International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2021; SP-9(2): 76-84

Received: 09-01-2021
Accepted: 12-02-2021

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Acrylamide in food products

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DOI: https://doi.org/10.22271/chemi.2021.v9.i2b.11970

Abstract
Acrylamide (AA, 2-propenamide) is a color less and odourless crystalline produced by the hydration of acrylonitrile. It dissolves in water, alcohol, and other polar solvents, but tends to be hydrolyzed into acrylic acid in an acidic and alkali environment (Hu *et al*., 2015). The highest concentrations of AA usually occur in potato chips, French fries, biscuits and roasted coffee EFSA (2015). However, the International Agency for Research on Cancer (IARC) classified the AA as a probable human carcinogen (group 2A) (IARC, 1994). fried potato products (French fries, chips, etc.) are highly susceptible to AA formation due to asparagine and reducing sugars content as well as the high temperatures applied during the frying process and the high surface to volume ratio (Parker *et al*., 2012). The principal strategies proposed to reduce AA in potato products are the selection of cultivar and storage conditions, the control of time and temperature of heat treatment, the application of different frying techniques (e.g. under vacuum), the use of asparaginase enzyme and hot water blanching as pre-treatments (Vincin *et al*., 2011).

Keywords: Acrylamide, IARC, asparagine

1. Introduction
Acrylamide is a well-known colourless and odourless crystalline compound, used for more than fifty years to synthesize polyacrylamides with numerous applications in papermaking, textile, cosmetics and as flocculants to clarify drinking water. This small compound is soluble in water, acetone and ethanol, has a high mobility in soil and groundwater and it is biodegradable (Zhang & Zhang, 2007) [9, 29, 37, 53, 60, 61]. The single (monomer) form of acrylamide, is recently discovered to be present in food, which is toxic to the nervous system. A carcinogen in rodents, and a suspected carcinogen in humans cause gene mutation and DNA damage (Erikson *et al*., 2005).
AA exhibits both weakly acidic and basic properties. The electron-withdrawing carboxamide group activates the double bond, which reacts with nucleophilic regents by addition reaction mechanisms. Many of these reactions are reversible, and the rate of reaction depends on the strength of the nucleophile. Examples are Michael and Diel-Alder additions and radical reactions. These reactions are of importance in biological systems. Reactions of the amide residue include hydrolysis, dehydration, alcoholysis, and condensation with aldehydes, while the vinylic double bond reacts with ammonia, aliphatic amines, phosphines, chlorine, bromine, bisulfite, and dithiocarbamates, as well as proteins (Vinci *et al*., 2012).
AA is produced industrially mainly for the synthesis of polyacrylamide, which has several applications in the cosmetic and packaging industries, in soil and conditioning agents, in the treatment of sewage and wastewater, and in the purification of drinking water; it is also found in tobacco smoke (El-Kholy *et al*., 2012; International Programme on Chemical Safety, 1985; Smith *et al*., 2000; Tareke *et al*., 2000; Vattem & Shetty, 2003; Zangrando *et al*., 2012) [15, 42, 49, 56, 57, 59].
AA is known to be neurotoxic, and several toxicological studies have demonstrated its genotoxic carcinogenicity in animals, thus indicating potential human health risks (Park *et al*., 2002; Rice, 2005; Rud´en, 2004) [39, 44, 45]. In 1994 the International Agency for Research on Cancer (IARC) classified AA as a possible carcinogen for humans (Group 2A), based on its carcinogenicity in rodents. AA's electrophilic double bond can interacting *in vivo* with cellular nucleophiles such as the sulfhydryl groups in reduced glutathione and in proteins, and to a lesser extent protein amino groups (Environment Canada and Health Canada, 2009; IARC, 1994; Medeiros Vinci *et al*., 2012; Pelucchi *et al*., 2011; Sanny *et al*., 2012) [42, 46, 57].

2. Occurrence and dietary intake
People are exposed to different amounts of acrylamide mainly through the diet. Acrylamide

occurrence in foods is being studied intensively since the original report of high levels of acrylamide found in food that are subjected to high temperature (Weisshaar *et al*., 2002).

Acrylamide primarily found in plant based foods; heat treated starchy foods such as potato, cereal and bakery products contains high levels of acrylamide Acrylamide is not found in foods that are not fried or baked such as boiling or microwaving (Eriksson *et al*., 2005) [17, 43, 52] and found very low levels in animal based food products such as meat and fish.

Estimation of acrylamide occurrence in food commodities is a great concern in many countries. Moreover, the predictions of dietary acrylamide intake have been made for populations in many countries consist of different dietary records. (Konings *et al*., 2003) [32]. These studies found that the amount of acrylamide was extremely higher in fried potato products (such as French fries and potato chips) followed by cereals, crisp breads, biscuits and other bakery products Table.1.

