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Review article

Traditional food processing and Acrylamide formation: A review

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ABSTRACT

Tradition methods that are applied for the processing of food commonly use relatively high temperature and long cooking time for the preparation of foods. This relatively high temperature and long processing time of foods especially in the presence of carbohydrate is highly associated with the formation of acrylamide. Acrylamide is a process contaminant that is highly toxic to humans and remains as a global issue. The occurrence of acrylamide in traditional foods is a major public health problem. Studies that are conducted in different countries indicated that traditionally processed foods are highly linked to the formation of acrylamide. Therefore, understanding the factors influencing acrylamide formation during traditional food processing techniques is crucial for ensuring food safety and minimizing exposure to this harmful chemical compound. Several research reports indicate that proper food processing is the most effective solution to address food safety concerns by identifying foods susceptible to acrylamide formation. This review aims to provide an overview of traditional food processing techniques and their potential contribution to the formation acrylamide and highlight the importance of mitigating its formation in food products. The information obtained in this review may be of great value to future researchers, policymakers, society, and manufacturers.

1. Introduction

Traditional food processing, including roasting, baking, and frying, enhances food flavor, aroma, color, and texture by inactivating enzymatic activities, killing microorganisms, and forming acrylamide [1,2]. Acrylamide is a toxic chemical compound that can be found in various foods, such as deep-fried, roasted, and baked products that are exposed to high temperatures [3,4]. Its presence in these foods has attracted significant attention from both consumers and researchers due to its potential health implications [5–7]. Acrylamide is a known carcinogen and has been linked to an increased risk of several types of cancer, including lung cancer, prostate cancer [8], and breast cancer [5,9]. Acrylamide is also a neurotoxin and has been shown to damage the nervous system in animal studies [10]. Acrylamide is found in a variety of foods, including roasted potatoes, French fries, bread, and coffee [11,12]. More likely, it is highly expected and found in different traditional Ethiopian foods [13] such as *Tela*, *Keribo*, and other street foods [14,15]. The amount of acrylamide in a food depends on the composition of the raw materials, the cooking method, the temperature, and the length of time that the food is cooked [16,17]. The levels of acrylamide can vary from µg/kg (ppb) to mg/kg (ppm) [18]. European Food

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Safety Association's (EFSA 2015) risk assessment revealed that fried potato products, coffee, crackers, soft bread, biscuits, and coffee are the most common sources of dietary acrylamide exposure [19]. Therefore, understanding the factors influencing acrylamide formation in traditional Ethiopian food processing methods is crucial for ensuring food safety and minimizing exposure to this harmful compound.

Acrylamide formation is a complex process influenced by multiple factors, including the Maillard reaction, Hydroxymethyl furfural (HMF) formation, caramelization reactions, and lipid oxidation [20]. Maillard reaction involves a series of complex chemical reactions between reducing sugars (e.g., glucose) and amino acids or proteins [21–23]. This non-enzymatic browning reaction occurs at elevated temperatures and leads to the formation of aroma, flavour compounds, and colour changes in foods [24]. Finally, Maillard reaction produce undesirable by-products like acrylamide during this process [25].

On the other hand, HMF is an intermediate compound that forms in the presence of reducing sugars under high-temperature conditions. It can be generated during food processing, especially in heat-treated products. HMF is also known to contribute to acrylamide formation through various reactions, including the Maillard and caramelization reactions [26]. Caramelization is another complex set of chemicals reactions that occur when carbohydrates are heated. This process involves the thermal degradation and polymerization of sugars, resulting in the formation of a brown colour and characteristic flavour [27]. Caramelization reactions can contribute to the production of acrylamide, with HMF being one of the intermediates in this pathway [26,28].

Lipid oxidation, a process in cooking, involves the degradation of fats and oils, while acrylamide is produced through various processes like pyruvic acid, B-alanine, aspartic acid, carnosine, and acrolein [29]. It involves the reaction between oxygen and unsaturated fatty acids present in food matrices. Lipid oxidation has been implicated in acrylamide formation through the generation of reactive oxygen species (ROS), which can react with carbonyl compounds to produce acrylamide [30]. This indicated that frying of poly unsaturated oils have positive correlation with acrylamide formations [31].

