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Methods for Determining the Potential of Acrylamide Formation and Its Elimination in Raw Materials for Food Preparation, such as Potatoes

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Introduction

It was recently detected that acrylamide, a compound assumed to be cancerogenic, may be formed at high concentrations during roasting, frying, or baking of certain foods (1). As shown by surveys, e.g., of the Swiss Federal Office of Public Health (2), potato products, such as potato chips, French fries, and roast potatoes, as well as breakfast cereals and crisp bread are the products of primary concern.

Investigation of the background of acrylamide formation, such as the chemistry involved, the identification of raw materials with a high potential of producing acrylamide, or the comparison of, e.g., various cultivars of potatoes, requires analytical tools. A GC-MS method for the analysis of acrylamide was described in ref. (3). Two additional tools are described in this paper: one for determining the potential of a raw material (primarily potato) to produce acrylamide and the other to determine the rate of the elimination of acrylamide, presumably by reaction with other food components. The paper finishes with a comparison of the potential of acrylamide formation of five different types of potato with the concentrations found in chips, hash browns, French fries, and roast potatoes prepared from these.

Experimental

The potential of acrylamide formation was determined by heating small test samples in an oven with ventilated air (gas chromatograph, ThermoQuest, various models): for instance, two portions of 20 g each of grated potato (2.5×7 mm holes, as typically used for preparing hash browns) or thin layers of dough were placed on two grids (6×10 cm) in the center of the oven and heated to 120° C for 40 min. Then

the first grid was removed and the second additionally heated to 160 °C for 20 min. The heated sample was mixed with water, butyramide was added and sample preparation continued as described in ref. (3).

Elimination of acrylamide was determined by addition of deuterated acrylamide (D_3-acrylamide, Cambridge Isotope Laboratories, Andover, USA) before heat treatment of the sample. For instance, to 20 g of grated fresh potato, 10 µl of a 1 mg/ml solution in acetonitrile was injected into 6–10 different particles by a microliter syringe (500 µg/kg referring to the wet potato). When the rates of elimination were high, up to 100 mg/kg of D_3-acrylamide was added in order to facilitate the measurement of the residual concentration. The acrylamide formed during the heat treatment and the residual D_3-acrylamide were determined by the method described in ref. (3), using methacrylamide added after heating as internal standard and butyramide to check method performance. Elimination of acrylamide was calculated in percent from the amount of D_3-acrylamide added and the residual concentration measured.

Dried potato was obtained by grating fresh potatoes and spreading this material on a towel, exposing it to the sun on hot summer days. Drying took about 4 h. The procedure resulted in 9–11 % residual humidity (determined after heating to 160 °C) and avoided the risk of acrylamide formation during the drying process. Tests confirmed that this procedure neither significantly altered the potential of acrylamide formation, nor affected the concentrations of fructose and glucose.

Potential of acrylamide formation

Concept

Raw foodstuffs, such as potato, do not contain acrylamide, but just the starting components for its formation. Foods in general and potatoes in particular vary in the amount of acrylamide formed upon exposure to a given thermal treatment. For instance, purified starch can be strongly heated virtually without acrylamide formation, whereas the same treatment of potato may result in high concentrations (4). The resulting acrylamide concentration depends on the concentration of the starting materials present, but probably also on the catalytic activity to support the reactions involved (perhaps including side reactions removing starting material from the pathway towards acrylamide). The subject is further complicated by the fact that also elimination must be taken into consideration: meat, for instance, never contains substantial amounts of acrylamide, probably not because of lacking formation, but because of rapid elimination (4).

At least as long as we are not certain about the background of the formation and elimination of acrylamide, the concentration to be expected in a given heated food must be predicted by an experiment involving a standardized heat treatment of the raw material.

The proposed experiment determines the "potential" of a sample to form acrylamide. Experimental data shows that it is impossible to determine an absolute potential, i.e. a complete conversion of the starting materials to acrylamide. The total quantity of acrylamide that can be formed seems to be far larger than that found in foods, because of concurrent elimination. The higher the temperature, the more acrylamide is formed, but also the faster is its elimination. For this reason, the "potential" to be determined is relative and refers to conditions to be specified.

The standardized conditions should reflect real cooking practices, but also enable a simple, reproducible experiment and produce results which are comparable for various types of food. The procedure proposed below determines a kind of worst case concentration resulting from prolonged heating at a fixed temperature in a dry state.

