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Research Article

Acrylamide in home-prepared roasted potatoes

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Potato is one of the world's most widely grown tuber crop, in which starch is the predominant form of carbohydrates. Potatoes can be prepared in many ways: boiled, fried or roasted. Frying and roasting potatoes at high temperatures result in an appetizing crust, but at the same time acrylamide can form. In this study, the concentrations of the acrylamide precursors, asparagine and sugars, were determined in five different Swedish-grown potato varieties, together with the acrylamide content after typical home-cooking procedures; oven-roasting of potato wedges and pan-frying of cubes of boiled potatoes. Pan-frying of boiled potato cubes resulted in higher levels of acrylamide (530 – 1100 µg/kg) than in the wedges (140 – 250 µg/kg). Blanching combined with a shorter roasting time was shown to be an efficient way of reducing the acrylamide content in roasted potato wedges, especially in the experiments performed after long-term storage, where the acrylamide content was reduced from 110 – 260 to 50 – 140 µg/kg. No correlation was found between precursor content and acrylamide content, and this finding emphasizes the need for further studies on factors affecting acrylamide formation, for example, the availability of precursors at the surface during cooking.

Keywords: Acrylamide / Blanching / Home cooking / Potato / Varieties

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1 Introduction

In Sweden, potatoes have been a staple food for many decades. Potatoes contain energy in the form of starch and are a good source of dietary fiber, vitamins and minerals [1]. Among common potato dishes today are oven-roasted potato wedges and fried boiled potatoes [2]. Potatoes are normally cooked before eating to make them palatable; during heating the starch will be gelatinized and available for digestion. Boiled potatoes have a high glycemic index (GI) and interestingly, French fries have a lower GI than boiled potatoes and give a similar degree of satiety on an energy-equivalent basis [3]. During frying and roasting the Maillard reaction takes place, affording food attractive sensory properties [4 – 6]. However, various hazardous compounds may be formed at the same time, such as acrylamide, a probable human carcinogen [7]. The main route for acrylamide formation is via the Maillard reaction between the amino acid asparagine and reducing sugars (glucose and fructose), but also sucrose [8 – 12]. The high levels of acrylamide, which have been found in commercially manufactured potato products, probably depend on the relatively high amounts of acrylamide precursors in potatoes [8, 13, 14]. Asparagine is the main nitrogen source in potato tubers, and different sugars are formed from starch during storage [1].

Much work has been devoted to the reduction of acrylamide in potato crisps and French fries [15 – 17], but literature data on acrylamide in home-cooked potato dishes are rare [18 – 20]. There is a need for national food authorities to collect scientific data on the levels of acrylamide formed during cooking as a basis for advice on healthy cooking for households, restaurants and catering enterprises.

In this study, we determined the concentrations of asparagine and sugars in five Swedish-grown potato varieties and the acrylamide content in home-cooked potato dishes with the aim of ascertaining whether any of the potato varieties studied was better suited for roasting or pan-frying than the others.

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2 Materials and methods

2.1 Potatoes

Four relatively new potato varieties, Asterix, Ditta, Fontane and Superb, and one well-established variety, Bintje, grown

Table 1. Experiments 1–3, performed in January 2006. Contents of glucose, fructose, sucrose and asparagine before oven roasting expressed on dry matter basis, and acrylamide content in roasted wedges/fried cubes expressed as µg/kg cooked product ($n = 2$)

