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RESEARCH ARTICLE

A Review on Acrylamide Mitigation Strategies in Various Processed Foods.

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Abstract

Acrylamide chemically prop-2-enamide is a low molecular weight, colourless, odourless, crystalline vinylic compound and reactive in air. The International Agency for Research on Cancer (IARC) under the World Health Organization (WHO) has classified acrylamide as "probably carcinogenic to humans" based on evidence in animal studies. Acrylamide is present in significant quantities in carbohydrate rich foods such as potato chips, French fries and bakery products up to 7000 ppb followed by protein rich foods up to 400 ppb. Studies on mechanism of acrylamide formation in heat treated food revealed that acrylamide in food largely resulted from Maillard reaction between amino acid, asparagine and reducing sugars. Several research studies have been conducted worldwide to reduce acrylamide content in various food products. The review summarizes works carried out on the mitigation strategies of acrylamide with respect to deep fat fried foods, microwave heated foods, baked and roasted food products. The possible strategies of acrylamide reduction were grouped into four categories i.e., selection of raw materials, changing formulation and product composition without affecting the taste and preferences of consumers, pre-treatment procedures and optimized processing conditions.

Introduction:-

An accidental discovery of acrylamide, a potential carcinogen in fried and baked foods by Swedish scientists and followed by the announcement of National Food Administration in Sweden (SNFA) during April 2002 that acrylamide was found in many types of food, created alarm among the food scientist and consumers. In general, deep fat fried potato products, roasted coffee beans and bakery products are the most important sources of acrylamide (EFSA 2015).

Acrylamide (AA) is a versatile organic compound that finds its way into many products in our everyday life. Acrylamide exists in two forms: a monomer and a polymer. The single unit form of AA is toxic to the nervous system, a carcinogen in laboratory animals and a suspected carcinogen in humans. The multiple unit or polymeric form is not known to be toxic. The monomeric form of AA is primarily used in research laboratories for electrophoresis. It is also used to produce grout, dyes, contact lenses and in the construction of dams, tunnels and sewers. Acrylamide polymers are used as additives for water treatment, flocculants, paper making aids, thickeners, soil conditioning agents, textiles, production of organic chemicals and ore and crude oil processing. Although the polyacrylamide is not toxic, a small amount of the AA monomer may leach from the polymer. There are two established legal limits for AA. One is related drinking water which is less than 0.5 ppb of un-coagulated AA and other involves percolation of monomeric form of AA from packaging materials into foods. The second one is defined not be detectable within limit of detection (LOD) of 10 µg AA in kg of foods (WHO 2005). However, daily intake of some tens of micrograms can be expected depending upon the dietary habits of individual. Report submitted by EFSA (2015) Panel on Contaminants in the Food Chain (CONTAM) revealed that mean and 95th percentile dietary AA exposures across surveys and age groups were estimated at 0.4 to 1.9 µg/kg body weight per day and 0.6 - 3.4 µg/kg per day, respectively. Studies carried out various agencies among different kind of processed foods revealed that carbohydrate rich foods such as potato chips, French fries and bakery products contain higher level of AA (400 ppb–7000 ppb) followed by protein rich foods with (5–400 ppb). The levels of AA in various food products of different countries are summarized in the Table 1.

Table 1:- Acrylamide (AA) content of various food products

Food category	Food item	Mean concentration (µg/kg)	Maximum (µg/kg)
Cereals and cereal-based products	Cereals and pasta(raw and boiled)	15	47
	Cereals and pasta (processed: toasted, fried, grilled)	123	820
	Breads and rolls	446	3436
	Pastry and biscuits (US 5 cookies)	350	7834
	Breakfast cereals	96	1346
	Pizza	33	763
Fish and seafood (breaded, fried, baked)		25	233
Meat and offal (coated, cooked, fried)		19	313
Milk and dairy products		5.8	36
Nuts and oilseeds		84	1925
	Potato purees/mashed/boiled	16	69
	Potato baked	169	1270
	Potato crisps (US 5 chips)	752	4080
	Potato chips (US 5 french fries)	334	5312
	Potato chips, croquettes (frozen, not ready-to-serve)	110	750
	Coffee (brewed), ready-to-drink	13	116
	Coffee (ground, instant or roasted, not brewed)	288	1291
	Coffee extracts	1100	4948
	Coffee decaffeinate	668	5399
	Coffee substitutes	845	7300
	Cocoa products	220	909
	Green tea (roasted)	306	660
Sugars and honey	Mainly chocolate	24	112
Fruits & Vegetables	Raw, boiled and canned	4.2	25
	Processed (toasted, baked, fried, grilled)	59	202
	Fruits (fresh)	<1	10
	Fruits (processed: dried, fried)	131	770
Miscellaneous	Alcoholic beverages (beer, gin, wine)	6.6	46
	Condiments and sauces	71	1168
	Infant formula	<5	15
	Baby food (canned, jarred)	22	121
	Baby food (dry powder)	16	73
	Baby food (biscuits, rusks, etc.)	181	1217
	Dried food	121	1184

Data were obtained from the Summary Report of the 64th Meeting of the Joint Food and Agriculture Organization of the United Nations/World Health Organization Expert Committee on Food Additives (http://www.who.int/). Acrylamide occurrence data for different food items analyzed from 2002 to 2004 were provided from 24 countries (WHO 2005). The total number of analytical results (single or composite samples) was 6752 with 67.6% from

Europe, 21.9% from North America, 8.9% from Asia and 1.6% from Pacific. No data from Latin America and Africa were submitted.

Studies on mechanism of AA formation in heat treated food during last one decade revealed that AA in food largely resulted from the Maillard reaction between amino acid asparagine (ASN) and reducing sugars (RS). Even though, several papers revealed that AA forms above 120 °C or higher temperature, there were reports confirming that this compound can be formed at temperatures below 100 °C, particularly in drying processes at 65–130 °C (Eriksson and Karlsson, 2005). Additional mechanisms of AA formation involving peptides, proteins, biogenic amines and lipids have been also reported.

