ACRYLAMIDE TOOLBOX 2019

FOODDRINK EUROPE

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CONTENTS

KEY CHANGES TO THE ACRYLAMIDE TOOLBOX SINCE 2013

- Existing tools have been examined and categories adjusted as appropriate.
- Potato-based products have been split into two categories – Potato-Based Snacks versus French Fries and other cut, (deepfried) Potato Products. While some of the tools are applicable to both categories there are a number of tools that, when implemented in both categories, don't deliver the same mitigation results due to processing and finished product attributes. French fries and other cut, (deep-fried) Potato Products are **not** ready-to-eat products like the Potato-Based Snacks, but still need final cooking by food business operators (FBO) or final consumers at home.
- Coffee products have also been split into two categories – Coffee and Coffee substitutes (mainly based on cereals and chicory). While there are certain similarities between the two categories, it was deemed more accurate to examine the categories separately when it came to mitigation measures.
- The section on Methods of Analysis and Sampling has been re-written to better describe issues surrounding measurement uncertainty, to describe the relevant requirements of the recent Commission Regulation[1], and also to describe CEN standardisation work on methods of analysis for Acrylamide in certain foodstuffs.
- Latest scientific publications and project updates (e.g. BBSRC LINK: producing low acrylamide risk potatoes/ wheat varieties) are included.

1 Commission Regulation (EU) 2017/2158 establishing mitigation measures and benchmark levels for the reduction of the presence of acrylamide in food. FBOs are to follow the procedures necessary to meet targets set to achieve the objectives of the Regulation and to employ sampling and analysis as appropriate to maintain their own performance.

SUMMARY

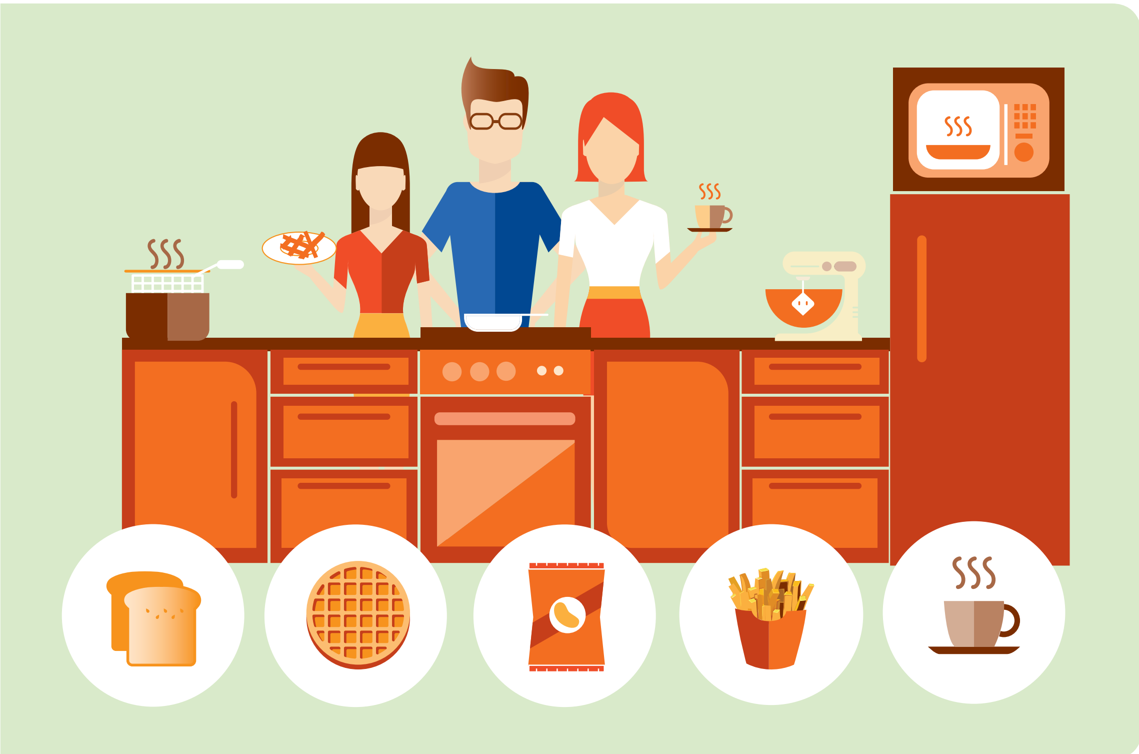
The FoodDrinkEurope Acrylamide "Toolbox" reflects the result of more than 15 years of cooperation between the food industry and national authorities of the European Union to investigate pathways of formation of acrylamide and potential intervention steps to reduce exposure.

The aim of the Toolbox is to provide national and local authorities, manufacturers (including SMEs) and other relevant bodies with brief descriptions of intervention steps which may prevent and reduce formation of acrylamide in specific manufacturing processes and products. As such, this toolbox is a useful tool to correctly implement Commission Regulation (EU) 2017/2158. It is in particular intended to assist individual manufacturers, including SMEs 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 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.

The Toolbox is not meant as a prescriptive manual nor a formal guide. 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:
http://www.fooddrinkeurope.eu/publication/fooddrinkeurope-updates-industry-wide-acrylamide-toolbox/

As of the 12th Revision of this document in 2009, FoodDrinkEurope has included information from food and beverage manufacturers in the USA, provided through the Grocery Manufacturers Association (GMA). This corroborates the global applicability and use of the Acrylamide Toolbox.

Lastly, to assist SMEs in the implementation of the Toolbox, FoodDrinkEurope and the European Commission, Directorate General for Health and Food Safety (DG SANTE), 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 22 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 new finding that many heated foods contained significant levels of acrylamide, a substance which until then was only known as a highly reactive industrial chemical, present also at low levels for example in tobacco smoke. 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.

A wide range of cooked foods – regardless of being prepared industrially, in catering, or at home – were found to contain acrylamide at levels ranging from a few parts per billion (ppb, mg/kg) to levels 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.

The toxicological data at the time suggested that this substance might be – directly or indirectly – carcinogenic for humans. Therefore, the European food and drink industry, working closely with the European Commission, national authorities and the wider scientific community, dedicated significant resources into researching the carcinogecity of the chemical, to better understand how it formed and to develop tools and techniques which could be used to mitigate its formation. 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. The latest JECFA evaluation of acrylamide published in 2010 confirmed the previous evaluations and concluded that a human health concern is indicated. However, JECFA also concluded that more data is needed to better estimate the risk from food consumption. At the EU level, progress in the research on acrylamide has been shared openly and regularly through stakeholder meetings, workshops and forums.

Since 2002 there have been a number of risk assessments undertaken for acrylamide (AA), the most recent of which was carried out by the Scientific Panel on Contaminants in the Food Chain (CONTAM) of the European Food Safety Authority (EFSA)[2]. The CONTAM Panel concluded that although the available human studies have not demonstrated that acrylamide is a human carcinogen, the Margin of Exposure (MOEs) based on the current levels of dietary exposure to acrylamide across surveys and age groups indicate a concern with respect to carcinogenic effects.

As no single solution exists to reduce AA levels in the range of foods in which it has been found, the food industry has taken on collective responsibility for the development of guidance on techniques which are known to be under development and also on steps which have been found to be practical in a commercial environment.

The resulting FoodDrinkEurope 'Acrylamide Toolbox', first published in 2005, is supported by the EU and national authorities, and represents the most complete collection of knowledge on AA formation and mitigation across a variety of foodstuffs. The present text is the 15th edition incorporating latest developments and knowledge. It also helps FBOs within the EU to comply with the requirements of Regulation (EU) 2017/2158.

The efforts of the food industry are on-going, as in many cases there are no easy (single) solutions due to the complexity of factors to be considered. This requires further research, which also includes work with academics, e.g. to reduce the natural occurrence of the precursor (e.g. asparagine) in raw materials.

2 EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain), 2015. Scientific Opinion on acrylamide in food. EFSA Journal 2015;13(6):4104, 321 pp. doi:10.2903/j.efsa.2015.4104 Available online: www.efsa.europa.eu/efsajournal

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.

Other theoretical 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. 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. In some product types it has been found that the acrylamide content decreases during storage. This has been observed in packed roast coffees where it is based on a temperature-dependent reaction.

Both asparagine and sugars are not only important and desirable nutrients, naturally present in many foods, but 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.

It is essential to take into account 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 highly dependent on natural variations in raw materials.

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

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 into account the huge variability between product recipes, designs of processes and equipment, and brand-related product characteristics even within a single product category.

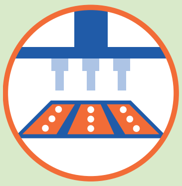
The following 14 parameters, grouped within each product category have been identified. (Note: Each parameter may not be applicable within all categories of products).

Agronomy

- Reducing Sugars
- Asparagine

Recipe (Basic Formula, Ingredients, Product Form)

- Raising/Leavening Agents
- Other Minor Ingredients (e.g. glycine and divalent cations)
- pH
- Rework
- Dilution/Piece Size
- Fermentation



Processing

- Thermal Input & Moisture
- Asparaginase
- Pre-Treatment
- Finished Product Colour
- Texture/Flavour

Final Preparation

- Consumer or End User Guidance

The main food categories/sub-categories defined in the Toolbox are as follows:

Potato-based snacks

- French fries and other cut, (deep fried) potato products

Cereal/Grain-based products

- Fine bakery wares
- Breakfast cereals

Fine bakery wares

- Biscuits
- Crackers
- Wafers
- Crisp Bread
- Gingerbread

Breakfast cereals

Coffee

- Roast and ground coffee
- Instant (soluble) coffee

Coffee substitutes (mainly based on cereals and chicory)

Baby biscuits, infant cereals and baby foods other than cereal-based foods

- Baby biscuits
- Infant cereals
- Baby foods other than cereal-based foods

However, it needs to be emphasised that **there is in most cases no single solution to reduce acrylamide** in foods, even within 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 and desired final product design.

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.

- **Commercial Application**: 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 and desired final product design. The validation of the suggested tools was assessed over the product shelf life. The legal status of the proposed measures has been evaluated.

- **Development**: These concepts have been evaluated in the pilot plant or in test runs in the factory and were successful to some extent to deliver measurable reductions, but not yet applied successfully under commercial production conditions. These tools may still have some risks to product attributes and/or inconsistent mitigation results. There may also be new applications of existing technologies, or tools at an agronomical level.

- **Research**: 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.

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 FoodDrinkEurope.

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 FoodDrinkEurope's intention to continuously update the Toolbox so as to reflect such developments.

THE CONCEPT OF ALARA

In light of the conclusions of the EFSA's risk assessment on acrylamide in food, the food industry should continue to reduce acrylamide in food products. The complete elimination of acrylamide from food is not possible. Therefore the principle objective shall be to reduce levels in food to as low as is reasonably achievable (ALARA).

ALARA AS APPLIED TO ACRYLAMIDE

In the context of acrylamide and other process contaminants, which are the result of naturally occurring chemical reactions in heated foods and for which there are currently no levels that regulators have agreed upon as being 'safe'. ALARA means that the FBO should make every reasonable effort (based upon current knowledge) to reduce levels in the final product and thereby reduce consumers exposure. ALARA could for example mean that an FBO changes parts of a process or even a whole process if technologically feasible.

The tools identified within the FoodDrinkEurope Toolbox are potential measures designed to limit acrylamide levels in the final product through interventions at various stages of production (agronomical, recipe, processing, and final preparation). They are based upon scientific knowledge and practical application in specific circumstances.

As technology develops, new and better tools for acrylamide reduction may become available. As part of a continuous process FBOs should review what tools are available on regular basis, and consider whether they can implement these tools into their processes or their product.

If a FBO chooses not to implement an available tool then the onus should be placed upon the same FBO to demonstrate why its application is believed to be unreasonable or ineffective.

Considerations may include:

- potential impact that use of a known acrylamide mitigation tool will have upon levels of acrylamide in the final product;
- potential impact that use of a known acrylamide mitigation tool may have upon the formation of other process contaminants, e.g. furan, and/or reduction in control of other hazards, e.g. microbiological;
- feasibility of implementing the identified controls, e.g. legal compliance, commercial availability of the mitigation tool, occupational health hazards, timescales and costs associated with upgrading or replacing plant equipment;
- impact that use of a known acrylamide mitigation tool will have on organoleptic properties and other quality aspects of the final product as well as product safety (the ideal method would have no adverse effects);
- known nutritional benefits of using certain ingredients in preference to others, e.g. use of whole grain cereals instead of refined cereals.