Concentration and dietary intake of food have significant variations, which depends upon cooking methods (Dybing *et al*., 2003) [13]. Factors such as difference in food composition, high temperature (more than 120 °C), and high carbohydrate, free asparagine, reducing sugars, pH, water content, ammonium bicarbonate and high concentration of competing amino acids could be the sources for variation in acrylamide level. (Medeiros *et al*., 2012).

Table 1: Amounts of acrylamide in different foods and food product groups. Adapted from Peterson (Elder *et al*., 2004) [14].

Product/product group	Acrylamide range (µg kg^{-1})
Bakery Products and biscuits	18-3324
Breads	<10-3200
Bread (toast)	25-1430
Breakfast cereal	<10-1649
Chocolate products	<2-826
Coffee substitute	80-5399
Dairy products	<10-130
French fries/chips	59-5200
Meats	<10-<116
Potatoes (Raw)	<10-<50
Potatoes chips/crisps	117-4215
Roasted coffee	45-9359

3. Mechanisms of formation

Acrylamide is not a substance that is added to food, but it is formed in food during heat processing. Research indicates that heating of food could be an important source of acrylamide formation. Acrylamide formed in a wide variety of foods, particularly carbohydrate (reducing sugars) rich foods cooked at above 120 °C upon frying, baking and roasting (De Meulenaer *et al*., 2008) [11]. However, acrylamide formation in potato fries taken place at below 120 °C at low moisture content and prolonged heating conditions (Gökmen *et al*., 2006) [22]. The basic formation routes of acrylamide in foods in shown in Figure 1. Acrylamide formation follows different routes in conjunction with the Maillard reactions system in food products, where the asparagine route is the major one for the formation of acrylamide.

3.1 Formation via Asparagine route

The major pathway leading for acrylamide formation in foods is a part of the Maillard reaction with free amino acid (asparagine) and reducing sugars (mainly glucose and fructose) (Biedermann *et al*., 2003) [1, 5, 6]. Maillard reaction is a non-enzymatic browning reaction occurring in foods during baking or frying. This happens at proper combination of carbohydrates, lipids and proteins for desirable colour, flavour and aroma (Figure 2). Asparagine, is the free amino acid present in potatoes in high level (93.6 mg per 100 g) needs carbohydrates to form acrylamide. The potential of acrylamide formation is strongly related to glucose and fructose content. Free asparagine concentration to be the main determinant of acrylamide formation in rye varieties and in cooked flours and doughs (mainly rye and wheat) (Hamlet *et al*., 2008) [25, 47]. Research has shown that the reducing sugars are the major limiting factors in potatoes, while asparagine (mainly in the cereal bran) is the major limiting factors in cereal products (Amrein *et al*., 2003) [1].

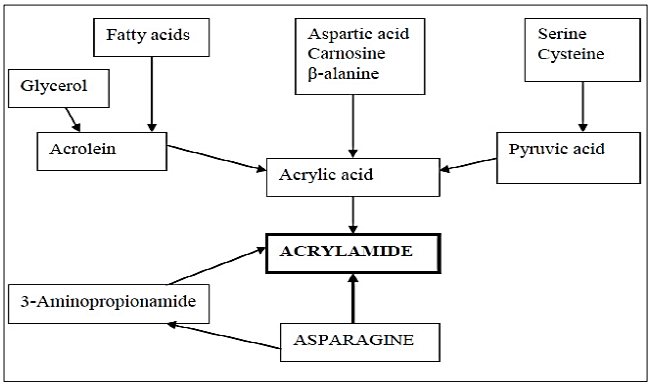


Fig 1: The basic formation routes of acrylamide in foods (Eriksson *et al*., 2005) [17, 43, 52]

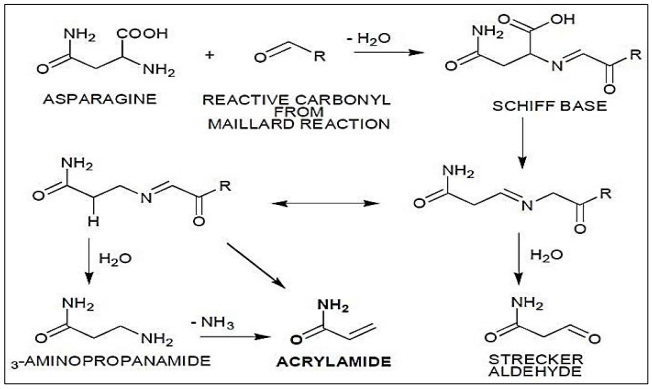


Fig 2: The basic formation routes of acrylamide in foods (Eriksson *et al*., 2005) [17, 43, 52]

3.3 Formation via alternative routes

Although formation of acrylamide in foods has its major routes through asparagine and reducing sugars, several other formation routes suggested via. Acrolein and ammonia. In the absence of asparagine, acrolein and ammonia to play a role in lipid rich foods to form acrylamide (Fig: 3). It is known that acrolein and acrylic acid are produced by degradation of lipids (triglycerides) in subject to high temperature (Umano *et al*., 1987) [51]. Degradation of amino acids with ammonia can give rise to acrylamide formation by thermal decomposition. Amino acids such as glutamine, cysteine and aspartic acid have also been found to produce low amounts of acrylamide (Sohn *et al*., 1986). However, stated that this mechanism might be irrelevant for acrylamide formation in foods.