Traditional foods contribute significantly to global food security, but lack of awareness and poor processing technologies lead to harmful chemicals [32]. Frequent consumption increases acrylamide levels, exposing people to health issues like cancer, reproductive issues, and kidney problems [24,33]. Limited knowledge and control of acrylamide formation in traditional foods, particularly in Ethiopia, and low awareness of health risks over roasted foods, make acrylamide consumption a global concern. Therefore, the review examines the role of the Maillard reaction, factors affecting, and health risks of acrylamide formation in different traditional foods, including street foods. Future scholars, legislators, society, and the food processing sector may find great value in this material.

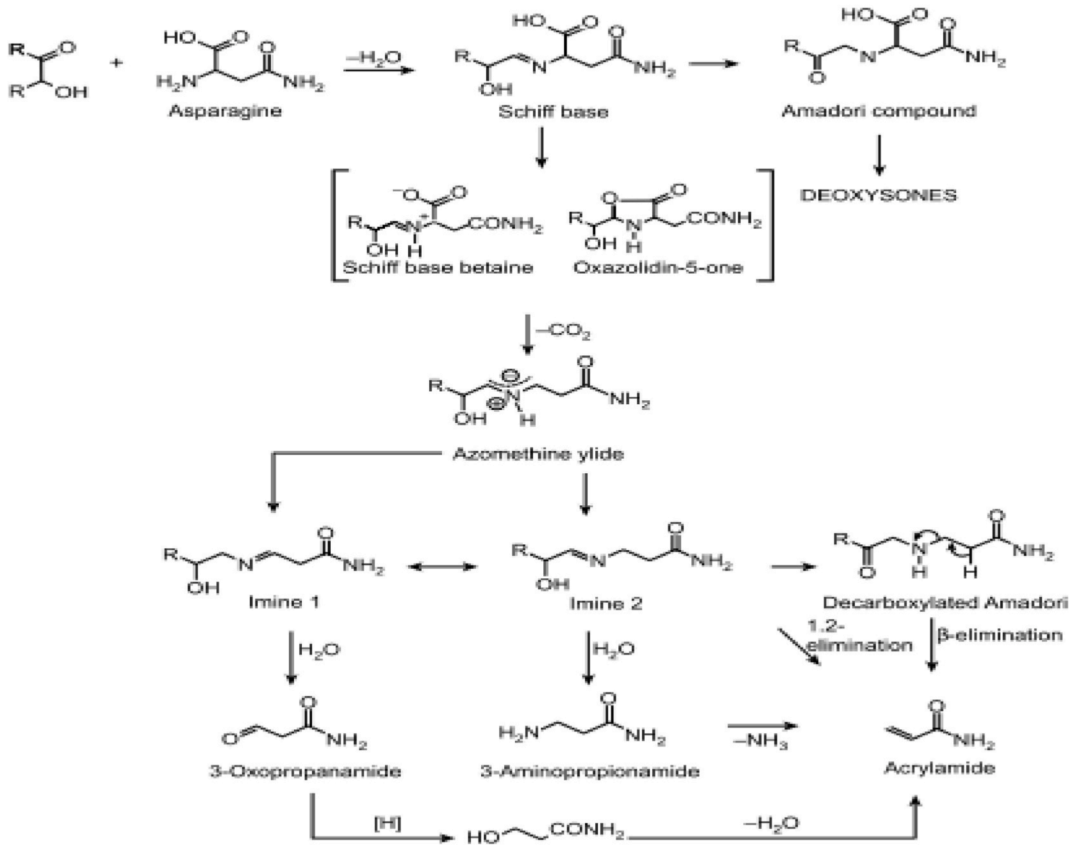

Fig. 1. Maillard reaction's mechanisms for producing acrylamide [38].