Acrylamide detection in human foods has led to extensive studies by Food and Agriculture Organisation (FAO), World Health Organisation (WHO) and other organization in European countries for exploring its formation mechanisms, levels of exposure, suitable analytical procedures and mitigation strategies in food stuffs. However, the awareness about the AA toxicity and level of health risk were found to be low among the developing and under developed nations. So it is necessary to summarize the recent research studies carried out by various industries and research bodies on alternative processing technologies for reduction of AA without affecting consumer tastes and preference etc. With this view, this review presents the mitigation mechanism carried out by Research Organisation as well as industries in order to have better understanding on control of AA during heat treatment with respect to deep fat fried, baked, extruded and roasted food products.

Acrylamide Mitigations Strategies:-

It is now well established that formation of AA in food products is linked with levels of AA precursors in raw material and type of processing condition which favours Maillard reaction. Thus, strategies for reduction of AA should be based on the removal or maintaining low level of precursors and interfering with Maillard reaction. Several research studies carried out worldwide to reduce AA content by many researchers. There are different organization such as Food and Agriculture Organisation (FAO), World Health Organisation (WHO), Joint Research Centre (JCR) of the European commission and The European Food Safety Agency (EFSA) put various efforts on AA reduction in thermally treated processed food products i.e. deep fat fried food products, baked products and extruded products, roasted products which are developed by using different raw material i.e. potato, cereals, coffee fruits and vegetables. EFSA's Scientific Panel on Contaminants in the Food Chain (CONTAM Panel) carried out a full risk assessment of AA in food. EFSA's experts provisionally completed this full risk assessment in July 2014. The Panel assessed the toxicity of AA for humans and updated its estimate of consumer exposure through the diet. EFSA publicly consulted on their draft scientific opinion in mid-2014. In September 2014, together with national partners in the Member States, EFSA published an infographic on AA to help increase awareness about this issue. The info graphic explains how AA forms and in which foods, and includes basic tips provided by national authorities on reducing AA exposure in the diet. The above studies and methods revealed that AA reduction can be achieved by following four major strategies.

Firstly, through the selection of raw material, the second way is changing the formulation and products composition as they contribute significantly for AA level in products. The third mechanism to reduce AA level in the end product is by following pre-treatment procedures. The fourth way to reduce the AA content is maintaining optimum processing condition. Reducing AA levels while maintaining product quality (flavour, colour, texture, safety, etc.) in commercial processed food, is a crucial challenge. Care should be given in consumer acceptability point of view while making the food with different conditions that prevent or reduce AA levels. Efforts taken by several researchers, industries and funding organization to reduce AA content in foods at different stages of commercial production are presented in the following sections and Table 2.

Table 2:- Summary of studies and findings on mitigation strategies of acrylamide formation tested in various foods

Mitigation Strategies	**Food Matrix**	**Conditions**	**Results**	**Reference**
Selection of Raw Material	Potato chips	Selection of cultivar	*Sante* variety potatoes with high RS and ASN showed high AA content (8825 μg/kg). *Savalan* variety potato with high asparagins concentrations and low reducing sugar showed low AA content (5112 μg/kg).	Aliabadi et al., (2013)

	Yeast leavened bread	Selection of wheat, rye and spelt cultivar	Variety with lower level of ASN, RS and proportion of ASN to total amino acid pool leads to product with less AA content.	Claus et al., (2006)
Fertilizer Application	Potato	Nitrogen fertilization	Increase in amount of ASN with higher dose of N application which leads to higher AA formation.	De Wilde et al., (2006); Lerner et al., (2006)
	Wheat	influence of Sulfur deficiency	Wheat grown under S deficiency resulted in 30 fold increase in ASN.	Muttucumaru et al., (2006); Granvogl et al., (2007); Curtis et al., (2009)
			Sulfur deficiency leads to ASN accumulation in flour fraction of wheat.	Shewry et al., (2009)
	Cultivated plants	Influence of salt, drought, pathogen attack and exposure to toxic metal	Exposure to above factor increases ASN accumulation.	Lea et al., (2007)
	Potato	Nitrogen deprivation	Large increase in sugar concentration.	Elmore et al., (2007)
Effect of Environment	wheat	Varieties of wheat grown under different location	*Einstein*, the best performer with an average grain ASN of 1.89 mmol kg^{-1}, while *Robigus*, the worst performer with 2.59 mmol kg^{-1}.	Curtis et al., (2009) and (2010)
	Wheat bread	Sprouting of Wheat due to unfavourable weather conditions	Bread prepared from sprouted wheat grain flour showed increased level of AA.	Claus et al., (2006b)
	Wheat and rye Bread	Harvest year	Higher temperature during harvest year resulted in high level of ASN leads to High AA in Bread.	Claus et al., (2006b)
Maturity stages	Potato chips	Immature tubers contained high RS	Matured tubers have to be selected for making potato chips to have less AA.	Seal et al., (2008)
	Banana fritters	Matured banana contains high RS	Immature or less matured banana has to be selected for making banana fritters.	Jinap et al., (2013)
Storage conditions	Potato	Low temperature storage leads to cold sweetening	Higher Hexose accumulation at 4^{O} C leads to more AA in chips.	Sowokinos (1990)
		Modified atmospheric storage	Maintaining low level of oxygen suppresses sugar accumulation.	Kumar et al., (2004)
Change of formulation and product composition	Baked Foods	Addition or removal of minor ingredients	Addition of roasted almond, poppy seed and sesame seeds leads to high AA in baked foods.	Weisshaar (2004)
	Wheat bread	Addition of 2% NaCl	2% NaCl lowers AA levels in wheat bread.	Claus et al., (2007)
	Potato flakes	Calcium salt spraying	Calcium salt spraying resulted in 30 to 40% reduction of AA in potato flakes.	FoodDrinkEurope AA Toolbox (2013)
	Extruded snacks	Blends of potato flour and semolina	70% potato flour and 30% Semolina composition showed higher AA when compared to 30:70 ratios.	Mulla et al., (2011)
	Wheat crackers	sugar type	Replacing invert sugar syrup by sucrose reduced AA by 60%.	Amrein et al., (2004)
		Baking agent & sugar	Replacing sodium bicarbonate with NH_4HCO_3 and sugar syrup with sucrose reduced AA by 60%.	
	Gingerbread	influence of NH_4HCO_3 and Tartaric acid	AA is significantly reduced when NH_4HCO_3 is replaced by $NaHCO_3$ and addition of extra Tartaric acid	Weisshaar (2004)

