and obtained from Merck (Darmstadt, Germany). The analytical column Zorbax SB-Aq (250 × 4.6 mm, 5 µm) was supplied by Agilent Technologies (Wilmington, DE, USA). Micro-spin centrifuge filters (0.45 µm) were obtained from Alltech Associates (Deerfield, IL, USA).

Working standards of acrylamide were prepared at concentrations of 0.1, 0.2, 0.3, 0.5, 1.0 and 2.0 µg/ml in 0.01 mM acetic acid. Carrez I and Carrez II solutions were prepared by dissolving 15 g of potassium hexacyanoferrate and 30 g of zinc sulfate in 100 ml of water, respectively.

### 2.2. Preparation of reaction mixtures for pyrolysis

A model system composed of fructose (or glucose) and asparagine was used for the determination of concurrent formation and degradation of acrylamide in the presence of monovalent ( $\text{Na}^+$ ,  $\text{K}^+$ ) or divalent ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ) cations. Reactants were combined in a 25 ml test tube (Pyrex closed system). The amounts of fructose, asparagine and cation were 5 µmoles in the reaction mixture. Total reaction volume was adjusted to 100 µl with water in each case, to promote the physical interaction of reactants. The pH value of the reaction mixture was 4.81. Adding 5 or 10 µmol of cation into the reaction mixture did not change the pH value.

Carefully closed test tubes containing the reactants were placed in an oil bath. Reactions were performed at 150 and 180 °C. After predefined heating periods of 5, 10, 15, 20, 30, 45 and 60 min, the tubes were immediately placed on ice.

### 2.3. Preparation of potato strips for frying

Potato was cut into strips (8.5 mm × 8.5 mm) using a French fry cutter and the strip length was adjusted to 70 mm. The strips were divided into three lots. One lot was kept as control without any pretreatment prior to frying. The strips of the other two lots were soaked in a solution of calcium chloride or sodium chloride at a concentration of 0.1 M. After dipping for 15, 30 and 60 min at room temperature, potato strips were withdrawn from the solution and drained for 2 min prior to frying. Two potato strips were dipped into 1 l of salt solution in each case. Frying of potato strips was performed using sunflower oil in a 5 l oil bath at 170 °C for 5 min.

### 2.4. Analysis of acrylamide

#### 2.4.1. Extraction of acrylamide from the pyrolysates

The pyrolysates were suspended in 1.0 ml of water and the aqueous extract was obtained by vortexing for 1 min. The mixture was transferred into a micro-spin centrifuge filter (0.45 µm) and centrifuged for 5 min at 5000 rpm. Twenty millilitres of clear extract was analysed by liquid chromatography-mass spectrometry (LC-MS) to quantify acrylamide. Each pyrolysate was supplemented with  $^{13}\text{C}_3$ -acrylamide (100 ng) as internal standard.

#### 2.4.2. Extraction of acrylamide from the fried potato strips

A procedure described by us elsewhere was used with minor modification (Şenyuva & Gökmen, 2006). Finely ground sample (1 g) was weighed into a 10 ml glass tube with cap. Carrez 1 (500 µl) and Carrez 2 (500 µl) solution were added and the volume was adjusted to 10 ml with 0.2 mM acetic acid. After mixing in a vortex mixer for 2 min, 1 ml of raw extract was transferred into a micro-spin centrifuge filter (0.45 µm) and centrifuged for 10 min at 10000 rpm at 0 °C. The clear extract (20 µl) was analysed by LC-MS to quantify acrylamide. Each sample was supplemented with  $^{13}\text{C}_3$ -acrylamide (100 ng).

### 2.5. LC-MS analysis of acrylamide

The quantification of acrylamide was performed by an Agilent 1100 HPLC system (Waldbronn, Germany), consisting of a binary pump, autosampler and temperature-controlled column oven, coupled to an Agilent 1100 MS detector, equipped with atmospheric pressure chemical ionisation (APCI) interface. The chromatographic separations were performed on a Zorbax SB-Aq column, using an isocratic mixture of 0.01 mM acetic acid in a 0.2% aqueous solution of formic acid, at a flow rate of 0.6 ml/min at 40 °C. Data acquisition was performed either in scan mode or in selected ion monitoring (SIM) mode using the interface parameters: drying gas ( $\text{N}_2$ , 100 psig) flow of 4 l/min, nebulizer pressure of 60 psig, drying gas temperatures 325 °C, vaporiser temperature of 425 °C, capillary voltage of 55 eV. Ions monitored were  $m/z$  72 and 55 for acrylamide,  $m/z$  75 and 58 for  $^{13}\text{C}_3$ -labelled acrylamide,  $m/z$  133 for asparagine and  $m/z$  181 for glucose or fructose.