Variety	Cooking method	Time min	Glucose mg/g	Fructose mg/g	Sucrose mg/g	Asparagine mg/g	Acrylamide µg/kg	DM[a)] (%)
Ditta	Roasting[b)]	20 + 25[c)]	29[a)]	21[a)]	11[a, d)]	11[a)]	250[a)]	29
	BS/Roasting[d)]	10 + 15	24	18	8	10	210	27
	Pan frying[e)]	4					890	36
Asterix	Roasting	20 + 25	17[b)]	14[b)]	9[a)]	10[a)]	270[a)]	39
	BS/Roasting	10 + 15	14	12	8	10	200	35
	Pan frying	3					1100	42
Superb	Roasting	20 + 25	25[c)]	22[a)]	16[b)]	11[a)]	210[a)]	34
	BS/Roasting	10 + 15	20	18	14	10	170	34
	Pan frying	4					1000	39
Fontane	Roasting	20 + 25	12[d)]	8[c)]	7[c)]	10[a)]	200[a)]	35
	BS/Roasting	10 + 15	9	7	5	10	180	34
	Pan frying	4					1100	44
Bintje	Roasting	20 + 25	13[d)]	10[c)]	12[d)]	11[a)]	140[b)]	35
	BS/Roasting	10 + 15	8	6	11	11	170[f)]	34
	Pan frying	4					530	44

a–e) Different superscripts in the same column indicate significantly different values ($p < 0.05$).
a) DM = dry matter (after roasting/frying).
b) Roasting (Experiment 1).
c) Time before + after mixing/turning the wedges.
d) BS/roasting = blanching for 4 min with salt followed by roasting (Experiment 2).
e) Pan frying of boiled potatoes (Experiment 3).
f) Single injection.

at the same place in the south of Sweden, were used for the experiments. The potatoes are sub-samples from a study on the quality properties of different potato varieties [21]. Fertilizers (120 kgN/ha), herbicides and fungicides against late blight had been applied according to Hagman and Olsson [21]. The tubers were harvested in September 2005, and after wound healing for two weeks at 15°C, the storage temperature was slowly reduced and then the potatoes were stored at 6°C at 98% relative air humidity. The total storage time at 6°C was 6 weeks (January experiments) or 16 weeks (March experiments). Before the experiments performed in January 2006, the tubers were reconditioned at 12°C for 14 days to reduce their sugar content. The dry matter contents of the tubers were 19–22% in January and 20–23% in March.

2.2 Experimental methods

The oven-roasting experiments were performed in ordinary household ovens (size 35 × 30 × 45cm; Oven I: Cylinda, Oven II: Electrohelios) according to recipes in common Swedish cookery books; conventional heating was used. Preliminary experiments were performed and the results formed the basis for determining the cooking time. The designs of the experiments performed in January and March are given in Tables 1 and 2. The potato wedges were weighed before and after cooking. The cooked potatoes were frozen, freeze-dried (only March experiments) and stored at –18°C before acrylamide analysis.

The first experiments in January 2006 (Table 1) were carried out to ascertain whether there was any difference in acrylamide content between the different potato varieties and to study the effect of blanching. The length of the tubers was 6–8 cm. For each variety, the potatoes were peeled and cut into six wedges. One wedge from each tuber was used for the analysis of glucose, fructose, sucrose and asparagine; these wedges were immediately frozen and stored at –18°C until analysis. The rest of the wedges were randomly divided into two batches for Experiments 1 and 2.

In Experiment 1, the oven temperature was set to 225°C, and thermocouples, type K, 0.1 mm, were used to monitor the oven temperature. The thermocouples were connected to a data logger and the temperature was recorded every 5 s. For each potato variety, 200 g of wedges was put on a baking tray; frying fat (Arla, butter and rapeseed oil, 15 mL) was poured over the wedges. Five trays were put into the oven; the potato wedges were roasted for 45 min, and were turned over and partly mixed after 20 min. A skewer was used to confirm that the potatoes were cooked.