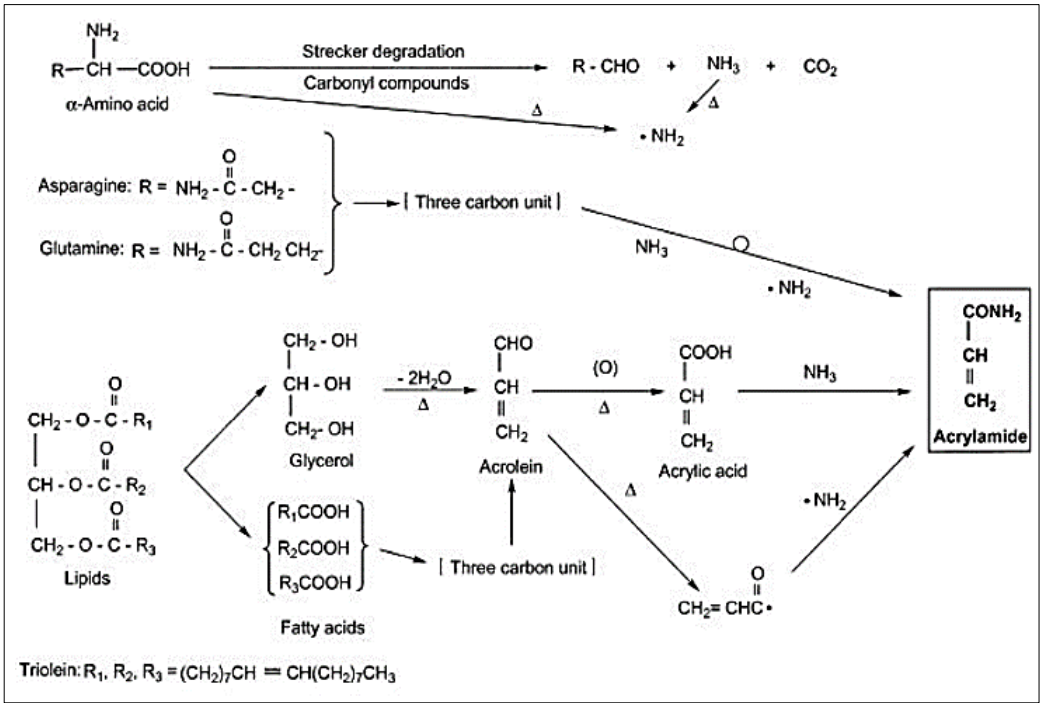


Fig 3: Hypothesized formation mechanism of acrylamide from an amino acid and a lipid

4. Detection method of acrylamide

4.1 GC-MS methods for the analysis of acrylamide in foodstuffs

Mixing with some water
↓
Swelling at 70 °C
↓
Extraction with 1-propanol
↓
Azeotropic evaporation of water/propanol
↓
Dissolution in acetonitrile
↓
Defatting with hexane
↓
GC-CI/MS

4.2 Rapid detection methods

4.2.1 Color indicating methods

The formation of AA is accompanied with color changes called the browning process in the Maillard reaction of reducing sugars with asparagine. Some studies have demonstrated the correlation between browning levels and AA concentrations in different food products, such as potato chips (Majcher & Jele, 2007; Pedreschi *et al*., 2007) [35, 40, 41], coffee and French fries. Early research on measuring food color adopted the L*a*b* system, an international standard for color measurement, where L* is the luminance or lightness component, a* (from green to red) and b* (from blue to yellow) are the two chromatic components Figure. 4. can be used as an indicator to evaluate AA levels in thermally processed products (Goekman *et al*., 2010).

