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Acrylamide in processed food

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■ **Abstract :** Acrylamide (2-propanamide) is colorless, non-volatile crystalline solid, soluble in water formed in food products during processing; specifically high temperature long time processing like baking, frying, etc. results in production of incremental amount of acrylamide.Acrylamide has been reported to increasethe incidence of cancer in rats at doses of 1-2 mg/kg bodyweight per day. International Agency for Research on Cancer(IARC 1994) classified acrylamide as "potentially carcinogenic substance to humans". Foods processed and cooked at high temperatures contain high level of acrylamide. Acrylamide content in French fries and breads ranges from 59-5200 and 10-3200 µg/kg, respectively. According to WHO (2005), the maximum permissible level of acrylamide is 21-140 µg/70 kg body weight for general population. Formation of acrylamide during processing of foods depend on food composition, temperature, time of processing& high carbohydrate, free asparagine, reducing sugars, pH and water content. Asparagine is the free amino acid present in potato in high level (about 90 mg/100g), needs free sugars to form acrylamide. However, many studies have revealed that the acrylamide formation in food products can be reduced by giving some pre-treatments like blanching, soaking, addition of cations and L-asparaginase enzyme to the foods. The objective of this review is to discuss the formation, mechanism and toxicological studies, ways to minimize acrylamide in heat-treated starch-rich foods.

■ **Key words :** Acrylamide and toxicity, Maillard reaction, High temperature food processing, Pre-treatments

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Food processing is the set of methods or techniques used to convert raw ingredients into food or food from other which can available throughout the year. The food processing involves process such as macerating and mincing, liquefaction, emulsion, cooking like boiling, broiling, frying and baking and other type of process like canning and other packaging like aseptic packaging. Processing of food can convert unpalatable or unacceptable raw material into desirable or palatable product. The main cause of food processing is to make food microbiologically safe to eat. As example harmful bacteria Stapylococcusaureus is destroy by cooking process and the pasteurization is the process which partially killing of micro-organisms also sterilization killing of micro-organisms and make food safe to eat and increase the shelf life of food . And it also removes toxins and inactivates the undesirable enzymes by heat treatment with water i.e. blanching. Heat processing has some major consequences like loss of nutrients like vitamin C and vit-B_2, caramelization and browning *i.e.*

maillard reaction. Caramelization is one of the most important non- enzymatic browning process occurs during dry heating and roasting of food with high concentration of carbohydrates (sugars) followed by isomerization and polymerization step. Caramelization leads undesirable effect like burned sugar smell and blackening. Browning process *i.e*. maillard reaction form high heat treatment with high carbohydrate and amino acid food which cause formation of toxic compound like Acrylamide.

Acrylamide (CH_2=CH-CO-NH_2: 2-propanamide) is a toxic compound which is colorless, non-volatile crystalline solid, soluble in water and has molecular weight of 71.08 kDa. Acrylamide has melting point of 84.5±0.3°C, and a high boiling point (136°C at 3.3 kPa/ 25 mm Hg; Norris, 1967; Ashoor and Zent, 1984; Eriksson, 2005). Becalski *et al.* (2003) has explained acrylamide is not a substance that is added in food but it is toxic compound which is formed during heat treatment or processing. De Meulenaer *et al*. (2008) studied on Comparison of potato varieties between seasons and their potential for acrylamide formationand have concluded the acrylamide formed in high carbohydrate (reducing sugar) foods cooked at above 120°C upon frying and baking and roasting. Eriksson and Torqvist revealed that the acrylamide is formed in foods if frying done in frying pan and heatingdone in oven or microwave oven but no acrylamide has been found in boiled product. In April 2002, a group of Swedish Researchers reported that acrylamide found in high levels in high carbohydrate (starch-rich) foods such as cereals, potato, coffee (Surdyk *et al.,* 2004; Tareke *et al.,* 2002; Svensson *et al.,* 2003). Zhang *et al.* (2005) reported food cooked and processed at high temperature contains high levels of acrylamide announced by Swedish National Food Administration in 2005.The amount of acrylamide in different food and food product groups are summarized in Table 1.