In Experiment 2, 250 g of potato wedges was placed in a saucepan containing 1 L boiling water with 0.5 g salt and heated for 4 min. The water was then poured off and the

Table 2. Experiments 4–6, performed in March 2006. Contents of glucose, fructose, sucrose and asparagine before oven roasting expressed on dry matter basis ($n = 2$), and acrylamide content in roasted wedges expressed as μg/kg cooked product ($n = 4$)

Variety	Cooking method	Time min	Glucose mg/g	Fructose mg/g	Sucrose mg/g	Asparagine mg/g	Acrylamide μg/kg	DM[a)] %
Ditta	Roasting[b)]	20 + 15[c)]	44[a)]	36[a)]	23[a)]	10[a)]	260[a)] ± 8	33
	BS/Roasting[d)]	10 + 15	46	36	17	11	140 ± 3	30
	B/Roasting[e)]	10 + 15	41	33	19	10	90 ± 4	30
Asterix	Roasting	20 + 15	22[b)]	19[b)]	8[b)]	10[a)]	200[b)] ± 8	35
	BS/Roasting	10 + 15	19	15	8	9	80 ± 8	32
	B/Roasting	10 + 15	21	17	8	10	100 ± 1	33
Superb	Roasting	20 + 15	30[c)]	27[c)]	20[c)]	11[a)]	180[c)] ± 15	34
	BS/Roasting	10 + 15	28	26	15	10	80 ± 2	29
	B/Roasting	10 + 15	31	29	16	10	110 ± 4	30
Fontane	Roasting	20 + 15	28[c)]	24[d)]	13[d)]	8[b)]	130[d)] ± 3	32
	BS/Roasting	10 + 15	22	18	11	9	50 ± 2	31
	B/Roasting	10 + 15	26	23	12	7	70 ± 4	32
Bintje	Roasting	20 + 15	21[b)]	18[b)]	13[d)]	12[c)]	120[d)] ± 15	33
	BS/Roasting	10 + 15	18	15	12	11	110 ± 7	29
	B/Roasting	10 + 15	20	17	12	10	60 ± 3	31

a–e) Different superscripts in the same column indicate significantly different values ($p < 0.05$).
a) DM = dry matter (after roasting/frying).
b) Roasting (Experiment 4).
c) Time before + after mixing/turning the wedges.
d) BS/roasting = blanching for 4 min with salt followed by roasting (Experiment 5).
e) Blanching without salt following by roasting (Experiment 6).

wedges were left for 2 min for most of the vapor to evaporate. Samples of the blanched wedges were taken for chemical analysis. The potatoes were roasted at the same oven temperature as in Experiment 1, but for only 25 min. The potatoes were turned over and partly mixed after 10 min.

In Experiment 3, four potatoes of each variety were boiled in water for 20 min, cooled to room temperature, peeled and cut into cubes (10 × 10 mm). The potato cubes were then fried in a cast iron frying pan for 3 to 4 min using the same frying fats as above. The cubes were stirred every minute.

The oven roasting experiments were repeated in March 2006 (Table 2) and were performed in the same way as Experiments 1 and 2, but in a different household oven. Experiment 4 was performed as Experiment 1, but the wedges were roasted for 35 min, and mixed after 20 min. Experiments 5 and 6 were performed as Experiment 2, but in Experiment 6, no salt was added to the blanching water.

2.3 Analyses

The dry matter contents of the potatoes before and after blanching, the roasted potato wedges and the pan-fried cubes were determined as described previously [22]. The asparagine concentration was determined after derivatization using HPLC and a fluorescence detector, and the glucose, fructose and sucrose concentrations using gas chromatography and a flame ionization detector [13]. The results are presented as means of two determinations and expressed as mg/g dry matter.

The acrylamide contents in the cooked potato samples were determined using HPLC and LC-MS/MS as described by Viklund et al. [22] with minor changes (Viklund *et al.*, submitted). The retention time for acrylamide was 8 min. Calibration curves in the interval 0 to 1000 ng/mL were determined on each day of analysis. Duplicate injections were made from each extraction. The difference between duplicate determinations was less than 6%. The acrylamide concentrations are expressed as μg/kg cooked product.

2.4 Statistical analyses

Statistical analyses were performed using Minitab Statistical Software v.13 (Minitab, Pennsylvania State College, USA). Significant differences were evaluated with the general linear model followed by Tukey's multiple comparisons test. A value of $p \leq 0.05$ was considered significant.

