ACRYRED

Deliverable 3.2 – DRAFT Strategic Agenda for Acrylamide Research in the Fields of Food Chemistry, Food Processing and Test Development (2024-2029)

Project Name	ACRYRED
Contractual Delivery Date	16/07/2024
Actual Delivery Date	06/12/2024
Working Group	WG3/WG5
Authors	Jane K Parker (University of Reading)
Grant Period	GP2

COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

Executive Summary

This draft strategy addresses the dual objectives of evaluating the health risks posed by dietary acrylamide and implementing immediate measures to reduce its levels in food products, while preserving quality and safety. Acrylamide has been the subject of scrutiny and research for over two decades. However, conclusive evidence of its impact on human health remains elusive and more toxicological evidence needs to be collected. A multidisciplinary approach combining toxicology, epidemiology, and risk impact modelling is critical to clarifying the potential risks and informing regulatory frameworks.

In parallel with long-term research, immediate actions should focus on reducing acrylamide levels across the food supply chain. Once the new legislation on maximum levels is in place, public awareness campaigns should be developed to educate consumers and stakeholders about acrylamide risks, advocating for practices that minimise exposure without compromising product appeal. Product reformulation efforts should emphasise maintaining taste and texture to ensure consumer acceptance, and also consider the scalability of mitigation techniques. Additionally, emerging food categories (high protein, high fibre products) and new formulations should consider acrylamide levels to ensure compliance with anticipated regulatory limits.

Key innovations include the development of predictive tools and real-time acrylamide and asparagine sensors, enabling manufacturers to monitor and control acrylamide formation dynamically. Scaling up successful laboratory-based mitigation strategies to industrial levels will address practical challenges, such as cost, regulatory compliance, and safety considerations.

The overall AcryRed strategy adopts a holistic approach for acrylamide mitigation measures, considering the entire supply chain from pre-harvest conditions to post-processing techniques. This comprehensive perspective ensures that mitigation efforts are both effective and sustainable. Enhancing the FoodDrinkEurope Acrylamide Toolbox with the latest research and involving a broader range of cross-disciplinary experts will further strengthen the strategy’s impact.

By balancing immediate mitigation with long-term research, this strategy positions the food industry to address evolving health and regulatory concerns while maintaining consumer trust and product quality. Collaborative efforts between academia, industry, and regulatory bodies will be pivotal in achieving these goals.

Authors

Authors		
Organization	**Name**	**Mail**
University of Reading	Jane K Parker	j.k.parker@reading.ac.uk
University of Minnesota	Christine Nowakowski	cnowakow@umn.edu
Contributors		
Organization	**Name**	**Mail**
Hacettepe University, TR	Burce Atac Mogol	burceatac@gmail.com
Lithuanian University of Health Sciences, LT	Elena Bartkiene	elena.bartkiene@lsmuni.lt
Middle East Technical University, TR	Alpan Bek	bek@metu.edu.tr
Institute of Food Technology, RS	Miona Belovic	miona.belovic@fins.uns.ac.rs
National Agricultural and Food Centre, SK	Zuzana Ciesarova	zuzana.ciesarova@nppc.sk
University Ss Cyril and Methodius, Skopje, MK	Elizabeta Dimitrieska-Stojković	edimitrieska@fvm.ukim.edu.mk
Université catholique de Louvain, BE	Yann Garcia	yann.garcia@uclouvain.be
Hacettepe University, TR	Vural Gökmen	vgokmen@hacettepe.edu.tr
Albanian Institute of Food and Innovation, AL	Erinda Hametaj	food4mind.al@gmail.com
Agricultural University of Tirana, AL	Rozeta Hasalliu	hasalliur@yahoo.com
Faculty of Natural Sciences and Mathematics, BA	Dino Hasanagić	dino.hasanagic@pmf.unibl.org
Agricultural University of Tirana, AL	Fatjon Hoxha	fhoxha@ubt.edu.al
State General Laboratory, CY	Dimitris Kafouris	dkafouris@sgl.moh.gov.cy
National Agricultural and Food Centre, SK	Kristina Kukurova	kristina.kukurova@nppc.sk
University for Business and Technology, XK	Violeta Lajqi Makolli	violeta.lajqi@ubt-uni.net
Spanish National Research Council, ES	Marta Mesias	mmesias@ictan.csic.es
Karlsruhe Institute of Technology, DE	Shpresa Musa	shpresa.musa@kit.edu
Technological University of Dublin, IE	Azza Silotry Naik	azza.silotry8@gmail.com
Catholic University of Croatia, HR	Petra Palić	petra.palic@unicath.hr