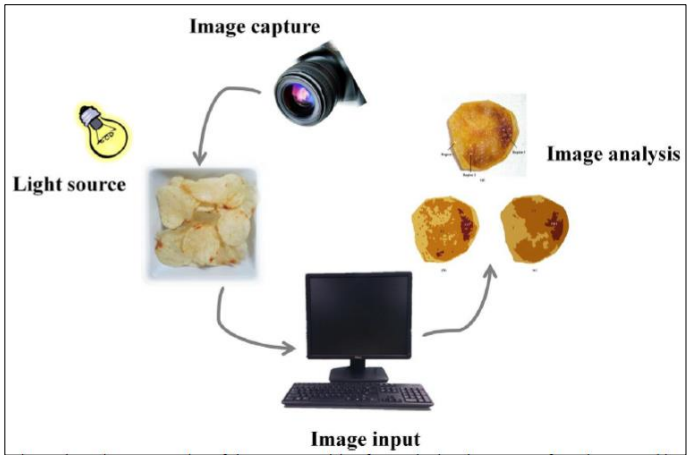


Fig 4: Schematic representation of the computer vision for monitoring the content of AA in potato chips (Gokeman *et al*., 2006)

4.2.2 Enzyme-linked immunosorbent assay (ELISA) Methods

ELISA is a rapid method based on the recognition of antigene antibody binding with high specificity and affinity, as well as the signal readout through optically detecting colored products catalyzed by enzyme labels. Because of the high specificity/affinity of antigene antibody recognition and the high efficiency of enzymatic catalysis.

ELISA has many advantages such as good sensitivity, selectivity, high-throughput, and its ability of coupling with other technologies, for example, biotin-avidin amplification and chemiluminescence. Therefore, ELISA has attracted

increasing attention in detecting AA in foods. In this new field, developing of appropriate antigens to obtain high-affinity antibodies and signal amplification are two key points (Chan, Hussein syah, & Sam, 2013) [10].

Therefore, ELISA has attracted increasing attention in detecting AA in foods. In this new field, developing of appropriate antigens to obtain high-affinity antibodies and signal amplification are two key points. Fig.5 shows the schematic representation for the preparation of complete antigen, antibody, and ELISA for AA detection

Zhang (2009) & Fu (2011) [9, 29, 37, 53, 60, 61] utilized this method to couple AA with bovine serum albumin (BSA) to synthesize an artificial antigen. This method is simple and convenient, but may result in low efficiency and even cause further loss of antigenic epitopes (Zhou, Zhang, Wang, & Zhao, 2008) [9, 29, 37, 53, 60, 61] For example, Quan, Chen, Zhan, and Zhang (2011) [9, 29, 37, 53, 60, 61] coupled AA with keyhole limpet hemocyanin (KLH) via glutaraldehyde, but no antibody was obtained because of the low antiserum titers during immunoreactions *in vivo* of rabbits.

The third method is using N-acryloxysuccinimide (NAS) as the hapten (Quan *et al*., 2011; Zhou *et al*., 2008). NAS contains the structures of AA and N-hydroxysuccinimide (NHS), which favors NAS to react with the amino group and conjugate AA to the carrier protein directly (Jameson & Wong, 2009). Zhou *et al*. (2008) used this method to synthesize a complete antigen with a high antibody-antigen association constant (kaff ¼ 6.7 ×107 L mol-1), which is comparable with antibodies stimulated by haptens with molecular weights in the range from 200 to 300 Da. This method shows advantages of high coupling efficiency, no requests of other reagents or activation.

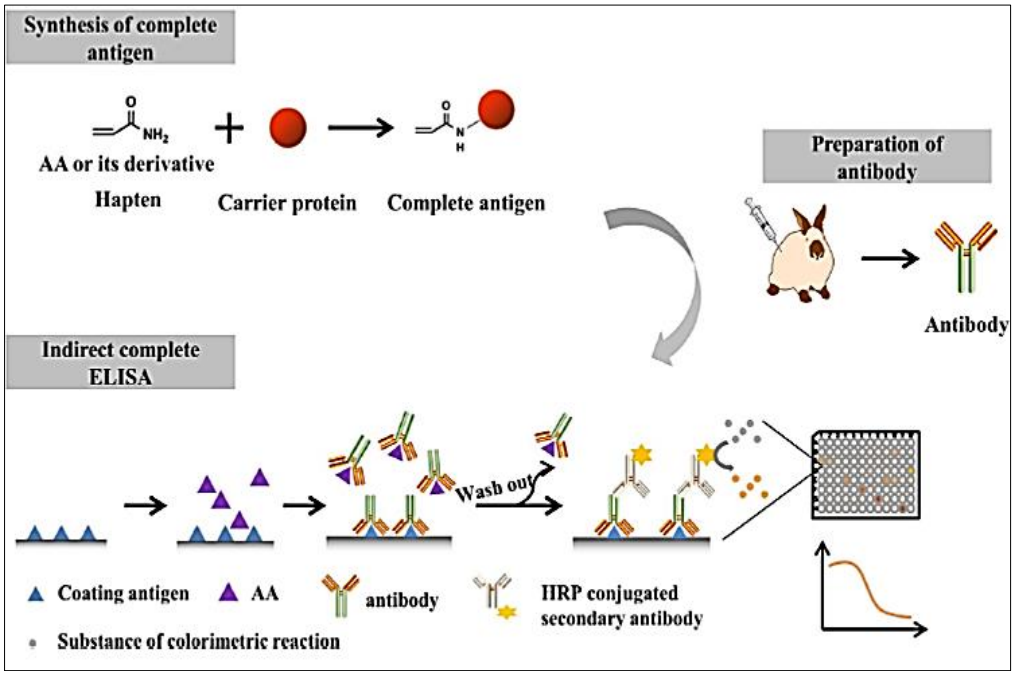


Fig 5: Schematic representation of the preparation of complete antigen, antibody and competitive indirect ELISA for AA analysis (Hu *et al*., 2014)