			reduced AA by one-third.	
	Potato crisps	Changing of slices / piece thickness	Thin cut potato crisps contain less AA when compared to thick cut crisps.	FoodDrinkEurope AA Toolbox (2013)
	Poori and Chapati	Changing of milling fraction	Wheat cultivar *lokwan* with lowest damaged starch (6.23%) content showed less AA content.	Mulla et al., (2010)
Pre treatment procedures	Fried Potato	Soaking with water and salt water	Soaking resulted in decrease of glucose up to 32 % leads to AA reduction short duration soaking in NaCl up to 5 minutes diminished AA formation.	Pedreschi et al., (2004)
		Addition of natural extract	Cut potatoes submerged in extract of green tea, cinnamon and oregano showed reduced AA by 62.39 and 70% respectively.	Morales et al., (2014)
		Addition of minced fish and legume proteins	Significant reduction of AA.	Rydberg et al., (2003); Vattem and Shetty (2005)
		Addition of hydrocolloids	Alginic acid and pectin are promising hydrocolloids in AA reduction.	Zeng et al., (2010)
	French Fries	Blanching	AA precursors were leached during blanching resulted in less AA.	Mestdagh, et al., (2008); Pedreschi et al., (2009)
		Fermentation	Short duration fermentation with lactic acid bacteria resulted in AA reduction up to 90 percent	Baardseth et al., (2006)
	French fries	Citric acid immersion	reduction of AA from 86% to 28%	Jung et al., (2003) Pedreschi et a.,l (2007a)
	Potato chips	Soaking and blanched in different salt solutions (KCl, NaCl and $CaCl_2$)	Reduction in the formation of acrylamide by 32, 46 and 55% respectively	Dorin Bakhtiary (2014)
	Potato chips	Blanching and addition of enzymes	Blanching and asparaginase immersion of sliced potatoes helped in AA reduction up to 90%	Pedreschi et al., (2011)
	Corn tortilla chips	Lime ($Ca(OH)_2$)	Reduction of 52 and 36% with lime concentration of 1%	Salazar et al., (2014)
	Wheat crackers and corn based products	Addition of Enzymes	Addition of Asparaginase to dough to reduce AA content to 70% in wheat crackers and 90% in corn based products	Hendriksen et al., (2005); Cieserova et al., (2006)
	Heat treated foods	Addition of antioxidants and natural extracts and phenolic compounds	Reduction of AA by exerting trapping effect on sugar by antioxidants	Kotsiou et al., 2011; Salazar et al., (2012); Morales et al., (2014); Urbancic et al., (2014)
	Emulsion system	Addition of phenolic compounds	Protocatechuic and gallic acid were more effective than trolox, caffeic and ferulic acid in AA reduction	Kali et al., (2011)
	Potato and Tortilla chips	Addition of piquin pepper oleoresin extract	potato and tortilla chips fried in piquin pepper oleoresin extract had less AA of 26 % and 77 % respectively compared to soybean oil fried chips	Salazar et al., (2012)
	Deep fat fried potatoes	Addition of Rosemary extract	Potato fried in rosemary extract added sunflower oil showed reduction in AA	Urbancic et al., (2014)
	Pooris	Addition of citric acid and calcium chloride	Addition of citric acid and calcium chloride showed reduction AA up to 54 & 72 % respectively	Mulla et al., (2010)
	Wheat bread	addition of glycine	Reduction of AA up to 90% when	Brathen et al., (2005)

			glycine was mixed with dough and 60% when glycine was sprayed on dough	
	Potato cakes	Addition of glycine	Reduction of AA up to 60% when potato cakes were dipped in glycine solution	Sahagian and Van Eijck (2005)
	Wheat crackers	Addition of cystiene and methionine	Reduction of AA up to 60% when cystiene and methionine added to dough	Levine and Smith (2005); Elder et al (2005)
	Crackers model	Addition of Casein	Reduction of AA up to 50%	Levine and Smith (2005)
	Bread & Potato products	Addition of divalent cations	Reduction of AA up to 50% at slightly acidic condition	Elder et al., (2004)
Optimum processing condition	Fried potato products	Frying Temperature and duration	High temperature frying (above 175 ºC) and longer duration resulted in higher level of AA	Gokmen and Mogol (2010); Mestdagh et al., (2008)
	Potato chips	Vacuum frying	AA reduction up to 94% by employing vacuum frying	Granda et al., (2004)
	Baked products	Steam injection baking	Reduction of AA up to 50 % when steam was injected during baking	Ahrne et al., (2007)
		Steam and IR heating baking	Reduction of AA up to 60 %	HEATOX (European project)
Post processing operation	Potato chips	Sorting Out of Overheated Items	High speed imaging system coupled with artificial neural network to detect AA rich chips	FoodDrinkEurope AA Toolbox (2013)

Selection of Raw Material

Success of any food processing industry depends upon the use of raw materials for processing. Generally, the raw material which has principally low reducing sugar and ASN content is preferred for frying and baking operation. So it is important to select right kind of cultivar, follow suitable agronomic practices and proper storage condition to have low level AA forming factors. It was demonstrated that ASN and reducing sugar are precursors for AA formation. Level of these precursors varies from crop to crop. In potatoes, ASN content ranges between 2010–4250 mg/kg and reducing sugars between 97–2550 mg/kg. ASN is the dominant free amino compound in potato tubers, typically accounting for approximately one-third of the total free amino acid pool (Elmore et al., 2007). Because of ASN is present at such a high concentration, sugar concentrations were initially expected to be the limiting factor for AA-forming potential. Friedman (2003) reported that selection of potato varieties with low levels of reducing sugars will play crucial role in AA reduction and a maximum of 1 g/kg reducing sugars has been suggested as a way to diminish significantly the formation of AA. Shepherd et al., (2010) showed that ASN and sugar concentrations contributed equally to the variation in AA-forming potential in a segregating breeding population, while Elmore et al., (2007) found that ASN as a proportion of the total free amino acid pool was the determining factor in AA formation. The experiments conducted by Aliabadi et al., (2013) on selection of potato cultivar for reduced AA in potato chips showed that highest AA content of (8825 μg/kg) in Sante variety potatoes, which contained the highest amount of reducing sugars and lowest AA content (5112 μg/kg) in Savalan variety which has highest ASN concentration and lower RS content.