2. Role of millard reaction pathway to formation of acrylamide

The Maillard reaction, a complex series of chemical reactions taking place between amino acids and reducing sugars, is responsible for the browning and flavour development in a wide variety of heat-treated foods [34]. However, recent studies have implicated the Maillard reaction as a significant precursor to the formation of acrylamide, a potentially harmful compound found in many cooked and processed foods [35]. The formation of acrylamide occurs predominantly during high-temperature cooking processes, such as baking, frying, and roasting. The Maillard reaction initiates with the initial reaction between amino acids (typically asparagine) and reducing sugars (such as glucose or fructose) [34]. This reaction leads to the formation of acrylamide precursors known as Schiff bases or Amadori compounds, which further undergo various chemical transformations to generate acrylamide through a sequence of complex reactions [25].

Maillard reaction is usually formed due to the combination of reducing sugars and amino acids as indicated in Fig. 1 shown below. Thus, starch food has the tendency to deesterified and produce simple sugar like fructose and glucose and at the same time free amino acids to make Maillard reaction. Specifically, the formation of acrylamide is high due to a reaction of free amino acids (asparagine) with reducing sugars. According to studies, acrylamide is absent from raw foods, but it can be found in foods that have been processed at temperatures above 120 °C, depending on the temperature and length of time [35,36]. Maillard reaction was crucial to the food industry because it also yields a variety of other chemicals that add flavor and aroma, including the melanoidin molecules that give baked, roasted, and fried foods their color. These comprise heterocyclic substances including thiophenes, oxazoles, furans, pyrazines, and pyrroles. Because these are the ingredients that give food the flavors, scents, textures, and colors that distinguish certain food types and brands and that consumers seek, it puts the food sector in a more challenging position [37].

The carbonyl group of the reducing sugar condenses with an amino group to initiate the Millard reaction. This results in the formation of a Schiff base, which cyclizes to yield an aldosylamine if the sugar is an aldose [39]. This would be glucosylamine in the case of glucose. After that, the aldosylamine is rearranged to yield an N-substituted 1-amino-2-deoxyketose, which is the ketotautomer of a 1, 2-enaminol. These are results of Amadori rearrangement [40]. Ketoses that generate corresponding Heyns rearrangement products include fructose. Following enolization, deamination, dehydration, and fragmentation, the products of the Amadori and Heyns rearrangement yield compounds containing one or more carbonyl groups [41].

An important reaction of carbonyl compounds is Strecker degradation, which is the process by which an amino acid is deaminated and decarboxylated to give an aldehyde. These carbonyl compounds react with amino groups and other components, resulting in the formation of many different flavor compounds. Melanoidins, which are brown nitrogenous polymers, are formed through the amine-catalyzed polymerization of reactive intermediates from the breakdown of Amadori and Heyns products [38].

3. Acrylamide formation pathways

The complexity of the Maillard reaction can be explained by the relationship between precursor concentration and several reactions involving reducing sugars and amino groups, resulting in the carbonyl compounds' ultimate synthesis. These carbonyl compounds react with amino groups and other substances to produce a variety of unique taste compounds. Among the processes involving carbonyl compounds is Strecker degradation, in which an amino acid is deaminated and decarboxylated to form an aldehyde [38]. Asparagine and a Strecker-type reaction are the main steps in the production of acrylamide. The proportions of distinct free amino acids to one another could also be important in figuring out how much of each product is produced in the end. For instance, the overall amounts of free amino acids may influence the rate and magnitude of the reaction's initial phase [42].

Therefore, the main factor influencing wheat and rye flour's ability to produce acrylamide is the amount of free asparagine present in the flour. Asparagine is an unusual amino acid since plants can accumulate incredibly large amounts of it. This typically occurs when plants have high nitrogen content and limited protein synthesis. It is implied that plants will use free asparagine as nitrogen storage if they are unable to store nitrogen in the form of protein. Because of its relatively high nitrogen to carbon ratio and low reactivity, asparagus is particularly well-suited for this purpose [43]. Stressors such as pathogen invasion, dehydration or salt stress, and exposure to hazardous metals like cadmium can cause asparagine to build up. Lack of nutrients other than nitrogen, such as potassium, sulphur, phosphorus, and magnesium, causes asparagine to accumulate. An increase in nitrogen supply exacerbates this issue.

