MEDWIN PUBLISHERS
Committed to Create Value for Researchers

Food Science & Nutrition Technology
ISSN: 2574-2701

A Review of Acrylamide Concentrations in Different Food Products; Associated Risks and Mitigation Strategies

Obsuman DM[1]* and Lelise T[2]

[1]Department of Post-Harvest Management, Jimma University, Jimma, Ethiopia

[2]College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia

***Corresponding author:** Obsuman Damena Muleta, College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia, Email: damanafobsuman@gmail.com or obsuman.muleta@ju.edu.et

Review Article

Volume 5 Issue 5

Received Date: September 10, 2019

Published Date: October 06, 2020

DOI: 10.23880/fsnt-16000227

Abstract

Acrylamide is a colorless, crystalline solid, soluble in water with Low but significant volatility having a molecular weight of 71.08 g/mol. It is known to be neurotoxic in both animals and humans, and has been classified as "probably carcinogenic to humans. The occurrence of acrylamide is first reported by scientists from the Swedish National Food Authority and the University of Stockholm in April 2002, and then after many scientists have done different research on the occurrence of acrylamide in different processed foods. Different researches indicated that most heat processed foods are an important source of acrylamide. Acrylamide is formed in a wide variety of foods, particularly carbohydrate rich foods cooked at above 120°C upon frying, baking and roasting. Although high temperature food processing such as frying, roasting, or baking, is most likely to cause acrylamide formation; boiling and steaming do not normally form acrylamide. According to the recent available research results on acrylamide content of foods the highest levels of acrylamide is reported in coffee substitutes and fried potato products with max 5400µg/kg and 4126.26µg/kg respectively. High temperature and longtime processing has direct influence on acrylamide formation in processed foods. Animal studies revealed that acrylamide adversely affects fertility, and has the potential to induce heritable damage at gene and chromosome level. A better understanding about acrylamide impacts on human health can guide to the development of enhanced food processes to reduce the acrylamide content of the diet. Efforts to decrease the creation of acrylamide in different foods have resulted in some achievements; however there is no universal approach that works for all foods. Though it may possible in some foods to reduce acrlymide, in some foods is maybe not possible. This paper is therefore aimed to review the concentration of acrylamide in different processed food products, associated risks of their consumption and mitigation strategies.

Keywords: Acrylamide; Processed Foods; Asparagine; Maillard Reaction; Health Effects of Acrylamide

Introduction

Acrylamide is a highly polar molecule, soluble in water, alcohols, acetone and acetonitrile slightly soluble in ethyl acetate, dichloromethane and diethylether; with low, but significant volatility and having a molecular weight of 71.08 g/mol [1]. It is a reactive chemical, which is used as a monomer in the synthesis of polyacrylamides, in the purification of water and in the formulation of grouting agents [2]. The topic of acrylamide in the diet appeared when Swedish National Food Administration (NFA) and researchers from Stockholm University announced their findings that acrylamide is formed in many types of food prepared/cooked at high temperatures in April 2002 [3]. It is formed as a consequence of the Maillard reaction, derived from the reaction between the free amino acid asparagine with reducing sugars or other carbonyl compounds [4]. It is reported that this molecule is a toxic and potentially cancer causing chemical [3].

Formation and degradation of acrylamide in foods is affected by acrylamide precursors such as free amino acids (mainly asparagine), reducing sugars and processing conditions like (baking time and temperature), moisture content and matrix of product [4]. It is known to be metabolized to glycidamide, a chemically reactive epoxide that forms DNA adducts [3]. Exposure to acrylamide leads to DNA damage and at high doses neurological and reproductive effects have been observed [2].

Almost all human beings are exposed to acrylamide as it is present in a broad range of food products since heated food is a part of our daily diet. Therefore; reducing the intakes of acrylamide would be beneficial in a risk perspective. To this effect; this paper is aimed to review the concentration of acrylamide in certain human foodstuffs heated in cooking or manufacturing ,associated risks of their consumption, and to provide information to the consumers and processors how to reduce Acrylamide occurrence in processed foods so as to practice healthy processing habit, and to avoid food processing that promote high percent of acrylamide formation.