Table 1 : Amounts of acrylamide in different food and food product groups (Elder *et. al.)*

Product/ product group	Acrylamide range (µg kg^{-1})
Bakery products and biscuits	18-3323
Breads	<10- 3200
French fries / chips	59-5200
Breakfast cereals	<10-1649
Chocolate products	<2-826
Potato chips/ crisps	117-4215
Potato (raw)	<10-<50

Acrylamide has been classified by the International Agency for Research on Cancer (IARC, 1994) as "potentially carcinogenic to humans", and in 2001, the scientific committee on Toxicity, Ecotoxicity and the environment determined its intrinsic toxic properties such as carcinogenicity, neurotoxicity, reproductive toxicity and genotoxicity. Acrylamide is genotoxic (mutagenic), which increases the incidence of cancer in rats at doses 1-2 mg/kg body weight per day. According to WHO2005, the maximum permissible level of acrylamide is 21-140 µg/70kg body weight for general population.

Formation mechanism of acrylamide :

Since the release of information on the formation of acrylamide during food processing, several hypotheses have been proposed on its development. All these are possible routes for acrylamide formation that could take place in a food processing scenario.

Motram *et al*. (2002) and Stadler *et al*. (2004) revealed that the main pathway of acrylamide formation in fried products is the reaction of free amino acid *i.e.* asparagine and carbohydrate *i.e*. reducing sugars. Therefore the contents of these precursors in fried products are important and have to be controlled. Maillard reaction has been indicated major pathway for the acrylamide formation and amino acid asparagine closely linked to the acrylamide formation. Coughlin (2003) and Tareke *et al.* (2000) explained the Maillard reaction is non-enzymatic browning reaction formed in foods during baking and frying. Non-enzymatic browning formedat combination of carbohydrate, proteins andlipids for desirable colour, flavor and aroma. Mottram *et al.* (2002) revealed that in formation mechanism of associated process is strecker degradation of amino acid by intermediates of maillard reaction. During the strecker degradation, the amino acid is decarboxylated and deaminated to form aldehyde which is proposed pathway for the formation of acrylamide: the amino acid go through the strecker degradation in the presence of carbonyl products from the maillard reaction resulting in the formation of acrylamide.

Martin and Ames (2001) studied on formation of strecker aldehydes and pyrazines in a fired potato model system further he has conclude that the free amino acid asparagine is present high level in potatoes 93.6mg/100g. Gertz and Klostermann (2002) explained that the food particularly oil and fat, an alternative pathway for the

formation of acrylamide through acrolein has been proposed as the mechanism via acrylic acid. Reports determined by Zhang *et al*. (2005) and Yasuhara *et al.* (2003) that the acrolein, together with asparagine, may accomplish definite levels of acrylamide under certain conditions, expressed a critical role for acrolein in the formation of acrylamide in lipid rich foods. Umano and Shibamoto (1987) studied on Analysis of acrolein from heated cooking oils and beef fat, he describe the lipid oxidation is one of important chemical reaction which form during the storage and processing of foods which has great effect on the quality of product. The lipids *i.e.* triglycerides form high amount of acrolein by the heat treatment. Then after acrolein can react with oxidation to produce acrylic acid. Both of the intermediates could then bring about acrylamide formation. The basic formation routes of acrylamide shown in Fig. 1.

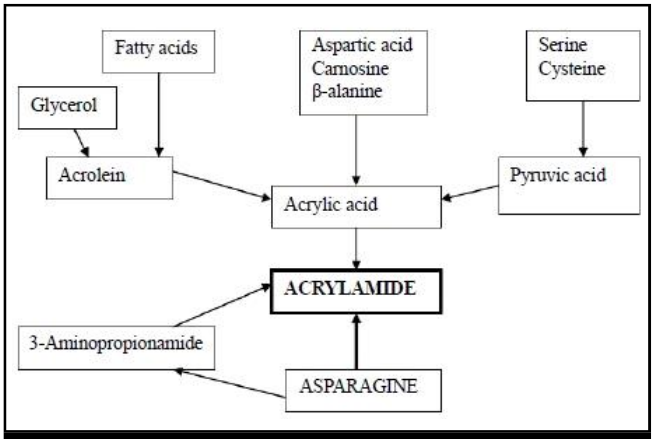

Fig. 1 : Basic formation routes of acrylamide (Eriksson, 2005)