International Hellenic University, GR	Maria Papageorgiou	mariapapage@food.teithe.gr
Aristotle University of Thessaloniki, GR	Adamantini Paraskevopoulou	adparask@chem.auth.gr
University of Aveiro, PT	Claudia Passos	cpassos@ua.pt
University of Warmia and Mazury in Olsztyn, PL	Tomasz Sawicki	tomasz.sawicki@uwm.edu.pl
Graz University of Technology, AT	Barbara Siegmund	barbara.siegmund@tugraz.at
Institute of Animal Reproduction and Food Research, PL	Małgorzata Starowicz	m.przygodzka@pan.olsztyn.pl
Agricultural University of Tirana, AL	Kapllan Sulaj	ksulaj@ubt.edu.al
University of Agriculture in Krakow, PL	Magdalena Surma	magdalena.surma@urk.edu.pl
University of Girona, ES	Liliana Vargas-Murga	liliana.vargas@udg.edu
Sonneveld Group BV, BE	Peter Weegels	peter.weegels@sonneveld.com
Greek Scientists Society, GR	Theo Zacharis	theo@greek-scientists-society.org

Legal Disclaimer

This Report is based upon work from COST Action ACRYRED, CA21149, supported by COST (European Cooperation in Science and Technology).

COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. Our Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation

Views and opinions expressed are, however, those of the author only and do not necessarily reflect those of the European Union or of the COST Association. Neither the European Union nor the COST Association can be held responsible for them.

Table of Contents

Introduction

The main aim and objective of the COST Action is to understand the potential for mitigating acrylamide formation in foods produced from grains by establishing a multi-disciplinary network bringing together plant breeders, the agricultural grain farming community, global grain traders, European food processors, toxicologists, academic researchers from relevant disciplines, public regulators, and relevant consumer and health interest groups and to coordinate research:

1) for a better understanding of different relationships between the profile of the raw materials and the final product quality (which includes acrylamide, sensory aspects, aroma and taste (flavour), texture, colour, etc.),

2) for novel processing technologies to reduce acrylamide formation in cereal-based foods, and

3) to define and agree upon rapid testing methods for free asparagine levels in cereals and acrylamide levels in cereal-based products.

This deliverable was developed based on round table discussions during the Zagreb joint WG3/WG5 workshop held on the 9th of April 2024 in Zagreb. Those who attended are listed as contributors.

Objectives of the document

The objective of this document is to fulfil AcryRed Deliverable 3.2: to propose a draft strategy for Acrylamide Research in the Fields of Food Chemistry, Food Processing and Test Development (2024-2029). This deliverable was developed based on round table discussions during the Zagreb joint WG3/WG5 workshop held on the 9th of April 2024 in Zagreb. It will be further developed to produce a final Agenda for the next 5 years for food chemistry, processing, and test development research (Deliverable 3.3).

1. Clarifying the Health Risks Associated with Dietary Intake of Acrylamide

Goal: Demonstrate unequivocally whether acrylamide is a matter of concern in humans.

- **Rationale:** Over 20 years on from the discovery of acrylamide in foods, the adverse effects on humans is still not confirmed.
- **Background:** High levels of acrylamide exposure, especially through industrial or occupational settings, can affect the nervous system, causing symptoms such as muscle weakness, numbness, and coordination issues. Acrylamide is also classified as a probable human carcinogen (Class 2a) however, evidence is based on animal studies at high doses. Even so, MOE for those with high acrylamide diets is estimated to be 50 (recommended maximum levels usually allow for an MOE of 1000. Also, there is doubt if the MOE approach, which assumes a linear dose response, is valid for acrylamide as the dose/response for acrylamide is proven to be hypolinear in animal and human studies. However, epidemiological studies, which are limited, show no link between acrylamide and cancer. Some evidence shows links with renal and ovarian cancers. One reason put forward is that detoxification of acrylamide seems to occur more rapidly in humans than in rodents, depleting acrylamide and reducing the potential to form glycidamide. Glycidamide is known to form adducts with DNA, however this is a minor reaction compared to other reactions occurring *in vivo*, all suggesting that acrylamide may be less harmful in humans. Evidence of carcinogenicity in humans is still inconclusive.
- **Approach:** Epidemiological studies need to be complemented with *in vitro* and *in vivo* toxicology. It is important:
  - to further our understanding of the mechanism and underlying biochemistry/ toxicology of acrylamide,
  - to further explore the "bioaccessibility" of acrylamide (how much is released from the food, how much is removed by other components of the diet) since the same dose of dietary acrylamide exposure results in very different absorption in the human body
  - to explore the bioavailability (how much is digested, absorbed and available for conversion to glycidamide). With a relatively short half-life in the body, what is the potential for DNA adduct formation?
  - and to evaluate the MOE approach for acrylamide in view of the previous.

