

The CIAA Acrylamide “Toolbox”



CIAA

Confédération des industries agro-alimentaires de l'UE
Confederation of the food and drink industries of the EU

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Key Changes to the CIAA Acrylamide Toolbox
Status December 2007

1. Reference to the **Acrylamide Pamphlets** for five key sectors: Biscuits, Crackers & Crispbreads, Bread Products, Breakfast Cereals, Fried Potato Products such as Potato Crisps and French Fries.
http://ec.europa.eu/food/food/chemicalsafety/contaminants/acrylamide_en.htm
2. The contributions of the Joint CIAA/EC Workshop on Acrylamide held in Brussels in 2006 are **now published** in a **Supplement of *Food Additives and Contaminants*** (vol. 24 (S1), 2007) and are **now cited in the Toolbox**.
3. New work on Acrylamide presented at the **ACS National Meeting**, 21-23 August 2007, Boston, USA., has been included where relevant, e.g.:
 - a. **Glycidamide formation** in food: included the recent findings of very low amounts of glycidamide formed via fatty acid hydroperoxides
 - b. The University of Leeds is developing a **kinetic model to predict acrylamide formation** under different processing conditions. The deliverable will be an “industry toolkit” to mitigate acrylamide in food (cereal based products and potatoes)
4. More **clearly discern interventions** tested at laboratory or pilot scale and those that have been assessed in **industrial trials**. To avoid confusion, a separate Table has been included that lists only those tools that were found by manufacturers to work in their industrial settings and may be applied either singly or in combination to mitigate acrylamide in commercial products (as an **Annex 1**).
5. Sub-section on **Regulatory Compliance**. New potential ingredients or processing aids need to undergo regulatory approval, including any health and safety considerations.
6. **Risk/Risk and Risk/Benefit Positioning** now a separate sub-section and link to recent publications.
7. **Key Changes to the Toolbox parameters** : (i) link to work done within the Heatox project; (ii) included some of the latest work presented at the ACS meeting in Boston; (iii) elaborated on tools that are applicable at industrial level (e.g. calcium salts in bread, asparaginase in certain biscuits, crispbread, cereals).

In summary (only key points):

Toolbox parameter	Product category	Change
Agronomical sugars	Potato	Target less than 0.3 and 0.4% sugar on a fresh wt basis for crisps and French fries, respectively, subject to seasonal variability
	Potato	Ensure that tubers are mature at time of harvesting (immature tubers tend to have higher sugar levels).
	Cereal	Relationship of sugars in cereals; latest info presented at the ACS meeting included
Agronomical asparagine	Potato	Effect of sulphur
	Cereal	Impact of fertilizer regimes and environmental factors on Asn. Added Crispbread and Asn in rye.
Recipe: Ammonium bicarbonate	Biscuits	Modified text and content to elaborate this measure in commercial applications
Recipe: Other minor ingredients	Potato	Update on calcium salts and further trials planned
	Bread	Use of Ca ²⁺ salts now changed to industrial application
Processing: Fermentation	Biscuits	Lower gassing yeasts, dough storage time, included
Processing: Thermal input and moisture control	Crisps	Vacuum frying: link to work of the Heatox project
	Bread	Steam baking, Infrared heating, added and link to Heatox project
	Coffee	Roasting technologies beyond existing ones have been tested but do not indicate a mitigation opportunity
Processing: Pretreatment	Biscuits, cereals, crispbread	Use of asparaginase is effective in certain products (biscuits, cereals, crisp bread) at industrial scale
Final Preparation: Product storage/shelf-life/consumer preparation	Coffee	AA amounts in roast coffee decrease over storage. Studies into the mechanisms of reduction are confirming this but no options identified to influence this reaction apart from increasing the temperature of storage

The CIAA Acrylamide “Toolbox”

Summary

The CIAA “Toolbox” reflects the results of several years of industry cooperation to understand acrylamide formation and potential intervention steps. Its aim is to provide brief descriptions of the intervention steps evaluated and, in many cases, already implemented by food manufacturers and other partners in the food chain. This approach is intended to assist individual manufacturers, including small and medium size enterprises with limited R&D resources, to assess and evaluate which of the intervention steps identified so far may be helpful to reduce acrylamide formation in their specific manufacturing processes and products. It is important that they assess the suitability of proposed mitigation steps in the light of the actual composition of their products, their manufacturing equipment, and their need to continue to provide consumers with quality products consistent with their brand image and consumer expectations. It is anticipated that some of the tools and parameters will also be helpful within the context of domestic food preparation and in food service establishments, where stringent control of cooking conditions may be more difficult.

A total of 13 parameters, grouped within the four major Toolbox compartments, have been identified. These parameters can be applied selectively by each food producer in line with their particular needs and product/process criteria. In addition, the stage at which the different studies have been conducted, i.e. laboratory, pilot, or in a factory setting (industrial), are aligned to the potential mitigation measures. This approach ensures that all pertinent tests and studies are captured independent of their immediate applicability to commercial production.

The Toolbox is not meant as a prescriptive manual nor formal guidance. It should be considered as a “living document” with a catalogue of tested concepts at different trial stages that will be updated as new findings are communicated. Furthermore, it can provide useful leads in neighbouring sectors such as catering, retail, restaurants and domestic cooking. The final goal is to find appropriate and practical solutions to reduce the overall dietary exposure to acrylamide. The latest version of the toolbox can be found at: www.ciaa.be.

To assist SMEs in the implementation of the Toolbox, CIAA and the European Commission, Directorate General Health and Consumer Protection (DG-SANCO) in collaboration with national authorities developed the *Acrylamide Pamphlets* for five key sectors: Biscuits, Crackers & Crispbreads, Bread Products, Breakfast Cereals, Fried Potato Products such as Potato Crisps and French Fries. Individual operators can use the tools outlined in the pamphlets to adapt their unique production systems.

The pamphlets are available in 20 languages on the following website: http://ec.europa.eu/food/food/chemicalsafety/contaminants/acrylamide_en.htm

Background

In April 2002, authorities, food industry, caterers and consumers were surprised by the unexpected finding that many heated foods contained significant levels of acrylamide, a substance known until then only as a highly reactive industrial chemical, present also at low levels for example in tobacco smoke. The toxicological data suggested that this substance might be – directly or indirectly – carcinogenic also for humans. Recent assessments by JECFA, WHO and SCF confirmed that such a risk cannot be excluded for dietary intake of acrylamide, but did not confirm that this would be relevant at the low dietary exposure level compared to other sources of exposure, e.g. occupational. At the EU level, progress in the research on acrylamide has been shared openly and regularly through forums such as the “Acrylamide Stakeholder meetings”, held in October 2003 and January 2005. A formal presentation was given to the Commission Working Group on 16 September 2005 where the Toolbox concept was supported by the Commission and national authority representatives: CIAA was urged to publish the first official version of the Toolbox without delay. The present text is the third edition incorporating latest developments and knowledge, including the key points that were presented at the joint CIAA/EC Workshop on Acrylamide held in Brussels in 2006¹. Furthermore, there has been an active and very close contact between the CIAA and HEATOX, and the outcome of the HEATOX project in relation to advice for industry and the catering sector is comparable with the Toolbox content. To avoid duplication of efforts, the results generated by HEATOX and relevant to industry/catering have been fed into the CIAA Toolbox (*HEATOX Final Report*, 12 April 2007, www.heattox.org).