Literature Review

Mechanisms of Acrylamide Formation in Foods

Acrylamide could be formed from naturally-occurring substances like carbohydrate, fat, protein) in certain foods as the result of high temperature processing [5]. During the typical heating of foods, reducing sugars react with amino acids initiating a cascade of events leading to the browning of foods known as the Maillard reaction [6]. Maillard reaction is a non-enzymatic browning reaction occurring in foods during extrusion cooking, roasting, popping, baking, pan-frying, deep-fat frying, barbecuing and autoclavation. This happens at existent of necessary starter reactants that is amino acids: proteins and reducing sugar [2].

The major mechanistic pathway in the formation of acrylamide in foods is a part of the Maillard reaction with free amino acid (asparagine) and reducing sugars (mainly glucose and fructose) [2,5,6]. Glycoconjugates of asparagine are the major source of Acrylamide in foods under low moisture conditions at elevated temperatures in the presence of reducing sugars or a suitable carbonyl source [7]. Zyzak, et al. [6] also suggested the necessity of carbonyls in the formation of acrylamide, from asparagine.

In addition to asparagine, other amino acids have been implicated in the formation of acrylamide. Preliminary studies have shown that other amino acids such as L-alanine and L-arginine are also capable of releasing acrylic acid at temperatures above 180°C, with yields within the same order of magnitude as aspartic acid [8].

Factors Affecting Acrylamide Formation in Processed Foods

The variations in varieties and quality of raw materials, formulations, process strategies, and process parameters could impact the formation of acrylamide in foods [9]. But the rate of acrylamide formation is affected by concentration of reactant, reactant ratio, temperature, pH, and water contained [5]. Water impacts the chemical route (Example hydrolysis of the imine) as well as the molecular mobility of the chemical constituents which indirectly contributes to the formation of acrylamide [10].

Glucose and fructose are the major reducing sugars in plant foods, and have the greater influence on acrylamide formation [5]. During the Study of Factors Affecting Acrylamide Levels in Model Systems; Ciesarova, et al. [10] reported that acrylamide is formed from fructose at lower temperatures and on the contrary, in the case of glucose high temperatures (above 140°C) were required to observe acrylamide.

A more important factor which affect the acrylamide yield appeared is the water content. According to Ciesarova, et al. [10] the minimum amount of acrylamide formation is observed in the range of the initial moisture content between 15 and 45%.

It has also been shown that PH affects acrylamide formation in processed foods. Studies on the effect of PH on the yield of acrylamide have reported reduced acrylamide content due to the lowering of the pH [11].

Temperature is another important factor which affects the acrylamide formation in processed foods. Higher amount of acrylamide formation occur at high temperature processing of foods. Ciesarova, et al. [10] obtained high yields of acrylamide at high temperatures in the mixture of potato starch with asparagine and glucose and/or fructose without water after 20 min heat treatment. Mikulikova, et al. [12] also reported that the acrylamide concentration in malt is dependent on the kilning temperatures and with the increasing temperature of kilning, the acrylamide content in malt increased to the temperature of 180 °C.

Acrylamide in Processed Food Products

A wide range of acrylamide levels, which may be achieved using different raw materials, ingredients, and cooking methods, were reported all over the world [9]. Acrylamide was found in many heat processed food items like processed vegetables, processed cereals, animal products and hot drinks.

Acrylamide in Processed Vegetables

Potato products are the most important contribution to the acrylamide exposure both on a high consumption of the products and on a relatively high content of acrylamide. Studies have been performed to determine the level of acrylamide in various fried foods of vegetable origin. Acrylamide content of vegetable based food items are presented in Table 1. Shamla & Nisha [13] conducted a research on acrylamide content of deep-fried snacks of India and obtained acrylamide content of potato chips ranging from 82.0 to 4245.6 µg/kg, acrylamide content of jack chips ranging from 46.2 to 2431.4 µg/kg, and acrylamide content range of 14.7 to 1690.5 µg/kg and 24.8–1959.80 µg/kg, for Plantain chips and Sweet plantain chips respectively.

Food Group	Acrylamide levels in µg/kg(Minimum – Maximum)	References
Crisps, potato/sweet potato	170 – 2287	who,2002
potato Chips	<50 – 3500	WHO,2002
Fried potato	58.40 -4126.26	Chen et al .,2012
Potato(French fries)	206	El-Ziney etal.,2009
Eggplant(grilled)	950	El-Ziney etal.,2009
crisps	42-1570	Pugajeva et al.,2014
crisps	310–2800	Konings et al.,2003
Cocktail snacks	60–3100	Konings et al.,2003
Potato crisps	310-2800	Hogervorst et al., 2007
French fries	<LOQ-1220	Hogervorst et al., 2007
Potato crisps	3200	Claeys et al., 2016
Fries	3300	Claeys et al., 2016

Table1: Summary of reported amounts of acrylamide (µg/kg) in vegetable based food products.

