**Risk benefit assessment of acrylamide in bakery products and bread.**

**Purpose**

The purpose of this conceptual paper was to introduce the risk – benefit approach to bakery products in relation to their acrylamide content. Acrylamide is a compound which gives rise to risks of cancer and several mitigating procedures have been in place for various products and processes. This paper concentrated on bakery products and took a risk benefit approach in relation to acrylamide.

**Design/methodology/Approach**

Papers published in peer reviewed journals were reviewed. A combination of keywords such as acrylamide, bakery products and risk/benefit were used to find sources. Additional sources, such as governmental and non-governmental organisations documents, were also used when relevant. After looking at the main characteristics of acrylamide, the potential benefit of bread was also looked at. The paper summarises known information on acrylamide and looks at the risk and benefit of bakery products in relation to this compound.

**Findings**

The risk analysis approach can be extended to include benefits so that a balanced conclusion can be reached whether a product is an acceptable part of the diet or not. Exposure to acrylamide was a function of the product type and preparation/process. Bakery products were a source of many nutrients and the risk regarding acrylamide may be controlled by careful product and process design.

**Originality**

There was contradictory information regarding how unsafe acrylamide is. In this paper, the risk benefit approach has been qualitatively used to bakery products to weigh both the risks and benefits of this product category.

Keywords: food safety, acrylamide, risk perception, risk, benefit, bakery products.

**Introduction**

Acrylamide is an organic molecule that is a genotoxic carcinogen, although much of this may be mediated by its metabolite, glycidamide (Bolger et *al.,* 2010 ; European Food Safety Authority EFSA, 2015). Over time, the risk of developing cancer may increase through the consumption of products containing high levels of acrylamide. Indeed, it has been shown that acrylamide could lead to cancers in animal studies (Bolger et *al.,* 2010) even if some human studies have shown limited links (Burley et *al.*, 2010 ; Krein et *al.*, 2021). In view of the evidence based on animal studies, the International Agency for Research on Cancer (IARC) classified acrylamide as a probable human carcinogen, placed in group 2A. The Food Standards Agency (FSA) in the UK has advised that levels of acrylamide should be as low as reasonably possible and embarked on a risk communication activity to educate consumers regarding acrylamide production in home cooking (Hamlet et *al.,* 2019).

There has been a lot of activities related to mitigating acrylamide formation in many products. All types of food heating (whether at home or during commercial processing) may lead to negative elements such as loss of lysine, off flavour and the creation of toxic compounds. Heating will result in the production of acrylamide through the Maillard reaction, although acrylamide formation can occur through various mechanisms (EFSA, 2015 ; Keramat *et al.*, 2011). Indeed, one of the main mechanisms of creation of acrylamide is through the reaction between reducing sugars and some amino acids and proteins upon heating. Specifically, the reaction between reducing sugars and asparagine is the main reaction at play. Controlling the formation of acrylamide requires knowledge of ingredient/product concentration in precursors, heat transfer and distribution profile knowledge as well as kinetics of reaction in function of temperature in a defined product (Seal et *al.*, 2008).

However, heat processing also leads to positive characteristics important for food quality and acceptability. These include browning and flavour creation. Hence, many products prone to acrylamide formation are products that are enjoyed for their sensory properties and some of those may also have substantial benefits such as nutrients that are present. In addition, there are more reserves whether acrylamide is really a food safety issue because the causal link between acrylamide intake and cancer risk is not strong (Krein et *al*., 2021) and some balanced view between risks and benefits should be used when considering products in relation to acrylamide.

This risk benefit approach has been used successfully in the past regarding the substitution of red meat by fish or the use of pesticides for example (Verhagen et *al*., 2021) and this paper took this approach to acrylamide in relation to bakery products. The objective of this paper was to look at the risks and benefits of bakery products, and in particular bread, in relation to acrylamide qualitatively.

**Methodology**

Papers published in peer reviewed journals were selected and reviewed. Science direct, web of science and google scholar were used to find related papers using a combination of keywords such as acrylamide, bakery products and risk/benefit. Papers were selected according to relevance and accuracy. Although a few historical papers were included, relevant papers published since 2010 were mainly selected. Additional sources, such as governmental and non-governmental organisations documents, were also used when relevant. Extensive cross referencing between papers was also used to find additional sources and in total 36 sources were included in this paper.