METHODS OF ANALYSIS AND SAMPLING

Today, many laboratories offer sensitive and reliable methods to analyse acrylamide in a wide range of foods. Previous issues with the extractability of acrylamide in certain food matrices were raised showing that a high extraction pH may significantly enhance the yield of acrylamide versus extraction under neutral pH. Work done by independent research groups 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 of reliable analytical methods is of major importance.

The main challenge for the analyst is the high variability of the food products themselves. This starts from the natural variability of a given raw material, for example 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, processing equipment capability, 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.

Also it should be noted that in the absence of a reliable rapid analytical methodology, it may not be practical for manufacturers to use existing analytical methods as a positive release control. Analysis is therefore a measurement which is more typically to be used for establishing baselines for levels in a particular product/line and for monitoring or verification of the success (or otherwise) of the mitigation steps and controls in place within a factory and the supply chain.

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.

No standardised sampling or analytical programmes can be defined within this document. In addition, the frequency of testing will depend on a wide number of factors including the variety of the raw material, seasonality, and country of origin. Subsequently at the processing plant, by the different productions lines, and process specifications.

ANALYSIS AND SAMPLING REQUIREMENTS UNDER EU LAW

FBOs within the EU should comply with the requirements on sampling and analysis requirements as specified within Annex 1 of Commission Regulation (EU) 2017/2158 establishing mitigation measures and benchmark levels for the reduction of the presence of acrylamide in food.

As regards sampling the Regulation states that:

(1) The sample shall be representative for the sampled batch.

(2) The sample shall be analysed in a laboratory that participates in appropriate proficiency testing schemes (which comply with the 'International Harmonised Protocol for the Proficiency Testing of (Chemical) Analytical Laboratories' developed under the auspices of IUPAC/ISO/AOAC) and uses approved analytical methods for detection and quantification. Laboratories shall be able to demonstrate that they have internal quality control procedures in place. Examples of these are the 'ISO/AOAC/IUPAC Guidelines on Internal Quality Control in Analytical Chemistry Laboratories'.

Wherever possible the trueness of analysis shall be estimated by including suitable certified reference materials in the analysis.

Additionally the Regulation sets minimum performance criteria for the selected method of analysis:

(3) The method of analysis used for the analysis of acrylamide must comply with the following performance criteria:

Parameter	Criterion
Applicability	Foods specified in this Regulation
Specificity	Free from matrix or spectral interferences
Field blanks	Less than Limit of Detection (LOD)
Repeatability (RSDr)	0.66 times RSDR as derived from (modified) Horwitz equation
Reproducibility (RSDR)	As derived from (modified) Horwitz equation
Recovery	75-110%
Limit of Detection (LOD)	Three tenths of LOQ
Limit of Quantification (LOQ)	For benchmark level < 125 μg/kg: ≤ two fifths of the benchmark level (however, not required to be lower than 20 μg/kg) For benchmark level ≥ 125 μg/kg: ≤ 50 μg/kg

As regards frequency the Regulation states that:

1. FBOs shall ensure that they undertake representative sampling and analysis of their products for the presence of acrylamide to verify the effectiveness of mitigation measures, i.e. that levels of acrylamide are consistently below the benchmark levels.

   Analysis of acrylamide can be replaced by measurement of product attributes (e.g. colour) or process parameters, provided that a statistical correlation can be demonstrated between the product attributes or process parameters and the acrylamide level.

2. FBOs shall ensure that a representative sample of each product type is taken for analysis of acrylamide concentration. A "product type" includes groups of products with the same or similar ingredients, recipe design, process design and/or process controls where these have a potential influence on acrylamide levels in the finished product. Monitoring programmes shall prioritise product types that have the demonstrated potential to exceed the benchmark level.

3. FBOs shall provide sufficient data to enable an assessment of the level of acrylamide and of the likelihood that the product type might exceed the benchmark level. Based on this assessment, the FBOs shall specify appropriate frequencies for analysis for each product type. The assessment shall be repeated if a product or process is modified in a way that could lead to a change in the acrylamide level in the final product.

4. FBOs shall undertake sampling and analysis at least annually for products that have a known and well-controlled acrylamide level. FBOs shall carry out higher frequency sampling and analysis of products having the potential to exceed the benchmark level.

5. If the analytical result, corrected for recovery but not taking into account the measurement uncertainty, indicates that a product has exceeded the benchmark level, or contains acrylamide at a level higher than anticipated (taking into account previous analyses, but lower than the benchmark level), then the FBOs shall carry out a review of the mitigation measures applied and shall take additional available mitigation measures to ensure that acrylamide level in the finished product is below the benchmark level. This must be demonstrated by the undertaking of a new representative sampling and analysis, after the introduction of the additional mitigation measures.

6. FBOs shall make the analytical results obtained from the analysis every year available on request to the competent authority together with descriptions of the products analysed. Details of mitigation measures taken to reduce levels of acrylamide below the benchmark level shall be provided for those products exceeding the benchmark level.

EUROPEAN COMMITTEE ON STANDARDISATION (CEN)

FBOs should also be aware that the CEN has published a method for the determination of acrylamide in bakeryware such as bread, toasted bread, crisp bread, butter cookies, and biscuits, as well as potato products such as potato chips, potato crisps, and potato pan cake and roasted coffee, by liquid chromatography in combination with electrospray ionization and tandem mass spectrometry (LC-ESI-MS/MS). This method has been validated in an interlaboratory study via the analysis of both naturally contaminated and spiked samples, ranging from 14,3 µg/kg to 9 083 µg/kg.

— EN standard 16618: 2015 Food analysis – Determination of acrylamide in food by liquid chromatography tandem mass spectrometry (LC-ESI-MS/MS)

CEN has also recently published a Technical Specification which specifies a method for the determination of acrylamide in cereal-based products, potato-based products and coffee by gas-chromatography mass spectrometry (GC-MS). The method has been single-laboratory validated via the analysis of spiked samples (French fries (uncooked), bread, water biscuit, infant cereal, biscuit, green coffee, roast coffee and instant coffee), ranging from 30 µg/kg to 1 500 µg/kg acrylamide. In addition, this method has also been studied by interlaboratory trial via the analysis of samples containing incurred acrylamide, ranging from approximately 200 µg/kg to 2 000 µg/kg. The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

— CENT/TS 17083:2017 Determination of acrylamide in food and coffee by gas chromatography-mass spectrometry (GC-MS)

MEASUREMENT UNCERTAINTY

Whilst many laboratories are able to analyse for acrylamide, there are many issues regarding intra-laboratory and intra-country competency that should be considered. For example in its 2009 scientific report on the *Results on the monitoring of acrylamide levels in food* (EFSA Scientific Report (2009) 285: 11), EFSA identified that for some commonly employed analytical methods there was still significant measurement uncertainty (MU) between results presented by different European Union Member States. The reported MU for LC-MS ranged between 6 and 53%, and for GC-MS between 0 and 64%. Furthermore the minimum and maximum values for LOD and LOQ ranged from 1 to 250 and from 3 to 500 µg/kg, respectively.

Therefore a further potential confounding factor for FBOs, on top of the natural variability within product, will be laboratory to laboratory and country to country comparability. Irrespective of the analytical method used, consideration should be given to the minimum requirements for submitting data to EFSA. These include a 'Limit of Quantification' of 50 µg/kg, based upon the data call made in June 2013.

It is best practice to check accreditation ISO/IEC 17025:2005 and validated methods of analysis before choosing to work with a laboratory.

FURTHER REGULATORY COMPLIANCE ISSUES

Any intervention must be evaluated for its wider regulatory impact, e.g. 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 for implementation/commercialisation.

In the case of the enzyme asparaginase, companies are today producing a commercial food-grade enzyme. As patent holders worlwide, they may sub-license the rights to food manufacturing and processing companies to incorporate asparaginase in their food production processes to lower the amounts of acrylamide.

GRAS status ("Generally Recognized As Safe") has been obtained from the USA 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 internationally.

Please also note that this non-exhaustive list covers countries where the products are either officially approved under specific conditions of use or where there are no legal restrictions for marketing:

Angola, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belgium, Benin, Bolivia, Bosnia-Herzegovina, Botswana, Burkina Faso, Burundi, Canada,Cambodia, Cameroon, Central African Republic, Chile, China, Columbia, Democratic Republic of Congo, Croatia, Cuba, Cyprus, Czechia, Denmark, Ecuador, Equatorial Guinea, Estonia, Ethiopia, Faroe Islands, Finland, France, F.Y.R.O.M., Gabon, Georgia, Germany, Ghana, Greece, Guinea, Guinea-Bissau, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Italy, Ivory Coast, Jordan, Kenya, Laos, Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Luxembourg, Madagascar, Malawi, Malta, Mexico, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Nigeria, Norway, Oman, Pakistan, Paraguay, Poland, Portugal, Qatar, Romania, Rwanda, Russian Federation, San Marino, Senegal, Singapore, Slovenia, Somalia, South Africa, Spain, Sri Lanka, Swaziland, Sweden, Syria, Tanzania, Togo, Tunisia, Uganda, United Arab Emirates, United Kingdom, USA, Vanuatu, Venezuela, Yemen, Zambia, Zimbabwe.

In November 2014, a genetically modified potato that silences several genes associated with asparagine production, along with genes that lead to bruising, was granted regulatory approval within the USA. Regulators in Australia and New Zealand are also currently reviewing the potato. Within Europe there is no current authorisation or application for its use.

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, decomposition of natural toxins or inadvertent formation of other undesirable substances). 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. Additional considerations are as follows:

- Frying potatoes at lower temperatures to a comparable endpoint can reduce acrylamide formation, but will require longer cooking times and may 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 (placing the mitigation measure in direct conflict with sodium programmes in many parts of the world). Recently, a risk-benefit analysis has been conducted on increased sodium intake as a potential risk factor for cardiovascular disease against the (presumed) risk of acrylamide exposure. Mitigation of acrylamide in biscuits and ginger bread was accompanied by a small increase in sodium intake. Around 1.3% of the population shifted from a sodium intake below to above 40 mg/kg body weight/per day.

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

It is important that food manufacturers 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 should be noted that measures aimed at reducing levels of acrylamide cannot be isolated from other considerations. Precautions need to be taken to avoid compromising the existing chemical and microbiological safety of the food. The nutritional qualities of products also need to remain unimpaired, together with their organoleptic properties and associated consumer acceptability. This means all minimisation strategies need to be assessed with regards to their benefits and any possible adverse effects. For example:

- When preventative measures for acrylamide are considered, checks should be made to ensure that they will not result in an increase in other process contaminants. These may include, for example, aldehydes, hydroxymethylfurfural, N-nitrosamines, polycyclic aromatic hydrocarbons, chloropropanols, ethyl carbamate, furan, heterocyclic aromatic amines and amino acid pyrolysates.
- Preventative measures devised for acrylamide must not compromise the microbiological stability and safety of the final product. In particular, attention needs to be paid to the moisture content of the final product, and in the case of jarred baby foods that the heat treatment is effective to reduce the microbial load to an acceptable level.
- It is recognised that acrylamide mitigation can cause detrimental changes to the organoleptic properties of the final product. The formation of acrylamide is intimately associated with the generation of the characteristic colour, flavour and aroma of cooked foods. Proposed changes to cooking conditions, or indeed raw materials and other ingredients, must be assessed from the perspective of the acceptability of the final product to the consumer.
- Preventative measures devised for acrylamide must not compromise the nutritional quality of the product as outlined above.
- Formal safety assessments, efficacy-in-use demonstration and regulatory approval may be needed for potential new additives, enzymes, and processing aids such as asparaginase. Some companies are producing asparaginase for use in food products and some countries have approved it as a processing aid.
- It should be noted that the extent of acrylamide formation can be quite variable, e.g. within a production batch made at the same manufacturing plant, or between plants using the same process, ingredients and formulations.
- Manufacturers need to be aware that variability in incoming raw materials and poorly controlled heating devices can complicate trials of mitigation strategies, by potentially obscuring changes in acrylamide levels.

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. 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.