It has been confirmed that a wide range of cooked foods – prepared industrially, in catering, or at home – contain acrylamide at levels between a few parts per billion (ppb, µg/kg) and in excess of 1000 ppb. This includes staple foods like bread, fried potatoes and coffee as well as speciality products like potato crisps, biscuits, crisp bread, and a range of other heat-processed products.

It is now known that acrylamide is a common reaction product generated in a wide range of cooking processes, and that it has been present in human foods and diets probably since man has cooked food.

Immediately following the initial announcement, the food industry within the EU took action to understand how acrylamide is formed in food, and to identify potential routes to reduce consumer exposure. From the onset of the acrylamide issue, the efforts of many individual food manufacturers and their associations have been exchanged and coordinated under the umbrella of the European Food and Drink Federation (CIAA), to identify and accelerate the implementation of possible steps to reduce acrylamide levels in foods. These efforts are also intended to explore how the learnings developed by industry might also be applied in home cooking and catering which contribute to more than half of the dietary intake of acrylamide.

¹ The proceedings of the Workshop are published in a Supplement of *Food Additives and Contaminants* vol. 24 (S1), 2007.

Acrylamide Formation

Most of the tools described in this document relate to what is now seen as the main formation mechanism of acrylamide in foods, i.e. the reaction of reducing sugars with free asparagine in the context of the Maillard reaction. In fact not only sugars but also reactive carbonyl compounds may play a role in the decarboxylation of asparagine – a necessary step in the generation of acrylamide. Several intermediates in the “dry” Maillard reaction cascade have been proposed, such as 3-aminopropionamide (3-APA). The role of this compound as a key transient intermediate has recently been confirmed through isotope labelled experiments in a cheese model (*J. Agric. Food Chem.* (2006) 54: 5933-5938). Very recent work has shown that acrylamide may also be found in relatively high amount (> 1000 ppb) in foods not subjected to typical cooking temperatures, such as dried fruits (e.g. plums, pears). The drying conditions of these products are typically < 80°C, and thus 3-APA may also play a role in the formation of acrylamide during the drying process that can extend over a period of several days (*Food Addit. & Contam.* (2007) 24:13-25).

Other pathways that do not require asparagine as a reactant have been described in the literature, such as acrolein and acrylic acid. The thermolytic release of acrylamide from gluten in wheat bread rolls was demonstrated as an alternative pathway (*Mol. Nutr. Food Res.* (2006) 50: 87-93). Based on molar yields, these mechanisms can be considered as only marginal contributors to the overall acrylamide concentration in foods.

In many cooking processes, the Maillard cascade is the predominant chemical process determining colour, flavour and texture of cooked foods, based on highly complex reactions between amino acids and sugars, i.e. common nutrients present in all relevant foods. The cooking process *per se* – baking, frying, microwaving – as well as the cooking temperature seem to be of limited influence. It is the thermal input that is pivotal: i.e. the combination of temperature and heating time to which the product is subjected.

Both asparagine and sugars are not only important and desirable nutrients, naturally present in many foods, they are also important to plant growth and development. In most foods, they cannot be considered in isolation, since they are part of the highly complex chemical composition and metabolism of food plants. The Maillard reaction depends on the presence of a mixture of these common food components to provide the characteristic flavour, colour and texture of a given product. Thus, most of the Maillard reaction products are highly desirable, including some with beneficial nutritional properties and health effects.

Consequently, any intervention to reduce acrylamide formation has to take due account of the highly complex nature of these foods, which therefore makes it very difficult to decouple acrylamide formation from the main Maillard process. The University of Leeds is developing a kinetic model to predict acrylamide formation under different processing conditions. The deliverable will be an “industry toolkit” to mitigate acrylamide in food (cereal based products and potatoes), and would ideally be integrated into the CIAA Toolbox once validation work has been completed.

It is essential to appreciate that elimination of acrylamide from foods is virtually impossible – the principal objective must be to try to reduce the amount formed in a given product. However, current knowledge indicates that for some product categories, what can be achieved is dependent on natural variations in raw materials.

Whilst the Toolbox can provide useful leads, its practical application in domestic cooking, and catering requires additional work.

Glycidamide Formation in Food

Glycidamide is the genotoxic metabolite of acrylamide and the potential formation of glycidamide in food has now been addressed. Researchers have shown that the epoxidation of acrylamide by fatty acid hydroperoxides - formed during lipid peroxidation - is another possibility for interactions of acrylamide with food constituents. Linoleic acid hydroperoxides can mediate the formation of glycidamide from acrylamide, albeit in minute amounts (ca. 1 µg/kg glycidamide was measured in French fries). Based on this preliminary work, the potential burden of glycidamide via food appears negligible (*Presentation of M. Granvogl, ACS National Meeting, 21-23 August 2007, Boston, USA*).

Methods of Analysis and Sampling

Today, many laboratories offer sensitive and reliable methods to analyse acrylamide in a wide range of foods. Issues with the extractability of acrylamide in certain food matrices were raised by Eriksson & Karlsson, showing that a high extraction pH may significantly enhance the yield of acrylamide versus extraction under neutral pH conditions (*LWT- Food Science and Technology* (2006) 39: 392-398). This observation suggests that the methods developed to date may underestimate the concentration of acrylamide in certain foods. Work done by independent research groups (Goldmann *et al.*, *Food Addit. & Contam.* (2006) 23:437-445, and Hajslova *et al.*, presentation at Cost 927 Workshop, Napoli, 2006) confirmed, however, that the “additional” acrylamide released at high pH is not due to the improved extractability of the analyte from the food matrix, but rather an extraction artefact formed due to the decomposition - under extreme pH conditions - of certain hitherto unidentified precursors. Consequently, the choice reliable of analytical methods is of crucial importance.

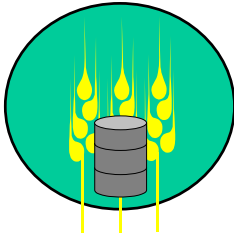
The main challenge for the analyst is the high variability of the products. This starts from the natural variability of a given raw material – any potato can be considered as “individual” with noticeable differences in composition and thus potential for acrylamide formation. Slight differences in product composition and process conditions, and even the location within the temperature range of one specific production line, may lead to major differences in acrylamide levels, often of several multiples between samples derived from the same product recipe made on the same production line.

Appropriate sampling and statistically relevant numbers of analyses are therefore essential to determine acrylamide amounts in products, and to assess the actual reduction achieved by the mitigation step(s) when conducted in a factory setting.

Definition and Use of the Toolbox Parameters

The summaries describing the various acrylamide reduction tools developed by industry are intended to be generic. It is necessary to take account of the differences between product recipes, designs of processes and equipment, and brand-related product characteristics even within a single product category.