4.2.3 Fluorescent sensing methods

Recently, a novel fluorescent sensing method based on AA polymerization and the unique photophysical properties of quantum dots (QDs) was proposed to detect AA (Hu *et al*., 2014) [29]. In this study, QDs containing carbon-carbon double bonds after modification of NAS polymerized under the UV irradiation, resulting in the decrease of the distance between QDs and the fluorescence intensity.

In the presence of AA, the distance of QDs became larger due to the participation of AA in the polymerization reaction, resulting in an increase in fluorescence intensity. Therefore, a correlation was established between the concentrations of AA and changes of fluorescence intensities after UV irradiation (Figure. 6).

The linear range and LOD were in the range of 35-350,000 mg and 35 mg kg, respectively. Compared with standard methods and electrochemical biosensing methods, the lower sensitivity of this method limits it to be used for detecting AA in various food samples (Liu *et al*., 2011; Noh *et al*., 2010; Tansakul *et al*., 2010) [31, 38, 53].

Fluorescent sensing methods show merits of visible signals, ease of operation, and no requirement for large scale instruments. However, compared with standard methods and electrochemical biosensing methods, low sensitivity and selectivity based on chemical reactions should be improved in further research.

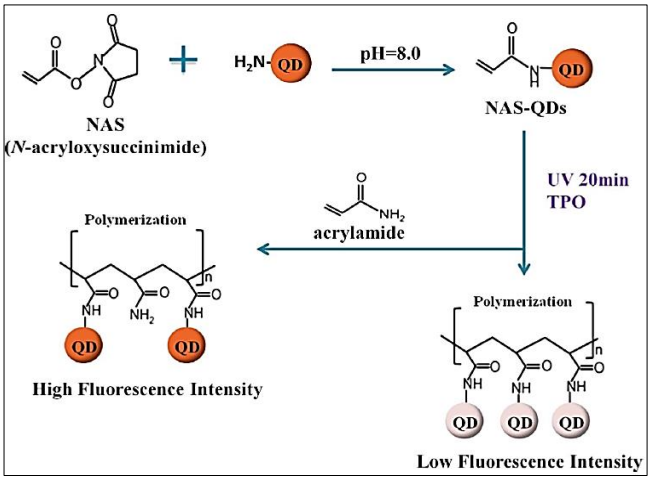


Fig 6: Schematic representation of the mechanism of the fluorescent sensing method for AA detection based on CdSe/ZnS quantum dots (Hu *et al*., 2014) [29]

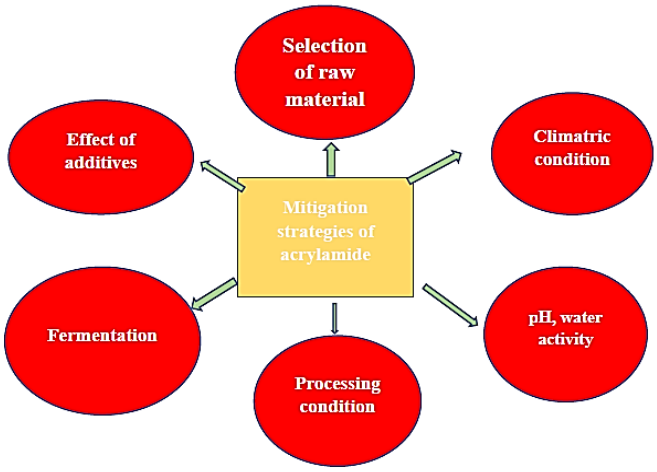
4.2.4 Electrochemical biosensing methods

A biosensor is a device used to detect an analyte that combines a biological component (bioreceptor) with a physicochemical detector (transducer) (Turner, Karube, & Wilson, 1987) [50]. Electrochemical biosensors, with electric signal (such as current and potential) output, have shown advantages such as rapidity, simplicity, automation, and sensitivity, leading to broad applications in food safety. Electrochemical biosensors have been proposed to detect AA in foods or complex matrices only in the past few years. The first trial for determining AA in wastewater was based on biocatalysis from microbial metabolism, including respiration and enzyme reactions. Ignatov, Rogatcheva, Kozulin, & Khorkina (1997) [28].