ACRONYMS USED

AA	Acrylamide
ALARA	As Low As Reasonably Achievable
Asn	Asparagine
Asp	Aspartate
BBSRC	Biotechnology and Biological Sciences Research Council (UK)
BLL	Bund für Lebensmittelrecht und Lebensmittelkunde e.V. (German food and drink manufacturers' association)
CAOBISCO	Association of the Chocolate, Biscuits and Confectionery Industries of the EU. For sector specific activities please consult: http://caobisco.eu/
CEEREAL	European Breakfast Cereal Association. For sector specific activities please consult: http://www.ceereal.eu/asp2/welcome.asp
FOODDRINKEUROPE	Organisation of Europe's food and drink industry
CCCF	Codex Committee on Contaminants in Foods
CEN	European Committee for Standardization/Comité Européen de Normalisation
Codex	Codex Alimentarius Commission
EC	European Commission
ECF	European Coffee Federation. For sector specific activities please consult: http://www.ecf-coffee.org/
ESA	European Snack Association. For sector specific activities please consult: http://www.esasnacks.eu
EFSA	European Food Safety Authority
EUPPA	European Potato Processors' Association. For sector specific activities please consult: http://www.euppa.eu/en/
FBO	Food Business Operator
FDA	Food and Drug Administration
FEI	Research Association of the German Food Industry
GAP	Good Agricultural Practice
GC-MS	Gas Chromatography-Mass Spectrometry
Gln	Glutamine
Gly	Glycine
HACCP	Hazard Analysis and Critical Control Points
JECFA	Joint FAO/WHO Committee on Food Additives
LC-MS	Liquid Chromatography-Mass Spectrometry
LINK	UK government/industry co-funded collaborative research for innovative and industrially-relevant research
LOD	Limit of Detection
LOQ	Limit of Quantification
MU	Measurement Uncertainty
SCF	Scientific Committee on Food (EU)
SME	Small and Medium size Enterprises
WHO	World Health Organization

POTATO-BASED SNACKS

Snacks made from potatoes *(Solanum tuberosum)* whether sliced and fry or fabricated products made from potato based ingredients (flakes, granules, etc.).

AGRONOMY: REDUCING SUGARS

General Considerations

Reducing sugars are one of the key reactants for the formation of AA and in the context of potato-based products the key reducing sugars are fructose and glucose. The sugar content of the tuber correlates well with the AA concentration in the product especially if the fructose/Asn ratio is <2.

The concentration of reducing sugars is generally regarded as a good indicator of the relative AA-forming potential of different batches of tubers of the same potato variety.

Commercial Application

- **Minimising reducing sugars is part of standard manufacturing practices**
- **Control of tuber storage temperature identified as good practice**
- **Use of sprout suppressants, where legally permitted, to prevent sweetening during storage**
- **These measures are implemented throughout the industry**

Controlling reducing sugars is currently the primary measure employed by the industry to reduce AA levels in potato-based snacks. This is achieved through:

- Selection of potato varieties with reducing sugar concentrations that are suitable for the product type.
- Minimising the risk of high reducing sugars by growing those low-sugar varieties best suited to the local growing conditions, by appropriate field selection, and by adherence to agronomy best practice.
- Ensuring tubers are mature at time of harvesting (immature tubers tend to have higher reducing sugar levels).
- Selecting lots based on reducing sugars content.
- Controlling storage conditions from farm to factory, e.g. managing temperature (at least above 6°C for long term storage, but temperature specified for the individual potato variety stored), and humidity to minimise senescent sweetening. Reduction of tuber sprouting with permitted sprout suppressants or techniques, and following GAP. For potatoes stored at lower temperatures, reconditioning at higher temperature (e.g. ambient) over a period of a few weeks. Storage conditions should always be appropriate for the specific variety.
- Selecting potato-based raw materials (flakes or granules) with the lowest possible reducing sugar level to deliver the appropriate product attributes.

[Note: Potato flakes are not typically produced from specific potato varieties, and so have the potential to be a highly variable ingredient, however there are a number of mitigation tools available to reduce levels of reducing sugars. Commission Regulation (EU) 2017/2158 requires that for each product, FBOs shall specify target values for reducing sugars in their dehydrated potato ingredients, and that the target value of reducing sugars in the products concerned shall be set as low as feasibly possible, taking into account all relevant factors in the design and production of the finished product such as the amount of potato ingredients in the product recipe, further possible mitigation measures, further processing of the dough, seasonality and the moisture content in the finished product. Where the content of reducing sugars is higher than 1.5% the FBOs shall provide data demonstrating that the level of acrylamide in the finished product is as low as reasonably achievable and that the benchmark level is achieved].

Future Opportunities

Breeding new potato varieties with lower reducing sugar content and/or less cold sweetening effect. Further optimise agricultural practices to minimise reducing sugars and Asn.

AGRONOMY: ASPARAGINE

Development	
Selection of crop varieties on the basis of typical free Asn: total free amino acids ratio	Recent research suggests that the impact of farming practices (e.g. fertiliser regimes) may have an effect on amino acid ratios in potatoes. Nitrogen and sulphur fertilisation may alter the ratio of free Asn/total free amino acids in a tuber, and research has suggested that this ratio is potentially of greater significance to the formation of AA in potatoes than previously thought: in particular, the Asn/glutamine (Gln) ratio. However, the effects of fertilisation are variety-specific, and so far no optimum amino acid ratio in potato has been established.

Research	
Control of Asn levels in tubers **Farming practices, e.g. fertiliser regimes** **Laboratory and field studies with new potato varieties**	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 weight, and 20-60% of total free amino acids. Asn levels do not correlate to reducing sugar levels. Also, on its own, the reducing sugar concentration of potatoes is not always directly proportional to the AA concentration observed in a potato product. The concentration of free Asn and the ratio of free Asn to other free amino acids (of which Gln is by far the most abundant) contribute to the variance in AA-forming potential, and should also be considered as indicators of the relative AA risk of different potato varieties. Varieties with a lower ratio of Asn to other free amino acids would be expected to have lower AA risk (for a given reducing sugar content). 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/amino acids levels Generally, increased nitrogen fertilisation raises the AA-forming potential of potatoes, and nitrogen fertilisation should be kept at the minimum level to ensure the health and yield of the crop. Sulphur fertilisation may mitigate the effect of high levels of nitrogen fertilisation. However, the effects of fertilisation levels are highly variety-specific and no general advice has been issued. In field trials in the USA, new potato varieties with reduced expression of an Asn synthetase genes in the tuber have up to 5-fold reduced amounts of free Asn. Heat-processed products derived from such tubers show comparable sensorial properties to their conventional counterparts, and much lower levels of AA (50-75% reduction). These varieties, two of which are now available for commercial cultivation, are considered to be GMO. At the time of writing such potatoes are not yet approved for commercial production within the EU, therefore the regulatory status should be checked.

General Considerations

- Effect of optimisation of the reducing sugar content in the raw materials on other components influencing nutritional properties.
- Minimising reducing sugar content needs to be balanced against processing methods and final product characteristics (colour, flavour, etc.).
- Elimination of defective materials as part of standard good manufacturing practice has proven to be an effective measure to reduce AA in the final product. This can be done through working with suppliers to ensure that incoming potatoes are checked whilst in storage, and again at plant, for defects (e.g. bruising and damage, viruses such as Spraing/TRV, fungal diseases, storage rots).

RECIPE: OTHER MINOR INGREDIENTS (AMINO ACIDS, CALCIUM SALTS AND CO-INGREDIENTS)

Commercial Application	
Certain minor or co-ingredients have the potential to contain comparatively high levels of AA which could impact upon levels in the final product	**Dough-based potato crisps, snacks and crackers** **Co-ingredients** Techniques associated with the production of some minor ingredients could result in high levels of AA in those ingredients, e.g. pre-processed cereals, processed sugars such as molasses, or certain processed spices/ flavourings used in the dough. These could potentially raise overall AA levels in the final product. There may be an impact with co-ingredients included in a composite product (e.g. pre-processed cereal pieces, vegetables, nuts, seeds) where they could be "cooked" several times over. This needs to be deliberately taken into account in product design, processing practices, and issues with processing equipment and performance.
Development	
In some wet dough-based systems, it may be possible to use the following substances, taking into account the requirements of the specific end product, and its production methods: ▶ **Amino acids** ▶ **Calcium salts**	**Dough-based potato crisps, snacks and crackers** **Amino acids** — Other amino acids may compete with Asn and can thereby reduce AA formation, or they may chemically react with AA, e.g. through Michael Addition. Shifting the balance away from Asn may help to reduce AA formation. — In some wet dough-based potato snacks, the addition of amino acids at levels showing a reduction in AA can produce unacceptably high levels of browning and bitter off-flavours. — At lower levels, amino acid use may have an AA-reducing effect while still maintaining acceptable colour impact. **Calcium salts** — Treatment of potato flakes with calcium salts during their production or addition of calcium salts in the dough recipe have demonstrated up to 30-40% reduction dependent on the product design and formulation. Too high levels can, however, generate undesirable product attributes.

RECIPE: PH

Commercial Application	
Addition of Acids – The use of acids and their salts has been successfully proven effective at commercial scale in some products	**Dough-based potato crisps, snacks and crackers** **Addition of acids and their salts** Addition of citric, lactic or ascorbic acid has been found to successfully reduce AA and is used commercially for some types of wet dough-based potato crisps, snacks and crackers. However, addition of acids to some products produced strong off-flavours. This taste impact was not observed in other cases – potential for success is very variable dependent on product design. Studies so far show that the effect of acids is dependent on the product design and can lead to quality issues unless carefully controlled.
Research Technologies Tested at Bench Scale	
Combined treatment of acid and glycine can be applied to balance flavour formation	**Acidulants in combination with Glycine (Gly)** In a potato cake model, the combined treatment of citric acid and Gly (each 0.39% in the recipe) had an additive effect in reducing the AA concentration. Citric acid inhibits certain flavour formations, compensated by the addition of Gly which favours the formation of certain volatiles.

RECIPE: DILUTION AND PIECE SIZE

Commercial Application	
Partial replacement with ingredients lower in key reactants can be effective	**Dough-based potato crisps, snacks and crackers** For some dough-based potato crisps, snacks and crackers, partial replacement of potato components by ingredients lower in key reactants can reduce AA formation potential, e.g. use of cereals with lower Asn amounts than potato, such as wheat, rice, or maize in the recipe. (Note: the possibility to amend recipes through substitution is limited by the impact upon the characteristics of the products e.g. expansion rates, texture, flavour).
Slice/piece thickness can reduce AA through the surface area/volume effect when taking into account finished product moisture and fry temperature profile	**Sliced Potato Crisps** In products that are fried to low moistures, reducing the surface to volume ratio (by producing a thicker cut crisp) may theoretically result in higher AA formation potential as it will require a higher temperature, or a longer fry time to reach the same moisture end. A thin cut potato crisp product would theoretically require less thermal input for the same fry time to reach the same moisture endpoint, and so offers lower AA forming potential. Slice thickness is, however, an important product characteristic for sliced potato crisps and is difficult to address without fundamentally altering the finished product.

RECIPE: FERMENTATION

Development	
Lower levels of AA can be achieved by fermentation	**Dough-based potato crisps, snacks and crackers** Fermentation reduces levels of key reactants for the formation of AA, and lowers the pH. The 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 and will potentially create off-tastes and reduce product stability.

General Considerations

There may not always be a synergistic effect derived from use of multiple recipe mitigation steps, i.e. specifically applying to asparaginase (see below) and lowering pH.

PROCESSING: ASPARAGINASE

Commercial Application	
Asparaginase may reduce AA in reconstituted dough-based products, but off-flavours can be created in some recipes	**Dough-based potato crisps, snacks and crackers** Asparaginase can significantly reduce the levels of AA in fabricated potato-based products. On a commercial scale the enzyme's effectiveness is recipe- and process-dependent and requires a delicate balance of reaction conditions and contact time to be effective. In some recipes, the excess Asn in potatoes may result in by-products (aspartic acid and ammonia) that can be formed in sufficient quantities to impart off-flavours.
Research	
Asparaginase may reduce AA in an optimised laboratory environment which, however, differs significantly from an industrial setting	**Sliced potato crisps** Treatment of fresh slices of potato with asparaginase has been found to be ineffective in pilot and industrial settings. This is because the enzyme cannot penetrate the potato slice/cell walls sufficiently to act upon the asparagine. Extended soak/pre-treatment of such thin slices of potato with asparaginase results in disintegration of the slice structure.