Claus et al., (2006) investigated the influence of cereal varieties on precursors and AA contents in yeast leavened bread using nine wheat, two spelt and two rye cultivars, confirming a crucial impact of the plant variety. ASN in wheat ranged from 8.7 to 24.9 mg/kg and corresponding increase in AA content from 14 - 74 μg/kg.

The study conducted by Rita C Alves et al., (2010) on AA contents in Espresso coffees by matrix solid-phase dispersion and GC–MS showed the influence of coffee species, roast degree, and brew length on AA formation. Mean acrylamide contents of medium roasted espressos (30 ml) were 1.16 ± 0.25 and 2.31 ± 0.43 μg for pure arabica and robusta samples, respectively. A 25% decrease was observed when comparing espresso prepared with medium and dark roasted coffee. As suggested by Nigel G. Halford et al., (2012), efforts to reduce acrylamide formation would be greatly facilitated by the development of crop varieties with lower concentrations of free asparagine and/or reducing sugars, and of best agronomic practice to ensure that concentrations are kept as low as possible. It is inferred from above studies that the cultivar with low level of reducing sugar, ASN and low proportion of ASN to total amino acid pool should preferably use in order to have less AA.

Effect of Fertilization on Acrylamide Formation:-

Application of fertilizers to the crop plants by farmers plays a major role in formation AA precursors in crop plants. The major determinant of AA forming potential in wheat, rye and potato is the concentration of free ASN (Postles et al., 2013). ASN is an unusual amino acid and it can be accumulated in plants at high concentrations when protein synthesis is low and plants have a plentiful supply of nitrogen, suggesting that plants use free ASN as a nitrogen store when they are unable to store nitrogen in the form of protein (Lea et al., 2007). De Wilde et al., (2006) demonstrated that Nitrogen fertilization positively influenced AA formation in potato products. Lerner et al., (2006) reported significant increase in amounts of ASN in wheat grains with higher nitrogen dosage, which was ascribed to an improved utilization. When a zero level of fertilizer (0 kg N/ha) was compared with the highest dosage (220 kg N/ha), the AA in breads increased four-fold from 10.6 to 55.6 mg/kg.

Whittaker et al., 2010 showed the effect of tuber mineral composition which influenced by both the mineral content and pH of the soil, on the expression of ASN and reducing sugars in tubers. The authors concluded that the cultivation location had a significant effect on the mineral composition of the tubers, and subsequently reducing sugar contents were negatively correlated with potassium and calcium and positively correlated with zinc and copper contents.

Effect of Environment on Acrylamide Formation:-

The effects of environmental conditions on ASN accumulation in wheat and rye grain have been demonstrated in an analysis of six wheat varieties grown at different locations over two harvest years in UK and of a range of rye varieties grown at locations in Hungary, France, Poland, and the UK and harvested during the years 2005 to 2007 (Curtis et al., 2009 and 2010).

Sprouting of cereal grains before harvest due to unfavorable weather conditions especially excessive moisture condition is a severe problem in cereal production. As a consequence, protease activities get doubled, resulting in significantly higher ASN levels in flour from sprouted wheat grains resulted in higher level of AA in breads produced from such flours. Therefore, flours from sprouted wheat or rye should not be used for bakery products, even when blended with other flours. Harvest year also has a crucial impact on ASN level in wheat and rye. ASN content was significantly lower in all samples harvested in the year 2004 harvest as compared to 2003. As a result, AA was also reduced in breads prepared from 2004 flour with a reduction of up to 62 % for the cultivar *Enorm*. These varying contents in ASN, crude protein and AA were ascribed to differing weather conditions. The growth period was extraordinarily dry in 2003, with the average temperature being 1-2 ^{0}C higher than in 2004 with approximately 300 more hours of sunshine.

The Effect of Maturity Stages on Acrylamide reduction:-

The levels of dry matter content, ratios of sugars to starch and ASN changes throughout the growth period of crop plants. Maturity and harvest time have been indicated to have a major influence on potato tuber sugar content. So it is crucial to select correct maturity stages to have less AA during processing. In case of potato early harvested tubers have low dry matter content (16%) and high concentrations of glucose and fructose compared to tubers harvested at maturity (Seal et al., 2008). The level of ASN in raw potatoes varies only within a narrow range, whereas the reducing sugar content can vary widely depending on variety, maturity and storage among other growing and processing conditions. Harvesting mature tubers will definitely contribute significantly to reduction of AA.

As against potato, matured banana had significantly higher concentrations of RS i.e., glucose and fructose when compared to less matured one. However, the concentrations of free amino acids at different maturity stages were relatively similar as revealed by Daniali et al., (2013) during their study on two varieties of banana (*Musaparadisiaca* variety *Awak* and *Abu*) on the formation of AA. They also reported that the formation of AA in both banana varieties was enhanced with an increase in both reducing sugars (glucose and fructose) during maturity. This research demonstrated that the formation of AA was strongly dependent on the concentration of both glucose and fructose than ASN content in banana fritters.

Influence of Storage Condition:-

The type and storage duration of raw material play major role in AA formation. To maintain supplies of raw material throughout the year, it is necessary for producers to store the same for periods of several months. Usually, potato is stored in cool temperature in order to avoid sprouting. However, storage of tubers below 8 °C is known to cause cold sweetening i.e., hexose accumulation in tubers stored which leads to increased levels of RS (Viklund et al., 2010). Reversible reduction of the reducing sugar levels can be achieved by keeping cold-stored tubers at 15^{o}C for a period of 3 weeks (Blenkinsop et al., 2002; De Wilde et al., 2005).