First quantified AA by defining specific respiratory activity (SRA) as the difference between the rate of oxygen consumption of *Brevibacterium* sp. And endogenous cell respiration after introduction of AA. The reduction of the concentration of oxygen and the current created from the metabolism of AA could be used to detect AA. The high selective combination between Hb and AA, outstanding sensitivity to the redox of electrochemistry, and little susceptibility to inference from food matrix endow this method with good application to detect AA in potato products. Making use of nanomaterials can not only increase the amount of Hb on the electrode and retain the bioactivity of Hb, but also improve the sensitivity via accelerating electron transfer and repeatability of the electrode.

However, multiple food samples such as breakfast cereal and coffee and its substitute should be tested to verify the versatility of electrochemical biosensors in the future this method can be utilized in the detection of AA in various foods just with one device due to its good correlation and wide linear range. Moreover, small, portable, highly integrated, and well organized array electrodes can be designed by using nanomaterials, which is the premise of rapid, on-line, and high-throughput detection of AA in thermally processed foods.

5. Mitigation strategies for acrylamide



5.1 Selection of raw material 5.2 climatric condition

The influence of variety, harvest year, fertilization and storage conditions on acrylamide formation have been studied in potato products and also in cereal product. The composition of potatoes vary with variety to variety and it relatively contains high amounts of reducing sugars, which is the major limiting factor in potato products for acrylamide formation of the positive influence of cereal varieties on precursors and acrylamide contents.

Therefore, controlling reducing sugars and asparagine may be a better option to reduce acrylamide in potato and cereal products respectively (David *et al.*, 2012). Potato varieties with low concentrations of reducing sugars can be an effective way to reduce acrylamide concentration.

5.2 Climatric condition

Climatic condition such as harvest year has a significant impact on asparagine and reducing sugars in potatoes. The asparagine content was significantly lower in all the samples from the harvest as compared to (Park *et al.*, 2005) [39]. This study concluded that an extremely hot summer will result in lower acrylamide generation. Fertilization is considered to be a key factor in crop production. A decrease in nitrogen fertilization enhanced reducing sugars concentrations, resulting in an increase of acrylamide formation in potato products; whereas inverse effects have been noticed for bakery products.

However, reducing sugars in wheat were not affected by fertilization. Generally, potato tubers are stored for several months in order to meet the supply throughout the year. Cold temperatures and senescent sweetening are the main causes of sugar accumulation in potatoes during storage (Blenkinsop *et al.*, 2002) [7]. Higher temperature storage (more than 8 °C), which results senescent sweetening is also related to sprout formation in potatoes. Storing potatoes at low temperature (below 8 °C) found to be an effective technique/tool to inhibit sprouting; temperature below 4-6 °C has a major effect on reducing sugar accumulation.

However, reducing sugars in potatoes are not significantly varied when potatoes are stored at 8 °C (Biedermann *et al.*, 2002) [1, 5, 6] and no changes are found in asparagine contents in potatoes stored at different temperature and time. In order to reduce acrylamide formation, potato tubers should be ideally stored at 8 °C (Kumar *et al.*, 2004) [33].

5.3 Effect of additives

5.3.1 Enzymes

Asparaginase, an enzyme that converts precursor (asparagine) into ammonia and aspartic acid, can reduce acrylamide formation in foods (Kumar *et al.*, 2004) [33]. It is commercially produced from *Aspergillus niger* or *Aspergillus oryzae* and found its most applications in potato and cereal products. Though it is a promising strategy for acrylamide reduction, it is rather expansive compared with other strategies (Pedreschi *et al.*, 2011) [40, 41].

5.3.2 Amino acids

The addition of amino acids or protein rich substances reduces the acrylamide content in foods (Vattem *et al.*, 2005) [56]. Amino acids such as glycine, cysteine, methionine, glutathione and lysine on acrylamide formation and its elimination kinetics was assessed in several studies. Formation of acrylamide decreased by 50% when cysteine and methionine were added to cracker and potato dough (Rydberg *et al.*, 2003) [43, 52].

5.3.3 Antioxidants

Addition of antioxidants has been found to influence the Maillard reaction, which results in acrylamide formation (Fernandez *et al.*, 2003). Antioxidants present in the rosemary extracts, bamboo leaves and green tea extract (Ou *et al.*, 2010) could effectively reduce acrylamide presence in

different heated foods. The exact mechanism on acrylamide formation is not yet understood, however it is proposed that it could interact with active aldehydes and block the oxidation of acrolein to a certain extent (Totlani 2006 & Granby 2008) [49]. Moreover, most of these studies are based on *in vitro* or small scale conditions and ultimately may not provide the similar results on commercial or industrial conditions (Zhang, 2007 & Zhang 2011) [9, 29, 37, 53, 60, 61].