## 3. Results and discussion

### 3.1. The effects of cations on acrylamide formation in asparagine–fructose reaction system

It has been shown that Maillard-driven generation of flavour and colour in heated foods can be linked to the formation of acrylamide. Free asparagine in combination with reducing sugars generates significant amounts of acrylamide when pyrolysed at temperatures greater than 120 °C (Mottram et al., 2002; Stadler et al., 2002).

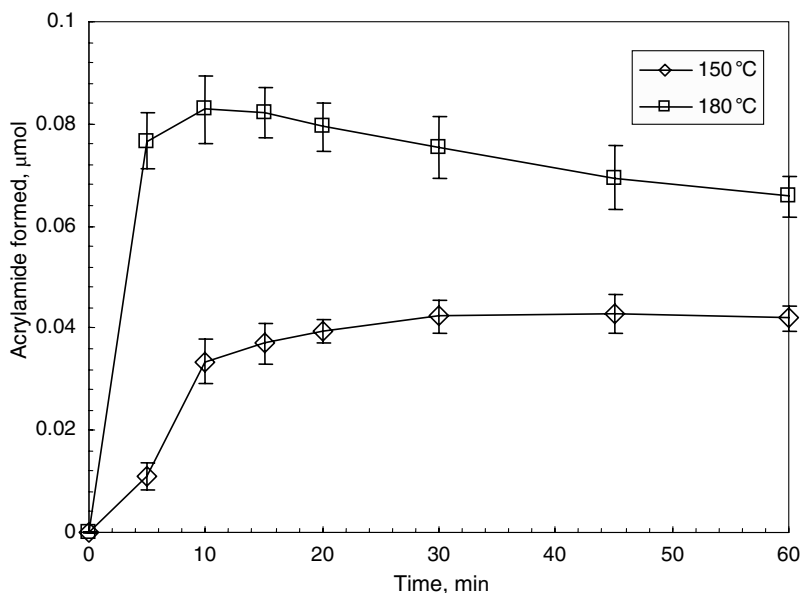


Fig. 1. Time and temperature-dependent formation of acrylamide ( $\mu\text{mol}$ ) from asparagine ( $5 \mu\text{mol}$ ) and fructose ( $5 \mu\text{mol}$ ) in  $100 \mu\text{l}$  water. Error bars represent standard deviations ( $n = 3$ ).

We heated equimolar amounts of asparagine and fructose at  $150$  and  $180$  °C in sealed glass tubes. The formation of acrylamide followed typical kinetic patterns (Fig. 1). The amount of acrylamide generated in the reaction mixture reached an apparent maximum after 10 min of heating at  $180$  °C, then, decreased slowly afterwards. Obviously, the content of acrylamide detected in the reaction mixture at  $180$  °C was the net result of the formation and degradation of this compound. Similar results have been reported for a model mixture composed of glucose and asparagine at various molar ratios and in food systems (Ehling & Shibamoto, 2005; Elmore, Koutsidis, Dodson, Mottram, & Wedzicha, 2005). The decline of the curves is most likely

due to polymerisation, as recently reported (Stadler et al., 2004).

When equimolar amounts of asparagine and fructose ( $5 \mu\text{mol}$  each) were pyrolysed without cations, a maximum of  $0.045 \mu\text{mol}$  and  $0.085 \mu\text{mol}$  of acrylamide was formed at  $150$  and  $180$  °C, respectively.

Yasuhara, Tanaka, Hengel, and Shibamoto (2003) have discussed the oxidation and/or thermal degradation of lipids in fried foods as a possible mechanistic route contributing to the formation of acrylamide via an acrylic acid intermediate. Lindsay and Jang (2005) tested this hypothesis by accelerating the oxidation during frying, through the introduction of ferric chloride to the surface of sliced