The following 13 parameters, grouped within the original Toolbox compartments, have been identified:



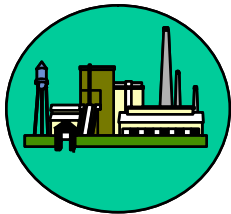
- Agronomical

- Sugars
- Asparagine



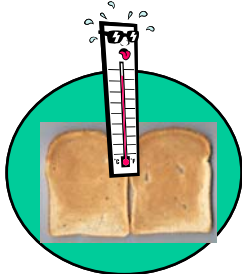
- Recipe

- Ammonium bicarbonate
- Other minor ingredients (e.g. calcium salts, glycine)
- pH
- Dilution
- Rework



- Processing

- Fermentation
- Thermal input and moisture control
- Pre-treatment (e.g. washing, blanching, asparaginase)



- Final Preparation

- Colour endpoint
- Texture/flavour
- Product storage/shelf-life/consumer preparation

However, it needs to be emphasised that **there is no single solution to reduce acrylamide levels in foods**, even in a given product category. Indeed, individual processing lines dedicated to the manufacture of the same product in one factory may need different applications of the proposed tools. As an example, modification of thermal input for comparable product quality can be achieved by frying at a lower temperature for an extended time span, or by “flash frying” for a very short time at higher temperatures. The choice will depend on the design and flexibility of the existing production equipment.

The summaries in this document also specify the level of experience available for a proposed intervention, i.e. trials conducted at (i) laboratory/bench, (ii) pilot, or (iii) industrial scale. Here, it is important to discern interventions tested at laboratory or pilot scale and those that have been assessed in industrial trials. To avoid confusion, a separate Table has been established that lists **only those tools that were found by manufacturers to work in their industrial settings** and may be applied either singly or in combination to mitigate acrylamide in commercial products (see **Annex**).

- **Laboratory Scale:** This indicates that - for the categories mentioned - only experimental work has been done to assess the impact of the proposed intervention. Most likely no quality tests (organoleptic, shelf-life studies, nutritional impact, etc.) have been conducted nor full assessment of the legal status or possible intellectual property rights for the given intervention. Large scale industrial application has either not yet been done or has failed in the specific context. This does not necessarily mean that the concept would not function for other applications.
- **Pilot Scale:** These concepts have been evaluated in the pilot plant or in test runs in the factory, but not yet applied successfully under commercial production conditions.
- **Industrial:** These interventions have been evaluated and implemented by some manufacturers in their factories. Application by other manufacturers may or may not be possible depending on their specific process conditions. The validation of the suggested tools was assessed over the product shelf life. The legal status of the proposed measures has been evaluated.

Most of these tools have been evaluated only in the industrial, food processing context. Their usefulness for caterers or domestic cooking will need to be assessed separately, given the differences in cooking conditions and the typically lower level of standardisation and process control in non-industrial settings.

Where available, literature references are provided for the tool descriptions. In many cases, however, the summaries also include unpublished information provided by individual food manufacturers and sectors contributing to the joint industry programme coordinated by the CIAA.

The tools described do not comprise an exhaustive list of mitigation opportunities. The work of both industry and academic researchers continues and is likely to provide additional intervention leads or improvements. It is CIAA's intention to continuously update the Toolbox so as to reflect such developments.

Regulatory Compliance

Any intervention must also be evaluated for its regulatory impact. For many products, the use of additives is strictly regulated and changes in recipes will not only affect the ingredient list but potentially also the product name and description and customs classification. Additionally, process conditions and equipment standards must continue to meet relevant official standards. New potential ingredients or processing aids need to undergo regulatory approval, including any health and safety considerations. For new plant cultivars, success in breeding must be followed by formal approval of the new seed. All these considerations can influence the choice of interventions and the time to implementation/commercialisation.

In the case of the enzyme asparaginase, two companies (Novozyme and DSM) are today producing a commercial food-grade enzyme. As worldwide licensees for the patent holders, they may sub-licence the rights to food manufacturing and processing companies to incorporate asparaginase in their food production processes to lower the amounts of acrylamide.

GRAS status has been obtained from the US FDA for both types of asparaginases in the products of intended use. JECFA reviewed asparaginase from *Aspergillus oryzae* at its 68th meeting in June 2007, and on the basis of available data and total dietary intake arising from its use concludes that asparaginase does not represent a hazard to human health (*Joint FAO/WHO Expert Committee on Food Additives (JECFA): Report on 68th meeting, Geneva, 19-28 June 2007*). However, regulatory permission to apply asparaginase in foods requires clarification, nationally and supranationally.

Risk/Risk and Risk/Benefit Positioning

Mitigation of acrylamide formation through changes in product composition and/or process conditions may have an impact on the nutritional quality (e.g. decreased nutrient bioavailability; changed flavour, taste/palatability, texture), and safety of food (e.g. inadequate reduction of microbial load or decomposition of natural toxins). There may also be potential loss of beneficial compounds generated during cooking which are known to have protective health effects, e.g. antioxidants and *in vitro* antioxidant capacity of heated foods, see: *J. Agric. Food Chem.* (2006) 54:853-859; *LWT- Food Science and Technology* (2007) 40:1849-1854.

- Frying potatoes at lower temperatures to a comparable endpoint can reduce acrylamide formation, but will require longer cooking times and can consequently increase the fat uptake (ref: industrial sources).
- Excessive blanching of potatoes results in further loss of minerals and vitamins.
- Using refined flour reduces acrylamide formation potential, but is seen as less nutritionally desirable compared with whole grain (bran) products.
- Replacing ammonium bicarbonate with sodium bicarbonate helps control acrylamide formation, but if applied systematically will increase sodium levels.

Therefore, for any proposed intervention, a risk/risk or risk/benefit comparison should be conducted to avoid creating a potentially larger risk.

Other Considerations

- **Manufacturer Specificity:** Each manufacturer needs to explore how a proposed intervention can be implemented in its specific situation; especially when moving from laboratory experiments or pilot plant trials to routine production in the factory to ensure comparable results under commercial conditions.
- **Interactions between multiple interventions:** Often more than one intervention step may be applied (see **Annex 1**). These individual interventions may lead to an overall reduction of the desired mitigation effect. Particularly in products with highly complex recipes like biscuits, it is very difficult to predict the “real life” impact of a given measure.
- **Process Compatibility:** Any proposed intervention also needs to be assessed for its feasibility and ability to be integrated into an existing factory setting. For example, is space available for any additional storage tanks to add a new ingredient? Will changes affect the line speed and thus the output and competitiveness of a factory? Are new components compatible with the existing equipment, for e.g. the possible corrosive effects of food-grade acids.

- **Natural Variability:** Foods are based on natural commodities like cereals, potatoes or coffee beans. Their composition varies between crop cultivars, harvest season, climatic conditions, soil composition and agronomic practices. Properties also change with storage and initial processing, e.g. extent of milling. These differences and their impact on acrylamide formation are so far poorly understood and can thus not be consistently controlled. Seasonal and year-to-year variability of raw materials can have a greater impact on acrylamide levels than any of the interventions implemented, and must be taken into consideration.
- **Process Variability:** There is a significant variability in acrylamide levels between products of even a single manufacturer, in many cases even within one product range. Thus, to assess the impact of a given intervention, especially if multiple changes are made in parallel, a sufficient number of analyses are needed to permit comparisons: single analyses are nearly always insufficient to evaluate the effect of an intervention for a given product.
- **Brand Specific Consumer Acceptance:** Each manufacturer needs to assess the impact of the proposed interventions on its brand-specific product characteristics. A modified product may well appear acceptable in principle, but after the modification may no longer match the consumer's expectation for an established brand. Thus, improvement of an existing product, in terms of reduced acrylamide content, may be more difficult to achieve than in the case of a newly developed product.