- This needs a collaborative, concerted and multidisciplinary approach from academia, research organisation and industry. From AcryRed's point of view, we need more toxicologists to join the Cost Action.

2. Risk impact modelling

Goal: Modelling the risk associated with acrylamide consumption

- **Rationale:** The primary reason for conducting risk impact modelling is to quantify and predict the actual impact of acrylamide exposure on public health, allowing for a more data-driven approach to risk management. By assessing potential health risks associated with various acrylamide levels, risk impact modelling provides a foundation for making informed decisions on setting regulatory limits and developing tailored industry practices. It also enables us to balance and prioritise health and safety objectives with practical considerations in the food production chain, contributing to a more focused, efficient, and scientifically grounded approach.

- **Approach:** Engagement with experts in human biology, toxicology, neurobiology, epidemiology and risk impact modelling for a broad range of cereal based products. This is a long-term project and requires more detailed mitigation information across the supply chain and across the cereal based product portfolio.

3. Awareness of Acrylamide

Goal: To provide a balanced view of acrylamide to all sectors of the population.

- **Rationale:** Whilst the jury is out on the potential harm caused by acrylamide, there is a need to spread awareness and minimise acrylamide in food products to as low as is reasonably achievable (ALARA – current legislation brought in in 2017) or to comply with benchmark limits (proposed by the EU commission for 2024). After obtaining more conclusive toxicological proof of the toxicity of acrylamide in humans followed by the EU regulation of acrylamide levels with Maximum Levels, Public Awareness campaigns are required to inform consumers.
- **Background:** There are diverse views on the possible adverse effects of acrylamide on human health, ranging from those who lobby for tighter regulations and maximum limits, to those who have no awareness, and those who don't care.
- **Approach:** Acquisition of data across Europe, collected from surveys. These can be targeted at the general population to determine their awareness of acrylamide and their perception of the relative risk compared to other known risks. It should also include perceptions of risk and attitudes of those in the baking sector.

4. Addressing Product Quality

Goal: Maintain or improve the textural and organoleptic properties of food products while reducing acrylamide levels.

- **Rationale:** Consumer preferences are predominantly driven by taste and cost. Therefore, minimising changes to texture and flavour is critical for the success of low acrylamide products.
- **Background:** Our review of acrylamide mitigation strategies (D3.1) highlighted that studies reporting successful new methods to reduce acrylamide often lacked any data related to flavour and texture.
- **Approach:** Conduct detailed sensory studies for the newly developed low acrylamide products using quantitative sensory profiling to understand the differences where ranking, rating and preference tests reveal significant differences.

5. The Whole Grain Dilemma

Goal: Production of wholegrain cereals with lower acrylamide potential

- **Rationale:** Although the food industry has worked hard to reduce acrylamide in cereal products, wholegrains still contain elevated levels compared to refined grains.
- **Background:** Whole grain cereals are valued for their high nutritional quality, containing greater amounts of fibre and minerals than their refined counterparts. As such, they can help lower cholesterol, lower blood pressure, and reduce the risk of heart disease, stroke, and type 2 diabetes. However, whole grain cereals also contain higher levels of asparagine which results in an increase in acrylamide concentration during processing. Reducing exposure to acrylamide could be achieved by replacing whole grain cereals with refined grains. However,

this shift would likely elevate other health risks, particularly in relation to non-communicable diseases.

- **Approach:** Focus on innovative methods to reduce acrylamide in wholegrain cereals considering risk benefit analysis.