Acrylamide in Processed Cereals

Cereals and cereal products are the second largest group of products contributing to acrylamide exposure [14]. Boyacı Gündüz & Cengiz [9] conducted a research on acrylamide contents of commonly consumed bread types in Turkey and obtained acrylamide content of (479 ± 325 µg kg−1) in whole wheat breads and 432 ± 214 µg kg−1 in rye bread samples. From the work of Fredriksson, et al. [15] free asparagine in wheat parts are reported to be 0.48 to 0.51, 4.88 to 4.99, 1.48, and 0.14 to 0.17 g kg-1 in the fraction of Whole grain flour, germ, bran, and Sifted flour, respectively .In addition free asparagine in rye was reported to be 1.07, 0.53 to 0.68, and 2.61 to3.18 in the fraction of Whole grain, Sifted flour, and bran of rye respectively. Since Acrylamide formation is related to free asparagine content existence of high concentration of acrylamide in whole grain may be due to the concentration of free asparagine in the bran parts of these grains. Boyac Gündüzand Cengiz [9] reported Acrylamide concentration of Wheat bran bread ,stone oven wheat bread, and white wheat bread to be 307 ± 258 µg kg−1, 171 ± 184 µg kg−1,and 121 ± 103 µg kg−respectively. Chen, et al. [16] obtained average acrylamide content of 22.62–44.92 µg/kg for rice roll, noodle, roasted bread, wafer biscuit and sauted nuts samples from China. Acrylamide contents in different processed cereal based foods were summarized in Table 2.

Studies on acrylamide content of alcoholic or non-alcoholic fermented beverages are very limited and only few surveys are available on acrylamide in alcoholic beverages. Dibaba, et al. [17] reported acrylamide content of 3440 µg/kg for Keribo (Ethiopian traditional fermented beverage) which is prepared from deep roasted unmalted barley at higher level of added sugar (1.5 kg/10 L) and 1320 µg/kg for Keribo prepared from light roasted unmaltedsample. Mikulikova, et al. [12] reported acrylamide content of 630–660 $\mu g.kg^{-1}$, and 2210 $\mu g.kg^{-1}$ for pale malts and Melanoidin malt respectively. It was revealed that Rye malts have lower acrylamide values in caramel and roasted malts compared to barley malts prepared at the same temperatures. Despite high acrylamide level in malts it was reported that it's content in all the analyzed samples of beers were under the LOQ (< 25 $\mu g.l^{-1}$).

Food Group	Acrylamide levels in µg/ kg(Minimum – Maximum)	References
Bakery products	<50 – 450	WHO,2002
Breakfast cereals	<30 – 1346	WHO,2002
Breakfast cereals	674	Claeys et al., 2016
Crisps, corn	34 – 416	WHO,2002
Bread, soft	<30 – 162	WHO,2002
Instant malt drinks	<50 – 70	WHO,2002
Beer	<30	WHO,2002
Fried rice crust	100.46 -491.76	Chen et al .,2012
Roasted biscuit	0.41 -484.17	Chen et al .,2012
Pancake	1.88 352.90	Chen et al .,2012
Maize(extruded cheese)	319	El-Ziney etal.,2009
Dutch spiced cake	260-1410	Hogervorst et al., 2007
Cornflakes	<LOQ-300	Hogervorst et al., 2007
Crisp bread	15-914	Hogervorst et al., 2007
Cookies	10-829	Hogervorst et al., 2007
Biscuit	10-1060	Pugajeva et al.,2014
Gingerbread	196-280	Pugajeva et al.,2014
Gingerbread	260–1410	Konings et al.,2003
Biscuits, grain	147-606	Pugajeva et al.,2014
Chocolate	22-116	Pugajeva et al.,2014
Peanut butter	107-118	Pugajeva et al.,2014
Karibo(barley based beverage)	1320-3440	Dibaba et al., 2018

Table 2: Summary of reported amounts of acrylamide (µg/kg) in cereal based food products.

