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ORIGINAL PAPER

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Brown potato croquettes low in acrylamide by coating with egg/breadcrumbs

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Abstract Potato croquettes are preparations of mashed potato or potato powder with milk powder or egg, fried in oil or baked in the oven. Product identity calls for fairly strong browning, which may cause high acrylamide contents. Prefabricates from the Swiss market resulted in products of intermediate acrylamide content (50–570 μg/kg), strongly depending on frying conditions. The potential of acrylamide formation of these products was modest, since the potato powder used was low in reducing sugars and asparagine. Defatted milk powder increased the 120 °C potential by 200–700 μg/kg (lactose), whereas egg was approximately neutral. Coating with egg/breadcrumbs resulted in stronger browning and at the same time in reduced acrylamide formation. It shields the potato from the heat by a material the browning of which is not linked with acrylamide formation. Croquettes prepared from fresh potato confirmed that coating with egg/breadcrumbs improves the product quality while strongly decreasing the acrylamide content.

Keywords Croquettes · Acrylamide · Potential of acrylamide formation · Lactose

Introduction

Acrylamide is a probable carcinogen [1] formed in roasted, baked or fried foods from the free amino acid asparagine with the help of a carbonyl compound, usually a reducing sugar [2]. Owing to a high asparagine content and high consumption, fried and roasted potato products are of major concern [3]. The World Health Organiza-tion [4] and the Scientific Committee for Food of the European Union [5] called for measures to reduce acryl-amide formation to a minimum, implementing the ALARA principle (as low as reasonably achievable). In the meantime, progress was made in several sectors, showing that exposure to acrylamide can be reduced substantially at modest costs or none at all.

In collaboration of cooks and analysts, the preparation of French fries was optimized for culinary quality and low acrylamide content [3]. Starting from standard commercial prefabricates or fresh potato of low sugar content, this optimum was linked with an acrylamide content of 40–70 μg/kg, which is 5–10 times less than usual so far. In a large campaign, cooks in the canton of Zurich were invited to send in what they consider good-quality French fries. They were asked to consider some simple measures to keep acrylamide formation low [6]. The median of the acrylamide concentration of the 157 samples received was 76 μg/kg. For the 118 samples prepared from frozen prefabricates, the median was 64 μg/kg. This confirmed that the previous optimization is realistic also in the practice of gastronomy.

For many Swiss consumers, roasted and baked potatoes are the most important source of acrylamide. The reducing sugars in the raw potato play a key role: acrylamide formation is approximately proportional. Starting from potato with 1 g/kg glucose and fructose, high quality, crispy Rösti or hash browns prepared by a gentle procedure contain about 500 μg/kg acrylamide [7]. Since most potatoes available from the Swiss retail market contain far more reducing sugar [8], the most relevant measure is making available potato of lower sugar content.

A further type of potato products, fried in oil or baked in the oven, comprises the croquettes, pommes noisettes, pommes duchesses and similar preparations made from mashed potato. Croquettes are of cylindrical shape, usually 2–5-cm long and of 0.8–2.5-cm diameter, traditionally prepared from mashed potato mixed with milk, butter and egg yolk or whole egg. Classically they are coated with egg and breadcrumbs. Today's frozen convenience products are made from potato and milk powder and are usually not coated. The characteristics of these products

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include rather strong browning, which is easily linked with a high acrylamide content. The study presented here concerns the acrylamide content of croquettes, the contribution of the various components used in the potato dough to acrylamide formation and the effect of the coating.

Experimental

Samples of frozen convenience products were bought on the local market, and those for gastronomy through the School of Hotel Management Belvoirpark, Zurich (October 2003). All products were manufactured in Switzerland.

The croquettes from fresh potatoes were prepared by the School of Hotel Management: potatoes (1.8 kg) were pealed, cut into pieces, cooked in a steamer, dried at 150 °C for 5 min and mashed. Then egg, salt and spices were added and the dough was shaped to cylindrical pieces of 2–2.5-cm diameter and 4–5-cm length (19–24 g per piece). Half of the croquettes were coated by turning them in whole egg, then in breadcrumbs.