Influence of water

The method should keep all conditions relevant for acrylamide formation under control. The water content is one of the most important factors. Cooking potato in water produces virtually no acrylamide, i.e. the presence of substantial amounts of water (wet products) inhibits the reaction. As shown in table 1, at conditions of a pressure cooker (about 120 °C, 20 min) the acrylamide concentration remained low. It will be shown below that heating of dry potato at the same temperature results in concentrations of around 1500 µg/kg (calculated for the initial wet mass to be comparable with table 1). It is concluded that acrylamide formation is restricted to cooking methods which first result in drying of at least a crust at the surface, i.e. frying, grilling, roasting and baking.

Table 1
Acrylamide in potato heated in wet environment during 20 min

Heating	*Acrylamide (µg/kg)*
100 °C (normal cooking)	<20
120 °C (pressure cooker)	25
160 °C (ASE apparatus)	800

Water does not totally avoid acrylamide formation, however: heating after addition of some water under pressure at 160 °C for 20 min in an accelerated solvent extraction (ASE) apparatus resulted in a dark, smelly liquid containing 800 µg/kg of acrylamide.

It was speculated that acrylamide was a side product of the Maillard reaction. In agreement with the above finding for acrylamide, Maillard reactions are inefficient in wet foodstuffs. They are not efficient either when a food is dry; they are most efficient at modest humidity (12–18 % according to (5)). Does this also apply to acrylamide formation?

The influence of humidity (10–20 % water) on acrylamide formation was tested experimentally using dried potato of the cultivar Agata, harvested in 2002, with a residual humidity of 9 %. Samples of 4 g were heated for 40 min under the conditions summarized in table 2. Relatively long heating was applied in order to render initial effects negligible, such as evaporation of residual water and slower heating of samples enclosed in a vial.

Table 2
Acrylamide concentration (data referring to dry weight) **and elimination of D_3-acrylamide in dependence of humidity; heating during 40 min**

No	*Treatment*		*Acrylamide (µg/kg)*	*Elimination (%)*
1	120 °C	open (dry)	8700	66
2	120 °C	closed, residual humidity (9 %)	11000	89
3	120 °C	closed, +10 % water	10000	94
4	140 °C	closed, +10 % water	11300	97
5	160 °C	open (dry)	8500	95.1
6	160 °C	closed, +10 % water	9900	98.6

Sample 1 was spread on a grid in the center of the oven, i.e. lost the residual humidity during a short initial period. 8700 µg/kg of acrylamide was found; 66 % of the D_3-acrylamide added was lost. Heating in a closed flask (under pressure of water vapor) in the presence of the residual humidity (9 %, sample 2) or after addition of 400 µl of water (totally 19 % humidity; sample 3) increased the acrylamide concentration only marginally. Comparison of the open sample 5 with the enclosed sample containing 19 % water (sample 6) after heating at 160 °C confirmed this result. In an analogous experiment, grated and dried potato of the cultivar Charlotte was heated to 160 °C for 40 min with 20 % water added. Compared to a sample heated on an open grid, the acrylamide concentration increased from 4000 to 6400 µg/kg.

The concentration of acrylamide depended little on a water content varied between 0 and 19 %. It even remained nearly constant whether heating occurred at 120, 140, or at 160 °C, but, as will be shown below, results concerning temperature-dependence obtained for other samples of potato were different, i.e. this performance cannot be generalized.

The stability of these results obscures the rather massive changes really involved, because strongly increased acrylamide formation was just about compensated by a correspondingly increased rate of elimination. The last column in table 2 shows the percentage of D_3-acrylamide which was lost during the heat treatment. At 120 °C, 9 or 19 % humidity enhanced the elimination of D_3-acrylamide from 66 % to 89 and 94 %, respectively. This means that with 19 % water, the proportion of residual D_3-acrylamide was reduced from 34 % to 6 % and the elimination was about 5.5 times faster. At 160 °C, 19 % humidity accelerated elimination by a factor of 3.5 (residual D_3-acrylamide reduced from 4.9 to 1.4 %).

To result in approximately constant concentrations, acrylamide formation must have also been increased several fold, i.e. against the initial impression, humidity in the range accelerating the Maillard reactions also increases acrylamide formation. No explanation is at hand, why elimination was accelerated to almost the same extent as formation (the two reactions are likely to take completely different routes).