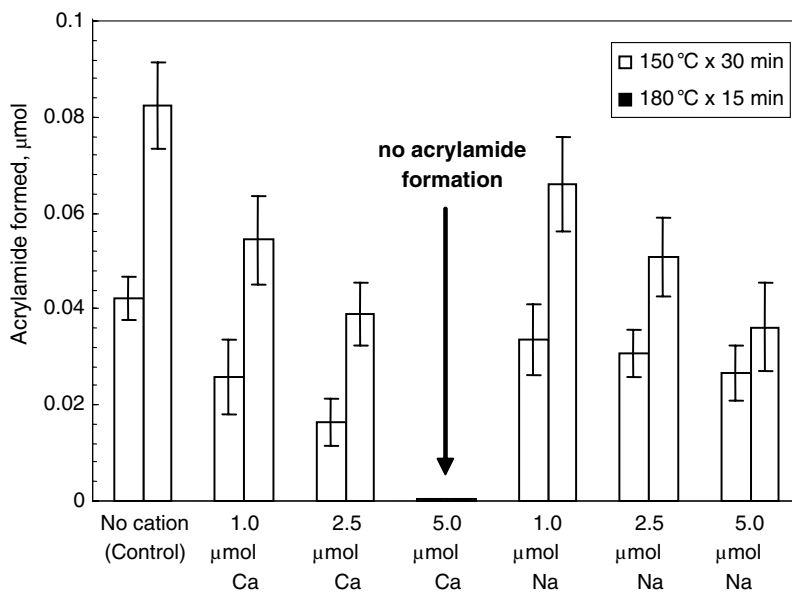


Fig. 2. Amounts of acrylamide formed ( $\mu\text{mol}$ ) from asparagine ( $5 \mu\text{mol}$ ) and fructose ( $5 \mu\text{mol}$ ) in  $100 \mu\text{l}$  water heated in a sealed glass tube, as influenced by the presence of  $\text{Ca}^{2+}$  and  $\text{Na}^+$  in the reaction mixture.

potatoes before frying. They found that the treatment of potato slices with 1000 ppm  $\text{Fe}^{3+}$  reduced acrylamide formation by 77% compared to the untreated control. They noted that the introduction of  $\text{Ca}^{2+}$  as a non-transition state cation also reduced acrylamide formation by 59%.

Investigating the role of different mono- and divalent cations in the formation of acrylamide, we found that pyrolysing the equimolar mixture of asparagine and fructose with equimolar amounts of divalent cations, such as  $\text{Ca}^{2+}$ , led to a complete inhibition of the formation of acrylamide. Meanwhile the Maillard reaction proceeded to form brown coloured end products. The maximum

amounts of acrylamide were measured at 15 and 30 min of heating at 180 and 150 °C, respectively, in the presence of mono- and divalent cations. Fig. 2 shows the effect of different amounts of  $\text{Ca}^{2+}$  and  $\text{Na}^+$  on the maximum amount of acrylamide formed during pyrolysis, in comparison to the acrylamide formed without the presence of any cation in the reaction mixture. The maximum amount of acrylamide formed during pyrolysis decreased as the amount of cation increased in the mixture.  $\text{Ca}^{2+}$  and  $\text{Na}^+$  differed in their effectiveness for the prevention of acrylamide formation. Although the monovalent cation  $\text{Na}^+$  prevented the formation of acrylamide