PROCESSING: THERMAL INPUT & MOISTURE

General Considerations

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 at a lower product temperature to optimise colour development and minimise AA formation.

Commercial Application	
Thermal input controls AA formation in the finished product **Controlling moisture helps to manage cooking control**	**Sliced and dough-based potato crisps, snacks and crackers** 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. Vacuum frying may not deliver desired product attributes given the lack of Maillard compounds formed. Additionally vacuum frying leads to much harder products and significantly changes the product characteristics. — For manufacturers that use high temperature flash-frying, rapid cooling helps to reduce AA formation. — Moisture regime in the fried product is critical for successful industrial implementation of cooking control. Hence, it is important to fry to the maximum end moisture content that makes an acceptable product. The target moisture level should be set as high as feasibly possible on a specific line and for a specific product, in line with expected quality and food safety standards, and taking into account relevant factors. The absolute minimum moisture content for sliced and dough-based potato crisps, snacks and crackers should not be lower than 1.0%. The baking/drying/frying exit temperature should be as low as feasibly possible on a specific line and for the specific product, in line with expected quality and food safety standards, and taking into account relevant factors. For sliced potato crisps typically the fryer exit temperature should not be higher than 168°C, whereas for dough-based potato crisps, snacks and crackers – where there are a greater variety of production methods, recipes and available mitigation measures – typically the temperature at the end of the baking/drying/frying process should not be higher than 175°C.

Other Considerations

FBOs should consider the effect of reducing the frying temperature on the fat content of the finished product (i.e. dropping the outlet frying temperature by about 5°C from design may lead to an increase in fat uptake when frying to the same moisture endpoint).

Although higher moisture levels may be an effective tool to reduced AA formation FBOs should also consider the subsequent impact this may have on product quality, shelf life, and/or microbiological damage.

FBOs should consider the effect of incomplete cooking on moisture levels in products, and the subsequent impact this may have on product quality, shelf life, and/or microbiological damage.

[Note: Most pellet products are fried at temperatures higher than 175°C because of their very short frying time and the temperatures needed to achieve the required expansion and texture of these products.

Furthermore, programmes to reduce sodium in pellet products can have unintended consequences with regards to the need to fry at higher temperatures to achieve the same expansion and texture].

PROCESSING: PRE-TREATMENT (E.G. WASHING, BLANCHING, DIVALENT CATIONS)

Commercial Application	
Blanching of potato sticks prior to processing	**Sliced potato crisps (Potato stick products only)** Blanching of potato stick-type products (sliced from whole potatoes) to remove sugars has been proven to reduce AA levels, in some product designs, without the same degree of negative side-effects affects on flavour, texture and oil content uptake as seen with standard sliced potato crisps. [Note: Some manufacturers report that, in some product designs, blanching does still have an impact upon texture].
Development	
Peeling and washing of potatoes prior to processing **Blanching of potato slabs prior to flake/granule production and blanching of potato slices**	**Sliced and dough-based potato crisps, snacks and crackers** It has been reported that in some potato varieties reducing sugars have been found at higher levels in the peel layer, and that peeling can help in overall reduction in these cases. However, the impact of peeling on overall AA levels is highly dependent on the potato variety and season. Blanching may be an option in the production of potato flour, flakes or granules. However blanching of sliced potato crisps is not desired as it results in loss of flavour, loss of texture and increased oil content of the finished product due to the disruption to the potato cells on the surface of the slices, and therefore is not a preferred mitigation tool.
	Sliced potato crisps Snacks machinery manufacturers have recently introduced patented Pulse Electric Field (PEF) technology. The PEF process works by perforating the cell walls of a potato slice, creating 'micro' holes that allow Asn and reducing sugars to be washed out of the potato in a cold wash. Whilst this technology has not proven to be effective in all applications, some companies have succeeded in using PEF as an alternative to blanching where the tubers are of a lower quality (i.e. higher reducing sugars content).

The addition of di- and tri-valent cations has been proposed to reduce the formation of AA	**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. Sensorial tests from laboratory scale 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. — The use of magnesium chloride gave rise to serious off-tastes.
Research	
The use of an acrylamide reducing yeast (ARY) has been proposed to reduce the availability of Asn prior to and/or during processing	**Dough-based potato crisps, snacks and crackers** Laboratory scale research using a patented, non-GMO, Asparaginase-expressing baker's yeast strain *(Saccharomyces cerevisiae)* has reported a reduction of up to 83% AA in potato-based snacks but has yet to be scaled up to a commercial production level in this food category. The yeast has been granted GRAS status in the USA. The yeast works by breaking down Asn in the raw ingredients into aspartate (Asp) and ammonia (nitrogen). Like Asparaginase treatments, the tool requires sufficient contact time to be effective, and the yeast's efficacy will be recipe and process dependent. For sliced potato crisps the yeast cannot penetrate the potato slice/cell walls sufficiently to act upon the asparagine. Extended soak/pre-treatment of such thin slices of potato with the yeast could result in disintegration of the slice structure (as with asparaginase).

PROCESSING: FINISHED PRODUCT COLOUR

Commercial Application	
In-line colour (optoelectronic or manual) sorting can be an effective measure to remove darker products which may in turn have a higher AA level **Finished product colour**	**Sliced and dough-based potato crisps, snacks and crackers** Elimination of darker coloured products by in-line colour sorting (optoelectronic or manual) has proven to be an effective measure to reduce AA. Darker coloured products are more likely to have come from individual potato tubers that are higher in reducing sugars, and these could potentially increase the AA level in a given sample by up to 25-50%. There is evidence to suggest that consumers dislike very pale products, however lighter coloured products could be acceptable for a consumer, if other organoleptic properties such as taste and texture are managed e.g. use of ingredients such as paprika to add back colour post-frying may compensate for lighter coloured potato crisps by providing additional colour. [Note: Within a batch of sliced potato crisps there will always be a degree of natural variation in colours, however extreme variation between individual crisps is likely to be the result of individual tubers which are higher in reducing sugars]. [Note: It is not always possible to use in-line optoelectronic sorting for potato stick-type products].

Research	
On-line or Near-line colour measurement	**Sliced and dough-based potato crisps, snacks and crackers** Continuous measurement of finished product colour may be (if properly calibrated) a reasonably reliable predictor of finished product AA-levels and could be used as a reference to demonstrate the effectiveness of an FBO's controls. [Note: Continuous measurement is more relevant for sliced potato crisps, as such products, due to variability within the tubers, will be less homogeneous than a product made from a potato dough]. However, colour alone cannot and should not be used as a substitute for sampling and analytical tests. Inference of AA based on colour would be a proxy or by-product of Maillard chemistry, i.e. colour formation which may not be equally well correlated for all product types, production lines or individual potato varieties.

Other Considerations

As part of good manufacturing practice, manufacturers should implement controls that may have an indirect impact upon AA levels in the final product, e.g. management of oil quality to ensure cooking temperatures are optimally maintained.

Removal of 'fines' from frying oil should be part of good manufacturing practices to avoid any dark over-cooked pieces' presence in pack.

FRENCH FRIES AND OTHER CUT, (DEEP-FRIED) POTATO PRODUCTS

AGRONOMY: REDUCING SUGARS

General Considerations

Reducing sugars are one of the key reactants for the formation of AA. The sugar content of the tuber correlates well with the AA concentration in the product especially if the fructose/Asn ratio is <2.

The concentration of reducing sugars is generally regarded as a good indicator of the relative AA-forming potential of different batches of tubers of the same potato variety.

Commercial Application	
Minimising reducing sugars is part of standard manufacturing practices **Control of tuber storage temperature identified as good practice** **Use of sprout suppressants, where legally permitted, to prevent sweetening during storage** **These measures are implemented throughout the industry**	Controlling reducing sugar is currently the primary measure employed by the industry to reduce AA levels in French fries. This is achieved through: — Selection of potato varieties with low reducing sugars that are suitable for the product type. Minimising the risk of high reducing sugars by growing those low sugar varieties best suited to the local growing conditions, by appropriate field selection, and by adherence to agronomy best practice. — Ensuring tubers are mature at time of harvesting (immature tubers tend to have higher reducing sugar levels). — Selecting lots based on colour assessment of a fried sample, as there is a good correlation between reducing sugar content and final fried colour. — Controlling storage conditions from farm to factory, e.g. temperature (at least above 6°C for long term storage, but temperature specified for the individual potato variety stored), and managing humidity to minimise senescent sweetening. Reduction of tuber sprouting with permitted sprout suppressants or techniques, and following GAP. For potatoes stored at lower temperatures, reconditioning at higher temperature (e.g. ambient) over a period of a few weeks. (Note: Some manufacturers have reported that for some specific potato varieties it is necessary to store potatoes at temperatures at >8°C, and that with good storage controls it is possible to keep them in good condition for longer periods of time without relying on higher amounts of sprout suppressant treatments. Storage conditions should always be appropriate for the specific variety.)

Future Opportunities

Breeding new potato varieties with lower reducing sugar content and/or less cold sweetening effect.
Further optimise agricultural practices to minimise reducing sugars and Asn.

AGRONOMY: ASPARAGINE

Development	
Selection of crop varieties on the basis of typical free Asn: total free amino acids ratio	Recent research suggests that the impact of farming practices (e.g. fertiliser regimes) may have an effect on amino acid ratios in potatoes. Sulphur deprivation may alter the ratio of free Asn: total free amino acids in a tuber and research has suggested that this ratio is potentially of greater significance to the formation of AA in potatoes than previously thought: in particular in the Asn/Gly ratio. So far no optimum amino acid ratio in potato has been established.

Research	
Control of Asn levels in tubers **Farming practices, e.g. fertiliser regimes** **Laboratory and field studies with new potato varieties**	**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 weight, and 20-60% of total free amino acids. Asn levels do not correlate to reducing sugar levels.** Also on its own, the reducing sugar concentration of potatoes is not always directly proportional to the AA concentration observed in a potato product. The concentration of free Asn and the ratio of free Asn to other free amino acids (of which Gln is by far the most abundant) should also be considered and may be better indicators of the relative AA risk of different potato varieties. 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/amino acids levels. In potatoes, the effect of sulphur is uncertain, and any advice on sulphur fertilisation to farmers would be premature based on the studies conducted so far. An increased ratio of other amino acids to Asn results in competition for reactants during the Maillard reaction, potentially affecting the proportion of AA formed in the overall Maillard process. In field trials in the U.S.A., new potato varieties with silenced Asn synthase genes in the tuber have up to 5-fold reduced amounts of free Asn. Heat-processed products derived from such tubers show comparable sensorial properties to their conventional counterparts, and much lower levels of AA (50-75% reduction). These varieties, two of which are now available for commercial cultivation, are considered as GMO. At the time of writing such potatoes are not yet approved for commercial production in the EU, therefore the regulatory status should be checked.

General Considerations

- Effect of optimisation of the reducing sugar content in the raw materials on other components influencing nutritional properties.
- Minimising reducing sugar content needs to be balanced against processing methods and final product characteristics (colour, flavour, etc.).
- Elimination of defective materials as part of standard good manufacturing practice has proven to be an effective measure to reduce AA in the final product. For example, this can be done through working with suppliers to ensure that incoming potatoes are checked whilst in storage, and again at plant, for defects (e.g. bruising and damage, viruses such as Spraing/TRV, fungal diseases, storage rots).

RECIPE: OTHER MINOR INGREDIENTS (AMINO ACIDS, CALCIUM SALTS AND CO-INGREDIENTS)

Development	
	Amino acids In laboratory trials glycine was not successful in lowering AA. **Calcium salts** Despite promising results on laboratory scale, calcium lactate did not give satisfying results when tested on an industrial scale.

RECIPE: PH

Development	
	Addition of low levels of acids to raw materials has shown synergistic benefits with calcium salts in small-scale pilot trials for crisps. However the same tests for French fries at laboratory scale showed serious sour off-taste. The use of acidulants (acetic, citric acids, lactic acid) and ascorbic acid in the French fry industry proved to be promising at laboratory scale as a mitigation tool. However, their application on the industrial production of French fries did not result in additional AA reductions compared to the standard product or should still be confirmed. Moreover, great care must be taken in order to avoid sour off-taste.