For a dough of white wheat flour and water, heating to 160 °C for 30 min yielded about ten times less acrylamide when containing some 10 % residual water than when really dry (open on a grid), i.e. performance seemed to be different, but was not further investigated.

For the procedure to determine the potential of acrylamide formation it was decided not to maintain a residual humidity. Firstly, in the kitchen roasting, frying or baking occurs at ambient pressure and, therefore, the residual humidity at temperatures above 100 °C is low. Secondly, the procedure would have become complicated. Thirdly, influences on the final result are minor (table 2). In practice, a small amount (20 g) of grated fresh potato or other test sample, such as dough, was exposed to an open oven atmosphere. As the exchange of air in the oven is limited, the small sample size supports rapid drying.

Figure 1 shows concentrations of acrylamide and D_3-acrylamide for a heat treatment of fresh potato (cultivar Charlotte, harvest 2002) at 120 °C during different amounts of time (samples from a homogenated lot heated individually). Concentrations refer to fresh weight (opposed to dry weight in table 1). Acrylamide formation started after about 10 min. The mass of the samples after heat treatment, expressed

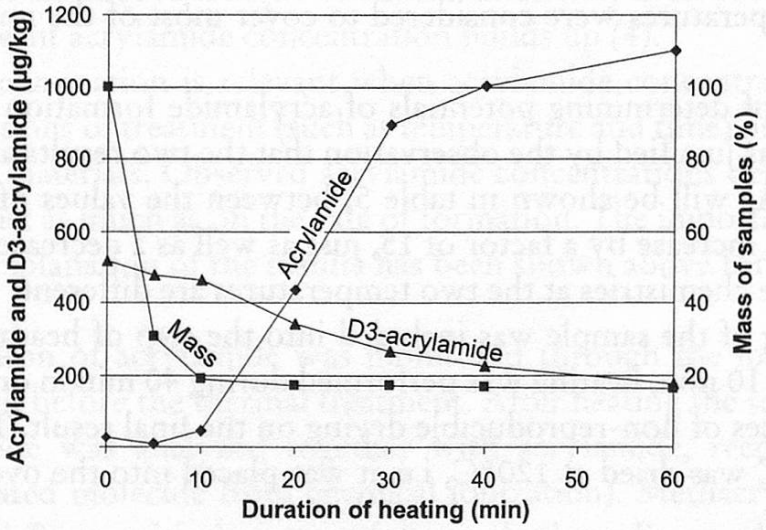

Figure 1 **Concentrations of acrylamide and elimination of D_3-acrylamide at 120 °C, starting with fresh potato; mass of the samples after heating as percent of the fresh mass**

in percent of the mass of the fresh potato, reflects the drying process. At the start of acrylamide formation, the mass of the sample was reduced to about 20%, i.e. the material was dried nearly completely. Concerning the elimination of D_3-acrylamide, data is not of sufficient precision to conclude whether or not it already started before drying.

Considerations concerning temperature and time

The potential of acrylamide formation should be determined under conditions which are characteristic for food preparation. Heating media often reach 180–200 °C (cooking plates, frying oil, oven temperatures during baking), but foods are cooled by water evaporation and can exceed temperatures of around 100 °C only after fairly complete drying. In the frying oil, the vapors form a cushion around the potato which hinders the heat transfer from the oil, helping to keep temperatures of the potato below that of the oil. Most foods (e.g. French fries, roast potatoes, bread) remain wet inside, i.e. temperature drops from a high value at the surface to around 100 °C below the crust. In conclusion, temperatures in foods usually form a gradient from around 100 °C to a substantially higher one at the browning surface. A temperature of 160 °C is rather high, since it causes most foods to turn dark or black within a short time.

The potential of acrylamide formation was determined at two temperatures: 120 and 160 °C. At 120 °C, acrylamide formation may be substantial, while elimination is modest, i.e. this result is indicative primarily for formation. Also competitive reactions are still relatively slow. For example, reducing sugars, assumed to be starting substances for acrylamide formation (4), undergo Maillard reactions and are no longer available then. At 160 °C, the rate of acrylamide elimination as well as of competitive reactions is high and the results primarily reflect such aspects. These two testing temperatures were considered to cover most of the important cooking processes.