Change of formulation and product composition:-

Addition or removal of minor ingredients:-

The formulation and composition i.e. recipe of food products contribute significantly to their AA levels. Addition or removal of certain minor or co-ingredients like pre-processed cereals, sugars, spices and modifying composition could potentially raise or decrease AA levels in the final product (FoodDrinkEurope AA Toolbox 2013). Weisshaar et al., (2004) studied the impact of roasted almonds, hazelnuts, sesame and poppy seeds in baked foods on AA formation. With the exception of hazelnuts, all other typical baking ingredients significantly increased the AA levels depending on the surface-to-volume ratio. Application of these ingredients in sweet bakery products as well as in bread rolls significantly enhanced AA content when they were applied directly to the surface. Frequent frying of minor ingredients may be a reason for increased level of AA.

Many authors reported a significant effect of NaCl on AA formation in model systems experimental food products. AA reduction up to 40 % was achieved when 1 % NaCl added to model mixture which might be explained due to inhibition of the formation of a Schiff base between reducing sugars and ASN (Gokmen and Senyuva, 2007). For some fabricated potato based products, partial replacement of potato components by ingredients lower in key reactants reduces AA formation potential, e.g. use of cereals with lower ASN amounts than potato (e.g. wheat, rice, maize) in the recipe (Food Drink Europe AA Toolbox, 2013).

Mulla et al., (2011) studied AA formation in extruded snacks prepared by using blends of potato flour and semolina in ratios ranging from 30:70 to 70:30 and found that maximum AA formation in the 70:30 blends under the extrusion condition of screw speed of 120 rpm, temperature of 170 °C and moisture content of 18 %. The extrudates so obtained showed AA content ranging from 704 to 1560 mg/kg which clearly demonstrated impact of products combination on AA formation. Arda Serpen et al., (2012) studied the effects of multi-grain (wheat, oat, rye, wheat bran, soya, maize) combinations on Maillard Reaction Products (MRPs) and total antioxidant capacity (TAC) in breads. Wheat bran-, soy- and maize-containing breads were efficient in suppressing the formation of 5-hydroxymethylfurfural. Wheat bran or maize associated breads were free of acrylamide or contained lower amounts of acrylamide.

In wheat crackers and gingerbread replacement of invert sugar syrup with sucrose reduced AA by 60 %. However, the products obtained were insufficiently browned and had to be coloured (Amrein et al., 2004). Various combinations of baking agents for AA reduction were tested and results showed that complete replacement of NH_4HCO_3 by $NaHCO_3$ reduced the AA content by over 70 % in ginger bread.

Changing of slices / piece thickness and milling fraction:-

AA forms on the surface layer of the potato product and therefore, size and cut shape of the product i.e. surface-to-volume ratio will also influence final AA content. A thin cut potato crisp product would require less thermal input for the same fry time to reach the same moisture endpoint, so in practice would form less AA (FoodDrinkEurope AA Toolbox, 2013). Mulla et al., (2010) studied variation in AA content of two Indian traditional products, chapatti and poori with respect to the damaged starch content during milling in whole wheat flour of Wheat cultivar '*lokwan*'.

Pre-treatment procedures:-

The principal objective of pre-treatment of raw materials is either to minimize the concentration of AA precursors or to minimize or to inhibit Maillard reaction during processing. It can be achieved following different treatments such as soaking, blanching, addition of antioxidants, natural extracts, etc. The efforts taken by different researchers, organization and industries in terms of different pre-treatments for reduction of AA are summarized below;

Effect of Soaking on Acrylamide Reduction:-

The Levels of reducing sugars can be lowered by soaking the cut potatoes in water at room temperature before they are fried. Pedreschi et al., (2004) demonstrated that glucose content in potato slices decreased slightly as the soaking time in water and salt water increased.

Effect of Blanching on Acrylamide Reduction:-

In industrial production of French fries, blanching of potato is considered as one of the important unit operation. During blanching enzymes are inactivated and a layer of gelatinized starch is formed which limits oil absorption and improves texture and colour of product. During Blanching, AA precursors were leached out, resulting in the reduction of AA content (Pedreschi et al., 2009; Gunilla A .I. Viklund et al., 2010).

Dorin (2014) conducted the study by soaking the blanched potato slices (85 ^{0}C for 3.5 min) in different salt solutions (KCl, NaCl and $CaCl_2$ solutions of 0.1 M for 5 min at 25 ^{0}C) on AA formation and sensorial quality of fried potato. Samples soaked in KCl, NaCl and $CaCl_2$ solutions resulted significant reduction in the formation of AA by 32, 46 and 55 % respectively in comparison with control. Belgin et al., (2007) employed microwave blanching by immersing the potato strips in boiling water and microwaving at 900 W prior to drying, par-frying, cooling and freezing. AA reductions for the samples microwave-blanched for 1, 2, 3, 4 min were 18, 48, 71 and 79 percentages respectively. Salazar et al., (2014) has analyzed the influence of lime ($Ca(OH)_2$) concentration during nixtamalization process on the physicochemical properties of nixtamalized corn flours and its effect on the AA content in tortilla chips prepared from them. The results showed that AA content was mainly affected by the ash, calcium, soluble fibre concentration in flour and pH value. Results showed that increased concentration of $Ca(OH)_2$ helped in AA reduction up to 52 %. The result suggested that controlling the concentration of $Ca(OH)_2$ during nixtamalization process can be used as an effective strategy for reducing AA formation in fried products produced from nixtamalized corn flour.

Effect of Fermentation on Acrylamide Reduction:-

Short duration fermentation of cut potatoes by addition of Lactic Acid Bacteria (LAB) before pre frying was helped in bringing down the AA level considerably up to 90 percent in French fries production (Baardseth et al., 2006, Weining Huang et al., 2008). Anese et al., (2009) studied the effect of chemical and biological pre-treatments on acrylamide formation in deep-fried potatoes. Prior to deep-frying, potatoes cubes were subjected to lactic acid fermentation in the presence or in the absence of glycine, as well as to immersion in an aqueous solution of the amino acid alone. Results showed that deep-fried potatoes subjected to the glycine and fermentation pre-treatments had 35% and 50% less acrylamide content than the water-dipped ones. Lactic acid fermentation in the presence of glycine reduced acrylamide formation up to 70%. Such a pretreatment did not affect the sensory perceived browning, flavor, sourness and crispness of the deep fried potatoes.