RECIPE: DILUTION AND PIECE SIZE

Commercial Application	
Thicker strips reduce AA through the surface area/ volume effect	AA is formed on the surface and the surface to volume ratio affects the quantity of AA formed. Decreasing the surface area to volume ratio by creating thicker strips/sticks of potato could be one way of reducing AA. However the strip cut dimension is specified by customers.

PROCESSING: ASPARAGINASE

Development	
Asparaginase may reduce AA in an optimised laboratory environment which, however, differs significantly from an industrial setting	Despite the fact that asparaginase reduced the AA content of the final product in preliminary laboratory experiments, the application in the industrial production of frozen parfried French fries could give various results. Some acrylamide reduction as well as no reduction was found during pilot-line or industrial tests, depending on the conditions of application of the enzyme. In a production line of blanched (non-parfried) chilled potato strips longer enzyme-substrate contact time is allowed, which leads to total asparagine depletion for the enzyme-treated fries after four days of cold storage.

PROCESSING: THERMAL INPUT & MOISTURE

General Considerations

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 compared to the one for browning. This explains why the end-phase of the frying process is critical and must be carefully controlled at a lower product temperature to optimise colour development and minimize AA formation.

For French fries the finished frying/oven-cooking of the prefried potato product is done by the professional end-user or by the consumer at home (see guidelines under 'final preparation').

Commercial Application	
For French fries, final preparation conditions are key as acrylamide is formed during final cooking	Par-frying does not produce significant levels of AA in the semi-finished product, nor does it determine the level in the final product.

Other Considerations

Effect of reducing the frying temperature on the fat content of the finished product (for example 9 mm fries: lowering the final frying temperature can lead to an increase in fat, when frying to the same colour endpoint). Effect of incomplete cooking on moisture level in products may have a subsequent impact on product quality, shelf life, and/or microbiological damage.

PROCESSING: PRE-TREATMENT (E.G. WASHING, BLANCHING, DIVALENT CATIONS)

Commercial Application	
Blanching of potato strips/ pieces prior to processing **Disodium diphosphate**	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. Blanching removes sugars in the outer surface layer of the potato strip (UGhent study). Addition of disodium diphosphate 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, which inhibits the Maillard reaction.
Development	
The addition of di- and tri-valent cations has been proposed to reduce the formation of AA	**Calcium salts** The addition of di- and tri-valent cations has been proposed to reduce the formation of AA in several potato products. — The use of calcium salts (calcium lactate, calcium chloride) in the French fry industry proved to be promising at laboratory scale. However, care should be taken to avoid undesired textural effects (hard texture) and bitter off-taste. In addition, it should be noted that calcium is not compatible with disodium diphosphates which is generally used to prevent grey discolouration. — The use of magnesium chloride gave rise to serious off-tastes.

PROCESSING: FINISHED PRODUCT COLOUR

Commercial Application	
Measure & manage finished (fried) product colour after final cooking to colour specification	A study conducted by Ghent University on the main parameters (reducing sugar content and colour evaluation) linked to AA in the final product revealed that the best correlation was achieved by colour determination (Agtron process analyser). 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. It has been identified that in some European countries consumer preference for French fries is to have them cooked to a golden brown colour rather than golden yellow. Use of food colourings as an ingredient in industrially produced products could be an effective tool to produce golden brown French fries in some countries. However, there are legal constraints on the use of food colourings in plain potato products in certain regions (e.g. EU). Lighter coloured French fries can be an acceptable product for consumers if other organoleptic properties such as taste and texture are managed.

Other Considerations

As part of standard quality procedures, manufacturers should implement controls which may have an indirect impact upon AA levels in the final product, e.g. management of oil quality to ensure cooking temperatures are optimally maintained.

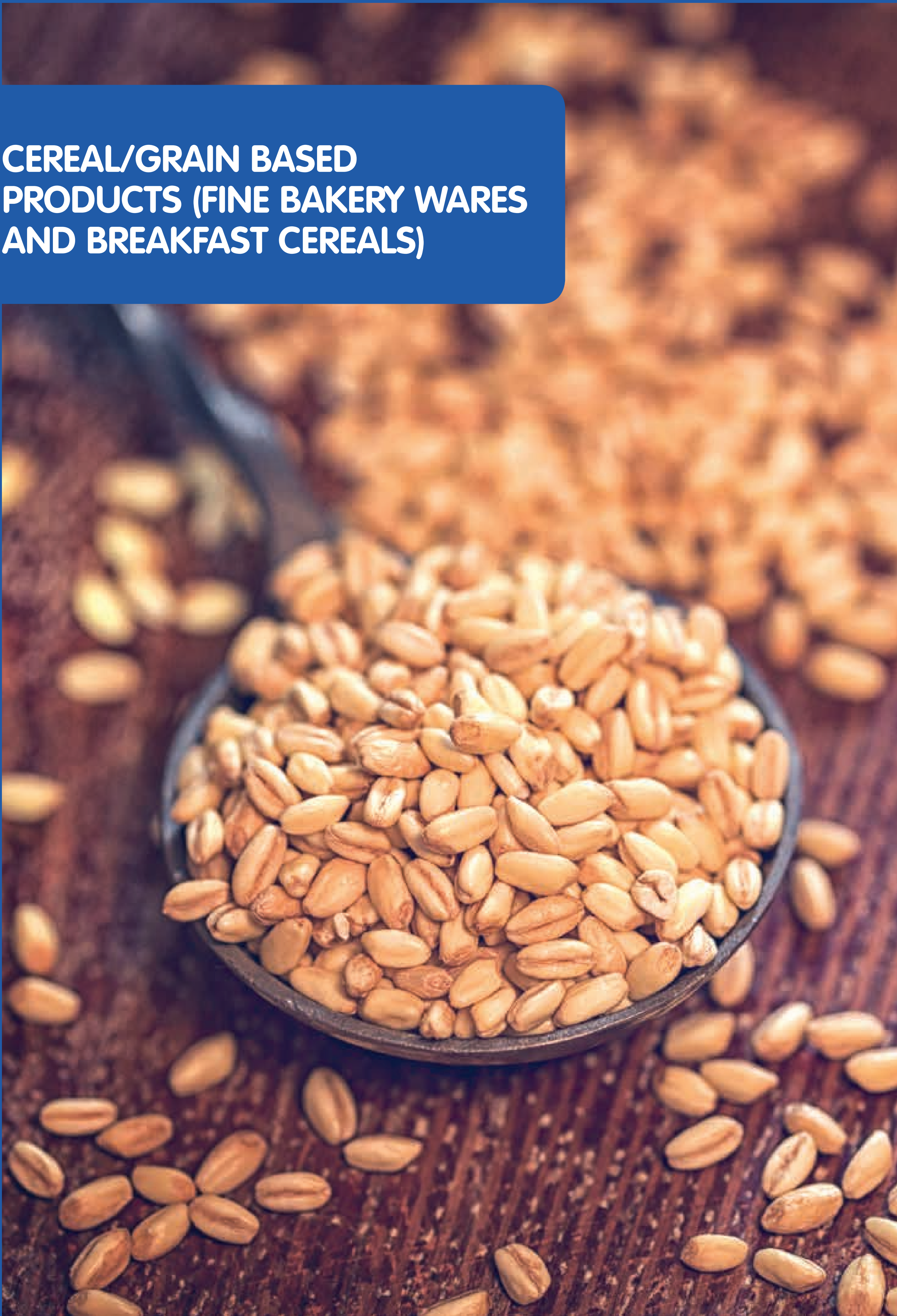
Modification of texture and flavour are not directly suitable as a tool to reduce AA, but are impacted by other interventions.

FINAL PREPARATION: CONSUMER AND RESTAURANT GUIDANCE

Commercial Application	
Advice to chefs and consumers	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:** — Preheat the cooking device (e.g. oven, air fryer) to correct temperature to between 180-220°C according to on-pack cooking instructions, depending on the products specifications and local requirements — Cook at 180-220°C for prescribed time — Cook to a golden (yellow) colour When cooking small amounts, reduce the cooking time. European Potato Processors Association (EUPPA) developed a specific tool presenting "Good frying Practices" to help consumers and restaurants: **www.goodfries.eu** The US FDA has a webpage listing the ways to reduce acrylamide "Acrylamide: Information on Diet, Food Storage, and Food Preparation", which can be found **here**[3].
Development	
"Fresh" prefabricated French fries 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 blanched 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 (a-amylase) may slowly release reducing sugars during cold temperature storage. 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 10-45 min).

3 https://www.fda.gov/Food/FoodborneIllnessContaminants/ChemicalContaminants/ucm151000.htm

CEREAL/GRAIN BASED PRODUCTS (FINE BAKERY WARES AND BREAKFAST CEREALS)



AGRONOMY: REDUCING SUGAR

General Considerations

The sugars composition of cereal grains is not a key determinant of AA formation and is therefore not considered relevant in the context of reducing acrylamide in Fine Bakery Wares and Breakfast Cereals.

Commercial Application	
Sugars composition of cereal grains is of less impact than the asparagine level in the raw materials[4]	Research confirms that Asn rather than sugars is the key determinant of AA formation in cereal products. Free Asn levels have been found to have a much greater impact than the levels of reducing sugars in wheat. Measurements for four soft wheat varieties in 2004 found 1 to 1.3% dry weight 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.

AGRONOMY: ASPARAGINE

General Considerations

Asn is the critical component which leads to the formation of AA in cereal products. Research shows that free Asn varies widely within one single variety, growing conditions on individual fields (e.g. impact of sulphur) and between cereal varieties. This is confirmed by university research on heated wheat flour, where it has been has shown that free Asn concentration is the key determinant. Because of the sources of variation (grain type, variety, growing conditions, climate), it is impossible to source wheat or any other grain with controlled low levels of Asn. Moreover, depending on the type of grain used a product has specific characteristics defining the product identity. Consequently, it is not possible to simply replace the grain by another grain without changing the product identity.

For these reasons, more fundamental knowledge is needed concerning the impact of agronomical practices and cereal varieties on Asn level. Therefore, Industry Partners support research proposals that aim to investigate breeding science to control Asn in wheat varieties. **FBOs should keep abreast of progress on research to breed new, low asparagine wheat through relevant trade associations and research institutes.**

Commercial Application	
Farmers should be aware of the importance of maintaining balanced sulphur levels for cereal cultivation	Free asparagine levels in cereals can become elevated during plant development when the plant is grown under stressed conditions, particularly in sulphur-deprived soils and therefore results in a higher risk of AA formation.
Farmers should avoid late and excessive application of nitrogen in consistency with Good Agricultural Practices on fertilization	Late application of nitrogen may increase free asparagine and total free amino acid concentration in wheat and other cereals, causing a concomitant increase in acrylamide-forming potential. Nitrogen fertilizer is required to maintain the yield and quality of the crop, but excessive application should be avoided.
Farmers should be guided to use appropriate crop protection measures to prevent fungal infection in consistency with Good Phytosanitary Practices	Fungal pathogen infection causes a significant increase in free asparagine concentration in cereal grain. It is therefore important to apply best practices on crop protection measures to prevent fungal infection.

4 Acrylamide: Update on Selected Research Activities Conducted by the European Food and Drink Industry, TAEYMANS ET AL.: JOURNAL OF AOAC INTERNATIONAL VOL. 88, NO. 1, 2005

Development	
Choice of wheat varieties **Lowering the proportion of wholegrain and/or bran in products will significantly impact nutritional quality and organoleptic properties of the product**	**Breakfast cereals** Choice of wheat with lower free Asn has led to products with lower AA levels, but current experience suggests that specifying low free Asn wholegrain is not yet possible. Using less whole meal (lower bran and germ) and more endosperm will be effective (as free Asn is more concentrated in the germ/bran), but will significantly compromise the product's organoleptic and nutritional properties. Most breakfast cereals are made from soft wheat. Soft wheat typically has higher protein/amino acid content which provide competing amino acids to the asparagine 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. For further information, please refer to full chapter on breakfast cereals, to be found later in this toolbox. **Cereal-based products** Current experience suggests that specifying low free Asn wholegrain is not yet possible, but that using less whole meal and/or bran and more endosperm will be effective (as free Asn is more concentrated in the germ/bran), but will significantly compromise the product's organoleptic and nutritional properties. Reducing the nutritional quality (i.e. less whole meal, fibre and other beneficial nutrients) would negatively impact its intake (in the worst case exacerbating deficiencies) as cereals are a major contributor to consumer intake. **Crisp bread** 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.