The potentials of acrylamide formation were determined by heating a 20-g portion of homogenated material on a grid in a gas chromatography oven at 120 °C for 40 min [9]. Acrylamide was analyzed by gas chromatography/mass spectrometry as described in Ref. [10].

The products were fried in 2 l of frying oil (Suprema Universal-Pflanzenöl, Migros, Zurich, Switzerland) heated by a 600-W laboratory heating plate equipped with a regulating thermometer and agitated by a magnetic stirrer. They were immersed in the oil using a basket of a household fryer.

Results

Convenience products

The acrylamide contents in croquettes and similar products prepared from the most important prefabricates available on the Swiss market are shown in Table 1. Products 1–7 were fried in oil or baked in an oven at the conditions specified by the producer (samples provided by Frigemo, Chur, Switzerland). Products 8–12 were fried in oil at a modest temperature until they rose to the surface of the oil. Even with this longer frying, the products remained rather pale. The acrylamide contents ranged from 30 to 570 μg/kg, with clearly higher values for the products fried until they were swimming on the surface.

For some frozen prefabricates, the 120 °C potential of acrylamide formation [9] was determined in order to evaluate the raw material, i.e.,. the potato used and the effect of the components added. This potential determines the amount of acrylamide formed in a given material upon a standardized heat treatment. In potato, usually the summed concentration of glucose and fructose is used as an indicator, since these sugars largely determine the acrylamide formation—asparagine and other relevant components are present at fairly constant concentration [11]. However, this neither suites potato powder produced from blanched potato (because asparagine is extracted) nor mixtures containing additional components (possibly introducing asparagine).

The potentials of the convenience products varied between 150 and 380 μg/kg (Table 2), i.e., they were rather low. In comparison, potatoes low in reducing sugar, as used for the production of potato chips (US terminol-

Table 1 Acrylamide contents in croquettes and related products prepared from frozen prefabricates at the conditions specified

Product		Conditions of preparation			Acrylamide (μg/kg)
		Medium	Temperature (°C)	Time (min:s)	
1	Croquettes	Oil	180	3:00	60
2	Croquettes	Oven	225	12:00	210
3	Croquettes Rösti	Oil	180	3:00	95
4	Croquettes Rösti	Oven	225	14:00	150
5	Croquettes coated	Oil	180	4:30	55
6	Pommes duchesse 16 g	Oven	225	13:00	30
7	Pommes duchesse 20 g	Oven	225	15:00	30
8	Croquettes	Oil	160–170	05:30	265
9	Croquettes	Oil	170	05:10	185
10	Croquettes	Oil	170	03:15	370
11	Croquettes	Oil	170	03:30	365
12	Pommes noisettes	Oil	170	03:15	570

Table 2 120 °C potentials of acrylamide formation (related to actual fresh weight) for some industrial prefabricates characterized by the labeled ingredients

Product		Potential (μg/kg)	Labeled composition
1	Croquettes	150	Potato powder, oil, defatted milk powder, egg white powder
2	Croquettes Rösti	380	Grated potato, oil, wheat/potato starch, egg white powder
3	Pommes noisettes	210	Potato powder, oil, defatted milk powder, egg white powder, glucose
4	Pommes duchesses	330	Potato powder, oil, defatted milk powder, egg white powder

Table 3 Contribution of the components used for preparing croquettes to acrylamide formation; model experiments using potentials of acrylamide formation

Composition	Potential (μg/kg)
Mashed potato	310
+8.2% defatted milk powder	1,210
+3.9 % lactose	1,100
+37.5% milk	505
+9% fresh egg yolk	305
+9% egg white	480
Breadcrumbs	≤10
+20% whole egg	45

Table 4 Potentials of acrylamide formation of the raw materials and their combination for industrial croquette manufacturing; values calculated on the basis of 40% dry weight

	Raw material	Potential (μg/kg)
1	Potato powder	70
2	Croquette admixture 1 with milk powder	8
3	Croquette admixture 2 without milk powder	6
4	Potato powder+admixture 1	120
5	Coating	50

ogy; crisps in British English), have a potential of around 100 μg/kg [12]. Cultivars characterized by higher sugar contents reach values of 1,000μg/kg, in exceptional cases even 2,000 μg/kg [11]. Storage at 4 °C easily increases the potentials to 6,000 μg/kg [12]. No conclusion can be drawn on the contribution of the ingredients other than potato. Interestingly, added glucose (Sample 3) had no significant effect.