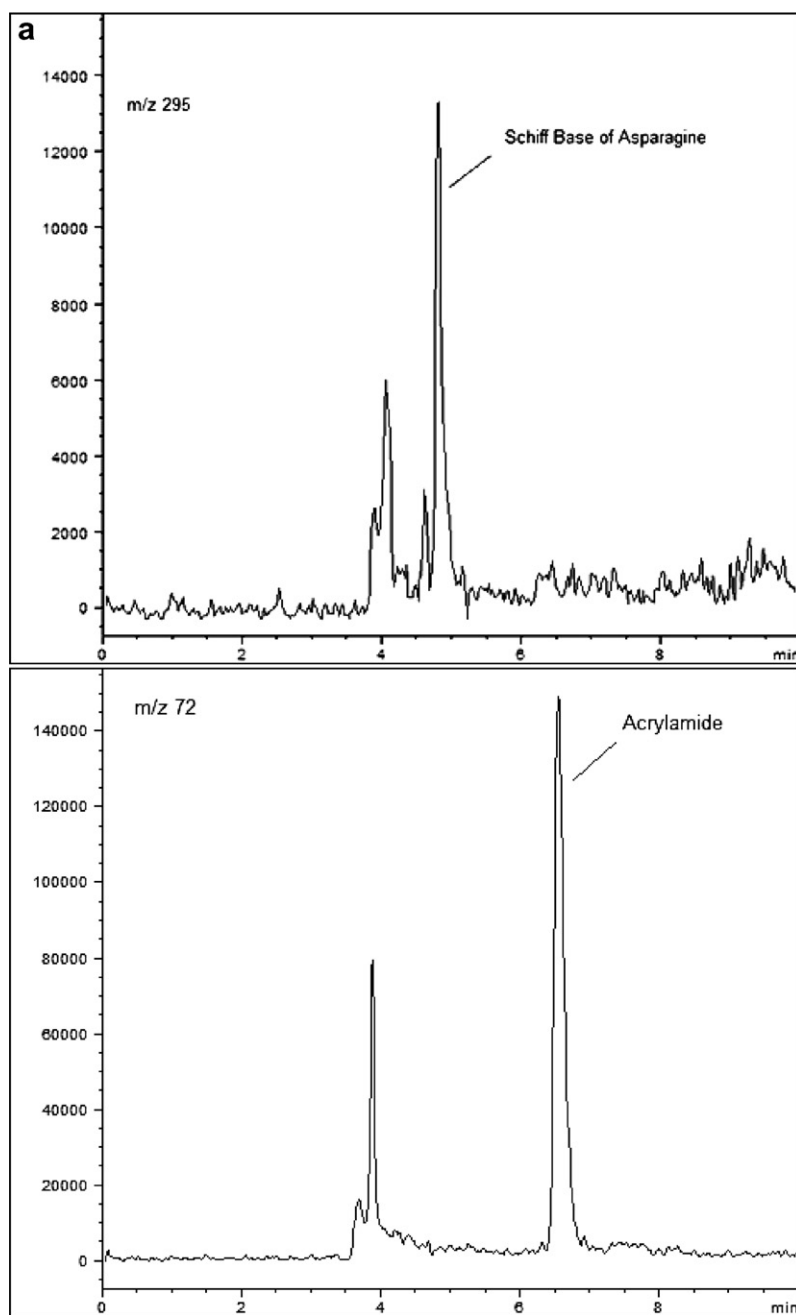


Fig. 3. Extracted ion chromatograms for pyrolysates after heating a mixture of glucose and asparagine (each 10  $\mu\text{mol}$  initially) at 150 °C for 20 min. (a) no cation and (b) 10  $\mu\text{mol}$   $\text{Ca}^{2+}$ .