FINE BAKERY WARES (BISCUITS, CRACKERS, WAFERS, CRISP BREAD AND GINGERBREAD)

This Toolbox section covers products as defined according to part E of Annex II of the Regulation (EC) No 1333/2008 on Food Additives: *"This category covers sweet, salty and savoury products, including prepared doughs for their preparation, such as cookies, cakes, muffins, doughnuts, biscuits, rusks, cereal bars, pastries, pies, scones, cornets, wafers, crumpets, pancakes, gingerbread, éclairs, croissants, as well as unsweetened products such as crackers, crisp breads and bread substitutes. In this category a cracker is a dry biscuit (baked product based on cereal flour), e.g. soda crackers, rye crisps, matzot"*: https://ec.europa.eu/food/sites/food/files/safety/docs/fs_food-improvement-agents_guidance_1333-2008_annex2.pdf

RECIPE AND PRODUCT DESIGN: WHOLE GRAIN PRODUCTS

Development	
Choice of wheat varieties **Lowering the proportion of wholegrain and/or bran in products will significantly impact nutritional quality and organoleptic properties of the product**	Free asparagine is the key determinant of acrylamide formation in cereal products. Accordingly, using wheat with a lower free Asn content has a lower acrylamide potential. However, it is currently not possible to specify for low Asn in cereal grains including for wholegrain products. Using less whole meal and/or less bran and germ and more endosperm may result in lower acrylamide levels (as free Asn is more concentrated in the germ/bran), but will significantly compromise the product's organoleptic and nutritional properties.

RECIPE AND PRODUCT DESIGN: RAISING AGENTS

Commercial Application	
Reducing or replacing NH_4HCO_3 in recipes as used in certain commercial applications is an option to lower AA, but the impact on organoleptic properties must be assessed	Replacing (fully or partly) NH_4HCO_3 with alternative raising agents (such as sodium bicarbonate and acidulants, sodium bicarbonate and disodium diphosphates with organic acids or potassium variants thereof) is a demonstrated way to relatively lower AA in certain products and on a case-by-case basis. Despite changes to flavour, colour and texture, several products (sweet biscuits and gingerbread) have been reformulated and commercialised. In most cases sodium salts were the replacement. However, 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. 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. Considerations should include that changes may result in organoleptic (taste, appearance, texture, etc.) or nutritional changes (increased sodium content) that influence product identity and consumer acceptance.

RECIPE AND PRODUCT DESIGN: ASPARAGINASE

Commercial Application	
Manufacturers shall consider using asparaginase to reduce asparagine to mitigate the potential for acrylamide formation	The use of asparaginase is proven to be one of the most efficient tools to reduce acrylamide levels and if used at low dosage rates has no negative impact on the organoleptic properties of the final product. For consideration, the efficacy of asparaginase is dependent on recipe, ingredients, moisture content and process (temperature, pH, time, distribution in dough), and therefore differs from product to product. In particular, experience shows that there is limited or no effect in recipes with high fat content, low moisture or high pH value.

RECIPE AND PRODUCT DESIGN: REPLACING WHEAT FLOUR WITH ALTERNATIVE GRAIN TYPES

Commercial Application	
Different types of grain are typically different in Asn-levels. Accordingly a partial replacement of wheat flour with an alternative grain flour may be an option	**Crisp bread** If crisp breads 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, and rye flour type 1800 replaced with type 997 was commercialised in one product. However, depending on the choice of the diluting material, this may change the product composition and characteristics considerably. **Short sweet biscuits** Where a product characteristic allows, manufacturers shall consider a partial replacement of wheat flour with alternative grain flour such as rice. For consideration, any change will have an impact on the baking and organoleptic properties. Different types of grains have shown different levels of asparagine (typical asparagine levels: rye > oats > wheat > maize > rice). The partial replacement of wheat flour by rice flour may be an effective measure when acceptable from a quality perspective. In particular for baby biscuits, consideration should be given to the potentially higher arsenic level in rice vs. wheat.

RECIPE AND PRODUCT DESIGN: CO-INGREDIENTS

Development	
Heat treated co-ingredients such as roasted/toasted nuts and oven-dried fruits may contribute to the acrylamide level in the final product	Manufacturers shall consider the impact of co-ingredients that may have the potential to raise acrylamide levels in the final product (e.g. roasted almonds; dried fruits as potential fructose source). Manufacturers shall have a change control procedure in place to ensure that a change in products sourced from suppliers does not result in inadvertently increased acrylamide levels. Manufacturers shall ensure that suppliers of heat-treated ingredients which are susceptible to acrylamide formation provide an ingredient acrylamide risk assessment and implement the appropriate mitigation measures.

RECIPE AND PRODUCT DESIGN: MINOR INGREDIENTS

Commercial Application	
Replacing fructose with glucose is very effective in reducing AA formation – particularly in recipes containing ammonium bicarbonate	For relevant products and where the product design allows, replacing fructose or fructose-containing ingredients (e.g. syrups, honey) with glucose or non-reducing sugars (e.g. sucrose) is seen an effective tool to reduce the AA formation – particularly in recipes containing ammonium bicarbonate. Reducing sugars are responsible for many of the characteristic flavours and colour in sweet biscuits. Fructose replacement by glucose retained original quality and texture in several commercial applications at a paler colour. When glucose-fructose syrups are used, the fructose content should be as low as possible. Considerations should accordingly include that replacing fructose or other reducing sugars may result in a modified product identity due to loss of flavour and colour formation.

Development	
Glycine addition impacts sensorial properties **Calcium salts give variable results and most have adverse flavour effects**	**Gingerbread** 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. Trials at bench scale with added calcium salts gives variable results, most affecting product quality. Not seen as option application on commercial plant level.
Glycine addition changes product colour/quality	**Short sweet biscuits** Glycine addition changes product colour and furnishes products of unacceptable quality.
Addition of glycine and calcium impact negatively key quality attributes	**Crisp bread** 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. Ca2+, whilst only slightly reducing AA, has an adverse effect on the flavour and texture at pilot plant level.

Development	
Addition of organic acids may be effective in combination with other potential mitigation measures. Application of this option is limited by resulting organoleptic changes	The addition of organic acids/adjustment of pH in combination with other recommendations may result in lower acrylamide levels. Decreasing the pH will influence the Maillard reaction in the direction of decreased acrylamide formation. However, this option is limited by resulting organoleptic changes (less browning, modification of taste). **Biscuits, crisp bread, gingerbread** In the absence of ammonium raising agents pilot-scale studies on **biscuits** have shown that pH and AA follow a linear trend with a reduction in AA of about 17% per unit drop in pH. In laboratory experiments with an intermediate product (**semi-sweet biscuit**) a 20-30% reduction of AA was achieved by adding citric acid to reduce the pH. 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) [3]. In **crisp bread** 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 3monochloropropanediol (3-MCPD).

RECIPE: SHAPE AND PIECE SIZE – BISCUITS, CRISP BREAD

Commercial Application	
For new product development, manufacturers shall consider piece size/ surface area to volume ratio during product design, as small product size potentially leads to higher acrylamide levels (heat impact)	In biscuits and crisp breads, the thicker the product, the lower the AA levels. This, however, significantly changes the product characteristics.

PROCESSING: FERMENTATION

Commercial Application	
Lower levels of AA in fermented products. Extension of fermentation time in bread may be an option to lower AA levels	**Crisp bread** Some baked products, such as crisp breads and crackers, can be made from fermented dough 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. Yeast rapidly assimilates Asn and aspartic acid, as well as sugars. Crisp bread, which is mainly produced with yeast, also shows significantly lower AA content for fermented variants versus cold bread (non-fermented variants). In crisp bread manufacture, other factors such as biscuit thickness and baking conditions must be seen in perspective.
Extended yeast fermentation time may be an option but warrants further study **Use of lower gassing yeast to decompose Asn faster**	**Sweet biscuits and crackers** Biscuit and cracker dough: 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. However, no studies on increasing fermentation time in crackers were reported in the latest CAOBISCO survey. The use of lower gassing yeast may be a mitigation option in some products since the latter is independent of Asn consumption. As more yeast activity is added this results in a faster decomposition of Asn at same overall gas generation rate.

PROCESSING: THERMAL INPUT & FINAL PRODUCT MOISTURE

Commercial Application	
Optimisation of thermal input has resulted in a reduction of AA	Manufacturers shall control thermal input by optimising baking temperature, temperature profile and time. As guidance, thermal input as result of temperature and time is essential rather than temperature alone to control product characteristics and acrylamide formation. Solutions may vary depending on the particular product and capabilities of existing processing equipment. **Crisp bread** In non-fermented crisp bread, reduction in process temperature and oven speed reduced AA by approx. 75%. The most important impact comes from securing that 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.

PROCESSING: FINISHED PRODUCT COLOUR

Commercial Application	
Manufacturers shall consider baking to a lighter colour endpoint in the final product if feasible to achieve the required quality, shelf life and food safety standards	**Hard sweet biscuits, crisp bread, breakfast cereals, bread substitutes** 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 were able to produce lighter coloured and less baked products, without increasing moisture content, the AA level could theoretically be reduced. Colour endpoint is an approach applied for (i) hard sweet biscuits with a reported ~10% reduction in AA and lighter colour, and (ii) crisp bread through reduced "final roast" with acceptable reduction in browning.

PROCESSING: TEXTURE/FLAVOUR

Development	
Manufacturers shall consider increasing the moisture specification for the final product if feasible for the particular product and process, in line with achieving quality (incl. physical properties), shelf life and food safety standards	**Biscuits** The reaction leading to the formation of AA (the Maillard reaction) is also the reaction 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 are warranted to assess feasibility and acceptance tolerance.

PROCESSING: REWORK

Commercial Application	
Manufacturers shall adjust product and process design to account for ingredients that could be heat treated several times and as a result raise acrylamide levels in final products (e.g. pre-processed cereal pieces, nuts, seeds, dried fruits, etc.)	The use of small quantities of rework is common practice today if within the specified range for colour formation. Although it is known that in general avoiding rework is reported to have no significant benefit in reducing acrylamide levels, manufacturer shall not use burnt products as rework. 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. In pilot studies with sweet biscuit dough, it has been shown that more AA is formed in biscuits baked from older dough (an increase of approximately 35% over 3 h). The extra AA could be accounted for by the measured increase in free Asn over time. Hence best practice should avoid where possible "dough aging" or reworking of aged dough. However, the most recent survey shows that there is no evidence that elimination of rework provides any benefit in terms of AA reduction when applied on an industrial scale. Other work conducted on non-fermented crisp bread has shown no significant effect on the formation of AA in the product.

FINAL PREPARATION

Commercial Application	
Preparation instructions of product pre-mixes at home or in catering establishments need to be provided	**Pack instruction** For product pre-mixes that are to be baked at home or in catering establishments, clear on-pack preparation instructions shall be provided to lead to levels below the Benchmark Levels.

BREAKFAST CEREALS

PRODUCT DESCRIPTION

Products primarily manufactured from cereal grains (such as corn/maize, wheat, barley, rye, oats or rice) that are generally designed to be eaten with milk (hot or cold).

For agronomy, please refer to section on **Cereal/Grain Based Products**.

RECIPE AND PRODUCT DESIGN: WHOLE GRAIN PRODUCTS

COMMERCIAL APPLICATION	
Using less whole meal and/or bran and more endosperm will significantly compromise organoleptic properties/product identity and nutritional quality of products with a negative impact on consumer intake of whole meal, fibre and other beneficial nutrients	All of the major grains may be used in breakfast cereals and some grains yield more AA than others within a common process. Different kind of grains have shown different distribution of asparagine, the pre-cursor for the formation of acrylamide, i.e. products based on maize and rice tend to have less acrylamide than those made with wheat, rye, oats and barley[5]. However, the choice of grain defines the food and therefore it is not possible to simply replace the grain by another grain without changing the whole product and losing the product identity the consumers like.