Acrylamide in Animal Products

Acrylamide can be produced as a result of thermal processing of meat products but abundantly lower contents were reported. Chen, et al. [16] reported great variation between acrylamide content of processed and cooked meat and reported average values of 22.62 µg/kg and 25.03 µg/kg for processed meat and cooked meat respectively. They also reported maximum values of 49.06 µg/kg and 78.57 µg/kg and minimum values of 2.31µg/kg and 2.71µg/kg in the samples of processed meat and cooked meat respectively. The acrylamide contents of animal based food groups are given in Table 3 & 4 below.

Food Group	Acrylamide levels in µg/ kg(Minimum – Maximum)	References
Bakery products	<50 – 450	WHO,2002
Breakfast cereals	<30 – 1346	WHO,2002
Breakfast cereals	674	Claeys et al., 2016
Crisps, corn	34 – 416	WHO,2002
Bread, soft	<30 – 162	WHO,2002
Instant malt drinks	<50 – 70	WHO,2002
Beer	<30	WHO,2002

Fried rice crust	100.46 -491.76	Chen et al .,2012
Roasted biscuit	0.41 -484.17	Chen et al .,2012
Pancake	1.88 352.90	Chen et al .,2012
Maize(extruded cheese)	319	El-Ziney etal.,2009
Dutch spiced cake	260-1410	Hogervorst et al., 2007
Cornflakes	<LOQ-300	Hogervorst et al., 2007
Crisp bread	15-914	Hogervorst et al., 2007
Cookies	10-829	Hogervorst et al., 2007
Biscuit	10-1060	Pugajeva et al.,2014
Gingerbread	196-280	Pugajeva et al.,2014
Gingerbread	260–1410	Konings et al.,2003
Biscuits, grain	147-606	Pugajeva et al.,2014
Chocolate	22-116	Pugajeva et al.,2014
Peanut butter	107-118	Pugajeva et al.,2014
Karibo(barley based beverage)	1320-3440	Dibaba et al., 2018

Table 3: Summary of reported amounts of acrylamide (μg/kg) in animal based food products.

Food Group	**Acrylamide levels in μg/kg(Minimum – Maximum)**	**References**
Coffee powder	170 – 230	WHO,2002
Coffee(soluble coffee(Robosta))	820	El-Ziney, et al.,2009
coffee	152-682	Khan, et al.,2017
Arabic coffee (*Qahwa)*	73-108	Khan et al.,2017
instant coffee	358	Mojska and Gielecinska, 2013
ground roasted coffee	179	Mojska and Gielecinska,2013
roasted coffee	300-600	Pugajeva, et al.,2014
Soluble coffee	790-980	Pugajeva, et al.,2014
Coffee	3800	Claeys, et al., 2016
Roasted coffee	2522	Claeys, et al., 2016
Instant coffee	3800	Claeys, et al., 2016
Coffee substitute	5400	Claeys, et al., 2016
Tea	10–97	Khan, et al., 2017
Roasted green tea	190-1880	Chen, et al., 2008.
Green tea	94-100	Chen, et al., 2008.
Oolong tea	19-142	Chen, et al., 2008.
Black tea	20-Sep	Chen, et al., 2008.

Table 4: Summary of reported amounts of acrylamide (μg/kg) in coffee and tea products.

Milk is rich in protein and sugar. So it is obvious that processing of milk at high temperature may lead to acrylamide formation. After examination of Acrylamide in milk samples with different types of additives using Spectrophotometry Method, Tomovska, et al. [18] reported acrylamide content starting with a range from 129.58 μg/l in a homogenized milk with instant coffee as additive, and up to 144.95 μg/l in pasteurized milk with instant coffee as additive, while the lowest value of 13.42 μg/l in chocolate milk (which already contains cocoa/chocolate).But without additives acrylamide content of 8.79 and 14.97 µg/l was reported for pasteurized milk and homogenized milk respectively.

Acrylamide in Hot Drinks

Acrylamide contents of coffee and tea samples are mostly dependent on various factors including roasting conditions and its origion. Mojska & Gielecinska [19] demonstrated roasting process had the most significant effect on acrylamide levels in natural coffee. Different studies reported higher acrylamide levels in Robusta coffee than Arabica coffee. Soares, et al. [20] reported higher acrylamide levels in Robusta coffee than Arabica coffee for a similar roast degree, and suggested this could be probably due to a higher initial amount of asparagine in Robusta coffee. Bagdonaite & Murkovic [21] also reported highest amount of acrylamide in Robusta coffee than Arabica coffee beans. In addition to this they reported that high quality Arabica coffee beans (Columbian Excelso and Uganda Organic Biocoffee) had a lower amount of acrylamide compared to lower quality Arabica coffee beans (Santos Brasil).