When there is a sulphur shortage, asparagine accumulates most in wheat grains, and in severe situations, it can increase up to thirty times. Sulphur shortage also raises the concentration of free glutamine in a similar manner. But asparagine can make up as much as half of all the unbound amino acid molecules [39]. The rise in grain asparagine that arises from growing wheat under severe sulphur deprivation is so great that even minute amounts of such grain entering the food chain could have a major effect on the risk of acrylamide, so it is imperative to apply sulphur fertilizer evenly throughout a wheat field.

Furthermore, sulphur feeding at a rate of 10 kg/ha may be very regular in agriculture, even though the extreme scenario of having no available sulphur may be rare. Even at this stage, wheat planted in sandy loam soil gains a lot more free asparagine in the grain compared to wheat given 40 kg/ha, which results in the formation of roughly 30 % more acrylamide in heated flour [39].

4. Factors affecting acrylamide formation

Acrylamide formation is a complex process that can be influenced by various factors. Some of the key factors affecting acrylamide formation in foods include:

Temperature: Acrylamide formation increases significantly at high temperatures, typically above 120 °C. Acrylamide synthesis tends to increase with increasing cooking temperature, and the acrylamide level was ∼2000 μg/kg at 170 °C, and ∼4000 μg/kg at

190 °C [16]. In addition, baking temperature on the production of bread has also reported and the results revealed that bread had a relatively low acrylamide level at lower temperatures, between 20 and 40 μg/kg, at about 180 °C. However, the acrylamide levels significantly increased to about 100–200 μg/kg as the baking temperature increased to 220 °C. This study underlined the critical role that temperature plays in the synthesis of acrylamide during baking and the necessity of careful temperature management to reduce its presence in baked goods [40]. The Maillard reaction, a chemical reaction between amino acids and reducing sugars, plays a major role in acrylamide formation, and higher temperatures accelerate this reaction.

Time: The duration of cooking or processing also affects acrylamide formation. Longer cooking times can lead to higher levels of acrylamide in food products. Recent research has provided knowledge about how cooking time affects the production of acrylamide in a variety of food products. The impact of frying time on the development of acrylamide in French fries was examined and the acrylamide concentration of the fries rose with an increase in frying time. For instance, after 2 min of frying, the levels of acrylamide were around 200 μg/kg; however, after 10 min of frying, the acrylamide content rose to about 1000 μg/kg. This implies that longer cooking times increase the chance of the Maillard reaction happening, which increases the production of acrylamide [44]. Similarly, baking time and acrylamide levels were found to positively correlate by the researchers. The amount of acrylamide in the biscuits increased dramatically when the baking time was raised from 10 to 20 min. The values of acrylamide were around 50 μg/kg during the shorter baking period and about 200 μg/kg during the longer baking time. These results emphasize how crucial it is to watch and regulate the cooking time when food is being processed in order to decrease the creation of acrylamide and lower any possible health hazards related to consuming it [17].

Food composition: Different types of foods have varying levels of naturally occurring asparagine, an amino acid that reacts with reducing sugars to form acrylamide. Foods such as potatoes, cereals, coffee beans, and bread are more prone to acrylamide formation due to higher levels of asparagine. A study that was published in the Journal of Agricultural and Food Chemistry [45] examined how the amount of sugar and amino acids in potato products affected the production of acrylamide. The researchers discovered that when potatoes were fried, those with higher asparagine and sugar contents had higher levels of acrylamide. According to the study, reducing sugars and free amino acids, especially asparagine, that were present in the raw materials were essential for the formation of acrylamide. This emphasizes how crucial it is to take into account the raw material composition during the food preparation process in order to minimize and regulate the generation of acrylamide [45]. Researchers contrasted various flour varieties, such as maize flour, rye flour, and wheat flour, in biscuit recipes. The findings showed that acrylamide levels were highly impacted by the type of flour used. Biscuits produced with wheat flour had more acrylamide in them than biscuits made with rye or corn flour. This discrepancy was explained by differences in the sugar and amino acid content of the various flours, highlighting how crucial component selection is in controlling the production of acrylamide [17]. Generally, acrylamide formation is directly linked to the sugar content in food products. Higher sugar levels contribute to increased acrylamide formation during cooking or processing.