The choice of determining potentials of acrylamide formation at two different temperatures was justified by the observation that the two results are hardly related to each other. As will be shown in table 5, between the values of 120 and 160 °C there may be an increase by a factor of 15, just as well as a decrease by a third. This suggests that the chemistries at the two temperatures are different.

Since drying of the sample was included into the step of heating to 120 °C and lasted for about 10 min, heating was performed during 40 min in order to avoid significant influences of non-reproducible drying on the final result. The sample to be heated to 160 °C was dried at 120 °C, i.e. it was placed into the oven together with the first sample.

To check the reproducibility of the determination, including heat treatment and GC-MS analysis, potatoes of the cultivar Agria, harvest 2001, were grated and homogenated. Four samples each were heated to 120 °C and 160 °C, respectively,

Table 3
Reproducibility of measuring the potential of acrylamide formation (n=4)

Temperature	*Acrylamide (µg/kg)*	*RSD (%)*
120 °C, 40 min	1680	6
160 °C, 20 min	2030	5

according to the protocol described above. As shown in table 3, relative standard deviations (RSD) were 6 and 5 %.

Coarse particles versus fine powder

If the precursor of acrylamide were a volatile compound, it could evaporate before reacting. Then the test result would be expected to depend on the size of the particles: as large particles hinder the escape, acrylamide concentrations would be higher. To check this aspect, dry coarsely grated Charlotte potato (different from Charlotte in fig. 1) was heated as such and after milling to a fine powder. Both were heated to 120 °C for 40 min and the powder spread as a thin layer in a low beaker. The powder contained 2570 µg/kg of acrylamide, the course particles 2410 µg/kg. Hence there does not seem to be an influence of the particle size.

Determination of acrylamide elimination

Acrylamide is a rather reactive component, as known from the fact that it reacts at body temperature with hemoglobin in the living organism (6). It could be expected, therefore, that it also reacts rather rapidly with food components when temperatures typical for baking, roasting, or frying are applied. In fact, acrylamide "disappears" at a rather high rate, presumably through bonding to reactive food constituents, such as thiol functions. The elimination may even occur at such a high rate that no relevant acrylamide concentration builds up (4).

The rate of elimination is relevant when acrylamide concentrations are correlated with conditions of treatment (such as temperature and time) or for comparison of different raw materials. Observed acrylamide concentrations depend on the rate of elimination just as much as on the rate of formation. The importance of the elimination for the explanation of the results has been shown above for the influence of humidity.

The elimination of acrylamide was monitored through the loss of deuterated acrylamide added before the thermal treatment. After heating the sample, the residual D_3-acrylamide was analyzed together with acrylamide, recording the mass m/z 75 (protonated molecule from chemical ionization). Methacrylamide was the internal standard. Some critical aspects of the method are discussed below.

Application of D_3-acrylamide

D_3-acrylamide should be added in a manner achieving a distribution within the material which reflects the situation of the acrylamide formed during thermal treatment as closely as possible. For instance, deposition of the whole amount in a small area could deplete the reaction partner and yield too low a result. To test this aspect, 10 µl of a 1 mg/ml D_3-acrylamide solution in acetonitrile was either injected into a single larger particle or distributed over some 10 particles. These results were compared with the addition of 100 µl of a 0.1 mg/ml solution spread over most particles. The rates of elimination after heating 40 min at 120 °C showed no significant difference (table 4), which indicates that the reaction partners are available in excess and the distribution of the added D_3-acrylamide is not critical.

Table 4
Elimination of D_3-acrylamide after addition in the modes indicated to dry grated potato (Agata, 40 min 120 °C)

Addition	*Elimination (%)*	*Acrylamide (µg/kg)*
10 µl into single particle	59	780
10 µl into several particle	55	800
100 µl at 10 sites	62	790
10 µl after 15 min drying	96	840

The last line of table 4 reports a result obtained from heating in two steps: the potato sample was heated to 120 °C for 15 min. Then the D_3-acrylamide was applied to the surface of a few particles and the heating resumed for 25 min. Now the elimination reached 96 %. The result for acrylamide confirms that the thermal stress did not differ significantly. After heating to 120 °C, the material was hard and the D_3-acrylamide remained on the surface, which probably caused it to evaporate. This indicates that D_3-acrylamide should be injected into the particles or be sucked up into a porous material (such as the sun-dried potato).