Effect of Enzymes Addition on AA Reduction:-

Effect of enzymes such as asparaginase on AA reduction has been studied in wheat cracker, corn based products and French fries (Cieserova et al., 2006; Franco Pedreschi et al., 2008). It has been reported that addition of asparaginase enzyme to dough reduced AA content by 70 % without any changes in the colour or flavour of the products in wheat cracker and up to 90 %in corn-based foods. Pedreschi et al., (2011) studied the effect of blanching and asparaginase immersion treatments before final frying in potato chips on AA reduction and achieved up to 90 % reduction in AA content when slices were blanched before asparaginase immersion.

Addition of enzyme to cereal-based products (Capuano et al., 2008 and 2009) was resulted in AA reduction up to 85-90% and no effect on products taste and appearance and is being already used for some products at industrial scale (CIAA, 2009). Some preliminary results achieved at lab scale highlighted that asparaginase pretreatment of green beans may represent a viable way to reduce AA concentration in roasted coffee as well. Up to now, two commercial products, Acrylaway (asparaginase form *Aspergillus oryzae*) from Novozyme and Prevent ASe® (Asparaginase form *Aspergillus niger*) from DSM are on the market for food applications. GRAS status has been obtained from the US FDA for both types of asparaginases.

Effect of Additives on Acrylamide reduction:-

The various studies conducted during 2007–13 were revealed that addition of antioxidants such as bamboo extract, phenolic compounds, extracts of wild oregano, thyme, cinnamon, bougainvillea, green tea, piquin pepper oleo resin and rosemary helped in reduction of AA in food products (Kotsiou et al., 2011; Kali Kotsiou et al., 2010; Shiyi Ou et al., 2010, Salazar et al., 2012; Rasim Alper Oral et al., 2014; Morales et al., 2014; Urbancic et al., 2014). It has been reported that antioxidants exert a trapping effect on sugars or 3-deoxy-2-hexosulose intermediate and consequently inhibit Maillard products formation (Totlani and Peterson 2007).

Kali et al., (2011) carried out experiments on the effect of standard phenolic compounds such as trolox, phenolic acids (ferulic, gallic, protocatechuic and caffeic acid) and secoiridoids extracted from virgin olive oil (VOO) on AA formation in an emulsion system. Addition of standard phenolic compounds reduced AA formation which was more pronounced at initial time of heating (20 min) reaching up to 70%.

Morales et al., (2014) evaluated the effect of natural extracts i.e. from wild oregano, thyme, cinnamon, bougainvillea and green tea on the formation of AA in fried potatoes. The Inhibition percentage of DPPH (Free radical scavenging activities) in these extracts ranged from 48–98 % with highest percentage for cinnamon extract (98 %) while wild oregano showed 48 % inhibition. Salazar et al., (2012) studied the AA-mitigating effect of piquin pepper oleoresin (piquin pepper oily extract in soybean oil) in both model and food systems.

Urbancic et al., (2014) evaluated the effects of rosemary extract on the stabilization of sunflower oil and the reduction of AA formation in potato during deep-fat frying. The synthetic antioxidants such as butylated hydroxyanisole, tertiary butylhydroquinone and tocopherols served as positive controls. The effectiveness order for inhibition of sunflower oil degradation and reduction of acrylamide formation in deep-fried potato was: rosemary extract > tocopherols > tertiary butylhydroquinone > butylated hydroxyanisole > control.

The study conducted by Mulla et al., (2010) on impact of several additives on AA reduction in pooris a traditional dish of India showed that addition of 10 µmol citric acid to one gram of flour and 100 µmol/g flour calcium chloride can reduce AA in pooris by approximately 54 % and 72% respectively without altering the sensory analysis of the products. Shiyi Ou et al., (2010) studied the effect of antioxidants on elimination and formation of acrylamide in model reaction systems and concluded that antioxidants could inhibit acrylamide formation in high-temperature processing foods through three ways.

Shiyi Oua et al., (2010) studied the effect of antioxidants, including tert-butyl hydroquinone (TBHQ), butylated hydroxy anisole (BHA), butylated hydroxytoluene (BHT), ferulic acid, epigallocatechin gallate (EGCG) and vitamin C (VC), and their corresponding oxidation products, were tested for their influence on elimination of acrylamide and inhibition of acrylamide formation.

Effect of Organic acids, amino acids and proteins on acrylamide reduction:-

The effect of organic acid and amino acids on AA reduction has been studied by many authors during last one decade (Gama-Baumgartner et al., 2004; Zhang et al., 2007). The authors demonstrated that addition of organic acid in food matrices was an efficient way to considerably diminish AA formation by lowering the pH and leaching out of free ASN and the reducing sugars from the surface layer. Lowering the pH using organic acids of the food system to reduce AA generation may attribute to protonating the α-amino group of ASN, which subsequently cannot engage in nucleophilic addition reactions with carbonyl sources.

Strip immersion of potato slices in citric acid solution of 10 g/L for reducing AA formation was studied by Jung et al., (2003) and results showed that significant reduction from 28 % to 86 %. However, this approach can cause souring of flavour if a precise procedure is not followed and also the frying oil can become rancid. Pedreschi et al., (2007a) confirmed that citric acid immersion reduce AA formation in French fries. Tartaric acid is often added to baking agents containing $NaHCO_3$ to enhance the leavening. Experiments conducted with the addition of some extra tartaric acid to dough showed that reduction of AA level of up to 33 % when tartaric acid addition increased from 0.195 % to 0.244 % and up to 44 % was achieved when tartaric acid increased from 0.244 % to 0.293 % of dough. This result showed that addition of extra tartaric acid brings down the pH and affect maillard reaction. Again, all products passed the sensory test and were used for final production. Similar effects were reported when lactic, tartaric, citric, and hydrochloric acids were added to semi-finished biscuits and cracker models (Graf et al., 2006; Levine and Smith, 2005). In all studies, AA decreased with increasing amounts of acid, thereby reducing the pH by 30 % (pH=1.5) or more its generation is significantly reduced due to hydrolysis of the carboxamide group leading to aspartic acid at lower pH. The impact of amino acids such as glycine, methionine, cysteine and glutathione on AA formation and its elimination was assessed in various studies (Brathen et al., 2005; Fink et al., 2006; Casado et al., 2010). The effect of amino acids may mainly be ascribed to competition with ASN in the Maillard reaction. The glycine addition to dough results in considerable reduction in amount of AA up to 90 % was achieved in the method of mixing and 16 percent in case of spraying. Sahagian and Van Eijck (2005) observed an almost 60 % decrease when dipping potato cakes in a glycine solution.