Contribution of the ingredients

For products consisting of a combination of raw materials it is of interest which component contributes how much of which starting material for acrylamide formation. Corresponding studies were performed for a typical recipe of the traditional type starting from fresh potato and an industrial convenience product.

For the traditional preparation, the contributions of the ingredients to acrylamide formation were determined by model mixtures starting from mashed potato (prepared in the laboratory) with a potential of acrylamide formation of 310 μg/kg (Table 3). Defatted milk powder (8.2%) was added (common additions are between 2% and 5%), which increased the potential to 1,210 μg/kg, i.e., by 900 μg/kg. Milk powder contains proteins which tend to decrease the potential for acrylamide formation through an enhanced acrylamide elimination [12, 13], but also almost 50% lactose, a reducing disaccharide. Indeed, adding 3.9% lactose instead of milk powder resulted in virtually the same potential of acrylamide formation. Addition of whole milk had the same effect. The 37.5% milk introduced about 1.8% lactose. The egg yolk had virtually no effect, while the egg white caused a weak increase of the acrylamide content.

Table 3 also shows the potential of acrylamide for the two components traditionally used for the coating. The breadcrumbs might have contained the 10 μg/kg acrylamide even before the heating was applied to determine the potential of acrylamide formation, which is in line with the observation that flour products have a low potential owing to an asparagine content which is some 50 times lower than that of potato [14]. The addition of 20% whole egg increased the potential, but the value remained low.

Potentials for components used by industry are listed in Table 4. When calculated with the approximately 40% dry matter of convenience products for preparing croquettes, the potato powder had a potential of acrylamide formation of merely 70 μg/kg. On the basis of the fresh weight of potato (about 20% dry weight), the potential of 35 μg/kg is lower than ever seen for fresh potato. This is due to the manufacturing process: the powder was produced from potato selected for the production of French fries (small tubers and small pieces sorted out), i.e., from a raw material rather low in reducing sugar. The potato was cut into small pieces and boiled in water for more than 30 min, i.e., the reducing sugar and asparagine were thoroughly extracted.

The mixture added to the potato powder to produce croquettes (product 2 in Table 4) had an extremely low potential of acrylamide formation (8 μg/kg calculated for 40% dry weight). The defatted milk powder (lactose) contributed little, as deduced from the potential of 6 μg/kg of the mixture without milk powder (product 3). When croquette admixture 1 was added to the potato powder (10 g/40 g/170 ml water), the potential increased by some 70% or 50 μg/kg. The potentials of the potato powder and the admixture were not additive, since each component contributed the major amount of one of the reaction partners for acrylamide formation: the potato provided the asparagine (although little owing to the previous extraction), while the milk powder was the major source of reducing sugar.

In conclusion, the addition of milk or milk powder to mashed potato increases acrylamide formation. The increase is substantial for croquettes prepared from fresh potatoes: some 200–700 μg/kg when 1–3% lactose (2–6% defatted milk powder) is added, which easily doubles the acrylamide formation when potato of low to intermediate content of reducing sugar is used. The increase is weaker when potato powder of reduced asparagine content is applied. The use of egg (traditional recipe) is preferable since egg is approximately neutral.

Effect of coating

Coatings prepared from breadcrumbs and egg provide strong browning through a material with a low potential of acrylamide formation (Table 3), which could be a way to achieve rather dark crusts containing little acrylamide.