Abbreviations used

AA: acrylamide; **Asn:** asparagine; **Caobisco:** Association of the Chocolate, Biscuits and Confectionery Industries of the EU; **EC:** European Commission; **GAP:** Good Agricultural Practice.

Agronomical: Sugars

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Industrial
Minimising sugars has been part of standard manufacturing practice

Reducing sugars are one of the key reactants for the formation of AA [1]. The sugar content of the tuber correlates well with the AA concentration in the product especially if the fructose/Asn ratio is < 2 [2]. Controlling sugar is currently the primary measure employed by the industry to reduce AA levels in crisps and French fries [3] by:

Control of tuber storage temperature identified as good practice

- Selection of potato varieties with low reducing sugars (target less than 0.3 and 0.4% sugar on a fresh wt basis for crisps and French fries, respectively, subject to seasonal variability)
- Lot selection based on reducing sugars content or colour assessment of a fried sample.
- Controlling storage conditions from farm to factory (e.g. temp. $> 6^{\circ}\text{C}$ identified as good practice for long storage [4], use of sprout suppressants following GAP, reconditioning at higher temp. (e.g. ambient) over a period of a few weeks).
- Ensure that tubers are mature at time of harvesting (immature tubers tend to have higher sugar levels).

These measures are implemented throughout the industry.

N-fertilisation may impact reducing sugar content

Future opportunities include:

- Breeding new potato varieties with lower reducing sugar content and/or less cold sweetening effect.
- Further optimise the agricultural practices to reduce sugars and Asn. The nitrogen fertiliser regime appears to influence the reducing sugar concentration of the potato tuber, i.e. increased reducing sugars (60 – 100%) upon lowering the field N-fertilisation [5].

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale, Industrial
Sugars composition of cereal grains is not a key determinant of AA formation

Research confirms that Asn rather than sugars is the key determinant of AA formation in cereal products. The sugars composition of cereal grain has not previously been considered relevant to breakfast cereal manufacture.

Measurements for four soft wheat varieties in 2004 found 1 to 1.3% dry wt of total reducing sugars as glucose (0.41 - 0.58%); fructose (0.17 - 0.2%) and maltose (0.36 - 0.55%). Sucrose was at 0.5 - 0.65%. AA formation showed no relation to total reducing sugars or to individual sugars concentration. Recent work has shown a wide variation of reducing sugars in different cereal grains and their fractions, e.g. fructose/glucose amounts are highest in wholemeal rye/wheat. Furthermore, Asn and fructose/glucose vary in tandem in soft wheat and rye. No correlation was found for bread wheat flours [6].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Pilot scale

No correlation to AA formation

Coffee

Sugar levels in the green beans (robusta, arabica) show no correlation to the amount of AA formed during roasting.

Chicory

Inulin and sucrose at approx. 67g/100g dried chicory, and reducing sugars approx. 1.9g/100g (dry wt). These amounts increase substantially during roasting. No relationship between sugar levels and AA formation during roasting [7].

Other considerations

Potatoes:

- Effect of optimisation of the sugar content in the raw materials on other components influencing nutritional properties.
 - Minimising sugar content needs to be balanced against processing methods and final product characteristics (colour, flavour, etc.).
-

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[6] Presentation of Peter Sadd, Premier Foods, ACS National Meeting, 21-23 August 2007, Boston, USA.

[7] CIAA Technical Report "Acrylamide Status Report December 2004" A summary of the efforts and progress achieved to date by the European Food and Drink Industry (CIAA) in lowering levels of acrylamide in food. Brussels, January 2005. (<http://www.ciaa.be>).

Agronomical: Asparagine (Asn)

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Lab scale
Currently no practical means available to control Asn level in potatoes

Asn, an important amino acid for plant growth, is the other key reactant for AA formation. In potatoes, Asn is the most abundant free amino acid, typically 0.2 - 4% dry wt, 20 - 60% of total free amino acids. Asn levels do not correlate to sugar levels.

So far no control of Asn levels in potatoes has been established.

Potential leads being explored include:

- breeding of lower Asn varieties
- impact of storage on free Asn levels

Impact of farming practices (e.g. fertiliser regimes) on Asn levels. In potatoes, the effect of sulphur is uncertain, and any advice on S-fertilisation to farmers would be premature based on the studies conducted so far [1,2].

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale
Selection of crop varieties with lower Asn would theoretically lead to reduced AA formation. However this has not proved to be a practical tool for commercial production

Asn is the critical component which leads to the formation of AA in cereal products [3]. Free Asn within and between cereal types varies widely. Year to year variations from one harvest to another are considerable and more fundamental knowledge is needed concerning the impact of agronomical practices and cereal varieties on Asn level. Sulphur-deprived soils have been shown to impact the free Asn concentrations in certain cereal crops considerably. The very dramatic effects of extreme sulphur deprivation are not relevant because the crops are stunted. However it does appear that there is an effect at levels realistic in farming. Even a 25% reduction in asparagine would achieve more than most interventions tested to date.

Choice of wheat with lower free Asn has led to products with lower AA levels [4]. The major soft wheat varieties in use in the UK are, perhaps by chance, those with lowest Asn concentration. In France, more variation is seen and selection of soft wheat varieties has been applied. After three years trial by one manufacturer it appears that environmental variation between growing sites is too large for such selection to work on a large industrial scale.

Current experience suggests that specifying low Asn wholegrain is not yet possible, but that using less whole meal and more endosperm will be effective but will change the product's organoleptic and nutritional properties [5].

Crispbread: analysis of rye samples has shown that environmental factors have more influence than rye variety. It has not been possible so far to identify which environmental factors have the most significant effect.

The importance of maintaining sulphur levels for cereal cultivation must be stressed to farmers

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Pilot scale

No mitigation options through crop selection due to narrow window of free Asn.

Contribution of marginal pathways not yet clarified.

Agronomic aspects not adequately studied and are considered long-term

Coffee

Free Asn concentrations in green coffee beans lie within a very narrow range, typically from 20–100 mg/100g, and thus do not provide the opportunity for possible control or reduction by selection of beans with relatively low amounts of free Asn. On average a tendency of slightly higher AA content of roasted Robusta beans have been reported which in some cases may reflect the concentrations of Asn in the green coffee beans [6, 7]. As identified during the CIAA/EC Workshop [8,9], modelling studies of AA formation in coffee will be important to understand to what extent Asn is a key reactant and the potential contribution of minor pathways (e.g. thermolytic protein cleavage) in this product category.

Chicory

The range of free Asn in chicory roots is relatively narrow (40 - 230 mg/100g). Studies at pilot scale show that Asn content of dried chicory is correlated to the formation of AA [4].

Other considerations

Impact of reducing free Asn on plant health and consumer nutrition.

In coffee, other “marginal” pathways not related to free Asn may become important for the formation of AA [6].