Khan, et al. [22] conducted studies on different brands and origin of coffees, and obtained acrylamide content of 152-682 µg/kg in coffee, 73-108 µg/kg in Arabic coffee. Soares, et al. [23] reported some preliminary data on acrylamide levels of standard espresso coffee (0.32–1.46 lg/30 mL or 10.7–48.7 lg/L).During quantification of acrylamide level of Turkish Black Tea, Instant and Turkish Coffee Samples . Canbay, et al. Obtained acrylamide content ranging from 4.48 to 15.71 µg/kg and 3.89 to 88.44 µg/kg in instant coffee and coffee samples respectively. Mojska & Gielecinska [19] reported acrylamide concentrations of 358 µ/kg in instant coffee and 179 µ/kg in ground roasted coffee samples in determining the acrylamide level in commercial samples of roasted and instant coffee and in coffee substitutes by LC-MS/MS method.

Khan, et al. [22] conducted studies on a total of 22 tea samples of two classes (black and green) and were found acrylamide content of <100 µg kg−1.It is reported that the acrylamide content of green types of tea samples were in the range of (10–18 µg kg−1) while in black tea acrylamide content in the range of 35 - 97 µg kg−1 were reported. Similar result was also reported by Liu, et al. [24] during quantitative analysis of acrylamide in tea by liquid chromatography coupled with electrospray ionization tandem mass spectrometry. Acrylamide content less than 100µg/kg were reported30tea samples; while acrylamide content of Black, oolong, and white and yellow tea samples were less than 20µg/kg. Acrylamide content of sun-dried green tea samples were also reported to be in the range of 46–94 µg/kg. Canbay, et al. also determined the acrylamide contents of Turkish black Tea Samples and reported that black Tea samples had acrylamide content ranging from 6.09 to19.85 µg/kg.

Health Risks of Acrylamide Intake

Acrylamide was found to cause extensive DNA damage in lymphocytes of ACR-fed rats. it was reported that the tail moment for lymphocytes of acrylamide -fed rats was 112.35 while that of the control acrylamide 0 and the mean amount of DNA in the tail of lymphocytes was 86.7% while that of the control was 0.87% [25].

Duan, et al. [26] studied toxic effects of Acrylamide on mouse oocyte quality and fertility in vivo and reported that acrylamide-treated mice had reduced Ovary weights and DNA methylation levels, resulted in oxidative stress and oocyte early stage apoptosis and aberrant oocyte cytoskeletons. ALKarim, et al. [25] detected acrylamide induced significant genotoxicity by using the alkaline comet test and in acrylamide fed rats Significant Ovarian shrinkage, uterine horns irregularities and kinking were reported compared to the control .It was reported that Ovaries of pregnant acrylamide -fed group showed vascularization of corpus luteum compared to the control ones and Significant differences were observed regarding the number and size of fetuses in the ACR fed rats compared to the control. In addition induced adverse effects were reported on male reproductive system for acrylamide administrated with the ordinary rat food that absolute weights of testes and seminal vesicles were significantly reduced in group treated with acrylamide, and decrease in male rat fertility were reported. Aras, et al. [27] reported significantly higher M-II stage oocytes in the control group compared to the Acrylamide treated groups during their study of ''In Vivo acrylamide exposure may cause severe toxicity to mouse oocytes through its metabolite glycidamide' and Concluded that systemic exposure of mice to acrylamide have toxic effects on mouse oocytes.

Researchers have enabled the advanced understanding of acrylamide-induced neuropathies. Acrylamide requires multiple exposures to produce neurotoxicity. Evidence of neurological effect has been observed following single oral doses of 126 mg/kg in rats and rabbits and 100 mg/kg in dogs [28]. Low-level, work-related exposure to ACR monomer is neurotoxic for humans [29]. Rodent studies (sub-chronic and chronic oral dosing), primate studies (oral and subcutaneous) and a human occupational study, support a NOAEL for acrylamide neuropathy of 0.5 mg/kg bw per day [3]. Workers in the People's Republic of China, who were exposed to acrylamide and acrylonitrile for 2 or more years, were assessed for neurological signs and haemoglobin acrylamide adducts. A correlation was demonstrated between levels of haemoglobin adducts and degree of peripheral neuropathy.