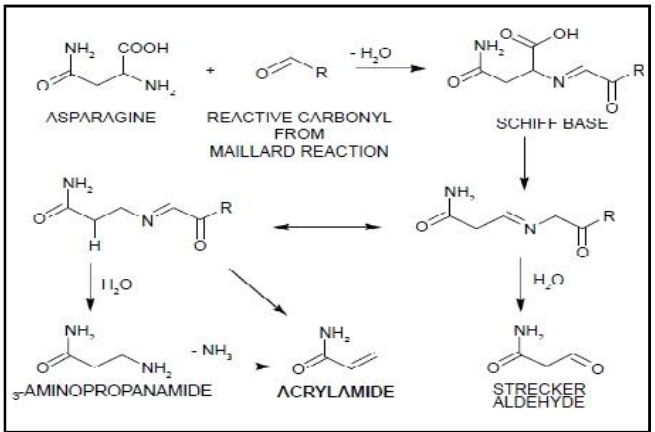

Fig. 2 : Mechanism for formation of acrylamide in heat treated foods (Vleeschouwer*et. al.,* 2007)

Toxicity :

International Agency for Research on Cancer has been classified acrylamide as a "probable human carcinogen" (IARC, 1994) also the Scientific Committee on Toxicity, Ecotoxicity and the environment determined its intrinsic toxic properties such as neurotoxicity, genotoxicity to both somatic and germ cell, carcinogenicity and reproductive toxicity. According to WHO (2005) maximum permissible level of acrylamide is 21-140 µg/70 kg body weight for general population. Friedman 2003 has been reviewed on Chemistry, Biochemistry and safety of acrylamide , in which shown two relevant effects of acrylamide *i.e.* Carcinogenicity and Neurotoxicity.

Carcinogenicity:

The carcinogenicity of acrylamide specifically refers to the substance ability to cause cancer. Carcinogen is substance or compound cause cancer. Acrylamide has carcinogenic to humans reported by IARC-1994. Keramat *et al*. (2011) reviewed the acrylamideis genotoxic (mutagenic) compound, which increases incidence of cancer in rats at doses of 1-2 mg/kg body wight per day. Rice 2005 has studies on rodent support the evidence that acrylamide is multicarcinogenic compound. It cause tumor to many organs such as lung, skin, uterus, mammalian gland and brain etc. The researches revealed that the two lifetime carcinogenicity caused by acrylamide in Fischer 344 and in both F344 and $B_6C_3F_1$mice (Friedman *et al.*, 1995; Johnson *et al.*, 1986; NTCR, 2008). Johnson *et al.* (1986) has explained that the male and female F344 rates exposed acrylamide in drinking water. The high dose 2mg/kg/day for 2year given both male and female rates *i.e.* Fischer 344, in which female rats increased incidence of tumor of mammary gland, thyroid gland, uterus, central nervous system, oral cavity etc., and male rats has increased incidence of tumor of thyroid gland and Scrotal mesothelium.

Mitigation strategies of acrylamide :

The reduction of acrylamide content in foods at industrial as well as household level can help public not only from food hazard but also to create methods about food safety. During recent years many simple and effective ways establishes for the reduction of acrylamide. Amrein and Bactman has been reported

that the limiting factor of potato products is carbohydrates *i.e*. reducing sugars. Hence selection of varieties of low reducing sugar potatoes is important strategy for acrylamide reduction (Olsson *et al.*, 2004; De Wilde *et. al.,* 2006). Elder revealed that the addition of di- and trivalent cations has been effective way to reduce acrylamide in manufactured potato products. Fouad Omer (2015) describe the using some pretreatment such as addition of NaCl,citric acid and tomato juice in different concentrations on processed potatoes for the reduction of acrylamide formation. Pretreatment with an L-asparaginase is sufficient to reduce acrylamide content, since L-asparagine is considered to be one of the main precursors for the acrylamide formation in products (Tareke *et al*.; 2002; Mottram *et al*., 2002 and Stadler *et al.*, 2002). Ciesarova (2006) studied on Impact of L-asparaginase on acrylamide content in potato products, has concluded the application of L-asparginase is convenient also pretreatment of dried potato products, where 90% reduction of acrylamide level. Acrylamide produce in high carbohydrate rich product such as potato and cereals, in cereals wheat and sorghum contain high amount of carbohydrate. Acrylamide can reduce from cereals by using germination pre-treatment because germination cause decrease carbohydrate *i.e*. starch content. Senhofa *et al*. (2016) has described α-amylase is main enzyme form during seed germination process which is responsible for initial degradation of starch granules.