**Acrylamide toxicity**

As mentioned, acrylamide is formed through various mechanisms but the main one is through the Maillard reaction when amino acids react with reducing sugars. Agricultural practices *(e.g.* variety used, harvest time…) and/or processing parameters (*e.g.* heating temperature, time…) are important factors in contributing to acrylamide formation (Seal et *al.*, 2008). Acrylamide absorption by the body is quick, and the compound is then widely distributed and metabolised through conjugation with glutathione and epoxidation to glycidamide (EFSA, 2015 ; Krein *et al*., 2021). The mode of action for the carcinogenicity is uncertain but it is probably genotoxic with glycidamide-DNA adducts formed throughout tissues. While other non-genotoxic mechanisms of carcinogenicity have been postulated (such as interactions with thiol groups in proteins) these are not thought as the main mechanism (Bolger *et al*., 2010). Species vary in their ability to metabolise acrylamide to glycidamide. Mice are very efficient at this conversion but it is unclear whether the metabolisation of acrylamide to glycidamide is as efficient in humans as in rodents (Bolger *et al.*, 2010; EFSA, 2015). The differences between the animal models used for these studies and humans make it difficult to translate these results between species (Krein *et al*., 2021). Indeed, the link between acrylamide and cancer is not easily shown in human. For example, a study following women for 11 years did not find a significant relationship between acrylamide intake (median dietary acrylamide intake was 0.23 mg/kg body weight /day) and breast cancer (Burley *et al.*, 2010). This may have been because intake in the group studied was generally low as it comprised mainly health conscious women. Indeed, in that study, only 0.3% of women exceeded the estimated mean intake of acrylamide (1g/kg body weight/ day) identified by JEFCA (2011). Neurotoxicity from high occupational exposure in humans has been reported (with levels *circa* 200 mg/kg/day) while those through food ingestion have not been observed because of the lower acrylamide doses (Krein *et al.*, 2021 ; Tardiff *et al*., 2010).

**Acrylamide exposure**

Acrylamide is an international issue and many reports have investigated products in various parts of the world, like for example in Nigeria (Akinosun et *al.*, 2020). Data are now available for the exposure to acrylamide from food for the populations of several countries around the world (Abt *et al.*, 2002). Before knowledge that acrylamide was commonly found in foods and that the population was exposed to it on a daily basis, the World Health Organisation (WHO, 1996) had suggested guideline values associated with excess lifetime cancer risks of 10-4, 10-5,and 10-6 as 5, 0.5, and 0.05 μg/litre, respectively. However, it was discovered that acrylamide was found in significant amount in several food products (Tareke *et al*., 2002) and acting on these values would have meant a large number of products to be withdrawn and this was not seen as proportional to the risk considering that humans had been in contact with acrylamide for centuries (Busk, 2010). Acrylamide has now been found in a range of products and at different levels. Table 1 shows acrylamide levels found in different products purchased in UK retails in 2018 (Hamlet *et al.,* 2019). Acrylamide monitoring by the FSA in response to European Commission Recommendation (EU) No. 2010/307 found that levels for some product were relatively high but that the trends over 4 years was for a general reduction in acrylamide content for some product (e.g. potato chips, biscuits), although most remained mostly unchanged (Hamlet *et al*., 2019). The proportion of products exceeding EC limits were low (5-7%) and constant over the survey (Hamlet *et al*., 2019). These results are similar to a previous survey carried out at European level by EFSA between 2007 and 2010 which showed levels to be usually constant, with some slight increase (e.g. coffee products) or decreasing (for processed cereal based food products, biscuits and rusks for infants and young children) and a small proportion of products over the threshold (3-20%) used at the time (EFSA, 2010). The EFSA did not consider acrylamide to be of concern for human health although it is acknowledged that acrylamide potentially increases risks of producing cancer (EFSA, 2015).