pH ***Level***: The pH level of food affects the Maillard reaction and subsequently impacts the formation of acrylamide. Foods with higher pH levels, such as alkaline products, tend to have lower acrylamide levels while acrylamide levels have drastically increased in systems that use raising agents like sodium bicarbonate (pH ~ 8), they have dropped in bread and biscuits when the pH level has been lowered. This can be explained by the fact that acrylamide synthesis increases with increasing pH when baking soda or ammonium carbonate is used to leaven bread. The fermentation process lowers the pH of dough because carbon dioxide is produced. It will reach a pH of 5 with yeast and a pH of 4.4–5 with sourdough [36]. Therefore, every food processing has an impact on the formation of acrylamide in different foods.

Storage Conditions: Storage conditions can affect acrylamide formation in certain foods. Storing raw potatoes at low temperatures can lead to increased sugar content, which can contribute to higher acrylamide levels during cooking.

Cooking Methods: Different cooking methods, such as frying, baking, and roasting, can influence acrylamide formation differently. Certain methods, like deep frying and high-heat baking, are associated with higher levels of acrylamide.

Food Additives: Some food additives can impact acrylamide formation. For example, ascorbic acid (Vitamin C) has been shown to reduce acrylamide levels in certain food products. It's essential to note that reducing exposure to acrylamide in food is a matter of managing and minimizing these factors through proper cooking techniques, ingredient selection, and food processing methods. Food manufacturers and consumers can adopt strategies like blanching, steaming, and using lower cooking temperatures to help mitigate acrylamide formation. In addition, antioxidant-pre fried potatoes lower the acrylamide concentration without appreciably changing their physicochemical, textural, or sensory characteristics of final products [8].

Water content: The amount of water in the food is a crucial component in the synthesis of acrylamide and is closely linked to the temperature and length of heating. Water is known to impact chemical components of a food matrix, including precursors of acrylamide, and potentially cause phase changes. Moreover, changes in activity and water content during heating may affect the rate at which acrylamide develops. It has been demonstrated that as long as the water evaporates and the temperature stays below 100 °C, there is no acrylamide in food. On the other hand, the lower the product's moisture content, the more acrylamide is produced at that particular temperature [46].

5. Traditional food types and acrylamide formation

Products like potato crisps, corn-based extruded snacks, and other savory nibbles are highly popular, particularly among younger consumers. The frying and baking operations have the potential to produce acrylamide, a hazardous substance, which these goods may contain [47]. Different countries in the world produce different types of traditional foods, for instance in Ethiopia there are a lot of traditional food, such as coffee, roasted and boiled tea, *Tella, bread, borde, beso, Keribo or Keneto*, *injera*, and *wot* (especially *doro wot* or chicken stew). Recently, street foods have also become popular and highly consumed by people, especially those living in towns and cities that frequently eat fried foods. There are no specifications for cooking, roasting, baking time, or temperature; mostly all these foods take a long time at the highest temperature before being ready for a meal. At this stage, the occurrence of caramelization or decomposition of sugars, lipid oxidations, and Maillard and hydroxyl methyl furfural is highly expected. These are precursors for the formation of acrylamide [48]. The primary source of acrylamide is a wide variety of baked or fried meals high in carbohydrates, such as coffee, breads, cookies, French fries, and potato crisps. Any food processing which involves exposing foods to high heat, especially in the presence of carbohydrates, can lead to the production of acrylamide. The direct heat from grills and open flames can cause the browning and charring of foods, initiating the Maillard reaction and subsequently acrylamide can be formed. Because the Maillard reaction is heat-driven, it can be found in a wide variety of foods that are roasted, baked, fried, or toasted, including coffee, cocoa beans, cereal products, potato crisps, baked goods, and infant meals [49]. Similarly, the roasting of coffee beans at elevated temperatures has been found to generate acrylamide in coffee products [11]. Infant diets based on processed cereal and vegetable-based non-cereal foods, potato chips, and snacks contain relatively high acrylamide [50]. Accurate and sensitive detection of acrylamide has become critical to food safety due to its toxicity and frequent occurrence in foods [46].