For the first time; Bull, et al., [30] demonstrated that acrylamide possesses carcinogenic properties. It was reported that acrylamide is capable of acting as a tumor initiator in the mouse skin. In addition, increased lung tumor yield in the strain was reported in A/J mouse independent of promoting agents. During two-year carcinogenicity study of acrylamide in Wistar Han rats with in utero exposure Maronpot, et al. [31] reported increased incidence of thyroid follicular neoplasms in males and females and in a non-statistically significant increase in mammary fibro adenomas in females.

Mitigation Strategies of Acrylamide Occurrence in Processed Foods

When cooking foods, the amount of acrylamide formed can be minimized in several ways. Based on the knowledge about the formation mechanisms various methods were developed by Food scientists around the world to mitigate the presence of acrylamide in fried food products. The chitosan-immobilized asparaginase has shown pronounced action in the mitigation of acrylamide in fried kochchikesel banana chips. Granda, et al. [32] reported vacuum frying reduced acrylamide formation by 94% in fried potatoes and reducing frying temperature reduce acrylamide formation. It was reported that Acrylamide formation decreased significantly in potato chips as the frying temperature decreased from 180 °C to 150 °C for the traditional method and from 140 °C to 118 °C for the vacuum frying [32].

For production of French fries, potato crisps and potato snacks with minimized acrylamide formation it is recommended to use selected potato cultivars having low level reducing sugars, avoiding use of potatoes stored below 60c and treating with calcium salts before frying [33].

It was reported that using additives such as salts, amino acids, cations and organic acids along with blanching of foods have reduced the concentration of acrylamide [34]. From the experiments with the potato powder model system, Mestdagh, et al. [11] concluded that the addition of free glycine and L-lysine gave significant acrylamide reductions while keeping the pH of the mixture at its original level. It was also reported that addition of organic acids and sodium acid pyrophosphate significantly mitigated the final acrylamide content potato powder model system. But this should be evaluated in a real food system. Ismial, et al. [35] investigated a reduction of acrylamide formation in potato chips by blanching in hot water (65 and 85°C) or soaking in solutions containing 0.05M citric acid, 0.1 M $CaCl2$ or NaCl, 0.1M glycine, L-glutamine or L-cysteine and reported a reduction percentage of 90.40, 88.88, 90.40, 73.58, 76.91, 85.20 and 76.96% respectively.

Fredriksson, et al. [15] conducted a research on 'Fermentation reduces free asparagine in dough and acrylamide content in bread' by using doughs and breads made in a model system; and reported that long time fermentation with yeast reduced acrylamide content in bread made with whole grain wheat by 87% and by 77% for breads made with rye bran. To minimize acrylamide formation in cereal based products Alimentarius [33] recommended avoiding over baking, decreasing final baking temperature and avoiding using reducing sugar in bread production. It was recommended to use malted and light roasted barely to minimize the amounts of acrylamide in Ethiopian traditional beverage like keribo (barley based beverage) [17]. Selection of commercial blends with higher Arabica percentages, and preferring shorter brews instead of long ones also used to minimize the acrlymide intake from processed coffee [36].

Summary and Conclusion

Acrylamide is a highly polar molecule which is formed by Maillard reaction during food processing. Formation and degradation of acrylamide in foods is affected by acrylamide precursors such as free amino acids (mainly asparagine), and reducing sugars. Processing temperature, moisture content and time of processing are the most important factors which affect the acrylamide yield in processed foods. A wide range of acrylamide levels, which may be achieved using different raw materials, ingredients, and cooking methods, were reported all over the world [9]. Potato products and coffee substitutes are the most important contributors with a relatively high content of acrylamide. Levels of acrylamide are reported in coffee substitutes and fried potato products with max 5400μg/kg and 4126.26μg/kg respectively.

Various pre-treatment procedures such as fermentation, blanching, soaking, enzymes addition, and others pre-treatment activities were proposed to be successfully used according to raw material for mitigating of acrylamide levels in industrial scale. Avoiding excessive cooking of foods and practicing low temperature and relatively short time cooking of foods were proposed to be used in minimizing acrylamide formation in foods. Eating plenty of fruit and vegetables and minimizing consumption of fried and high temperature cooked foods is advisable to decrease the risk of acrylamide intake.