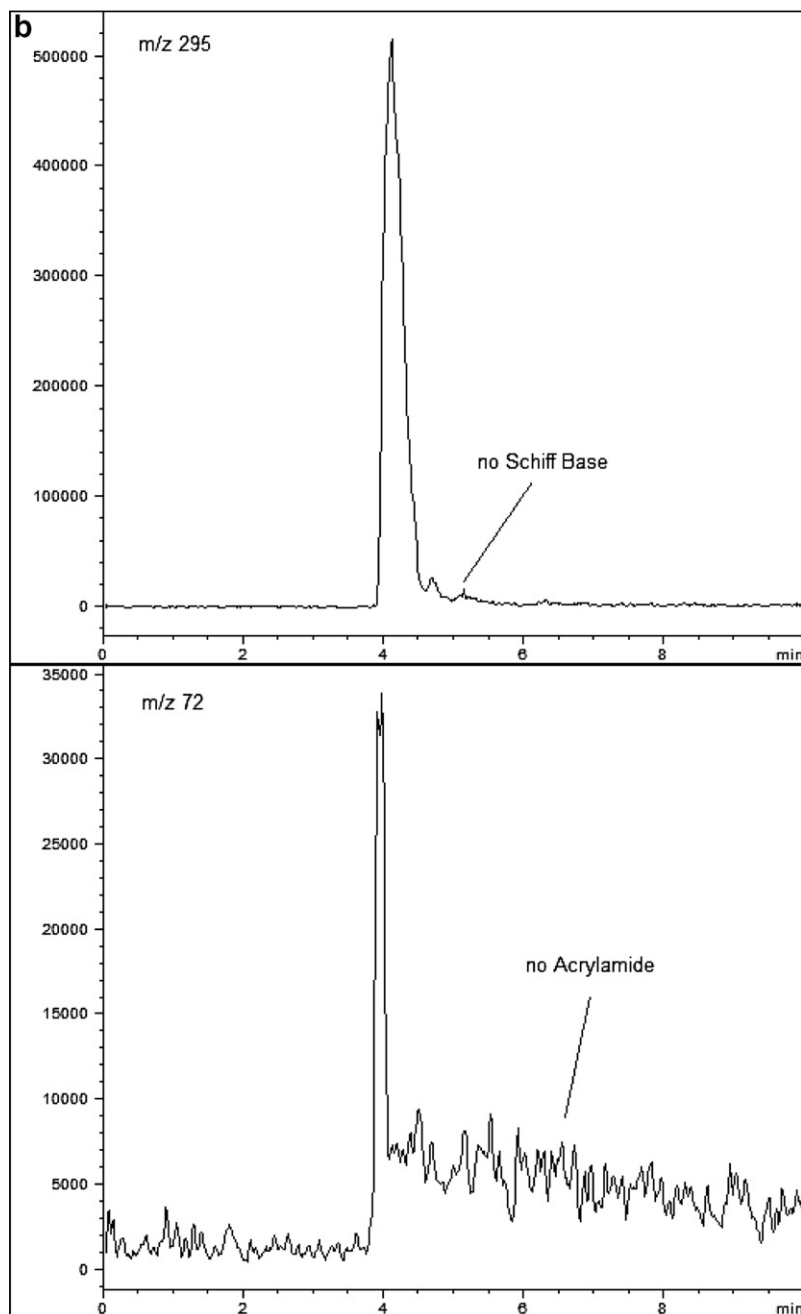


Fig. 3 (continued)

to a certain extent, it was less efficient than the divalent cation  $\text{Ca}^{2+}$ .

Other cations, namely  $\text{Mg}^{2+}$  and  $\text{K}^{+}$  ions, exhibited similar behaviour on the inhibition of acrylamide formation to those of  $\text{Ca}^{2+}$  and  $\text{Na}^{+}$ , respectively (data not shown). So, it is clear that the effect of mono- and divalent cations toward the prevention of acrylamide formation during the Maillard reaction occurs in a systematic manner.

Lindsay and Jang (2005) have hypothesised that ionic associations involving the ions and charged groups on asparagine and related intermediates were likely to be involved. However, no concrete proof of this hypothesis has been provided yet, and information about how the

presence of cations would affect the formation of typical Maillard reaction products is still lacking. In order to investigate any possible interaction between the charged groups of asparagine and the divalent cation, a reaction mixture composed of glucose, asparagine and  $\text{Ca}^{2+}$  was heated at  $150\text{ }^{\circ}\text{C}$  for 15 min. Mass spectrometric analyses of pyrolysates did not confirm any ionic associations between the charged groups of asparagine and  $\text{Ca}^{2+}$ . Zhou et al. (2003) have reported that  $\text{Ca}^{2+}$  may form a complex with poly(acrylamide), but such a complex was also not confirmed between  $\text{Ca}^{2+}$  and acrylamide in this study.

The presence of cations in the reaction mixture influenced the rate of decomposition of acrylamide precursors

significantly. Adding cations into the reaction mixture increased the rate of glucose decomposition while most asparagine remained unreacted.

Mechanistic studies have proposed that *N*-glycosides and related compounds formed in the early phase of Maillard reaction are key intermediates leading to acrylamide (Stadler et al., 2002, 2004; Yaylayan, Wnorowski, & Perez-Locas, 2003; Zyzak et al., 2003). The first step in acrylamide production is the formation of a Schiff base between the carbonyl and  $\alpha$ -amino group of asparagine by means of the dehydration of the *N*-glycosyl compound. Our results showed a clear impact of  $\text{Ca}^{2+}$  on acrylamide formation. When  $\text{Ca}^{2+}$  was lacking in the reaction mixture, both the Schiff base of asparagine (MW 294) and acrylamide (MW 71) formed during heating at 150 °C for 20 min, as clearly seen in the corresponding extracted ion chromatograms (Fig. 3a). However, the presence of  $\text{Ca}^{2+}$  prevented the formation of the Schiff base, and thus, of acrylamide during heating (Fig. 3b).

### 3.2. The effects of cations on acrylamide formation in potato strips

Potato products such as French fries and crisps were among the food items containing highest amounts of acrylamide (Swedish NFA, 2002 UK; Şenyuva and Gökmen, 2005; FSA, 2002). Therefore, we decided to confirm the effect of mono- and divalent cations on acrylamide formation in French fries during the frying process. It has been successfully shown that acrylamide formation takes place mainly at the surface and in near-surface regions, because during the process of frying, the conditions in this part of the potato strip becomes favourable for acrylamide formation, as a result of simultaneous drying (Gökmen, Palazoğlu, & Şenyuva, 2006; Taubert, Harlfinger, Henkes, Berkels, & Schömig, 2004). So, any treatment that inhibits the reaction responsible for the formation of acrylamide on potato surface would be a viable approach to limit the amount of acrylamide formed during frying. Dipping potato strips into the solutions of calcium chloride or

sodium chloride was, therefore, applied as a simple pre-treatment prior to frying in this study.