5.3.4 Mono and divalent cations

Mono and divalent cations (Na+ and Ca2+ or Mg2+) added to the dough showed a remarkable effect on acrylamide reduction (Elder *et al*., 2004) [14]. In addition, polyvalent cations also capable to reduce acrylamide formation during heating. These ions could interact with asparagine so that prevent the Schiff base intermediate formation and thus acrylamide generation (Tomoda *et al*., 2004) [48].

5.4 Effect of processing conditions

- Most of the strategies proposed to reduce the acrylamide are focused on the processing stage. The important factors that influence the process of acrylamide formation are: heating temperature and time, blanching and frying (Ciesarová *et al*., 2006).
- The prolonged baking temperature and time combination (260 °C, 20 min) decreased the acrylamide content in foods (Vleeschouwer, 2007 & Anese, 2010) [55].
- Conduction and radiation heat transfer are more effective in acrylamide reduction than convection baking ovens. Moreover, the combination of conventional and dielectric (microwave) heating found to be suitable for reduction of acrylamide in bakery products. Baking at high relative humidity proved to be effective for reducing acrylamide in bakery products (Sadd *et al*., 2008) [25, 47].

5.5 Effect of PH, water activity and fermentation: Maillard reaction has strong influence on pH. It is known that high pH affect nutrients in foods (Eriksson, 2005) [17, 43, 52]. Researchers showed that the reduced pH drastically reduces acrylamide content during frying and baking (Jung, 2003 & Grob, 2007) [5, 6, 23]. Any acid treatment reduces the pH of foods and results in formation of Maillard associated substances. (Delatour *et al*., 2004) [12].

Water activity in food plays a major role in reducing acrylamide formation. Acrylamide forms in food only when the water activity is below 0.8, whereas the acrylamide formation is high at water activity of 0.4 and below (Hoenicke *et al*., 2005) [27].

Fermentation controls the rate of acrylamide formation in food by maintaining precursor composition and pH. Prolonged fermentation time (at least an hour) was found to be suitable for acrylamide reduction in bread and fried potato products. Combined lactic acid fermentation with blanching found suitable for higher acrylamide reduction in potato products (Baardseth *et al*., 2006) [4].

6. Acrylamide metabolism

After consumption, it is demonstrated that AA is rapidly and completely absorbed by the gastrointestinal tract in rats via the circulation and is distributed to the peripheral tissues [39]. The fate of AA in humans seems to be qualitatively similar to that in rodents (Fennel *et al*., 2005) [20, 58].

One exploratory study in healthy volunteers have confirmed that AA can cross the blood–placenta barrier in a human placenta *in vitro* model as well as the blood–breast milk barrier *in vivo* in lactating mothers.

AA is metabolized via at least 2 main pathways. It may be conjugated to N-acetyl-S-(3-amino-3-oxopropyl) cysteine by glutathione-S-transferase (GST), or it may be converted to glycidamide in a reaction catalyzed by the cytochrome P450 enzyme complex (CYP450), where this metabolite is known to be more reactive toward DNA and proteins than the parent AA compound (Sumner *et al*., 1999) [58]. Figure.7.