In addition ways for reducing the levels of acrylamide in food through changes in formulation, processing and other practices should be investigated further. On the other hand, awareness among retail units and end users about the toxicity of acrylamide should be created by food safety authorities and mass media on the toxic effect of acrylamide.

Acknowledgements

The authors would like to acknowledge Jimma University College of Agriculture and Veterinary Medicine for their advice and material supports during the writing of this review paper.

References

1. Weisshaar R (2004) Acrylamide in heated potato products–analytics and formation routes. European Journal of Lipid Science and Technology 106(11): 786-792.
2. Lingnert H, Grivas S, Jägerstad M, Skog K, Törnqvist M, et al. (2002) Acrylamide in food: mechanisms of formation and influencing factors during heating of foods. Scandinavian journal of nutrition 46(4): 159-172.
3. World Health Organization (2002) Health Implications of Acrylamide in Food: Report of a Joint FAO/WHO Consultation, WHO Headquarters, Geneva, Switzerland.
4. Ubaoji KI, Orji VU (2016) A review on acrylamide in foods: Sources and implications to health. Mgbakoigba: Journal of African Studies 6(1).
5. Das AB, Srivastav PP (2012) Acrylamide in snack foods. Toxicology mechanisms and methods 22(3): 163-169.
6. Zyzak DV, Sanders RA, Stojanovic M, Tallmadge DH, Eberhart BL, et al. (2003) Acrylamide formation mechanism in heated foods. Journal of agricultural and food chemistry 51(16): 4782-4787.
7. Blank I, Robert F, Goldmann T, Pollien P, Varga N, et al. (2005) Mechanisms of acrylamide formation. In Chemistry and safety of acrylamide in food Springer, Boston, MA, pp: 171-189.
8. Yaylayan VA, Stadler RH (2005) Acrylamide formation in food: a mechanistic perspective. Journal of AOAC International 88(1): 262-267.
9. Boyacı Gündüz CP, Cengiz MF (2015) Acrylamide contents of commonly consumed bread types in Turkey. International journal of food properties 18(4): 833-841.
10. Ciesarova ZU, Kiss EU, Kolek E (2006) Study of factors affecting acrylamide levels in model systems.Czech journal of food sciences 24(3): 133.
11. Mestdagh F, Maertens J, Cucu T, Delporte K, Van Peteghem C, et al. (2008) Impact of additives to lower the formation of acrylamide in a potato model system through pH reduction and other mechanisms. Food chemistry 107(1): 26-31.
12. Mikulikova R, Sladarsky VUP, Svoboda Z, Sladarsky VUP, Belakova S, et al. (2008) Monitoring of acrylamide in the course of malting and in beer. Kvasny Prumysl (Czech Republic).
13. Shamla L, Nisha P (2014) Acrylamide in deep-fried snacks of India. Food Additives & Contaminants: Part B 7(3): 220-225.
14. European Food Safety Authority (2008) Results on acrylamide levels in food from monitoring year 2008. EFSA Journal 8(5): 1599.
15. Fredriksson H, Tallving J, Rosen J, Åman P (2004) Fermentation reduces free asparagine in dough and acrylamide content in bread. Cereal Chemistry 81(5): 650-653.
16. Chen YH, Xia EQ, Xu XR, Ling WH, Li S, et al. (2012) Evaluation of acrylamide in food from China by a LC/MS/MS method. International journal of environmental research and public health 9(11): 4150-4158.
17. Dibaba K, Tilahun L, Satheesh N, Geremu M (2018) Acrylamide occurrence in Keribo: Ethiopian traditional fermented beverage. Food Control 86: 77-82.
18. Tomovska J, Stojanovska S, Tasevska J, Krstanovski A, Menkovska M (2017) Examination of Acrylamide in Milk Samples with Different Types of Additives Using Spectrophotometry Method. European Journal of Nutrition & Food Safety 7(3): 171-178.
19. Mojska H, Gielecinska I (2013) Studies of acrylamide level in coffee and coffee substitutes: influence of raw material and manufacturing conditions. Roczniki Państwowego Zakładu Higieny 64(3): 173-81.
20. Soares CM, Alves RC, Oliveira MBP (2015) Acrylamide in coffee: Influence of processing. In Processing and Impact on Active Components in Food, Academic Press, pp: 575-582.
21. Bagdonaite K, Murkovic M (2004) Factors affecting the formation of acrylamide in coffee. Czech journal of food sciences 22(1): 22.
22. Khan MR, Alothman ZA, Naushad M, Alomary AK, Alfadul SM, et al. (2017) Occurrence of acrylamide carcinogen in Arabic coffee Qahwa, coffee and tea from Saudi Arabian market. Scientific reports 7: 41995.
23. Soares C, Cunha S, Fernandes J (2006) Determination of acrylamide in coffee and coffee products by GC-MS using an improved SPE clean-up. Food additives and contaminants 23(12): 1276-1282.
24. Liu J, Zhao G, Yuan Y, Chen F, Hu X (2008) Quantitative analysis of acrylamide in tea by liquid chromatography coupled with electrospray ionization tandem mass spectrometry. Food chemistry 108(2): 760-767.
25. ALKarim S, ElAssouli S, Ali S, Ayuob N, ElAssouli Z (2015) Effects of low dose acrylamide on the rat reproductive