Table 5 Acrylamide concentrations in croquettes before and after coating with egg and breadcrumbs

Product	Duration of frying at 170 °C (min)	Acrylamide (μg/kg)
Croquettes 1	2.5	460
Croquettes 1 coated	2.5	80
Croquettes 2	3	190
Croquettes 2 coated	3	40
Croquettes 3	3	70
Croquettes 3 coated	3	25
Croquettes 4	4	35
Croquettes 4 coated	4	25

Table 6 Acrylamide contents in uncoated and coated croquettes prepared from fresh potato

	Duration of frying (s)	Acrylamide (μg/kg)
Potato 1, 3.7 g/kg reducing sugar		
Uncoated	130	280
Coated	135	50
	Duration of frying (s)	Acrylamide (μg/kg)
Potato 2, 0.5 g/kg reducing sugar		
Uncoated	280	250
Coated	135	40

This was confirmed by coating commercial noncoated croquettes. Four products of similar size from different producers were coated in the laboratory with fresh egg and breadcrumbs. The uncoated croquettes were fried until they were swimming on the oil surface; the coated ones were fried for the same time as the uncoated ones. As shown in Table 5, the acrylamide content in the noncoated croquettes varied between 35 and 460 μg/kg. The coated croquettes showed clearly stronger browning and at the same time contained substantially less acrylamide (factor up to 5.8).

The effect of the coating was particularly strong where acrylamide formation in the uncoated croquette was high. To some extent, the acrylamide content still reflected the potential of acrylamide formation of the core, perhaps owing to asparagine migrating from the potato into the coating (sap sucked to the surface during the frying process) or crust formation reaching into the potato.

Homemade croquettes

In Switzerland, many restaurants offer "homemade" croquettes. An experiment was performed at the School of Hotel Management with the scopes of determining the acrylamide content of such croquettes, the influence of the sugar content of the potato and the shielding effect by coating. Croquettes were prepared from potato mash with a rather low and a moderately high content of reducing sugar: a mixture of potatoes of the cultivars Erntestolz and Bintje resulting in a content of glucose plus fructose of 0.5 g/kg fresh weight (potato 1) and from Agria potatoes from 4 °C storage containing 3.7 g/kg reducing sugar (potato 2). From these, croquettes of traditional (rather large) size were prepared (see Experimental), half of which were coated by egg and breadcrumbs. They were fried in oil with a starting temperature of 170 °C (dropping to about 160 °C) until optimum culinary quality was obtained.

In the uncoated products, the acrylamide content depended little on the sugar content (Table 6). The product from potato 2, with the low sugar content, was, however, fried more than twice as long, resulting in a firmer crust. Browning was, nevertheless, weaker. The acrylamide contents (250 and 280 μg/kg) were between those of conventional and optimized French fries and were lower than average contents in roasted potato products.

The coating with whole egg and breadcrumbs provided the brown color corresponding to the traditional product characteristic. Browning was virtually identical for the two potatoes, i.e., it was exclusively from the coating. Acrylamide contents were 5 times lower and independent of the potato used (frying times were equal), i.e., potato properties are no longer important when the product is coated.

Conclusions

Croquettes and related fried or baked potato preparations are traditional items of the Sunday menu. Many consumers expect a strongly browned product with a crust around a fine mashed potato preparation. Strong browning of potato is, however, linked with high acrylamide contents.

In Switzerland, most convenience products of this type are uncoated. They remain rather pale even after frying longer than suggested by the producers, which seems to be due to the use of powder from strongly blanched (extracted) potato. Acrylamide contents averaged 240 μg/kg, although with strong variation.

For the convenience products investigated, about half of the potential of acrylamide formation originated from the 2–6% defatted milk powder added as a binder. Potato is rich in asparagine, but contains rather little reducing sugar. Milk powder introduces lactose (a reducing sugar) supporting the transformation of this asparagine to acrylamide —even though lactose only has a low efficiency in promoting acrylamide formation. This support of acrylamide formation can be avoided by using egg (egg yolk or whole egg) instead of milk powder.

Traditional coating with breadcrumbs and egg is an excellent way for obtaining strong browning of the crust without much acrylamide formation. Coating is particularly effective when potato with a high potential of acrylamide formation (high in reducing sugar) is used, as must be expected for the preparation in private homes from potato of modest suitability. The coating protects the potato from crust formation (resulting in acrylamide) and results in browning through a Maillard reaction involving

little asparagine. So far it is the only potato product where strong browning can be decoupled from high acrylamide formation.

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