AA formation was decreased by almost 50 % when cysteine and methionine were added to crackers (Levine and Smith, 2005). The reduction in AA is ascribed to reaction of reactive SH-groups of amino acids which react with previously formed AA to form cysteine-S-β-propionamide (S-(3-amino-3-oxopropyl)-cysteine) (Fluckiger and Salih, 2006). However, cysteine has limitation to its applicability in foodstuffs, in particular, it weakening gluten and results in flatter breads. Furthermore, an off flavour can be observed at higher levels (Claus et al., 2008).

It is reported that addition of minced fish and legume proteins to potato products prior to frying significantly reduced AA contents (Rydberg et al., 2003; Vattem and Shetty, 2005). Corresponding trials in cracker models (Levine and Smith, 2005) showed an almost 50 % reduction when casein was used. Proteins bear reactive nucleophilic SH- and NH_2-groups of amino acid side chains which can form stable adducts with AA similar to those formed by cysteine (Lingnert et al., 2002).

Yun Cai et al., 2014 studied effect of Chlorogenic acid on AA formation through promotion of HMF formation and 3-aminopropionamide deamination. In the asparagine/glucose Maillard reaction system (pH = 6.8), addition of chlorogenic acid significantly increased acrylamide formation and inhibited its elimination. In contrast, the quinone derivative of chlorogenic acid decreased acrylamide formation.

Effect of divalent cation on acrylamide reduction:-

Adding divalent cations such as Ca^{2+} or Mg^{2+} to the dough prior to baking, decreased AA contents of the products. Elder et al., (2004) reported an almost 20 % decrease in AA when these ions were applied and a decrease of up to 50 % at slightly acidic conditions (pH 5.5), which are common in many foodstuffs. Similar effects were reported for bread, where Ca^{2+} caused a 30 % reduction in AA content (CIAA, 2006) and crackers (Elder et al., 2005). Gokmen and Senyuva (2007) studied the impact of bivalent ions on AA formation in potato products and reported an almost linear negative correlation between AA formation and added Ca^{2+} concentration.

Effect of Hydrocolloids on acrylamide reduction:-

The effects of eight hydrocolloids such as agar, alginic acid, carobgum, carrageenan, gelatin, hydroxypropyl Distarch phosphate (HDP), pectin and xanthan gum on AA formation were studied (Zeng et al., 2010) by using two model systems i.e. chemical and snack model. At 2 % (w/w), pectin, alginic acid and xanthan gum (20 %) significantly reduced AA formation in chemical models. Hydrocolloids used to modify the texture of various food products by functioning as gelling or thickening agents (Kohajdova and Karovicova, 2009). The modified structure interfered with molecular interaction of Maillard reaction which resulted in the reduction of AA. In the fried snack model, effective inhibition of AA formation (30 %) by most of the hydrocolloids was observed only when the concentration was increased to 5 %. The findings suggest alginic acid and pectin are promising inhibitors of AA formation and immersion time is an important determinant for their effects against AA formation in fried potato products.

Optimum processing condition:-

Range of temperature, time duration and moisture level of the product play a major role during food processing. As our primary aim is reduction of AA in food products it is important to optimize the above parameters to have less AA level without compromising the taste and preference of the consumers. Several studies were carried out by researchers as well as industries on optimum processing condition and alternate processing technologies were summarized below.

For conventional fried potato products, frying temperatures above 175 °C have been shown to increase levels of AA significantly. Intense frying condition i.e. high temperature and prolonged frying leads darker fries and higher level of AA formation (Mestdagh et al., 2008). However, use of lower temperatures for extended cooking times can affect quality such as increased moisture, which results in loss of consistency/crispness and increased fat uptake which can have health implications (Foot et al., 2007). So it is necessary to have control on oil temperature preferably less than 175 °C and frying duration to have less AA in food products. Further reduction in the formation of AA can be achieved by lowering the temperature to 150 °C toward the end of cooking. AA reduction may be achieved by low temperature vacuum frying and short frying times. Among several deep-fat frying technologies, vacuum frying has a significant strategic importance for future fried manufacturing and in reducing AA formation. Granda et al., (2004) applied vacuum frying for producing potato chips and they could reduce AA formation by 94 %.

Sensory quality of baked products is depends upon the surface colour of the products and there is a strong correlation noticed between crust colour and AA formation in baking. It is observed that the formation of crust starts when the surface temperature of the bread is over 100 °C. A dehydration process accompanies crust formation; therefore, the exact temperature and moisture content of the crust, duration of baking are the important factors in AA formation. Studies showed strong correlation among AA formation, baking temperature and time (Ahrne et al., 2007; Brathen et al., 2005). Ahrne et al., (2007) studied the level of AA formation in three types of baking system i.e. baking in a deck oven without air circulation, steam and falling-temperature baking systems at 200, 230 and 260 °C Their results showed that the lowest crust temperature for which traces of AA were detected was approximately at 150°C and that formation of AA apparently started at approximately 120–130 °C. The authors revealed that steam injection during baking resulted in 50 % less AA formation when compared to baking without steam and lowering oven temperature after 5, 10 and 15 min of baking reduced AA concentration by 67 %, 36 % and 35 %, respectively. However the above baking condition resulted in the lighter crust colour which may not be liked by consumers sensorily. The authors also suggested that steam baking of bread to approximately the same colour level as that produced by traditional baking to leads considerably lower AA levels in baked foods. The above studies were also confirmed by HEATOX, a European project on rye crisp bread. Alternative heating techniques such as IR baking, it is possible to obtain a sensory profile almost identical to that of conventionally baked bread, with considerably lower AA content up to 60 percent (HEATOX, 2013).