3 Results and discussion

All roasted potato wedges and pan-fried boiled potato cubes had an appetizing appearance. Blanching made it possible to reduce the roasting time while still obtaining potato wedges with similar eating quality. The wedges were soft inside with a golden yellow surface; the pan-fried cubes were cooked to a somewhat darker color (golden brown). Acrylamide was found in all cooked samples. Performing cooking experiments in ordinary household ovens may give larger variations in acrylamide contents than in laboratory-scale experiments; however, there is a lack of literature data on acrylamide in home-cooked potato dishes. Our results show that although there was some temperature difference between the two ovens, the same two potato varieties gave the highest acrylamide in both ovens and the variety with the lowest acrylamide was the same in both ovens.

The results of the experiments performed in January are presented in Table 1. There is a clear tendency towards higher contents of acrylamide in blanched as well as unblanched potato wedges of Ditta and Asterix than the potato wedges from the other varieties. The lowest acrylamide value in unblanched wedges, 140 μg/kg, was found in Bintje, and this was significantly different from the others. The highest value, 270 μg/kg, was found in Asterix. The dry matter content in the oven-roasted wedges was generally 34–35% and did not differ significantly between blanched and unblanched samples, which indicates that the wedges had reached the same degree of cooking. Ditta had the lowest dry matter content and Asterix the highest, and thus there was no linear correlation between dry matter content and acrylamide content.

Table 1 gives the contents of glucose, fructose, sucrose and asparagine before oven roasting. The potatoes had only been stored for a short time after harvest (September–January) and their initial sugar content was therefore expected to be rather low, making the potatoes suitable for roasting/frying with regard to acrylamide formation [19, 23–27]. The potatoes had also been reconditioned for 2 weeks to further reduce the sugar content. The glucose content of the unblanched samples was significantly different for all varieties, being highest in Ditta, and lowest in Fontane and Bintje. The fructose and sucrose contents also differed significantly between most of the varieties. It is interesting to note that the glucose content was generally slightly higher than the fructose content, which in turn was somewhat higher than the sucrose content. After blanching, the sugar content was generally reduced by 10–20%, and this reduction was significant for glucose and fructose for all varieties except for fructose in Fontane. The concentration of asparagine was 10–11 mg/g in all varieties studied, and did not change significantly after blanching.

Blanching reduced the content of acrylamide. This is in accordance with results from research on potato crisps and French fries, where blanching has been shown to reduce the sugar content and the acrylamide content by up to 90% [28], but sometimes no reducing effect of blanching was observed [23]. However, the reduced amount of acrylamide in the blanched samples in our study may also be due to the shorter cooking time. There was no obvious correlation between the contents of sugars or asparagine and the content of acrylamide in the potato wedges.

Pan frying of boiled potato cubes is a fast and common cooking practice in Sweden, however, according to our results, the content of acrylamide was generally three to four times higher in the pan-fried cubes than in the oven-roasted wedges of the same variety, but no correlation was found with the sugar content. The high levels of acrylamide may be explained by the high surface-to-volume ratio of the cubes as acrylamide is mainly formed in the outer layer exposed to heat, and the heat transfer is more efficient during contact heating (pan frying) than convection heating (oven). The acrylamide content in Bintje was about half of that in the other varieties, which indicates that Bintje is a good potato for pan frying after boiling.

The oven roasting experiments were repeated in March to determine whether the reduction of acrylamide by blanching was maintained after a longer storage time (16 weeks) at 6°C, and to investigate whether the addition of salt to the blanching water had any effect (Table 2). In the unblanched samples, the significantly highest acrylamide content was found in Ditta (260 μg/kg), followed by Asterix (200 μg/kg), while the significantly lowest acrylamide content was found in Fontane (120 μg/kg) and Bintje (110 μg/kg). In a Finnish study, it was found that the acrylamide content in French fries and oven-baked potato slices varied from undetectable to 570 μg/kg [20], and in a report from the USA, levels of acrylamide after oven baking frozen French fries at 232°C for 16–24 min were found to be 198–725 μg/kg [18].