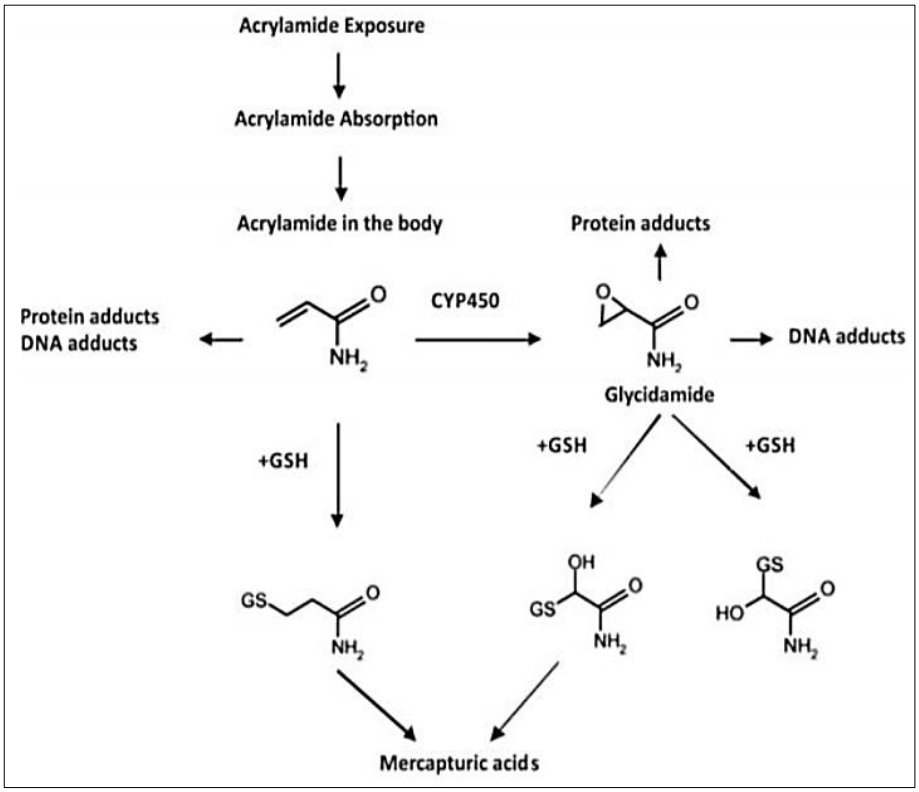


Fig 7: Proposed metabolic scheme of acrylamide (Sumner *et al*., 1999) [58]

6.1 Toxicity of acrylamide

6.1.1 Neurotoxicity

Neurotoxicity is a major consequence of AA exposure, and considerable attention has been drawn to this area of investigation. This compound is considered to be a cumulative neurotoxicant in rodents as well as in humans (Miller *et al*., 1986) [36].

Acrylamide neurotoxicity in occupationally exposed populations has been ascertained by various epidemiological studies (He *et al*., 1989) General symptoms of neurotoxicity in humans are a characteristic ataxia, skeletal muscle weakness, weight loss, distal swelling, and degeneration of axons in the central and peripheral nervous systems (Hagmar *et al*., 2001).

6.1.2 Genotoxicity and carcinogenicity

The genotoxicity of AA and its major metabolite glycidamide had been investigated in several studies. A study by Alzahrani in mice showed that single doses of AA at 10, 20, and 30 mg/kg and repeated doses of 10 mg/kg for 1 and 2 weeks significantly induced DNA damage compared to the control group as shown by elevation in micronuclei and chromosome aberrations in mice bone marrow cells (Alzahrani *et al*., 2011) [2].

6.1.3 Reproductive toxicity

Reproductive toxicity of AA in humans has not been demonstrated; however, in rats, the No-observed adverse effect level for reproductive toxicity was assessed to be 2 to 5 mg/kg/d (Exon *et al*., 2006) [18]. In another study, reproductive toxicity was also revealed in AA-treated female mice, where a decline in the viability of mouse granulosa cells, the number of corpora lutea, and progesterone production was observed (Wei *et al*., 2014).

6.2 Mechanism of AA detoxification

One way to possibly help lower the risk of toxicities from AA is to increase glutathione levels by consuming sulfur-containing foods such as onions, garlic, and cruciferous vegetables such as broccoli and brussels sprouts or foods that contain significant amounts of cysteine, which is an essential substrate for the synthesis of glutathione, such as onions, garlic, cruciferous vegetables, and red peppers. Foods such as poultry, yogurt, and eggs also contain significant amounts of the amino acid cysteine (Ubaoji *et al*., 2016) [54].

7. Conclusion

The major limiting factors responsible for the formation of acrylamide in potato and cereal products are reducing sugars (glucose and fructose) and free asparagines (amino acids) respectively. For commercial production of potato products, select cultivars with low levels of reducing sugars taking into account seasonal and regional variability for high temperature processes such as frying and baking. Avoid using potato tubers stored below 6°C and maintain ideal storage temperature of about 8°C. However, retailers and consumers are unaware of the selection of cultivar and safe storage temperature. Therefore the advantages of these conditions have to be well informed to retailers and consumers through campaign by mass media and concerned food safety authority. Blanching in water followed by frying at controlled temperature-time combinations might be a better option to reduce the acrylamide formation in potato products. Use of additives such as amino acids, asparaginase enzyme, cations and antioxidants are reported effective for acrylamide reduction in bakery and cereal products. Nevertheless, the additives should not alter the quality and consumer acceptability of food products. Yeast fermentation is a promising technology, which will reduce the free asparagine precursor content in cereal products such as wheat bread. Combination of yeast fermentation and blanching will substantially reduce the acrylamide content in potato products. However, the strategy or approach developed for potato products are not applicable /transferable to other food products such as bakery and cereal products. A strong positive correlation exists between baking temperature and time and formation of acrylamide; whilst the use of flour with low asparagine content might decrease the content of acrylamide in bakery products. By introducing steam in conventional or traditional baking system, it is possible to reduce the acrylamide content in baked products. The strategies developed so far to mitigate acrylamide formation studied on lab conditions, which may not be suitable for commercial process. Therefore further work is necessary to explore different possibilities studied in the laboratories on industrial conditions. Reducing acrylamide in food products while protecting other quality aspects and reducing dietary acrylamide exposure still remains a major challenge.

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