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Recipe: Ammonium bicarbonate

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Not applicable

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale and

Industrial

Reducing or replacing NH_4HCO_3 in recipes, which is now used in certain commercial applications is an option to lower AA, but the impact on organoleptic and nutritional (sodium) properties must be assessed

Biscuits

Replacing NH_4HCO_3 with alternative raising agents is a demonstrated way to relatively lower AA in certain products and on a case-by-case basis [1]. To achieve the correct balance of gas release during baking, and optimum texture, flavour and colour, combinations of NH_4HCO_3 , NaHCO_3 and acidulant are often required. Experiments have shown that NH_4HCO_3 can promote the production of AA in gingerbread [2]. NH_4HCO_3 increases the formation of sugar fragments (glyoxal and methylglyoxal) that react rapidly with Asn to furnish AA in higher yield than the native reducing sugars under “mild” conditions [3].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Not applicable

Other considerations

Loss/change of colour, loss of leavening/stack height, flavour defects, texture defects, increase in sodium.

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Recipe: Other minor ingredients

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Lab & Pilot scale

Addition of competing amino acids such as glycine or deactivating Asn by calcium salts have shown reduction potential

Further trials in the use of calcium salts to mitigate AA are planned

Amino acids

Other amino acids may compete with Asn and can thereby reduce AA formation, or they may chemically react with AA for example through Michael addition. Shifting the balance away from Asn may help to reduce AA formation.

- Some AA reduction has been found in laboratory scale trials where potato slices have been soaked in solutions of various amino acids with differing impacts on the amount of AA reduction [1 - 4].
- In a potato cake model, the combined treatment of citric acid and glycine (each 0.39% in the recipe) had an additive effect in reducing the AA concentration. Citric acid inhibits certain flavour formation which is compensated by the addition of glycine that favours the formation of certain volatiles [5].

Calcium salts

The addition of di- and tri-valent cations has been proposed to reduce the formation of AA in several potato products.

- Laboratory research using calcium salts found AA reduction in potato crisps, not attributable to a lower pH [4]. Sensorial tests claimed good acceptability, but industry experience with calcium use suggests bitter off-flavours and brittle textures – this requires confirmation with products fried to same moisture content.
- Further research into the potential use of calcium is planned for French fries.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Industrial

Replacing fructose with glucose is very effective in reducing AA formation, particularly in recipes containing ammonium bicarbonate

Industrial

For bread, addition of Ca²⁺ salts has shown to reduce the formation of AA

Biscuits

Reducing sugars are responsible for many of the characteristic flavours and colour in sweet biscuits, and their replacement with sucrose causes severe loss of colour. However, very promising results have been achieved by replacing fructose with other reducing sugars such as glucose. When glucose-fructose syrups are used, the fructose content should be as low as possible [6].

Gingerbread

In pilot trials, glycine addition (1 % in the recipe) decreased AA content ~2.5 fold and enhanced browning, but with a clear impact on the sensorial properties of the product [7].

Bread

Compared to normal fortification in UK flours (0.3 % CaCO₃), additional 1% CaCl₂ to a simplified commercial bread recipe resulted in a ca. 35% reduction of AA.

However, calcium propionate resulted in more than 90% increase in AA. This effect was not due to the propionic acid. Adding Ca^{2+} to bread via the tin releasing agent has a clear effect in reducing AA and may be an option as most of the AA is formed in the crust [8, 9].

Different studies show that glycine addition may lead to a reduction of AA in yeast-leavened bread, flat breads and bread crusts. However, it has also been suggested that addition of high amounts of glycine may lead to reduced yeast fermentation. Spraying glycine on the surface of bread dough (8-times consecutively) affords only a marginal reduction of AA (~ 16%) [1, 10].

Lab and Pilot scale

Addition of Ca^{2+} or Mg^{2+} to certain bakery products/ breakfast cereals and of glycine to crispbread/ breakfast cereals may be options

Breakfast cereals

In breakfast cereal production, manufacturers generally use sucrose and small amounts of malt in the cereal itself because reducing sugars darken the cereal too much. Honey, glucose, fructose and other reducing sugars are used in the sugar coat applied after toasting so they do not influence AA formation [5, 6]. In the light of today's knowledge, one would consider carefully any proposal to add reducing sugars at the cooking stage. Several trials show no effect of malt on AA formation, it seems likely that Asn content dominates at the levels of malt used.

Many breakfast cereals are fortified with Ca^{2+} , and manufacturers could explore the benefit for those not so fortified. The manufacturers who report trials have seen no significant effect of calcium addition. At pilot plant scale, glycine has been found to reduce AA formation by up to 50% in some types of wheat flake. The addition of glycine is limited by formation of dark colour and a bitter taste.

Crispbread

The level of AA can be affected by glycine at 3% (w/w) resulting in a reduction by approx. 78%. However, the colour may well be affected and an undesirable sweet flavour introduced [6]. Ca^{2+} , whilst only slightly reducing AA, has an adverse effect on the flavour and texture at pilot plant level.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Not applicable

Other considerations

- Potatoes:
 - environmental impact
 - calcium chloride: corrosion of the equipment
 - frying oil stability and organoleptic properties/ citric acid
- Bakery products for diabetics: greater potential of AA formation if sucrose is replaced by fructose [7].
- Calcium dosing and nutritional aspects to be considered.
- Potential adverse effect of glycine to be considered.

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Recipe: pH

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

See section "Processing: pre-treatment".

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Laboratory

Addition of organic acids has only been effective when combined with a change to leavening agents, and then with only marginal impact

Biscuits, Crispbread, Gingerbread

Laboratory experiments with an intermediate product (semi-sweet biscuit) have shown that reducing pH by addition of citric acid can lead to 20-30% reduction of AA in the intermediate product [1].

Addition of citric and tartaric acid (~0.5% in the recipe) decreased AA content approx. 3-fold in gingerbread versus a control, but resulted in a product of insufficient quality (acidic taste, less browning) [2]. In crispbread and biscuits, the pH has an impact on the organoleptic properties of the final product.

Models have shown that in certain bakery products lower pH in combination with fermentation can lead to an increase in another undesired process chemical, namely 3-monochloropropanediol (3-MCPD) [3, 4].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Not applicable

Other considerations

Organoleptic properties, product shelf-life and the potential formation of other undesired compounds such as 3-MCPD must be individually assessed. Citric acid is corrosive to some grades of steel and this should be considered before an extended factory trial is conducted.

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Recipe: Dilution

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Industrial
Partial replacement with ingredients lower in key reactants

For some preformed/reconstituted products, partial replacement of potato components by ingredients lower in key reactants reduces AA formation potential, and has been implemented, e.g. use of cereals with lower Asn amounts than potato (e.g. wheat, rice, maize) in the recipe [1].

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale
Individual studies required, depending on recipes; impact on nutritional quality and organoleptic properties needs to be assessed

Crispbread
If crispbreads are produced with cereal grains that are low in Asn, then consequently products low in AA are expected. It is possible to dilute the Asn-containing material in certain cases. Depending on the choice of the diluting material, this may change the product composition and characteristics considerably [2].