The results obtained for potato confirmed that divalent cations are capable of inhibiting the formation of acrylamide. Without any pre-treatment, as much as  $711 \pm 33 \mu\text{g}/\text{kg}$  of acrylamide formed upon frying potato strips at 170 °C for 5 min. The amount of acrylamide could be decreased by dipping potato strips into the solutions of sodium chloride and calcium chloride. The amount of acrylamide formed decreased as the dipping time increased for both sodium chloride and calcium chloride. However, when water was used alone for that kind of pretreatment, the results were inconclusive, having only a limited effect on the amount of acrylamide formed during frying as was also noted previously by other researchers (Grob et al., 2003; Haase, Matthäus, & Vosmann, 2003; Kita, Bräthen, Knutsen, & Wicklund, 2005). So, the inhibition of acrylamide formation during frying was mainly attributed to the presence of mono- or divalent cations in the potato strips after the dipping treatment, rather than the reduction of acrylamide precursors by dipping (Table 1).

As also observed in the reaction mixture composed of asparagine and fructose, the divalent cation,  $\text{Ca}^{2+}$  was more effective than the monovalent cation  $\text{Na}^+$ . When compared to the amount of acrylamide formed in potato strips without pre-treatment, percentage inhibition of acrylamide formation increased to ca. 95% by dipping in calcium chloride solution for 60 min at room temperature (Table 1). In addition, the sensory quality of the fried potatoes, in terms of golden yellow colour, crispy texture and salty taste could also be maintained. As shown in Fig. 4, fries prepared by dipping in 0.1 M  $\text{CaCl}_2$  solution had similar surface colour to that of the control. This was the evidence that the Maillard reaction had taken place on the surface of the potato strips, leading to the formation of colour without the formation of acrylamide.

Lowering the pH or the concentrations of acrylamide precursors as suggested by other researchers to limit acrylamide

Table 1  
Effect of dipping into calcium chloride and sodium chloride solutions on the inhibition of acrylamide formation during frying

| Dipping               |            | Loss by dipping treatment, (%) <sup>a</sup> |          |            | Acrylamide ( $\mu\text{g}/\text{kg}$ ) <sup>b</sup> | Inhibition (%) |
|-----------------------|------------|---|----------|------------|---|----------------|
| Solution              | Time (min) | Glucose                                     | Fructose | Asparagine |   |                |
| Water                 | 15         | 3   | 4        | 3          | $655 \pm 18$  | 8              |
|                       | 30         | 7   | 9        | 8          | $628 \pm 59$  | 12             |
|                       | 60         | 17  | 21       | 19         | $589 \pm 41$  | 17             |
| 0.1 M NaCl            | 15         | 6   | 5        | 7          | $430 \pm 58$  | 40             |
|                       | 30         | 11  | 9        | 12         | $328 \pm 39$  | 54             |
|                       | 60         | 17  | 18       | 20         | $302 \pm 41$  | 58             |
| 0.1 M $\text{CaCl}_2$ | 15         | 5   | 6        | 6          | $151 \pm 14$  | 79             |
|                       | 30         | 9   | 8        | 11         | $60 \pm 8$  | 92             |
|                       | 60         | 19  | 17       | 21         | $40 \pm 3$  | 95             |

<sup>a</sup> Glucose, fructose and asparagine concentrations of potato strips were 0.45, 1.82 and 1.86 g/kg (fresh weight).

<sup>b</sup> The concentration of acrylamide formed upon frying at 170 °C for 5 min in potato strip without pretreatment (control) was  $711 \pm 33 \mu\text{g}/\text{kg}$  ( $n = 3$ ).