RECIPE AND PRODUCT DESIGN: REDUCING SUGARS

COMMERCIAL APPLICATION	
Reducing sugars (e.g. fructose and glucose) and ingredients containing reducing sugars (e.g. honey) may contribute to the AA burden, if added prior to heat-treatment stages	Reducing sugars (e.g. fructose and glucose) and ingredients containing reducing sugars (e.g. honey) are sometimes added for organoleptic reasons and process functionalities (binding clusters for cluster formation). If added prior to heat-treatment stages they can act as precursors to acrylamide formation. In this case, controls over addition rates must be established and implemented at point of addition.

5 Source: MAP Milling Project – Measure and control of mycotoxins, pesticides and acrylamide in grain milling sector. Project funded by the European Commission under the research and technological development programme 'Integrating and strengthening the ERA' (2002-2006)

RECIPE AND PRODUCT DESIGN: HEAT-TREATED INGREDIENTS

Commercial Application	
Heat-treated ingredients such as roasted/toasted nuts and oven-dried fruits may contribute to the acrylamide level in the final product	Heat-treated dry-added ingredients may contribute to AA. Low-roast almonds contain about 10 fold less AA than high roast almonds. Peanuts and hazelnuts contain less than a fifth of asparagine as compared to almonds so they yield much less AA. Where baked pieces are used in muesli, their recipe should be reviewed following the advice for biscuits. The acrylamide contribution from heat-treated dry-added ingredients (e.g. roasted/toasted nuts and oven-dried fruits) to the total acrylamide value must be assessed in the HACCP, and alternative ingredients considered if the contribution is likely to bring the finished product above the benchmark levels as per Commission Regulation (EU) 2017/2158. For ingredients over 150 ppb acrylamide, the assessment shall include: a. a register of ingredients over 150 ppb acrylamide b. verification steps, e.g. audits of suppliers HACCP and/or analyses c. consideration of acrylamide risks in suppliers HACCP (by the supplier) d. a change control procedure to ensure that no changes are made that inadvertently increase acrylamide levels (by the supplier). Some dried fruits (e.g. prunes, pears) were reported to contain AA. Tests were therefore made of some ingredients commonly added to mueslis and flake-with-fruit cereals. Dried fruit and nuts may make up around 25-50% of muesli by weight, raisins and sultanas generally predominate. There was no measurable AA in raisins of several kinds and origins, dried apple, dried cranberries, candied papaya or candied pineapple. Low levels were found in dried bananas, dried coconut and prunes.

RECIPE: ASPARAGINASE

Research	
Not a satisfactory Asn reduction in cooked and toasted coarse grain cereal due to necessary time and temperature constraints at industrial level, preventing the appropriate conditions for the enzyme to significantly reduce Asn	Insignificant Asn reduction in a cooked toasted coarse grain cereal. Trials at laboratory and pilot-scale in collaboration with an enzyme supplier show different levels of efficiency based on process design, type of grain, particle size of grain, moisture content, achievable time and temperature profile as well as other recipe parameters. The use of enzymes in breakfast cereal processes is difficult because of low moisture contents which makes enzyme penetration into the grain or food matrix difficult. Many breakfast cereal processes use coarse flours or chopped grains which are not readily penetrated by the enzyme. Typical processes for making breakfast cereals contain heating steps that lead to the de-activation of the enzyme. Nevertheless, breakfast cereal manufacturers continue to investigate if asparaginase can be applied in certain breakfast cereal processes and recipes. In particular, when the cereal is in a flour dough format and when the process enables a sufficient time, temperature and moisture content for asparaginase to reduce asparagine levels significantly. The latter provided there is no negative effect on flavour or risk of residual enzyme activity. When research shows promising results, the scale-up of a process with asparaginase needs to be investigated. This may lead to significant process changes and may impact product quality.

RECIPE AND PRODUCT DESIGN: MINOR INGREDIENTS

Development	
Sugars are usually added after the toast	In breakfast cereal production, manufacturers in Europe generally use sucrose and small amounts of malt in the cereal itself because reducing sugars darken the cereal too much. Where alternatives to sucrose may be used, one should verify that these do not increase AA levels. Added fructose tends to cause severe browning. Honey, glucose, fructose and other reducing sugars are generally used in the sugar coat applied after toasting so they do not influence AA formation.
The impact of malt on AA formation requires further study	One manufacturer reports that malt, specifically malted barley, has been shown to reduce AA in breakfast cereals. However, the impact of malt requires further study and today the effect cannot be considered as a general rule.
Addition of calcium chloride requires further study	The addition of calcium and glycine is under investigation at laboratory and pilot scale. Many breakfast cereals are fortified with $Ca2+$, and manufacturers could explore the benefit for those not so fortified. A manufacturer reports that calcium chloride has been shown to reduce AA in breakfast cereals at pilot scale. The flavour appears to be acceptable for calcium chloride up to 0.4 to 0.5% of solids. Flavour validation is in progress.
Addition of glycine is under investigation at pilot scale	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. Due to the high reaction rate of glycine, even at smallest addition levels, trials to date were not successful to control the effect of glycine on colour, flavour and taste with requirements for product moisture, texture and shelf life: Manufacturers added glycine in the pilot plant with other amino acids (proline & lysine) and found that glycine and proline did reduce AA but all three amino acids imparted an unacceptable bitter flavour to the product.
Positive effect of antioxidants not evident	Manufacturers also report trials with various antioxidants (vitamin C & E) in pilot plant trials, (with no reduction found in AA).
Research	
Addition of lysine is not a reliable tool for acrylamide mitigation from pilot plant experiments	At pilot plant scale, lysine has been found to reduce to a certain degree the formation of acrylamide in modified processing conditions to produce a type of wheat flake. However, due to small addition levels and impact on sensorial properties of the product, the addition of lysine does not represent a reliable way to mitigate acrylamide.

RECIPE AND PRODUCT DESIGN: PH

Development	
Reduction of phosphate salts can lead to less acrylamide formation (limited applicability due to adverse effects on sensorial attributes)	Reduction of phosphate salts has been proven to reduce acrylamide in breakfast cereals at pilot plant scale. However, this shows adverse effects over the sensorial attributes (colour, flavour, texture) which limits its applicability.

PROCESSING: THERMAL INPUT AND MOISTURE

Commercial Application	
Optimisation of thermal input has resulted in a reduction of AA in breakfast cereals ▶ **Do not over-bake or over-toast; avoid the incidence of burnt product** ▶ **Identify the key critical heat-treatment step(s) to focus acrylamide reduction/control efforts** ▶ **Control heating temperatures, times and feed-rates to achieve typical minimum moisture contents after the final heat-treatment steps to help avoid the generation of acrylamide spikes** ▶ **It is important to measure the moisture content as well, and express acrylamide concentration on a dry mass basis to eliminate the confounding effect of moisture changes.**	In general, higher heating temperatures and longer heating times generate higher acrylamide levels. An effective combination of temperature and/or heating times to minimise acrylamide formation minimises acrylamide formation, without unacceptably compromising the taste, texture, colour, safety and stability (shelf-life) of the product. 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). One manufacturer reports that for breakfast cereals, this concept was evaluated and results showed that AA correlates with moisture but does not correlate well with colour. Therefore, at constant moisture (for toasted products), AA is expected to be constant under conditions of breakfast cereal processing. However, other manufacturers report that they evaluated lower heating temperatures and (separately) shorter heating times and, although both do reduce AA, they adversely affect product colour and taste. Different combinations of heating temperature and time were also examined and it was found that all the combinations that produce an acceptable colour & flavour also have a similar acrylamide level. This suggests that the scope to reduce AA by optimising thermal input may only be restricted to certain breakfast cereal recipe/process combinations. AA content tends to be well correlated with moisture content of toasted product (as lower moisture content is usually generated by a higher thermal input), but manufacturers generally apply both maximum and minimum ranges for moisture as a part of routine quality management, and raising the moisture content tends to compromise shelf-life. Typical Minimum Moisture Content (g/100g) for consideration: — Toasted products: 1 g/100 g for extruded products, 1 g/100 g for batch cooked products, 2 g/100 g for steam rolled products — Direct expanded products: 0,8 g/100 g for extruded products — Baked products: 2 g/100 g for continuously cooked products — Filled products: 2 g/100 g for extruded products — Other drying: 1 g/100 g for batch cooked products, 0,8 g/100 g for gun puffed product Measurement systems should be calibrated at least annually and these operating conditions controlled within set limits. These tasks should be incorporated into a HACCP pre-requisite programme.

RECIPE: REWORK

Development	
There might be an impact of rework on acrylamide levels under specific circumstances	Reworking product back through the process has the potential to generate higher acrylamide levels through repeated exposure to the heat-treatment steps. Manufacturers shall assess the impact of rework on acrylamide levels and, if significant, focus on reducing or eliminating rework.

PROCESSING: FINISHED PRODUCT COLOUR

Research	
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	A correlation between acrylamide and the colour in breakfast cereals is a case-by- case situation and could not be established generally. However, manufacturers shall have procedures in place (e.g. temperature controls/monitoring) to prevent the incidence of burnt product, as this may give rise to consumer dissatisfaction and acrylamide spikes.

COFFEE

AGRONOMY: REDUCING SUGARS

Development	
No correlation to AA formation	Sugar levels in the green beans (Robusta, Arabica) show no correlation to the amount of AA formed during roasting.

AGRONOMY: ASPARAGINE

Development	
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**	Free Asn concentrations in green coffee beans lie within a 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.

Other Considerations

Other "marginal" pathways not related to free Asn may become important for the formation of AA.

PROCESSING: ASPARAGINASE

Research	
Applying asparaginase enzymes in coffee may have application opportunities in particular for steam-treated coffees	The applicability of asparaginase enzyme treatment of green coffee is limited. The European coffee industry and enzyme suppliers have worked together in applied research and in practical trials to assess the use of asparaginase to destruct asparagine, one of the major precursors of acrylamide. The green coffee bean is a very dense, hardly permeable raw material and additional processing steps (steam treatment and soaking in a water bath) are required for the enzyme to be effective. However, the steam treatment/enzyme treatment process has potential relevance only for a very modest fraction of coffee production. It affects the taste profile in a way that is not compatible with the desired sensory properties of the majority of coffee blends. Asparaginase treatment therefore cannot be expected to achieve serious acrylamide mitigation percentages in overall coffee manufacturing. In any further specific assessment it is recommended to include the following findings and considerations: — Trials as referenced in the above have been made under laboratory/pilot plant conditions only. Scaling up will require an assessment of the suitability of treatment conditions as applied in laboratory/pilot plants for application at commercial plant scale in line with good manufacturing practices. The food safety aspects and impact on sustainability of the finished product should be taken into account as well. — Any green coffee enzyme process would be a new and an additional process for roast coffee and soluble coffee manufacturing. This process cannot be integrated into the existing roast coffee manufacturing processes and will accordingly require new plants and facilities, except for potential capacities in existing decaffeination and green coffee steam treatment facilities after required adaptation to the enzyme process. The acceptability of the impact on flavour has to be assessed on an individual case-by-case basis depending on green coffee type, the percentage of the enzyme-treated coffee in the total blend and the specific quality targets of the product.

PROCESSING: THERMAL INPUT & MOISTURE

Development	
Roasting technologies beyond existing ones have been tested, but do not indicate a mitigation opportunity	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. 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.

Other Considerations

Results on coffee have led to the conclusion that only very limited process options are available to reduce the AA level without affecting the quality and consumer acceptance of the product.

PROCESSING: PRE-TREATMENT

Development	
Pre-drying of green beans and decaffeination have no significant impact on AA	Pre-drying of green beans: green coffee dried to lower moisture content prior to roasting (from typical green coffee moisture of 10-12% to approximately 7%) did not show an impact on AA level in the roasted product. Decaffeination: trials showed that roasting of decaffeinated green coffees (covering the commercially important decaffeination processes) resulted in AA levels of same magnitude as roasting of corresponding untreated coffees when roasted to comparable roasting endpoints.

PROCESSING: FINISHED PRODUCT COLOUR

Commercial Application	
Colour is an important process control point and linked to the sensory properties of the product	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).

Other Considerations

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. polyphenols and melanoidins, and formation of other undesirable products under extreme roasting conditions need to be considered.