JEFCA (2011), the Joint FAO/WHO Expert Committee on Food Additives, estimated that the mean intake of acrylamide was 1g/kg body weight/ day (for consumer with high dietary exposure, the estimate was 4 g/kg body weight/ day). The margin of exposure (MOE) relates the amount of a toxin that has no adverse effect to the amount/exposure of that toxin and can be used to characterise the risk. Any MOE recorded as lower than 10000 indicates that the risk is significant (EFSA, 2015). JEFCA (2011) calculated MOEs, using a No-Observed-Adverse-Effect Level (NOAEL) of 0.2 mg/kg body weight/day, for the average and high consumer, of 200 and 50 respectively (JEFCA, 2011). Tardiff *et al*. (2010), calculated a MOE for neurotoxicity for an average consumer to be 300 and 500 when based on acrylamide and glycidamide, respectively. For cancer, the MOE were calculated as 200 and 1200 for acrylamide and glycidamide, respectively. This indicates human concern as acrylamide is both a genotoxic and carcinogenic. In 2015, the EFSA (2015) estimated intake in a European survey found this to be 0.4-0.9 μg/kg body weight/ day (and the 95th percentile was between 0.6 and 2.0 μg/kg body weight/ day). Other studies have confirmed this. Elsewhere, a study in Colombia found a MOE between 185 and 979 (Barón Cortés *et al*., 2021) using a Benchmark dose’s lower one sided confident limit (BMDL) of 0.17 mg/kg as advised by EFSA (2015) for carcinogenic effects. Tardiff *et al*. (2010) have estimated a tolerable daily intake of 2.6 g/kg body weight/day for acrylamide and 16 g/kg body weight/day for glycidamide. It seems that the levels of intake from food is low but there is also concern that there is various levels of intake depending on age, with children and adolescent being more exposed. The situation is worse for babies because of their body weight and MOEs have been calculated as low as 40 even if the source of acrylamide was a single 15 g portion of a breakfast cereal (Curtis and Halford, 2016). Exposure to acrylamide is usually high for children and adolescent throughout the world (Abt *et al.,* 2022).

**Acrylamide in bakery product**

A full exposure analysis through bakery products would require accurate quantitative data from diets and local concentrations in acrylamide in the products consumed. This could then allow for risk characterisation to be looked at. The source of acrylamide in the diet depends on the country but bakery products have been found to be one of the main sources in many parts of the world (Keramat *et al*., 2011). Indeed, although bread is low in acrylamide, it is the main contributor of acrylamide in countries such as France, Germany and Sweden because of the quantities ingested (Curtis and Halford, 2016). Hence, for many countries, baking products come second in terms of contribution to the diet with acrylamide contributions to the diet at around 20%, after potato products at 50% (Keramat *et al*., 2011). This is also the case in the UK. For example, in a study with middle aged women in the UK, bakery goods were found to be the second contributing source of acrylamide (17%) after potato chips (28%) (Burley *et al.*, 2010). Adding together, bakery goods, bread (17%) and biscuit (9%) contributions gives 43% as a contribution from these few cereal based products, showing that this group is the main contributor of acrylamide to those women. In addition to the country, age can affect exposure to acrylamide through bakery products. For example, bread represents 10% of acrylamide contribution in the Netherlands general population but 19% in adolescents in Belgium (Keramat *et al*., 2011).

The level of acrylamide in bakery products varies widely as this category covers many products. Even in bread, there are many factors that can influence the level of acrylamide such as whether it is soft or crunchy bread, fermented or not and the type of cereal used (Sarion *et al*., 2021). These parameters must be reported accurately especially if various breads around the world are analysed and compared.

The highest levels of acrylamide are detected in the crust of breads while many bakery products have low content except for crisp bread which has been found to have a high content of acrylamide (Keramat *et al*., 2011). A European survey from 2010 to 2014 found bread to have relatively low levels of acrylamide 42 g/kg (EFSA, 2015). However, it can be a major contributor of acrylamide in the diet, especially for some groups. Indeed, the same survey found ‘Soft bread’ to be the second contributor to the total exposure of children just after ‘Potato fried products’ (EFSA, 2015). A follow up survey (Hamlet *et al*., 2019) from 2014 to 2018 found that bakery products such as biscuits, crackers and crisp breads had higher acrylamide content than soft bread, with a mean of 223 g/kg and 17g/kg in 2018, respectively. Over the period 2014-2018, there was a statistically significant reduction in acrylamide in the biscuit/cracker/crisp bread category but not in the soft bread one (Hamlet *et al*., 2019).