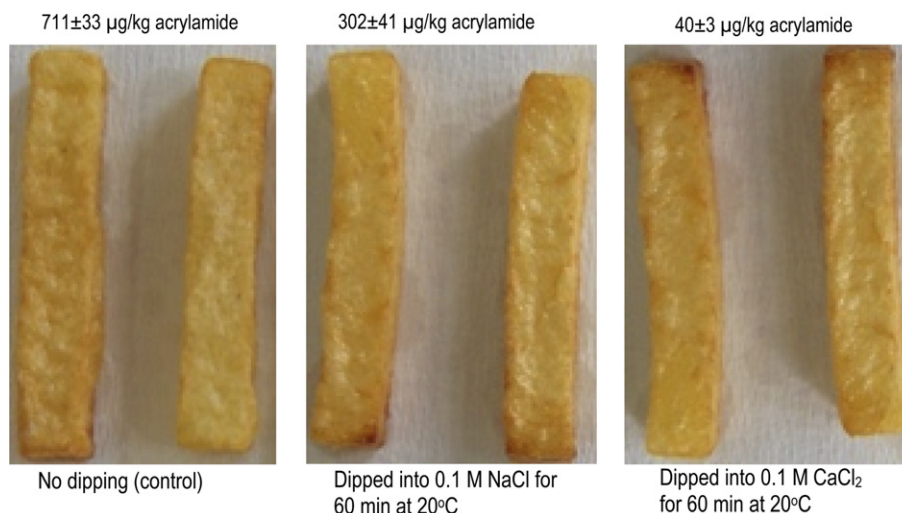


Fig. 4. Images of potato strips after deep frying at 170 °C for 5 min, which indicate dipping treatment (0.1 M  $\text{CaCl}_2$  or NaCl for 60 min) has no adverse effect on the formation of colour.

formation is difficult to put into practice since the final product has a noticeable sour taste or unsatisfactory surface colour (Jung, Choi, & Ju, 2003; Kita et al., 2005).

Based on the results obtained for fried potatoes here, dipping of potato strips into a solution of calcium chloride at moderate concentrations may be a viable approach for the minimisation of acrylamide content, in commercial as well as in homemade foods. Calcium chloride, as a food additive (E 509), is widely used as a firming agent during processing. It could now be used by the food industry to control the formation of acrylamide.

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### References

- Becalski, A., Lau, B. P.-Y., Lewis, D., & Seaman, S. (2003). Acrylamide in foods: occurrence, sources and modeling. *Journal of Agricultural and Food Chemistry*, 51, 802–808.
- Biedermann, M., & Grob, K. (2003). Model studies on acrylamide formation in potato, wheat flour and corn starch; ways to reduce acrylamide contents in bakery ware. *Mitt. Geb. Lebensm. Unters. Hyg.*, 94, 406–422.
- Ehling, S., & Shibamoto, T. (2005). Correlation of acrylamide generation in thermally processed model systems of asparagine and glucose with color formation, amounts of pyrazines formed, and antioxidative properties of extracts. *Journal of Agricultural and Food Chemistry*, 53(12), 4813–4819.
- Elder, V.A., Fulcher, J.G., Leung, H.K., & Topor, M.G. (2005) Method for reducing acrylamide formation in thermally processed foods such as snack foods and bakery products. US Pat. Appl. Publ., 27 pp, Cont.-in-part of US Ser. No. 372,738. CODEN: USXXCO US 2005064084 A1 20050324 Patent written in English. Application: US 2004-929922 20040830.
- Elmore, J. S., Koutsidis, G., Dodson, A. T., Mottram, D. S., & Wedzicha, B. L. (2005). Measurement of acrylamide and its precursors in potato, wheat, and rye model systems. *Journal of Agricultural and Food Chemistry*, 53, 1286–1293.
- European Commission. Scientific Committee on Food: Opinion of the Scientific Committee on Food on new findings regarding the presence of acrylamide in food, 3 July 2002: Brussels, Belgium, 2002.
- FAO/WHO Consultation on the Health Implications of Acrylamide in Food. Summary report of a meeting held in Geneva, 25–27 June 2002; WHO: Geneva, 2002.
- Friedman, M. (2003). Chemistry, biochemistry, and safety of acrylamide. *A Review Journal of Agricultural and Food Chemistry*, 51, 4504–4526.
- Gökmen, V., Palazoğlu, T. K., & Şenyuva, H. Z. (2006). Relation between the acrylamide formation and time–temperature history of surface and core regions of French fries. *Journal of Food Engineering*, 77, 972–976.
- Grob, K., Biedermann, M., Biedermann-Brem, S., Noti, A., Imhof, D., Amrein, T., et al. (2003). French fries with less than 100 µg/kg acrylamide. A collaboration between cooks and analyst. *European Food Research and Technology*, 271(3), 185–194.
- Haase, N. U., Matthäus, B., & Vosmann, K. (2003). Acrylamide formation in foodstuffs minimizing strategies for potato crisps. *Dtsch. Lebensm.-Rundsch.*, 99, 87–90.
- IARC Monographs. Acrylamide; International Agency for Research on Cancer, 1993.
- Information of acrylamide in food. Swedish National Food Administration: Uppsala, Sweden, 2002. Available from: <<http://www.slv.se>>.
- Johnson, K. A., Gorzinski, S. J., Bodner, K. M., Campbell, R. A., Wolf, C. H., Friedman, M. A., et al. (1986). Chronic toxicity and oncogenicity study on acrylamide incorporated in the drinking water of Fischer 344 rats. *Toxicology and Applied Pharmacology*, 85, 154–168.
- Jung, M. Y., Choi, D. S., & Ju, J. W. (2003). A novel technique for limitation of acrylamide formation in fried and baked corn chips and in French fries. *Journal of Food Science*, 68, 1287–1290.
- Kita, A., Bräthen, E., Knutsen, S. H., & Wicklund, T. (2005). Effective ways of decreasing acrylamide content in potato crisps during processing. *Journal of Agricultural and Food Chemistry*, 10.1021/jf049269i.
- Lindsay, R. C., & Jang, S. (2005). Model systems for evaluating factors affecting acrylamide formation in deep fried foods. *Advances in Experimental Medicine and Biology*, 561, 329–341.
- Mottram, D. S., Wedzicha, B. L., & Dodson, A. T. (2002). Acrylamide is formed in the Maillard reaction. *Nature*, 419, 448–449.