Industrial
Roasted nuts and dried fruits may contribute to AA

Breakfast cereals
All of the major grains may be used in breakfast cereals and some grains yield more AA than others within a common process. Wheat yields markedly more AA than maize, oats or rice. However, the choice of grain defines the food.

Other ingredients used in cereal products may contribute to AA. Low-roast almonds contain 3 to 10 fold less AA than high roast almonds. Peanuts and hazelnuts yield much less AA than almonds. Where baked pieces are used in muesli their recipe should be reviewed alongside the advice for biscuits. Some dried fruits (e.g. prunes, pears) are recently found to contain AA [3].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Industrial
Recipe modification to accommodate lower % of high AA-forming constituents

Chicory
Lowering the chicory content by 3% in the recipes for coffee surrogates and partial substitution with, for example roasted barley, achieves marginal reduction but has an impact on organoleptic properties [1].

Other considerations

Cereals: Asn is more concentrated in the bran so use of refined grain may reduce AA. However, the fibre and other beneficial nutrients of bran would be lost, and the product characteristics would also change [4].

Potatoes: implication for consumer acceptance and products characteristics.
Denomination of product may change based on the dilutions with other cereal grains.

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Recipe: Rework

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Not applicable

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale

Knowledge inadequate to assess impact of rework on AA formation

Biscuits

Based on studies conducted in Germany, rework in certain bakery wares may have an impact on the amount of AA present in the final product [1]. For example, a 16% reduction of AA in gingerbread has been shown without rework. Other work conducted on non-fermented crispbread has shown no significant effect on the formation of AA in the product [2].

Breakfast cereals

For those breakfast cereals where rework can be used, no effect on the formation of AA is so far reported. The number of distinct processes and recipes is such that manufacturers should test each case.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Not applicable

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Processing: Fermentation

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Lab scale
Lower levels of AA achieved by fermentation

Fermentation reduces levels of key reactants for the formation of AA, and lowers the pH.
Use of *Lactobacillus* to treat potatoes has been proposed. However, this option is currently not suitable for use in the context of present processes and available equipment.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Lab, Pilot & Industrial
Lower levels of AA in fermented products.
Extension of fermentation time in bread may be an option to lower AA levels

Use of lower gassing yeast to decompose Asn faster

In sweet biscuits, control of dough storage time may be a good practice

Biscuits

Some baked products, such as crispbreads and crackers, can be made from fermented doughs so as to develop specific textures and flavours. Compared to similar non-fermented products, the level of AA in the fermented variants is generally lower [1]. Yeast rapidly assimilates Asn and aspartic acid, as well as sugars. Crispbread, which is mainly produced with yeast, also shows significantly lower AA content for fermented variants versus cold bread (non-fermented variants). In crispbread manufacture, other factors such as biscuit thickness and baking conditions must be seen in perspective [2].

Biscuit and cracker doughs: long yeast fermentations are an effective way of reducing Asn levels. Fructose levels increase at moderate fermentation times, but the yeast later absorbed this, so the net effect on AA was beneficial [3].

The use of lower gassing yeast may be a mitigation option in some products, as more yeast activity is added which results in faster decomposition of Asn, at same overall gas generation rate.

Sweet biscuits: more AA is formed in doughs that have been allowed to age (35% increase over 3h), i.e. increase in free Asn in dough over time [3].

Bread

Lab scale trials have shown that extended yeast fermentation may be one way to reduce AA content in bread [4]. Yeast preferentially removes Asn and a study in the UK showed a 50% reduction of AA after 1h fermentation time [5]. This observation warrants further study.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Not applicable [6]

Other considerations

Fermentation leads to increased glycerol and in combination with lower pH (addition of acids) may favour the formation of 3-MCPD [7].

Long reaction times and compatibility with industrial processing and effect on finished product quality need to be considered.

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Processing: Thermal input & moisture control

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Industrial
Thermal input controls AA formation in the finished product

Crisps

Thermal input rather than temperature alone is critical to controlling product characteristics. This needs to take account of temperature and frying times and processing equipment.

- Different solutions to optimise thermal input to manage AA have been implemented in line with existing processing equipment.
- Vacuum frying offers an alternate thermal input control system, however this technology is not widely available and has limited throughput capacity [1].
- For manufacturers that use high temperature flash frying, rapid cooling helps to reduce AA formation.

For French fries, final preparation conditions are key

French fries

Par-frying does not produce significant levels of AA in the semi-finished product, nor does it determine the level in the final product.

Lab scale
Par-frying and high temp drying using dry steam

It is the final preparation that has the controlling influence. See section "Final Preparation" for positive action taken.

Moisture content has a strong influence on the activation energy of browning and AA formation. At low moisture contents, the activation energy for AA formation is larger as compared to the one for browning. This explains why the end-phase of the frying process is critical and must be carefully controlled [2]. Industry is already frying to a maximum end moisture content to make an acceptable product.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Industrial
Optimisation of thermal input has resulted in a reduction of AA in crispbread

The formation of AA during the baking of cereal products is closely related to the combination of moisture content and baking temperature/time (thermal input). If products could be baked to the same moisture, but with less colour development, less AA would be formed even though longer baking times would be required [3, 4].

Crispbread

In non-fermented crispbread, reduction in process temperature and oven speed reduced AA by approx. 75 %. The most important impact is coming from securing that the end humidity is as high as tolerable from a quality point of view. However, other products may suffer significant changes to colour, flavour and texture [5 - 7].

Breakfast cereals

There is one report of a reduction in AA for a baked breakfast cereal when a two-zone oven with a cooler section replaced a single zone oven. Multi-zone ovens and toasters are the norm for large manufacturers and they have not found benefit without significant changes to organoleptic properties.

Lab & Pilot scale
Alternative baking technologies such as infrared heating seem promising

Steam baking during the last 5 min. of bake is effective in reducing AA

Two manufacturers have found that the conditions associated with minimum energy use are also associated with least AA formation. Thus there may be a dual benefit from optimisation to minimise energy use in baking.

AA content is well correlated with moisture content however manufacturers generally apply both maximum and minimum ranges for moisture as a part of routine quality management.

Bread

The impact of new baking techniques such as air impingement and infrared radiation baking on AA formation in the crust has been studied within the Heatox project [1]. Using infrared heating, it was possible to reduce AA content in flat bread cakes by 60% with retained sensory properties. The effect of steam baking during the final part of baking was also studied and afforded a reduction of AA by 40% in white bread, maintaining the sensory quality [1, 8].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Coffee

At the beginning of roasting the AA formation starts rapidly. After reaching a maximum within the first half of the total roast cycle the AA level decreases with continued roasting. Final finished product levels are at only 20 - 30% of the maximum level, final concentration being dependent on the target degree of roast and the total roast time. Darker roasting in general, and extending the roast time by using lower roasting temperatures, tends to reduce the AA level but both parameters need to be fixed in narrow ranges to achieve the target flavour profile [5, 6, 9].

Different to most other food categories, the AA concentration in coffee decreases with increasing thermal input/darker roasting. The hypothesis is that at higher temperatures, as applied during coffee roasting, reactions leading to the depletion of AA dominate towards the end of the roasting cycle. These reactions are as yet not understood, but the hypothesis is supported by studies in model systems that show an increase and subsequent decrease of AA over temperature, explained by potential polymerisation or reaction of AA with food components [10].