Acrylamide does not normally evaporate from a test sample. This was concluded from an experiment involving dry potato of the cultivar Charlotte. 10 µl of D_3-acrylamide solution was injected into several particles. One sample was spread on a grid, while the other was tightly wrapped in aluminium foil. After heating, the aluminium foil was extracted together with the sample. In the wrapped sample, the acrylamide concentration was 1100 µg/kg, whereas it was 1300 µg/kg in the openly heated sample; elimination of D_3-acrylamide was 34 % compared to 30 %.

If the reaction partners involved in the elimination of D_3-acrylamide are really present in non-limiting amounts, the reaction should be of pseudo first order. In an experiment with dry potato (Agata, harvest 2002) heated to 120 °C during different amounts of time, the rate of elimination decreased as shown in figure 2. A similar result was shown in figure 1.

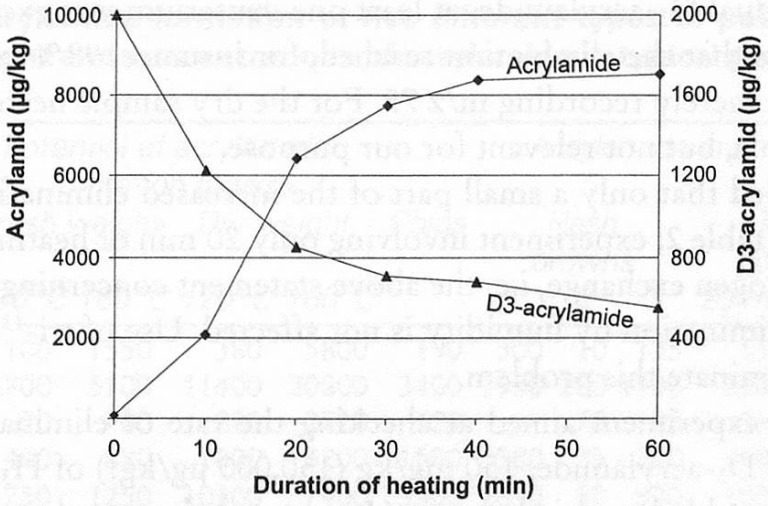

Figure 2 **Acrylamide concentrations and D_3-acrylamide elimination during heating of dried potato at 120 °C**

Deuterium exchange?

At elevated temperatures, D_3-acrylamide might undergo deuterium-hydrogen exchange. As the exchange is expected to proceed stepwise, it should result in increased signals for m/z 74 and m/z 73 (one or two deuterium atoms being exchanged, starting from m/z 75, the proton adduct of the intact molecule resulting from chemical ionization). For three test samples, intensities of the signals m/z 72 (H_3-acrylamide) to m/z 75 are shown in figure 3.

Potato samples spiked with D_3-acrylamide and heated to 120 °C did not show relevant exchange, independently of whether they were dry or contained 19 % water. After heating of the humid sample (19 % water) to 160 °C for 40 min, however, the intensity of the signal m/z 74 even slightly exceeded that of m/z 75, and the signal m/z 73 (also ^{13}C-isotope of H_3-acrylamide) was significantly enhanced.

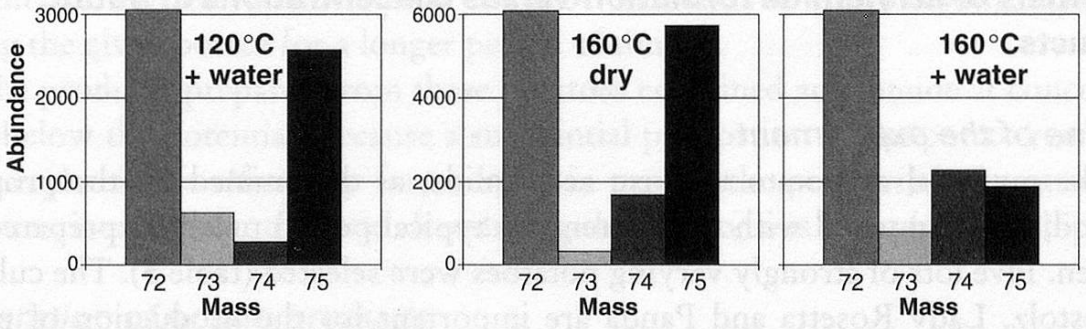

Figure 3 **Signals of CI-MS for acrylamide and D_3-acrylamide as obtained after heat treatment to 120 and 160 °C with and without humidity**

100 mg/kg D_3-acrylamide was added, of which about 2 mg/kg was left. From some 60 % of the residual D_3-acrylamide, at least one deuterium was exchanged. For our analysis it means that the elimination reached, for instance, 98 % rather than 99 %, as concluded by merely recording m/z 75. For the dry sample heated to 160 °C, the exchange is visible, but not relevant for our purpose.