PROCESSING: TEXTURE/FLAVOUR

General Considerations

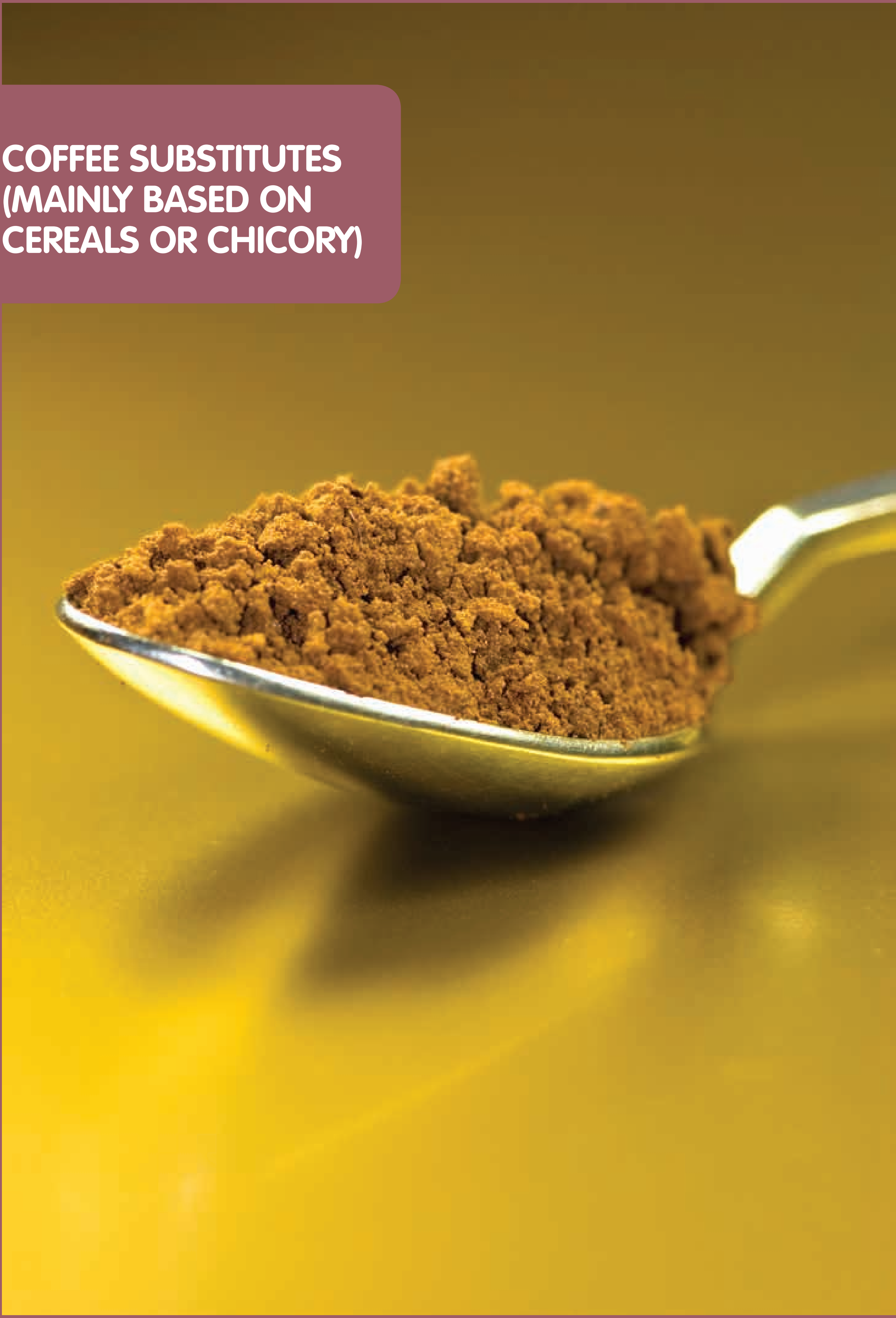
Organoleptic properties are finely tuned by careful selection of green coffee blends, roasting conditions, and processing technologies. Flavour and aroma are crucial to the identity of the products, and any blend/technology changes – however minor – to the existing products will have major impact on the organoleptic properties and subsequently on consumer acceptance.

FINAL PREPARATION: CONSUMER AND RESTAURANT GUIDANCE

General Considerations

Typical brewing equipment transfers AA almost completely into the beverage. The cup/beverage concentrations for roast coffee and soluble coffee are similar. Espresso brewing may, however, show lower transfer rates due to specific extraction conditions. 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 ~ 5-7g for roast coffee and ~ 2g of soluble coffee per cup, respectively).

COFFEE SUBSTITUTES (MAINLY BASED ON CEREALS OR CHICORY)



AGRONOMICAL: REDUCING SUGARS

Development	
No correlation to AA formation	**Coffee substitutes mainly based on cereals** Sugar levels in the cereals (e.g. barley) show no correlation to the amount of AA formed during roasting. **Coffee substitutes mainly based on chicory** Sugar levels in chicory show no correlation to the amount of AA formation during roasting.

AGRONOMICAL: ASPARAGINE

Development	
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 substitutes mainly based on cereals** The amount of asparagine in cereal (e.g. barley) is relatively low (about 30 mg/100g) and will determine the final amount of acrylamide in the roasted cereal product. **Coffee substitutes mainly based on 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.

Other Considerations

Other "marginal" pathways not related to free Asn may become important for the formation of AA

RECIPE: OTHER MINOR INGREDIENTS

Research	
Calcium and magnesium salts are not effective in reducing AA in coffee. Adding calcium or magnesium has been evaluated not to be a tool to reduce AA level in chicory	**Coffee substitutes mainly based on chicory** Results from laboratory studies showed a significant reduction in roasted chicory AA level after a 2h soaking in calcium and/or magnesium ions bath[7]. It resulted in 40-95% lower AA level with magnitude depending on salts and concentration and when compared to untreated chicory roasted under similar conditions (i.e. temperature and colour). Although these preliminary results are promising, these considerations have to be included: — The treatment shows a very significant impact on sensory properties. — Scaling up trials evidenced significant food safety and environmental concerns.

7 Reduction of acrylamide in roasted chicory by impregnating with an aqueous solution comprising divalent cations, EP 2160948, Viviane Andrée Claude Theurillat-Moritz, Wolfgang-Oliver Stephan Chmiel, Valérie Martine Jeanine Leloup, Eric Dossin (10.5.10)
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RECIPE: DILUTION & PIECE SIZE

Commercial Application	
Recipe modification to accommodate lower percentage of high AA-forming constituents	**Coffee substitutes mainly based on chicory** Lowering the chicory content by for example 3% in the recipes for coffee substitutes and partial substitution with, for example, roasted barley or chicory fibres, achieves reduction, but has an impact on organoleptic properties.

PROCESSING: ASPARAGINASE

Research	
Application of asparaginase enzyme treatment for coffee substitutes (mainly based on cereals or chicory) is limited	**Coffee substitutes mainly based on cereals** The applicability of asparaginase enzyme treatment of the cereal grain prior to roasting is limited because roasted cereal products are based on the intact grain. In general terms, exposing intact cereal to asparaginase does not appear to measurably reduce acrylamide levels in the finished product. **Coffee substitutes mainly based on chicory** Laboratory scale trials reveal up to 70% reduction in AA in raw chicory when treated for several hours in an asparaginase solution at appropriate temperature. However, this treatment has a significant impact on final product quality and food safety.

PROCESSING: THERMAL INPUT & MOISTURE

Development	
Roasting technologies beyond existing ones have been tested but do not indicate a mitigation opportunity	**Coffee substitutes mainly based on cereals** In cereals (e.g. barley) AA is formed at temperature above 120°C, with a maximum at 150°C. Above 150°C, the AA level decreases with continued roasting. Final finished product levels are at only 30-40% of the maximum level, final concentration being dependent on the target degree of roast. Darker roasting in general tends to reduce the AA level but this parameter needs to be fixed in narrow ranges to achieve the target flavour profile. **Coffee substitutes mainly based on chicory** In chicory, AA is formed at temperatures >130°C, with a maximum at 145°C. Above 150°C, rapid decrease of AA begins and colour development starts due to caramelisation (degradation of sucrose). Decreasing the roasting temperature and concomitantly increasing the roasting time, favours the loss of AA. Possible mitigation therefore involves over-roasting (by increasing temperature above 150°C and/or roasting time). This strong heat treatment has a significant impact on the final product's quality (colour development, change of taste) and on its acceptance by the consumer (especially regarding to traditional products such as roasted chicory or chicory and coffee mix).

PROCESSING: PRE-TREATMENT

Development	
Soaking of cereal prior to roasting has no significant impact on AA generation	**Coffee substitutes mainly based on cereals** Soaking is a common process applied to cereal prior roasting. However, soaking has no significant impact on AA generation.

PROCESSING: FINISHED PRODUCT COLOUR

Commercial Application	
Colour is an important process control point and linked to the sensory properties of the product	**Coffee substitutes mainly based on cereals** Colour is an important indicator of roasting degree and directly related to the organoleptic properties of the product (see section "Processing: thermal input & moisture" for more details). **Coffee substitutes mainly based on chicory** Colour development results mainly from caramelisation of sugars, and colour is an important end-point of roasting degree and attribute for consumer acceptance (see section "Processing: thermal input & moisture" for more details).

PROCESSING: TEXTURE/FLAVOUR

General Considerations

Organoleptic properties of coffee substitutes (mainly based on cereal or chicory) depend on roasting conditions, processing technologies and recipe. The resulting flavour and aroma are essential to the identity of the products and any changes to the existing products (process/recipe) may have significant impact on consumer acceptance.

BABY BISCUITS, INFANT CEREALS AND BABY FOODS OTHER THAN CEREAL-BASED FOODS

Product description: According to DIRECTIVE 2006_125_EC on "processed cereal-based foods and baby foods for infants and young children", they comprise:

a. 'processed cereal-based foods' which are divided into the following four categories:

- simple cereals which are or have to be reconstituted with milk or other appropriate nutritious liquids;
- cereals with an added high-protein food which are or have to be reconstituted with water or other protein-free liquid;
- pastas which are to be used after cooking in boiling water or other appropriate liquids;
- rusks and biscuits which are to be used either directly or, after pulverisation, with the addition of water, milk or other suitable liquids.

b. 'baby foods' other than processed cereal-based foods.

RECIPE: OTHER MINOR INGREDIENTS

Commercial Application	
In certain technologies, avoid adding ingredients that may contribute to increasing reducing sugars in the recipe	**Infant cereals** In whole grain, roller-dried infant cereals, reducing sugars addition to the mix (e.g. fruits, honey, fructose), leads to a higher amount of AA in the final product.

Commercial Application	
Recipe may impact AA in jarred baby foods	**Baby foods other than cereal based foods** Product containing sweet potatoes or prunes/plums are of greater risk, due to relatively higher amounts of AA precursors.
Recipe has a major impact on final AA level	**Baby biscuits** Generally applicable to whole grain biscuits, reducing sugars in the recipe may lead to higher amounts of AA in the final product.

Important considerations

Any changes (lowering) of thermal input to reduce acrylamide in baby foods must be carefully considered due to (more severe) microbiological risks.

PROCESSING: ASPARAGINASE

Commercial Application	
Asparaginase is very effective in certain infant cereal processes and is applied commercially	**Infant cereals** Different technologies are employed to manufacture infant cereals, e.g. extrusion, roller drying. Most ingredients contain a large proportion of cereal flours, and recipes are usually characterized by high water content in the wet mix hydrolysis step, enabling the use of asparaginase. Provided the incubation/residence time, temperature, and mixing conditions are controlled, asparaginase addition can result in a significant decrease (up to 80%) of asparagine.

Development	
Asparaginase can be effective in baby biscuits	**Baby biscuits** Depending on the technology, reductions in the range of 30-60% have been observed in baby biscuits.

PROCESSING: THERMAL INPUT AND MOISTURE

Commercial Application	
Optimisation of thermal input and moisture results in a reduction of AA in baby foods containing prunes	**Baby foods, other than processed cereal-based foods, containing prunes** Substantial amounts of acrylamide can be generated at temperatures lower than 100°C under conditions that resemble the drying of foods, such as plums. It is probable that prolonged boiling and/or pasteurisation are responsible for the observed increase in acrylamide. Modification of processing/manufacturing conditions under which prunes/prune puree are prepared controls AA formation in the finished product. Cooking under wet conditions at 120°C for 1h, shows less formation of acrylamide depending on the variation in asparagine content in the raw fruit, recipe and pH of the product.

FURTHER READING

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http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.304.01.0024.01.ENG&toc=OJ:L:2017:304:TOC

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