Trials on new/alternative roasting technologies have been conducted. Using a steam/pressure roasting pilot plant unit resulted in a reduction potential of up to 10% in comparison with conventionally roasted sample of similar quality - not indicative of a significant mitigation opportunity.

Chicory

AA is formed at temperatures > 130°C, with a maximum at 145°C. Above 150°C, rapid decrease in AA due to process-related loss. Colour development > 150°C due to caramelisation (degradation of sucrose). Decreasing the roasting temperature and concomitantly increasing the roasting time, favours the loss of AA.

Lab & Pilot scale
Roasting technologies beyond existing ones have been tested but do not indicate a mitigation opportunity

Other considerations

Coffee: results have led to the conclusion that only very limited process options are available to reduce the AA level without affecting the quality respective the consumer acceptance of a product.

Crisps/French fries: effect of reducing the frying temperature on the fat content of the finished product (for example 9 mm fries: lowering the final cooking temperature from 180°C to 170°C leads to a 5 – 10 % increase in fat, when frying to the same colour endpoint). Effect of incomplete cooking on moisture level in products and subsequent impact on product quality, shelf life, microbiological damage.

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Processing: Pre-treatment

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Industrial

For French fries, blanching is the most important tool to control AA.

Addition of sodium acid pyrophosphate reduces pH and thus lowers potential of AA formation

Lab & Pilot scale

Crisps: Variable success with washing or pH control

Asparaginase may reduce AA in reconstituted dough-based products

French fries

The blanching process is the most important tool to control the reducing sugars (by removing and/or adding) to the required level of the colour of the specification of the final product and thus AA.

Addition of sodium acid pyrophosphate directly after blanching of French fries is used to avoid discolouration of uncooked strips and has a secondary effect of reducing AA by lowering pH.

Crisps

Different solutions to control key reactants, have been implemented, with various success, dependant on existing processing equipment:

- Washing
- pH control

See also section “Recipe: Other Minor Ingredients” where the same tools can be envisaged as a pre-treatment for French fries and sliced potato crisps.

Reconstituted Potato Products

Laboratory and pilot plant trials have shown that asparaginase significantly reduces the levels of AA in potato dough based products [1]. However, the same effect is not found in sliced or chipped potato products. If the potato cells remain intact, asparaginase will not reach the substrate (Asn).

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Industrial and pilot scale

Use of asparaginase is effective in certain products (biscuits, cereals, crisp bread)

Biscuits

Asparaginase has been shown to be effective in hard doughs, but much increased enzyme addition was needed to achieve a reduction in AA for short doughs (only 5 - 20% reduction in AA compared with reportedly up to 70 % in some hard semi sweet doughs). Nevertheless this has a high potential for AA reduction especially in high moisture, neutral pH systems at elevated temperatures [2]. Industrial scale trials using asparaginase are now in progress.

Roller dried Cereal

Industrial trials with a oat/rice/wheat cereal product that is roller dried showed that asparaginase - added during the wet mixing hydrolysis step - decreased AA by ~ 40 % in the final product. Further trials will be conducted to optimise mixing time / temperature and enzyme concentration.

Lab & Pilot scale

Difficulty in scale-up of the asparaginase

Crispbread

Initial industrial scale trials on non-fermented crispbread have shown a reduction in acrylamide of 30 - 50%.

Breakfast cereal

Many breakfast cereals use coarsely chopped grain rather than flour as ingredient and it is expected that the enzyme will not penetrate well in such material. Trials have shown that on a very small scale asparaginase can reduce Asn in some breakfast cereal doughs. However the effect was not observed on pilot or factory trial scale. Further trials are in progress to try to resolve the effect of scale.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Lab scale

Use of asparaginase to be assessed at pilot and industrial scale, taking into consideration applicability and impact on quality/sensorial attributes

Coffee

Pre-drying of green beans: green coffee dried to lower moisture content prior to roasting (from a typical green coffee moisture of 10-12% to approximately 7%) did not show an impact of the initial green coffee moisture on the AA level in the roasted product [3].

Decaffeination: trials showed that roasting of decaffeinated green coffees (covering the commercially important decaffeination processes) results in AA levels of same magnitude as roasting of corresponding untreated coffees when roasted to comparable roasting conditions.

Asparaginase: enzymatic processes claiming an AA reduction of 10-90% has been filed as a patent [4]. A laboratory-scale trial where the enzyme was added to a green coffee extract and after treatment the extract reincorporated into the green bean, afforded a marginal reduction on roast coffee basis. However, the potential impact on quality / sensorial properties have not yet been addressed. Further studies at lab & pilot scale are planned.

Chicory

Asn reduction: as described above.

Other considerations

The regulatory status and safety assessment *re* the use of asparaginase is now becoming clearer within the EU. Denmark and France have approved the use of two commercial asparaginase enzymes in specific products.

Operating Concerns:

- use of asparaginase in industrial scale trials does not appear to meet laboratory / pilot trial predictions due to scale up issues with mixing and reaction conditions
- negative effects of acids on corrosion of processing equipment, and on product organoleptic characteristics
- negative environmental impact e.g. co-product recovery, water treatment.

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Final Preparation: Colour endpoint

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Industrial

Cook to a golden yellow colour.
In-line elimination of dark crisps

French fries

The cooking instructions on the packaging have been revised to achieve a golden yellow colour for the finished product.
Following these revised optimised cooking instructions results in lower AA levels [1,2]

Crisps

Elimination of dark coloured crisps by in-line optical sorting has proven to be an effective measure to reduce AA.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Industrial

Colour is a characteristic property of many products, but selected products could be modified without reducing consumer acceptability, e.g. if they are subsequently chocolate coated

The Maillard reaction, which leads to the production of AA, also produces the colours and flavours which give baked cereal products their essential characteristics. If, though, one was able to produce lighter coloured and less baked products, but without increasing the moisture content, the AA level could theoretically be reduced. [3, 4, 5]

In some cases a darker colour may be associated with less AA e.g. some breakfast cereals [3, 6].

In bread, the endpoint colour does in most cases reflect AA content [7].

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Pilot scale & Industrial

Colour is an important process control point and linked to the sensory properties of the product

Coffee

Colour is an important indicator of roasting degree and directly related to the organoleptic properties of the product. Darker roast coffees have less AA than light roast coffees (see section "Processing: thermal input & moisture control" for more details) [3, 4, 8].

Chicory

Colour development results mainly from caramelisation of sugars, and colour is an important end-point of roasting degree and attribute for consumer acceptance.

Other considerations

In the case of coffee, roasting to darker colour is not considered an option to relatively lower AA due to the importance of the sensory attributes of the product. Additionally the effects of process changes on levels of desirable constituents (e.g. antioxidant capacity: studies have shown that in parallel to lower AA levels at darker roasting the antioxidant activity measured as *in vitro* radical scavenging capacity is decreasing as well [9]) and formation of other undesirable products under extreme roasting conditions need to be considered.