Predictive modeling has been widely applied in food processing systems recently to generate safe and high-quality food. It is better to understand how temperature and roasting duration affect traditionally processed food safety and to apply proven methods to forecast the amount of acrylamide production and optimize the high temperature process [51].

5.1. Roasted coffee

Coffee is a widely consumed and widely enjoyed hot beverage worldwide, serving as a staple across all societal groups [52]. Due to its widespread cultural acceptance and growing economic interest, coffee consumption is now an essential component of social life in many parts of the world. Coffee and coffee-related drinks are consumed widely by a large number of people and have become an essential element of everyone's daily diet [18]. However, the right time and temperature combination during this traditional roasting of coffee is not well known. This could favour the development of toxic compounds due to Maillard reaction. Maillard reaction is responsible for the development of the aroma, flavour, and colour of coffee. Studies revealed that due to uncontrolled roasting time and temperature, a significant level of acrylamide in coffee is reported [50]. Moreover, the acrylamide content in coffees varies based on raw material species, process conditions, and brewing time [52]. For instance, Ethiopian mothers, usually use wood and charcoal to roast their coffee bean as a heat source, which is difficult to manage the temperature of the metal or clay pan during roasting. Elias et al. (2017) [50] evaluated 24 traditionally roasted coffee samples and found an acrylamide with mean value of 210 μg/kg. This indicates that, most of the traditionally roasted coffee bean samples developed acrylamide. Food safety is seriously jeopardized by acrylamide in heated foods, especially for young children and babies. Exposure affects a broad spectrum of populations and is influenced by eating habits and food processing [50]. Human milk samples have been shown to contain acrylamide and the amount of acrylamide in their breast milk mainly depends on their feeding habits [53]. As a culture, Ethiopians mostly drink coffee three times per day and drink three up to four cups once. Therefore, totally the person who drinks coffee will have nine to twelve coups per day. Drinking such traditionally roasted coffee frequently could increase the level of acrylamide above the limit of recommended dietary intake, and the amount of acrylamide highly depends on the type of brewed coffee. For instance, instant coffee has the highest amount of acrylamide [52]. Consumption of acrylamide beyond the recommended limit may result different health problems. The first and the most common heath problem is cancer however, little information is available about the amount of acrylamide level and its health impacts for different groups of the society. In Ethiopia, female consumes more coffee than male. According to Basaran & Aydin, (2020) [18], in Turkey males have higher acrylamide exposure than females, with males at 0.49 μg/kg bw per day, and females at 0.46 μg/kg bw per day. On the other hand, the previous author found higher acrylamide exposure in females than in males, male: 0.41 μg/kg bw per day, female: 0.44 μg/kg bw per day; male: 0.15 μg/kg bw per day, female: 0.19 μg/kg bw per day). Similar findings shows that the exposure of acrylamide depends on demographic characteristics (sex, age, smoking, and body mass index [35]. Thus, to protect the people from different health problems due to the acrylamide content in coffee drinks, efforts should be made, and awareness should be given to the society.