6. Holistic Approach to Acrylamide Mitigation

Goal: A concerted approach to acrylamide reduction which considers interdependent pre- and post-harvest conditions.

- **Rationale:** Whilst the genetic, environment and management aspects are typically considered together during agronomy trials, the post-harvest factors such as supply chain conditions, product formulation and processing affecting asparagine and ultimately acrylamide levels are rarely taken into consideration.
- **Background:** Since 2002, there have been 91k publications in Scopus covering various aspects of acrylamide in food. It is not uncommon for those in the field of agronomy to overlook the quality of the final products, or for those in the area of food processing to underestimate the extent of the variability in the supply chain.
- **Approach:** More multidisciplinary research spanning the whole food chain.

7. Development of Predictive Tools of Acrylamide

Goal: Development of better tools to predict the outcome of selected mitigation strategies in different products.

- **Rationale:** Accelerating product development will improve response times when products fall out of specification or when new regulatory limits are introduced.
- **Background:** As demonstrated in D3.1, acrylamide mitigation is highly matrix dependent. Currently there are no universal rules, and each product has to be tested for each mitigation strategy under specific processing conditions. For instance, antioxidants may be effective in one context but not in another, and the efficacy of polyphenol-rich products can vary significantly.
- **Approach 1:** This should be addressed using a bottom-up, fundamental approach to gain a deeper understanding of the underlying chemistry involved in mitigation strategies, particularly focusing on the role of antioxidants and the role of competition in the Maillard reaction.
- **Approach 2:** An ambitious and alternative strategy would involve leveraging machine learning to develop algorithms capable of predicting acrylamide formation from a specified set of well-characterised starting materials and processing. To achieve meaningful results, a substantial collaborative grant is essential to generate sufficiently large data sets. Some data can be mined from the literature (a large job in itself). A more holistic approach could be taken which extends to modelling of other indicators of product quality from agronomy to taste and toxicology. Can we determine which steps are more influential for which types of products?

8. Scale up of Mitigation Strategies

Goal: Test successful laboratory scale mitigation strategies on a larger scale

- **Rationale:** Strategies developed in a laboratory are not necessarily scalable to pilot plant or full manufacturing capacity.
- **Background:** The reasons for failure to scale up processes are numerous, but some fundamental issues include changes in the time-temperature profiles which can significantly affect relative reaction rates, altering the efficacy of mitigation strategies. Enzyme handling may introduce safety and handling challenges when implemented on a larger scale. These challenges can include:

    Cost Implications: The financial burden associated with scaling up enzyme use may not be feasible for all operations.

    Labelling Issues: In certain regions, the use of specific enzymes can complicate product labelling and regulatory compliance.

    Safety Concerns during Manufacturing: Enzymes may require special handling due to potential inhalation risks, skin irritations, or other health hazards.

    Increased Cleaning Requirements: Larger-scale operations may necessitate enhanced cleaning protocols for unit operations to manage enzyme residues effectively.

  Addressing these challenges is essential for the successful scaling of mitigation processes in food production

- **Approach:** Selection of the more successful and more robust mitigation strategies to test at pilot scale using equipment in academia, research organisations and industry.

9. Focus on Newly Emerging Product Categories

Goal: Ensure that acrylamide levels in new emerging products are i) as low as reasonably achievable and ii) would comply with proposed benchmark levels if set.

- **Rationale:** New products developed for health and sustainability may not necessarily have been optimised with acrylamide in mind.
- **Background** The food industry is experiencing an unprecedented period of innovation and productivity as product developers work to address consumer needs, balancing the challenges of both malnutrition and obesity, while also meeting sustainability targets shaped by the dual pressures of public health and climate change. Increases in protein, fibre and micronutrients, reductions in fat, sugar, and salt, and incorporation of more sustainable ingredients can significantly influence the acrylamide levels in the final products, highlighting the complexity of creating healthier and safer foods that still meet taste and quality expectations.
- **Approach:** Testing of new products on the market and during development. Raising awareness that for example increases in protein may be accompanied by greater asparagine levels, and a greater acrylamide potential.

10. Update the FoodDrinkEurope Acrylamide Toolbox

Goal: Revise and enhance the FoodDrinkEurope Acrylamide Toolbox to incorporate new methods and product categories.