Regulation 2017/2158/EU establishes benchmarking levels for acrylamide in various products that can be attained through mitigating procedures (European Commission, 2017). Benchmark levels for wheat based soft bread and non-wheat based soft bread are 50 and 100 g/kg, respectively. Other bakery products have been set up with higher levels, for example 350g/kg for biscuit wafers and 400 g/kg for crackers (European Commission, 2017). Various surveys around the world have found biscuits had a high range in acrylamide content and that many samples exceeded the 350 g/kg European benchmark (Pasqualone *et al*., 2021). This is probably due to the higher surface area of these products.

Several mitigation strategies have been investigated to reduce the acrylamide content of bakery products. Shortening baking time is the first obvious mitigating procedure for baked products in terms of acrylamide production as the Maillard reaction is the main mechanism leading to the creation of acrylamide. The use of ingredients with low asparagine content or non-reducing sugar can also be good avenues for acrylamide reduction. The use of additional microorganisms and fermentation parameters has also been investigated (Nachi *et al*., 2018). Mitigation methods highlighted by the European Commission (2017) make a distinction between fine bakery ware (biscuits, cookies, crackers…) and bread products and include agronomy and product/processing design. Overall, strategies that have been investigated can be broadly classified into those altering processing control (*e.g.* using lower temperatures/heating time, heating type, flour milling, fermentation) or ingredients (*i.e*. with low level of precursors) and the use of additives (*e.g.* asparaginase, organic acids or compounds with antioxidant properties). Some techniques such as the use of asparaginase that have been successfully used for cereal products are also investigated in other products such potato-based products (Ciesarová *et al.,* 2010). Mitigation methods have also looked at the agricultural side. The avoidance of sulphur deficiency during wheat cultivation (Curtis and Halford, 2016; Raan *et al*., 2020) or potential selection of wheat breeds lacking a specific gene leading to low free asparagine (Oddy *et al*., 2021) could be some of the main mitigating elements at this stage. There may also be opportunities to develop bread products by using mixes of grains as this has been shown to reduce acrylamide (Serpen *et al*., 2012). These products could also be perceived as healthier as they contain less wheat. Reviews of mitigation methods that can be used for bakery products have been done by Mesias and Morales (2016) and Sarion *et al*. (2021).

Consumers may need to be educated on the benefits of these products with lower levels of acrylamide. Indeed, lowering of acrylamide may also be accompanied by lowering of important characteristics for the consumer in terms of organoleptic quality and this may reduce the products acceptability. For example, both low temperature and the use of alternatives to reducing sugars, such as sweeteners, will have an impact on product quality such as reduction in browning as the creation of acrylamide and crust colour in bread have been shown to be correlated (Dessev *et al*., 2020). This may lead to lower sales as consumers will not purchase products with lower perceived quality (in terms of colour or/and flavour). Good approaches investigate organoleptic changes in parallel to the mitigating investigations (Nachi *et al*., 2018). When developing or investigating new products, the colour should be considered an important parameter, not just for consumers’ acceptance but also because of the potential link to acrylamide production. This approach was for example considered while investigating the characteristics of resistant starch enriched cookies (Rojhani *et al*., 2022). In addition to sensory issues, as highlighted above, mitigating methods could themselves also involve a risk because of the formation of additional toxic compounds or increased microbiological risks and methods are being researched that minimise those (Sarion *et al*., 2021).