Soaking:

Acrylamide content of fried potato slices controlled by the different soaking treatments. Soaking carried out by deeping fruits/ vegetables / cereals in water for respective time and also carried out in different solutions like salt solution, acid like citric acid etc. Pedreschi reported that the soaking of potato slices in tap water for 60min led to reduce acrylamide content by 35.55% as well as soaking of potato slices in distilled water for 90min decreased acrylamide content by 58% after frying at 170°C. Fouad Omer (2015), studied on The effect of using some pretreatments on Reduction of Acrylamide formation in processed potatoes, he has describe that in relation to tomato juice and combined treatments either "0.5% citric acid +3% NaCl" or "1% NaCl + tomato juice + 0.5% citric acid", results indicated that these three treatment had same effect on reduction of acrylamide, where sample treated with these three treatment acrylamide not detected in fried potato. These three treatment highest effect on acrylamide reduction and improve the sensory properties of product.

Blanching:

Blanching is pretreatment which carried out at the temperature 95° C for inactivation of enzymes for few minutes. Blanching is mostly done for the fruits and vegetable processing which improves the texture of products. Blanching has two techniques including steam blanching and water- submersion blanching both used for inactivation of enzymes. Pedreschi and Moyano (2005) studied on effect of predrying on texture and oil uptake of potato chips, further he concluded theblanching process has significant effect on reduction of acrylamide content and the reduction rages from 73.58 to 97.97%. Blanching process reduces the acrylamide in french fries by treating before the frying which can leaching out reducing sugar, in this way inhibition the non-enzymatic browning reaction, cause less or lighter red french fries. Samir Abdel *et al*. (2013) has been determined the highest reduction of acrylamide resulting those samples which blanched in MgCl (0.1 M), L-cysteine (0.05 M), and 0.01 M citric acid solutions, 97.97, 97.17 and 93.43%, respectively and soaking of potato chips in phenolic acid solution cause greatest reduction of acrylamide contentreduction ranges from 31.81 to 98.03%.

Antioxidant:

Antioxidant is substance which prevents oxidation of fat or fat containing food products. Several research studies determined that the addition of antioxidant compounds to the dough prior the baking process may be successfully used to reduced acrylamide formation not only by inhibition of formation of acrylamide but also inhibition of the overall rate of the maillard reaction. Zhang (2005) and Zhang (2008) has describe the antioxidant present in bamboo leaves, tea extract, rosemary extracts, which effectively reduce acrylamide which formed in different heated foods.

Cations:

Most of researches revealed that addition of divalent cations such as Mg^{2+} or Ca^{2+} to the dough before the baking resulting remarkable effect on reduction of acrylamide content from food products. Elder *et al.* (2004)

studied on Methods for reducing acrylamide in thermally processed foods, furher he concluded that the adding divalent cations Mg^{2+} or Ca^{2+} resulting 20% reduction of acrylamide as well as the researcher Goakman *et al.* (2007) has describe that the glucose equimolar amount of mono-valent , divalent and trivalent cations like K^{+}, Ca^{2+}, Mg^{2+}, Zn^{2+}, Fe^{3+} cause to a 97% or more reduction of acrylamide at 150°C for 20min.

L-asparaginase enzyme:

Zuzana Ciesarova studied that the commercial application of L-asparaginase enzyme for elimination of amino acid *i.e.* L-asparagine without disturbing the sensory quality of the processed products, which treated before heat treatment. Further he was concluded L-asparaginase application to be one of the successful ways for acrylamide reduction in potato products such as French fries and chips. About 90% reduction of acrylamide level was achieved after the incubation of 2U of enzyme/1 g of wet dough at 20 °C for 30min and heat intake of 185 °C, 5min. The researcher Zyzak *et al.* (2003) studied on Acrylamide formation mechanism in heated foods, he has evaluated the effectiveness (99%) of L- asparaginase to reduce acrylamide formation in mashed potato product heated in microwave oven.

Conclusion :

Acrylamide is formed during thermal process in bakery products as consequence of the maillard reaction, where reducing sugar such as glucose and fructose react with free amino acid *i.e.* asparagine at heating temperature above 120 °C. Major limiting factor of cereals asparagine as well as limiting factor of potatoes reducing sugar, therefore the commercial level production select low levels of reducing sugar potatoes. Many methods and treatments for the reduction of acrylamide in potato product has been reported.The pretreatments like L-asparaginase reduced acrylamide about 90% and also blanching process has significant effect on reduction of acrylamide rages from 73.58 to 97.97%. Additives such as cations effective for reduction of acrylamide in bakery and cereal products.The recent risk characterization of acrylamide concludes that the evidence of acrylamide posing a cancer risk for human has been strengthened. Therefore, reducing acrylamide formed in baked foods is still a major concern.

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