The contents of glucose and fructose in the unblanched samples were significantly highest in Ditta, and lowest in Asterix and Bintje. The sucrose content was significantly highest in Ditta and lowest in Asterix. Also in this series of experiments, blanching reduced the sugar content, and the reduction was generally greater when salt was added to the blanching water.

Blanching resulted in significantly lower levels of acrylamide except for Bintje blanched with salt. There is no clear effect of the addition of salt in the blanching water and this may be due to the low salt concentration compared with other investigations [29]. The aim of blanching is to speed up the gelatinization of starch, which starts at 58–60°C in potatoes [1], and affects the softness of the potato tissue. In our study, blanching for 4 min was equivalent to 10–20 minutes oven roasting. This is due to the more efficient heat transfer in hot water than in the hot air in the oven [30], and thus a shorter roasting time can be applied.

Interestingly, the contents of the acrylamide precursors glucose, fructose and asparagine were practically the same in Asterix and Bintje (no significant differences), but the acrylamide content in roasted wedges of Asterix was almost double that in Bintje, and this difference is significant. Figure 1 shows acrylamide data plotted against the contents of glucose and fructose from the experiments carried out in

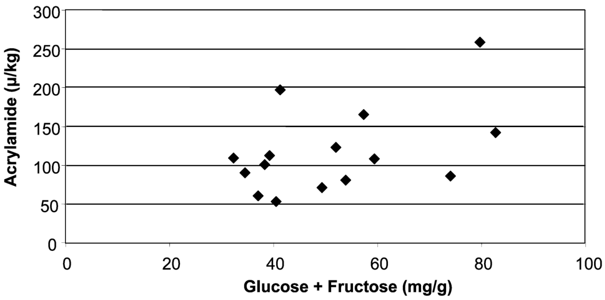

Figure 1. Acrylamide content in oven-roasted potato wedges plotted against the combined content of glucose and fructose.

March. The combined content of glucose and fructose covers a wide range (33 – 82 mg/g), but we did not find any linear correlation between the content of reducing sugars and the acrylamide content in the wedges. From these results we conclude that also parameters other than reducing sugars are important for the formation of acrylamide; perhaps competition for reaction, and availability of the precursors, which is influenced by cell damage, leakage and mass transport.

By comparing the results from the two series of experiments (Tables 1 and 2), it is obvious that the concentrations of glucose and fructose in March were generally over 20% higher than in the January samples; in Fontane potatoes, the glucose and fructose concentrations were over twice as high. Generally, the sugar content in potatoes increases during storage, and this is especially pronounced at low storage temperatures [13]. Despite the higher sugar content, the acrylamide contents in the March experiments were lower than in the January experiments (except for Ditta). This result was unexpected, as several studies on French fries have shown a correlation between sugar and acrylamide content (for a review see [15]). The finding may be explained by the use of different ovens with different energy efficiencies and varying oven temperatures. The recorded temperature profiles from the experiments showed that the average temperature in both ovens was 205°C and varied with ±7°C in oven I and ±4°C in oven II. Generally, the consumer is not aware of the actual oven temperature and this can be different from the temperature setting. Thus, there is a need for better temperature controlled domestic ovens. Another explanation may be that the potato tissue had softened during the long storage period and thus a shorter time was needed for the wedges to be properly cooked.

4 Concluding remarks

In conclusion, the total roasting time is an important factor in the formation of acrylamide. Our results show that blanching combined with a shorter roasting time is an easy and efficient way of reducing the acrylamide content in oven-roasted potato wedges; the lowest acrylamide content was found in Bintje. Pan frying of boiled potato cubes resulted in high levels of acrylamide; the lowest amounts were again formed in Bintje. The asparagine content did not differ significantly between the potato varieties and was not affected by blanching. Storage increased the sugar concentration but this was not reflected in the acrylamide levels in the roasted wedges. No correlation was found between precursor content and acrylamide content, and this emphasizes the need for further studies on the transport of precursors to the surface and by then their availability for acrylamide formation during cooking.

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