It is concluded that only a small part of the increased elimination observed for humid samples (table 2; experiment involving only 20 min of heating) resulted from deuterium-hydrogen exchange, i.e. the above statement concerning the acceleration of acrylamide elimination by humidity is not affected. Use of tri-^{13}C-labeled acrylamide would eliminate this problem.

In a further experiment aimed at checking the rate of elimination as deduced from the loss of D_3-acrylamide, 150 mg/kg (150,000 µg/kg!) of H_3-acrylamide and 10 % water were added to dried potato (Agata) and the sample enclosed in a vial. After heating to 120 °C for 40 min, 37 mg/kg H_3-acrylamide were determined, compared to 12 mg/kg without addition (formed from endogenous material), i.e. 25 mg/kg of the H_3-acrylamide found was related to the addition, which corresponds to an elimination of 84 %. This is less than the 96 % determined for D_3-acrylamide. The difference could easily result from the extremely large addition, which was necessary to override the amount formed from endogenous material. The experiment confirmed that elimination of acrylamide is fast even at temperatures as modest as 120 °C.

Calculation of the eliminated acrylamide?

The elimination of acrylamide formed during heat treatment does not directly correspond to the elimination observed for the added D_3-acrylamide, since D_3-acrylamide is removed during the whole period of the thermal treatment, whereas acrylamide is only formed during the process, i.e. is exposed to heat only during part of the time. For this reason less acrylamide is removed than D_3-acrylamide. A calculation is complicated by the fact that acrylamide formation occurs at a rate which decreases with time.

Potentials of acrylamide formation *versus* concentrations in potato products

Outline of the experiment

The potential of potato to form acrylamide, as determined by the proposed method, was compared with the contents in typical potato products prepared in a kitchen. Five lots of strongly varying potatoes were selected (table 5). The cultivars Erntestolz, Lady Rosetta and Panda are important for the production of potato chips. Since they typically contain low concentrations of reducing sugars, they enable the production of chips with a minimum of browning (data on sugar contents will be reported in ref. (4)). Erntestolz, Lady Rosetta and Sirtema were from

Table 5
Potentials of acrylamide formation of five different types of potato referring to fresh or dry weight and concentrations of acrylamide in typical products prepared from these

Potatoes	*Potential of acrylamide formation (µg/kg)*				*Acrylamide in products (µg/kg)*						
	Fresh weight		*Dry weight*		*Chips*	*Hash browns*			*Roast potatoes*		*French fries*
	120 °C	*160 °C*	*120 °C*	*160 °C*		*1*	*2*	*3*	*20 min*	*30 min*	
Erntestolz	100	1550	380	5800	190	300	10	135	15	100	210
Erntestolz 4 °C	2800	5100	11400	20800	3400	1950	200	1100	330	3400	10300
Lady Rosetta	70	700	270	2720	120		70	80	35	150	100
Panda 2001	440	880	1600	3200	1500	580	25	260	40	340	2030
Sirtema	1750	1250	10300	7400	3500	2650	50	900	100	550	2510

the harvest 2002 (few weeks after harvesting), whereas the potatoes of the cultivar Panda were from 2001, i.e. about one year old. Half of the Erntestolz potatoes were stored in a cooling room at 4 °C for 15 days and analyzed separately to demonstrate the effect of cooling. Sirtema is an early potato of low dry mass and with an elevated content of reducing sugars.

For every type of potato, the potential of acrylamide formation was determined in duplicate for samples of five potatoes each. The average deviation between the results was 8 %. For the five types of potato, the mean of the two results obtained at 120° C varied between 70 and 2800 µg/kg (referring to fresh weight), hence by a factor of 40. Storage of the Erntestolz at 4 °C increased the potential from 100 to 2800 µg/kg, i.e. by a factor of 28. Upon rising the temperature from 120 to 160 °C, the results for non-cooled Erntestolz and Lady Rosetta strongly increased (factors of 15 and 10, respectively), whereas those for Sirtema decreased by a third. This indicates that formation and elimination were accelerated to a different extent.