- Rydberg, P., Eriksson, S., Tareke, E., Karlsson, P., Ehrenberg, L., & Törnqvist, M. (2003). Investigations of factors that influence the acrylamide content of heated foodstuffs. *Journal of Agricultural and Food Chemistry*, 51, 7012–7018.
- Şenyuva, H. Z., & Gökmen, V. (2006). Interference-free determination of acrylamide in potato and cereal-based foods by a laboratory validated liquid chromatography–mass spectrometry method. *Food Chemistry*, 97, 539–545.
- Şenyuva, H. Z., & Gökmen, V. (2005). Survey of acrylamide in Turkish foods by an in-house validated LC-MS method. *Food Additives and Contaminants*, 22(3), 204–209.
- Stadler, R. H., Blank, I., Varga, N., Robert, F., Hau, J., Guy, P. A., et al. (2002). Acrylamide from Maillard reaction products. *Nature*, 419, 449–450.
- Stadler, R. H., Robert, F., Riediker, S., Varga, N., Davidek, T., Devaud, S., et al. (2004). In-depth mechanistic study on the formation of acrylamide and other vinylogous compounds by the Maillard reaction. *Journal of Agricultural and Food Chemistry*, 52, 5550–5558.
- Tareke, E., Rydberg, P., Karlsson, P., Eriksson, S., & Törnqvist, M. (2002). Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *Journal of Agricultural and Food Chemistry*, 50, 4998–5006.
- Taubert, D., Harlfinger, S., Henkes, L., Berkels, R., & Schömig, E. (2004). Influence of processing parameters on acrylamide formation during frying of potatoes. *Journal of Agricultural and Food Chemistry*, 52, 2735–2739.
- UK Food Standards Agency. Food Standards Agency study shows Acrylamide in food. Available from: <<http://www.foodstandards.gov.uk/>>, 2002.
- Yasuhara, A., Tanaka, Y., Hengel, M., & Shibamoto, T. (2003). Gas chromatographic investigation of acrylamide formed in browning model systems. *Journal of Agricultural and Food Chemistry*, 51(14), 3999–4003.
- Yaylayan, V.-A., Wnorowski, A., & Perez-Locas, C. (2003). Why asparagine needs carbohydrates to generate acrylamide. *Journal of Agricultural and Food Chemistry*, 51, 1753–1757.
- Zhou, J., Sun, G., Han, Z., Liao, G., Wu, R., Zhang, Q., et al. (2003). Static light scattering study of the formation of partially hydrolyzed poly(acrylamide)/calcium (II) complexes. *Polymer Preprints*, 44, 907–908.
- Zyzak, D. V., Sanders, R. A., Stojanovic, M., Tallmadge, D. H., Eberhart, B. L., Ewald, D. K., et al. (2003). Acrylamide formation mechanism in heated foods. *Journal of Agricultural and Food Chemistry*, 51, 4782–4787.