organs structure, fertility and gene integrity. Asian Pacific Journal of Reproduction 4(3): 179-187.

26. Duan X, Wang QC, Chen KL, Zhu CC, Liu J, et al. (2015) Acrylamide toxic effects on mouse oocyte quality and fertility in vivo. Scientific reports 5: 11562.
27. Aras D, Cakar Z, Ozkavukcu S, Can A, Cinar O (2017) In vivo acrylamide exposure may cause severe toxicity to mouse oocytes through its metabolite glycidamide. PloS one 12(2): e0172026.
28. Konings EJM, Baars AJ, Van Klaveren JD, Spanjer MC, Rensen PM, et al. (2003) Acrylamide exposure from foods of the Dutch population and an assessment of the consequent risks. Food and Chemical Toxicology 41(11): 1569-1579.
29. Pennisi M, Malaguarnera G, Puglisi V, Vinciguerra L, Vacante M, et al. (2013) Neurotoxicity of acrylamide in exposed workers. International journal of environmental research and public health 10(9): 3843-3854.
30. Bull RJ, Robinson M, Laurie RD, Stoner GD, Greisiger E, et al. (1984) Carcinogenic effects of acrylamide in Sencar and A/J mice. Cancer Research 44(1): 107-111.
31. Maronpot RR, Thoolen RJMM, Hansen B (2015) Two-year carcinogenicity study of acrylamide in Wistar Han rats with in utero exposure. Experimental and Toxicologic Pathology 67(2): 189-195.
32. Granda C, Moreira RG, Tichy SE (2004) Reduction of acrylamide formation in potato chips by low-temperature vacuum frying. Journal of Food Science 69(8): E405-411.
33. Alimentarius C (2009) Code of Practice for the Reduction of Acrylamide in Foods (CAC/RCP 67-2009) Joint FAO. WHO Food Standards Programme: Rome, Italy.
34. Baskar G, Aiswarya R (2018) Overview on mitigation of acrylamide in starchy fried and baked foods. Journal of the Science of Food and Agriculture 98(12): 4385-4394.
35. Ismial SAMA, Ali RFM, Askar M, Samy WM (2013) Impact of pre-treatments on the acrylamide formation and organoleptic evolution of fried potato chips. American Journal of Biochemistry and Biotechnology 9(2): 90-101.
36. Alves RC, Casal S, Oliveira BP (2007) Factors influencing the norharman and harman contents in espresso coffee. Journal of agricultural and food chemistry 55(5): 1832-1838.
37. Claeys W, De Meulenaer B, Huyghebaert A, Scippo ML, Hoet P, et al. (2016) Reassessment of the acrylamide risk: Belgium as a case-study. Food Control 59: 628-35.
38. Guenther H, Anklam E, Wenzl T, Stadler RH (2007) Acrylamide in coffee: review of progress in analysis, formation and level reduction. Food Additives and Contaminants 24: 60-70.
39. Hogervorst JG, Schouten LJ, Konings EJ, Goldbohm RA, den Brandt PA (2007) A prospective study of dietary acrylamide intake and the risk of endometrial, ovarian, and breast cancer. Cancer Epidemiology and Prevention Biomarkers 16(11): 2304-2313.
40. Pugajeva I, Zumbure L, Melngaile A, Bartkevics V (2014) Determination of acrylamide levels in selected foods in Latvia and assessment of the population intake. In 9th Baltic Conference on Food Science and Technology "Food for Consumer Well-Being", pp: 111.