5.2. Roasted and boiled barley tea

Roasted and boiled tea has extensively used as hot drink in the world especially in Africa and Asia countries. Nowadays, cereal drinks like barley tea, oat tea, and buckwheat tea made from the whole roasted grain in hot water are popular throughout East Asia [54,55]. Barley, a high-fiber cereal, is used as a coffee-like beverage in Ethiopia and is also used in traditional medicine in China [55]. However, due to high roasting temperature and long roasting time, the formation of acrylamide is real [45,55]. Instead of using coffee, people are using highly roasted and boiled barley tea to remain active when they are tired. In addition, tea made from boiled roasted barley is used commonly when there are festival or family ceremonies. In nature, this product is very sweet and selected by children and elder people. During roasting of barely, aroma, flavour and enhancement of some important constitutes are improved [56]. Furthermore, the occurrence of "flour odor" and "fishy odor" could perhaps be attributed to the creation of aldehydes, ketones, and esters during the roasting process. Evidences in different countries show that the roasting temperature of barely is above 120 °C with long roasting time of over 35 min [28,56]. Such conditions are suitable for the formations of unhealthy chemicals or acrylamide which affect consumers negatively by causing different diseases. During this practice, a "burnt odor" may arise because of the Maillard reaction, which produces volatile chemicals like furan [28]. On the contrary, it was discovered that acrylamide exposure from moderate, typical, and over-brewed tea consumption does not present a risk to one's health for cancer (429–6200) or neurotoxicity (476–4000) [31].

5.3. Keribo

Keribo is an Ethiopian traditional fermented drink that recently gained a great popularity and consumed in different ceremonies like holidays and weddings. In different parts of Ethiopia, Keribo is also known as Keneto, Gasilo, Mawudad, and Filiteria, and Coca-Cola due to its colour resembling with Coca-Cola [4]. Keribo is prepared from over-roasted barley with sever heat treatment above 120 °C, which lead to the formation of acrylamide. Since Keribo is a beverage made from starchy food or from roasted barely dominantly, when the barely is exposed to at high temperature and long time, the starch start to degrade to monosaccharides or to fructose and glucose. As the same time, the protein also becomes degraded to different amino acids such as aspartic acid or asparagine. Therefore, when reducing sugars and free amino acids react together, they form acrylamide due to the precursor of millard reactions. As the report made by Quartey et al. (2024) [49], Ethiopia is the leading country in east and West Africa where the morbidity and mortality are raising due to process contaminants or acrylamide. To reduce the risks due to acrylamide, there has to be research focused on optimization of the roasting temperature and time during roasting barley for Keribo processing.

5.4. Tella

Tella, Borde, Shamita, Korefe, Keribo, Cheka, Tej, Ogol, and Booka are well-known examples of locally fermented alcoholic drinks in Ethiopia. These beverages range in total alcohol concentration from 1.53 to 21.7 % (v/v) [57]. Among these, Tella, traditional beer, is the most traditional fermented alcoholic beverages that is consumed in different regions of the country [57]. Over two million hectolitres of traditional Ethiopian beverage, Tella, are produced in homes and drinking establishments each year, making it the most widely drank alcoholic beverage in the country [58]. Tella is consumed frequently by Ethiopian people especially by people who live at the countryside and breast-feeding mothers who have low breast milk are used highly to increase breast milk to feed their babies. In cities and towns, Tella is prepared and used mostly during festivals get-togethers, holidays and social ceremonies. This shows that if Tella has acrylamide content, large groups of the people would be affected due to high and frequent consumptions of Tella.

Tella is made using malted barley, wheat, maize, millet, sorghum, teff (*Eragrostis teff*) and hope leaves (*Rhamnus prinoides*), as well as naturally occurring microbes [59]. Additionally, in the countryside "Abshilo" or "kita" is also used to thick the remedies and shorten fermentation time and increase the taste of Tella. Abshilo or kita is made from teff/finger millet flour and sometimes maize flour [59]. This traditional processing of Tella uses deeply roasted maize or finger millet. This deep roasting could lead to the formation of acrylamide.

The processing contaminates or acrylamide of Tella is not yet explored and considered as an issue in the country. When grains are roasted at high temperature, there is degradation of starch to monosaccharides and free amino acids particularly asparagine. Since maize is rich in starch and protein and when it is exposed to high temperature above 120 °C acrylamide formation is highly initiated.