**Risk Benefits of bakery products in relation to acrylamide**

Some sources of acrylamide, such as smoking, are purely consumed for their hedonistic value. The level of acrylamide or glycidamide bound to hemoglobin in red blood cells (which is a measure of exposure) is three to five times higher in smokers than non-smokers (Virk-Baker *et al.,* 2016). Each individual accepts the risk from smoking, and all the chemicals involved, in exchange for the hedonistic aspect. Acrylamide levels are low in alcoholic beverages such as beer which was found to contain 0–72 g/kg in acrylamide with a maximum of 363 g/kg (Okaru and Lachenmeier, 2021) and represents a low carcinogenicity risk in front of the alcohol and other compounds present. For non-smokers and moderate drinkers of alcohol trying to limit their acrylamide intake, it would be useful to have a risk benefit approach regarding different products. Many fine bakery product are probably also consumed for their organoleptic quality rather than their nutritional content as they are high in fat and sugar. However, amongst bakery products, bread is known as a source of many nutrients in a European diet and limiting its intake because of a perceived risk in relation to acrylamide may lead to less nutrients provided to the individual through this product.

Indeed, bread is a source of vitamins and minerals even if this is very much dependent on the process and especially the milling step which helps deliver refined products. The extraction rate when producing flour is especially important as vitamins from the B group and minerals are lost when white flour is produced (Cauvain and Clark, 2019). Further heat processing also impacts the vitamin levels and fortification in calcium, iron and B vitamins of flour has been used to counteract this loss of nutrient. Even taking these into account, bread remains a good source of nutrients in the diet.

Wholegrain products are seen as healthier by consumer and when compared to the white flour versions, these products are more nutritious in both vitamins and fibre (Cauvain and Clark, 2019). However, whole grain products also contain higher levels of asparagine (Mesias *et al.*, 2022) and hence will lead to higher levels of acrylamide. Acrylamide intake will probably increase as consumers are advised to increase whole grain products consumption and a quantitative risk benefit analysis may be required.

Home baking may be less controlled than industrial baking. This may lead to increased intake of acrylamide because of higher temperature used during home baking and little control of time. Also, specific behaviours (*e.g.* high consumption of a particular product, over-cooking…) can influence the total dietary exposure to acrylamide. For example, toasting can be a major source of acrylamide and it is recommend to limit browning through toasting at home. Indeed, acrylamide levels have been reported to increase from levels less than 5 μg/kg in a soft bread slice to 11–161 μg/kg after toasting (Curtis and Halford, 2016). However, this is product dependent and while for potato frying, behaviour could influence acrylamide production and intake by up to 80%, this was only 8% when looking at the behaviour relating to bread toasting (EFSA, 2015).

In addition, risk understanding and perception are also important factors when considering consumers. An FSA report found that despite risk communication carried out in the UK, knowledge and awareness of acrylamide was low in consumers (FSA, 2017). Additional information regarding mitigating acrylamide formation at home did not help as people found this confusing or were put off by technical information such as the MOE (FSA, 2017). In that study, most consumer did not consider acrylamide as a risk even after being provided information, although many were willing to change their behaviour – showing a disconnect between their risk perception and behaviour (FSA, 2017). The survey was analysed later by Houdi and Puttock (2020) and acrylamide was found to be the food risk of lowest concern for consumers.

As can be seen, the management of acrylamide production is multifactorial and should take into account consumer behaviour in addition to the technical elements related to the product, process and ingredient. This area requires further research and will no doubt give rise to several new avenues to be investigated.

**Conclusion**

The risk of acrylamide from bakery product is relatively high as these are consumed in large quantities and contribute a large portion of acrylamide in the diet. A risk assessment of acrylamide and the mitigating methods used to reduce its level need to be made while taking into account the benefit that these products bring beyond the purely hedonistic ones. For example, if intake of bread is reduced, reduction of acrylamide but also reduction of fibre and other important compounds. It would be interesting to carry out a product based risk benefit analysis in relation to a product like bread for example. While this paper concentrated on acrylamide, other toxic compounds present in bread and bakery products could be the focus of such risk benefit assessments. These could include furans for example, which are produced at the same time as acrylamide. The practical implication of such risk benefit analysis is that, in the future, consumers will be able to make the decision of purchasing, consuming and enjoying the organoleptic or nutritional properties of a product while understanding the level of risk involved.

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