Dry weights were determined from the samples heated to 160 °C and used to recalculate the potentials of acrylamide formation for dry weights. These results may be understood as indications for a worst case scenario, i.e. as the maximum concentration of acrylamide which could be encountered after roasting, frying or baking the given potato for a longer period of time.

The products prepared from these potatoes contained acrylamide at concentrations below the potential, because a substantial proportion of the potato remained wet (acrylamide is efficiently formed just in part of the product) or because heat exposure, in particular the time after drying the potato, was short (potato chips).

Preparation of potato products

The potato products were cooked under standardized conditions:

- Chips were prepared by Zweifel Pomy-Chips AG (Spreitenbach, Switzerland) using laboratory equipment. Conditions of temperature and time were the same

for all samples: the oil temperature was 175 °C at the start and dropped to 150 °C during frying; duration of frying, 3 min.

- Hash browns ("Rösti") 1: potatoes were cooked in a steamer and stored in the refrigerator overnight. Then they were pealed and grated (7×2.5 mm holes). In a frying pan, 2 spoons of oil was preheated during 5 min at "4" of a scale reaching "6". Then power was reduced to "3" and 300 g of potato was introduced and formed to a cake of 17 cm diameter. It was roasted during 20 min, then turned and heated for another 10 min.
- Hash browns 2: grated potato taken from the preparation of product 2, but heating on the first side was reduced to 17 min, that on the second to 9 min.
- Hash browns 3: the oil was preheated at "6" for 5 min. Then 300 g of potato (same as above) was introduced and fried at "5" during 15 min, every 3 min mixing up the cake of 17 cm diameter.
- Roast potatoes: raw potatoes were cut into cubes of around 12 mm and spread on a baking sheet covered by baking paper. The stove was preheated to 210 °C. Then the potatoes were heated for 20 or 30 min. They were turned at half time.
- French fries: fresh potatoes were pealed and cut to a square profile of 6 mm, then pre-fried in oil at 140 °C for 3 min, using a household deep fryer with a thermostat. Then they were fried in oil at 170 °C for 3.5 min, 175 g of potato being added to 3 l of oil.

Chips

In the chips, acrylamide concentrations closely approached some of the potentials when considering that chips contain some 40 % oil. This reflects the fact that potato chips lose nearly all water (residual humidity of 1–2 %), i.e. acrylamide is formed throughout. The concentrations are clearly related to the potentials. A detailed comparison is difficult, however, because different types of potato behave differently, e.g. dry at different rates. Most of the acrylamide is formed towards the end of the drying process, i.e. during the last seconds of the frying process (7).

The increase in the acrylamide content resulting from cooling the Erntestolz potatoes to 4 °C corresponded to a factor of 18, underlining the importance of avoiding strong cooling.

For four types of potato, the results clearly better correlated with the potentials determined at 120 °C than at 160 °C. In fact the chips may have never reached the oil temperature (150 °C at the end). The concentration in the Panda, however, was higher than the potential measured at 120 °C when correcting for the oil content.

The chips from Erntestolz and Lady Rosetta did not show any browning, whereas those from the cooled Erntestolz and the Sirtema were dark.

Hash browns

The results for the hash browns 1 and 2 show the strong dependence of the acrylamide contents on the duration of heating: a reduction by 4 min (from 30 to

26 min) reduced the concentrations 10–50 times, demonstrating that the formation follows a long drying process virtually without acrylamide formation. Probably more acrylamide was formed during the last minute than during the whole rest of the time.

The hash browns from the cooled Erntestolz and Sirtema were rather dark, whereas those of the non-cooled Erntestolz and Lady Rosetta did not show virtually any browning even after 30 min. The correlation between browning and acrylamide concentrations was striking.

The product from the Sirtema potatoes differed from the others in terms of humidity: it was visibly wet, which suppressed browning and acrylamide formation for a long time. This might explain the extreme increase in the acrylamide concentration with the slightly longer duration of heating.

Roast potatoes

The results for the roast potatoes again show an enormous difference between the products heated for 20 or 30 min: 10 extra minutes increased the acrylamide concentrations by a factor of up to 10.