In coffee, AA is formed in high concentrations during the first minutes of roasting at the rate of >7 mg/kg. The increase of roasting time leads to the degradation of AA. Kinetic models and spiking experiments with isotope labeled AA showed that more than 95 % of AA is lost during roasting (Skog K and Alexander, 2006; Taeymans et al., 2004). However, the roasting conditions have an important influence on the typical coffee aroma and taste that are desirable to consumers. Therefore, the optimization of the roasting conditions with respect to a reduction of the AA formation and maintaining the product quality has not been realized yet. Recent reports have proclaimed that AA is not stable in commercial coffee that is stored in its original container (Andrzejewski et al., 2004).

Mizukami et al., (2008) optimized the green tea (Houjicha) processing by applying roasting treatments to reach AA reduction without affecting the quality. The two most important odorants were separated and identified with aroma extract dilution analysis were 2-Ethyl-3,5-dimethylpyrazine and 2-ethyl-3,6-dimethylpyrazine. The AA contents in tea infusions amounted to 2.0 and 4.0 μg/l by roasting at 160º C for 30 min and at 180º C for 15 min, respectively. It was found out that degradation of tea catechins was minimized in so far the roasting temperature did not exceed 160º C. Although it is debatable whether AA formation occurs higher than 120 or 150º C, it is unanimously accepted that thermal treatment of foods and drinks at 180º C or higher results in formation the highest AA levels. To be more specific, when tea samples were roasted at 180º C for 10 min, the greatest AA amounts were formed. Application of higher temperatures and prolonged processing times initiated a drop in the AA content. Furthermore, an analysis of 82 tea samples revealed that the ASN content in tea leaves was a more important factor than the RS contents as regards the AA formation in roasted products (Mizukami et al., 2006).

Commercial biscuits and potato chips were subjected to vacuum treatments at different combinations of pressure; temperature and time (Monica Anese, 2010) in order reduce AA contents. Results showed that acrylamide removal was achieved only in samples previously hydrated at water activity values higher than 0.83, and that, a maximum of acrylamide removal was obtained between 5 and 15 min of vacuum treatment at 6.67 Pa and 60º C. Increasing oil temperature and heating duration in deep-fat frying of potato chips can improve textural quality but worsen the chemical safety of AA formation (Ana Arias-Mendez et al., 2013).

A 2D model including heat and vapor transfer and AA reactions were developed (Joseph, 2012). The model was validated against experimental data, consisting of the plantain core temperature and average water and acrylamide contents using two different typical plantain-based foods, i.e. ‘‘tajadas’’ (thick product) and ‘‘tostones’’ (thin product), in which the acrylamide contents were found to be 0.24 and 0.44 mg/ kg (fat-free dry basis), respectively. The simulations highlighted that non-isothermal heat treatment is a good strategy to reduce the acrylamide content up to 50% reduction. However, controlling the ASN content in the raw material through maturity stage selection or by implementing immersion pretreatments is an easier way to mitigate the acrylamide net amount in plantain products.

Post Processing Operations:-

It has been reported that shorter frying times followed by post drying step resulted in low-moisture potato chips. Additionally, the posts-drying treatment gave significant decreases in AA formation in potato chips (Kita et al., 2004).

Sorting Out of Overheated Items:-

Several studies reported that excellent linear relationships between browning and AA accumulation in chips and in model systems (Pedreschi et al., 2005). The "Centre pour l' Agronomie et l'Agro-Industrie de la Province de Hainaut" (CARAH) and a Belgian industrial partner (Rovi-Tech SA.)developed a high-speed imaging system coupled with artificial neural networks (ANN) computing, which consists in a fully automatic device that takes a snapshot of every chip tested, then issues result for both colours category and AA concentration. The system is intended for analysis of incoming potato batches as well as for checking pre fried chips for quality control in food distribution (FoodDrinkEurope AA Toolbox, 2013).

Conclusion:-

Acrylamide has been added to the list of food-borne toxicants by WHO, FDA and other international organization because of its Carcinogenic and Neuro toxic nature. Human being are directly exposed to AA due to large scale consumption of heat treated foods which are rich in ASN and reducing sugar i.e. baked, deep fat fried, extruded and coffee bean based products. Many studies have been conducted by researchers on mode of AA formation in different foods, toxicity, risk level exposure and mitigation strategies in different countries. However reduction of AA in thermally abused food products still a major concern. In developing and under developed nation the awareness about the AA risk due to food exposure is very poor when compared to developed countries.

At present, food industries are considering various approaches to reduce the AA formation in food products with the help of different bodies such as the European Food Safety Agency (EFSA) on AA reduction and sponsoring some projects such as HEATOX (Heat-generated Food Toxicants). However, awareness among retail units and end users about the toxicity of AA is very low. Therefore Food safety authorities of different countries and mass media should create awareness about the toxic effect of AA to different section of people. Care should be given while selecting the raw material as raw material with low ASN and reducing sugar will significantly reduce AA level. Efforts is needed among plant breeders and genetic engineers in developing low ASN and low reducing sugar varieties which help in reduction of AA formation. Various pre-treatment procedures such as soaking, blanching, fermentation, enzymes addition, organic acid addition, use of hydrocolloids can be effectively used according to raw material for mitigating AA levels in industrial scale. Under different pre-treatment followed by researchers it is showed that blanching and immersion of sliced potatoes in asparaginase solution helped in AA reduction up to 90% followed by short duration fermentation of potato slices with lactic acid before frying. The study also revealed that modern process techniques such as vacuum frying steam and IR treatment helped in AA reduction up to 94%.

Nevertheless, maintaining optimum processing conditions such as frying time, temperature and moisture content is considered as one of best strategies to reduce AA content in food products.

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