- **Rationale:** The last update to the toolbox occurred in 2019, and numerous studies have since proposed alternative methods that should be incorporated. Additionally, new product categories are now being included in the regulation for the first time and must be addressed in the updated toolbox.
- **Background:** First distributed in 2004, the toolbox has been tailored for use by the food industry across a wide range of products. The latest update in 2019 reflected 15 years of research, but further advances in mitigation strategies have emerged since then. Many of these involve novel enzyme technologies, (not limited to asparaginase) to reduce asparagine, the key precursor in cereal products. Others for example include the sustainable use of polyphenol-rich plant-derived by-products. Often, a combination of reformulation, enzyme technologies, and processing techniques is employed to achieve the lowest possible acrylamide levels.
- **Approach:** Collaboration with FDE and relevant academic and industry stakeholders including AIBI and COCEREAAL.

11. Development of sensors for asparagine and acrylamide

Goal: Development of asparagine sensors for rapid real-time screening of asparagine in cereal crops and acrylamide sensors for quality control.

- **Rationale:** Food manufacturing is in need of rapid testing to make real time manufacturing adjustments to minimize acrylamide. Asparagine sensors could play a role in early detection of the key precursor, allowing manufacturers to proactively adjust their processing conditions.
- **Background:** In cereal-based products, asparagine is usually the limiting factor for acrylamide formation, therefore reduction in asparagine is an effective strategy to mitigate acrylamide.
- **Approach:** Collaboration with experts in sensor technologies.

12. Creation of Cross Disciplinary Platforms

Goal: Increase cross-disciplinary representation in AcryRed and AcryRed activities.

- **Rationale:** Currently, AcryRed predominantly comprises academics in food processing and food analysis, as well as those in the field of agronomy.
- **Background:** Strategies outlined above are heavily reliant on further work on toxicology and epidemiology to confirm the nature of the risk that acrylamide poses on human health. Laboratory scale mitigation strategies are often limited in their application by the requirements of industry.
- **Approach:** The way forward is in creating a cross-disciplinary platform which includes more experts in toxicology, epidemiology, nutrition, greater representation from industry, food service and restaurateurs on the one hand, and from relevant EU bodies, trade associations, consumer associations and non-governmental organizations on the other. How do we attract these?

Conclusion

This strategy is designed to address the potential health risks of acrylamide in food by both prioritising long-term research on the potential harm to humans as a result of dietary acrylamide, and implementing immediate reduction measures for use by industry, food service and home use.

At the core of this strategy is a commitment to understanding the potential carcinogenic risks of acrylamide. While acrylamide is classified as a probable human carcinogen, its impact at typical dietary levels remains inconclusive. Animal studies suggest a risk, yet epidemiological evidence in humans is lacking and also biochemical markers indicating potential toxicity provide so far, no evidence. To address this knowledge gap, a multidisciplinary research effort combining toxicology, epidemiology, and risk impact modelling is essential.

The immediate need, however, is to reduce dietary exposure to acrylamide. Public awareness campaigns after maximum levels have been agreed will inform consumers and industry stakeholders of the risks, while product development will prioritise reducing acrylamide without compromising taste or texture, ensuring that low-acrylamide products remain attractive to consumers and conform to current and proposed regulations. Emerging “future foods” should also consider acrylamide levels, maintaining consumer safety as new products are developed. Scaling up effective lab-scale strategies will address the practical challenges of large-scale production, ensuring these approaches are feasible across the food industry.

The strategy seeks to enhance the FoodDrinkEurope Acrylamide Toolbox by including recent strategies developed to mitigate acrylamide and should involve a wider range of cross-disciplinary experts in tackling acrylamide reduction. This collaborative approach will integrate insights from toxicology, epidemiology, industry, nutritionists and regulatory bodies, creating a unified front to assess the risks of acrylamide and ensuring that mitigation strategies are effective and sustainable.

Advanced predictive tools and real-time asparagine and acrylamide sensors are also in development to help manufacturers monitor acrylamide levels quickly and accurately, enabling better compliance with current and anticipated regulations.

In balancing the immediate need for risk reduction with a commitment to long-term research, this strategy positions the food industry to provide safer products while addressing evolving health concerns. The overall Acryred strategy will take a holistic approach to production, considering all stages from pre-harvest to processing, to address acrylamide formation factors in a way that spans the entire food chain.