There is a fair correlation between the potentials and the concentrations. The concentration in Sirtema products remained relatively low presumably because of the high water content: the dry weight corresponds to 17 % of the fresh weight, compared to 25–28 % for the other cultivars. This was paralleled by the browning, which was clearly weaker than for the product from the cooled Erntestolz.

French fries

The first French fries produced, heated to 170 °C for 2 min, were of excellent quality, but the acrylamide concentrations were too low to obtain significant differences (several samples below 20 µg/kg). The 3.5 min were longer than needed, but provided clear results. Cooling of the Erntestolz increase the acrylamide concentration by a factor 50. The acrylamide concentration in the French fries from Sirtema again remained surprisingly low, but their soft structure again suggests the influence of a high water content.

Conclusions

Acrylamide concentrations found in heated foodstuffs are the result of concurrent formation and elimination. An investigation of the background needs to take elimination in consideration. The addition of deuterated acrylamide before heating provides an indication of the rate of elimination, although the percentage of loss of the added deuterated acrylamide is not identical with the elimination of acrylamide formed during the heat treatment.

Investigation of the background of acrylamide formation and the comparison of different raw materials presuppose an analytical tool enabling the determination of the potential of acrylamide formation under specified, standardized, and repro-

ducible conditions. The proposed method provides an indication of the acrylamide concentration that must be expected in a given raw material under worst case conditions, i.e. drying of the whole of the foodstuff, at 120 and 160 °C.

Fried, roasted or baked potato products contain acrylamide at concentrations which strongly depend on conditions (underlining the need for a standardized procedure). Concentrations correspond to a fraction of the potential and are clearly correlated to the potentials, although also reflecting specific properties of a given cultivar.

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Summary

A method for determining the potential of acrylamide formation of a given foodstuff raw material is described as a tool for the investigation of the background of acrylamide formation and for the comparison of different raw materials. It involves a standardized heat treatment under dry conditions at 120 and 160 °C. The two results are little related to each other: compared to heating to 120 °C, treatment at 160 °C may cause an increase of the concentration by a factor exceeding 10, just as well as a substantial decrease. Concentrations found after heat treatment are a result of acrylamide formation and elimination. Elimination was determined by the addition of deuterated acrylamide before heat treatment. For five types of potato, the experimental potential of acrylamide formation was compared to concentrations determined in potato products prepared under standardized conditions, i.e. potato chips, hash browns (Rösti), French fries and potato cubes baked in an oven.

Zusammenfassung

Eine Methode zur Messung des Potentials zur Acrylamidbildung eines gegebenen Lebensmittelrohstoffs wird beschrieben als Werkzeug zur Untersuchung des Hintergrunds der Acrylamidbildung und zum Vergleich verschiedener Rohstoffe. Sie basiert auf einer standardisierten Erhitzung unter trockenen Bedingungen auf 120 und 160 °C. Die beiden Resultate sind voneinander ziemlich unabhängig, da Erhitzung auf 160 °C gegenüber 120 °C sowohl eine Zunahme um einen Faktor von mehr als 10, aber auch eine deutliche Abnahme bewirken kann. Die gefundenen Konzentrationen sind das Resultat simultaner Neubildung und Elimination. Die Elimination wird durch Zugabe von deuteriertem Acrylamid vor der Erhitzung gemessen. Für fünf verschiedene Kartoffeln werden experimentelle Potentiale mit Konzentrationen in Rösti, Bratkartoffeln, Pommes frites und Chips verglichen.

Résumé

Une méthode est décrite pour la détermination du potentiel de formation de l'acrylamide dans une matière première alimentaire. Elle sert pour la recherche des sources et pour la comparaison de différentes matières. Elle est basée sur un réchauffement standardisé à condition sèche à 120 et 160 °C. Les deux résultats sont assez indépendants l'un de l'autre, puisque par rapport à 120 °C, chauffer à 160 °C peut provoquer une augmentation d'un facteur de plus de 10, mais également une claire diminution. Les concentrations trouvées sont le résultat de formation nouvelle et d'élimination simultanée. L'élimination est mesurée par l'addition d'acrylamide deutéré avant chauffage. Pour 5 pommes de terre différentes, les potentiels expérimentaux et les concentrations dans les «röstis», pommes de terre rôties, pommes frites et chips sont comparées.

Key words

Acrylamide, Heated foods, Acrylamide formation, Potato products, Food processing

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