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Final Preparation: Texture/flavour

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

Not applicable

Modification of texture and flavour are not suitable as a tool to reduce AA, but are influenced by other interventions.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

Pilot scale

Close correlation to moisture, an important organoleptic attribute

Biscuits

It is unfortunate that the reaction leading to the formation of AA, the Maillard reaction is also that which develops flavour and colour. In some products (e.g. gingerbread) reducing sugars, such as glucose or fructose, are deliberately added so as to achieve particular flavours (and colour). Such products also tend to be higher in AA. Not to add the reducing sugars would reduce the amount of AA, but at the expense of flavour development.

Products which are baked at a high temperature and to a low final moisture content so as to have a 'crisp' texture tend to be higher in AA. Those such as shortbread which are baked at low temperature and for a long time are lower in AA. Individual studies warranted to assess feasibility and acceptance tolerance [1].

In crispbread, the thicker the bread, the lower the AA levels. This, however, significantly changes the product characteristics.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Organoleptic properties are finely tuned by careful selection of green coffee blends, roasting conditions, and processing technologies

Coffee

Flavour and aroma are crucial to the identity of the products, and any blend/ technology changes - however minor - to the existing products will have major impact on the organoleptic properties [2, 3, 4].

Chicory

Valid as for coffee described above.

Other considerations

In the case of coffee, any minor changes to the blends / process will significantly impact the sensory properties and consumer acceptance.

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Final Preparation: Product storage/shelf-life/consumer preparation

Potato (Potato products for frying, roasting, baking, but mainly French fries and potato crisps)

User advice

French fries:
cook until a golden
yellow colour

French fries

Follow exactly the product specific cooking instructions on the packaging.

Frying products:

- cook at maximum 175°C for prescribed time
- do not overcook
- cook to a golden yellow colour
- when cooking small amounts, reduce the cooking time.

Oven products:

- do not overcook
- cook to a golden yellow colour
- when cooking small amounts, reduce the cooking time.

Industrial

“Fresh”

prefabricates may
have higher sugar
contents toward
end of product
shelf life if
blanching time is
too short

A study performed in Switzerland has shown that “fresh” prefabricates of French fries and hash browns stored at 4°C up to end of shelf life had relatively higher amounts of reducing sugars versus the same products that were kept frozen. The authors claim that residual enzyme activity (α -amylase) may slowly release reducing sugars during cold temperature storage [1]. The very short blanching time (5 min.) used in this study is not representative of industrial production of chilled or deep frozen French fries (blanching 15 - 45 min.).

Crisps

Storage does not influence the level of AA in the finished products.

Cereal (e.g. bread, crispbread, biscuits/bakery wares, breakfast cereals)

No impact of
storage

Biscuits and breakfast cereals

Storage does not influence the level of AA in finished products.

Toasting of bread
to a light golden
colour

Bread, toasted

Toasting bread to a light golden colour.

Coffee and Coffee Mixtures (e.g. roast and ground, soluble coffees, coffee mixtures)

Lab scale

AA amounts in
roast coffee
decrease over
storage. Studies
into the
mechanisms of
reduction are
confirming this but
no options
identified to
influence this

Coffee

Brewing: typical household and non-household brewing equipment transfers the AA of the roast coffee almost completely into the beverage. Espresso brewing may however shows lower transfer rates due to specific extraction conditions [2].

Soluble Coffee vs. Roast Coffee: similarly, in soluble coffee AA is efficiently extracted and concentrated into the final soluble coffee. After preparation/brewing the cup/beverage levels for roast coffee and soluble coffee are similar due to different typical recipes (with ca. 5-7g for roast coffee resp. ca. 2 g of soluble coffee per cup).

reaction apart from increasing the temperature of storage

Shelf-life: AA amounts in packed roast coffees decrease over storage time [2, 3]. This is based on a temperature-dependent reaction. However, an immediate mitigation opportunity is not expected as freshness is one of the key quality parameters for coffee [4]. Research to determine the fate of AA in roasted coffee during storage indicated that AA interacts with the coffee matrix by an as yet unknown mechanism and that the bound AA remains in the filter residue after brewing and is not extracted into the brew at typical brewing conditions [6]. No measures have been identified to date that influence this process (other than increasing the storage temperature).

Chicory

Similar behaviour in coffee mixtures as compared to pure soluble coffees [3].

Other considerations

Other risk factors such as spoilage susceptibility resulting from mitigation measures must be taken into account.

Finish frying (catering)/ optimization of the fryer temperature program is important to ensure that temperature does not drop below a given limit after loading the fryer [5].

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Annex 1. Tools successfully tested at industrial level to mitigate acrylamide (AA)

Toolbox Compartment				
Product Category	Agronomical	Recipe	Processing	Final Preparation
French fries	<ul style="list-style-type: none"> - Choose potato varieties with low sugar levels - Don't use potatoes stored < 6°C - Control the levels of reducing sugars (target < 0.4 % fresh wt) or fry test the potatoes 	-	<ul style="list-style-type: none"> - Blanch potato strips in hot water for a longer period of time to remove reducing sugars - Cut thicker strips 	<ul style="list-style-type: none"> - Follow on-pack instructions - Control the temperature & time of final cooking - When cooking smaller amounts, reduce cooking time - When frying, do not cook > 175°C - Aim for a light golden colour
Potato crisps	<ul style="list-style-type: none"> - Choose potato varieties with low sugar levels - Don't use potatoes stored < 6°C - Control the levels of reducing sugars (target < 0.3 % fresh wt) or fry test the potatoes 	-	<ul style="list-style-type: none"> - Control the temperature/time of cooking & final moisture content - Vacuum frying is an alternative - If flash frying : ensure rapid cooling - In-line color sorting to remove dark crisps 	-
Bread	<ul style="list-style-type: none"> - For wheat grain, the importance of maintaining sulfur levels in the soil must be stressed to farmers 	<ul style="list-style-type: none"> - Avoid adding reducing sugars in the recipe - The addition of calcium salts, e.g. calcium carbonate and sulphate, may reduce the formation of AA 	<ul style="list-style-type: none"> - Control the baking time and temperature to prevent excessive browning in the crust 	<ul style="list-style-type: none"> - When toasting bread, aim for a light golden color
Crispbread	<ul style="list-style-type: none"> - For wheat grain, the importance of maintaining sulfur levels in the soil must be stressed to farmers 	-	<ul style="list-style-type: none"> - Non-fermented crispbread: control process temp. and oven speed - Control the final moisture content 	-
Biscuits/bakery wares	<ul style="list-style-type: none"> - For wheat grain, the importance of maintaining sulfur levels in the soil must be stressed to farmers 	<ul style="list-style-type: none"> - Replacement of ammonium bicarbonate with other raising agents - If possible avoid using fructose 	<ul style="list-style-type: none"> - Asparaginase is a tool for certain biscuit and cereal applications - Do not overbake 	-
Breakfast cereals	<ul style="list-style-type: none"> - For wheat grain, the importance of maintaining sulfur levels in the soil must be stressed to farmers 	<ul style="list-style-type: none"> - Minimise reducing sugars in the cook phase - Consider the contribution of other inclusions e.g. roasted nuts, dried fruits 	<ul style="list-style-type: none"> - Do not over bake or over toast - Manage the toasting to achieve a uniform colour for the product 	-