Furthermore, finger millet is distinguished by several colour variations (brown, white, and light brown cultivars); a high content of dietary fiber, carbohydrates, phytochemicals, and essential amino acids; and the presence of vital minerals [60,61]. Finger millet is rich in carbohydrate and proteins when these components are exposed to high temperature during the baking of the K**ita** there could be production of free amino acids and reducing sugars which are used as source of millard reactions and acrylamide. Usually, **Kita** is very sweet due to degradation of poly saccharides and free amino acid formations and these all are preconditions for millard reactions. Therefore, acrylamide is more likely expected during **Kita** baking at high temperature. However, there is a recent controversial report, when grain is roasted at high temperature above 150 or 180 °C the formation of acrylamide start to degrade [32]. Therefore, research has to be done on Tella to get a clear information about acrylamide content. Then once the presence is confirmed, looking for options to reduce the level of acrylamide production in Tella is important via optimization of the roasting temperature and time.

5.5. Kolo

The Amharic word "Kolo" denotes a typical and traditional ethnic staple meal that is eaten throughout Ethiopia and Eritrea. Well-roasted, dehulled kolo is eaten as a snack or mixed with other roasted seeds [62] and spices. Kolo is frequently consumed alone or combined with other toasted grains, such as pulverized nut, chickpea, and sunflower head [63]. Kolo has a reasonably long shelf life if it is packaged properly; it can keep for a year or longer. This could be because of the spices and relatively low moisture content, which reduces water activity [64,65].

Kolo is prepared from roasted barley and the development of acrylamide is predicted. Asparagine, a free amino acid, reacts with reducing sugars when barely grain is roasted, leading to a high production of acrylamide. Furthermore, oxidation of lipids during roasting may result in the formation of acrylamide. Food goods derived from plants, like cereal grains, contain high levels of acrylamide because of natural precursors (reducing sugars and asparagine) [3]. Research has shown that when asparagine is free in fatty meals, acrylamide can also be generated from acrolein; acrolein supplies the carbonyl group that facilitates asparagine's conversion into acrylamide in significant proportions [66]. When reducing sugars and free asparagine combine at high temperatures, acrylamide is formed [3]. Researchers have shown that processed foods at 120 °C or higher contain different amounts (concentrations) of acrylamide depending on the processing temperature and duration, whereas raw foods are free of acrylamide. Each product has a variable concentration of acrylamide [7] based on its amino acid and sugar content. The high starch content of barley and the intense heat treatments used during roasting may have created ideal circumstances for the production of acrylamide in Kolo, comparable to the findings of [4] for roasted barley that was used in production of Keribo. Grain heat treatment can produce a variety of reactions, including millard and hydroxyl-methyl furfural, which give roasted grains their desired color and flavor [67]. The quantity of research on acrylamide levels in food has been enormous, however aside from a work published by Refs. [3,4], much research has not been done particularly on Ethiopian traditional cuisine. Their study on the content of acrylamide in coffee powder, French fries, potato chips, and Keribo, is concentrated only in and around Addis Ababa, Ethiopia. According to studies, the acceptable daily intake of acrylamide for neurotoxicity is 40 g/kg bw/day, and for carcinogenic effects, it is 2.6 g/kg bw/day [68]. However, a high quantity of acrylamide is predicted in roasted barley and other foods that have undergone heat processing. Dibaba et al. (2018) [68] revealed that concentration of acrylamide was noticeably higher in the Keribo sample, which was prepared from intensely roasted unmalted barley (3.44 g/kg). This suggests that Kolo's roasting process has likely raised the product's acrylamide level above the permitted limit, which could have an impact on a lot of customers' health. Moreover, Kolo is highly consumed by mothers who have low breast milk production during lactation. Usually, mothers are supposed to eat Kolo frequently to increase the breast milk to feed their children here, indirectly, or directly children are highly vulnerable to the acrylamide. Therefore, such issues are considered in any stakeholders to mitigate the problems to keep the children and mothers from toxic compounds. Thus, a study on Kolo's acrylamide content and possible mitigating measures for lowering its acrylamide levels has to be carried out and recorded.

Glycine addition and asparagine treatment are two techniques that have been used to lower the amounts of acrylamide in certain meals [69]. Methods of physical processing like blanching, soaking, and pH reduction impact the amount of acrylamide produced [66]. The production of acrylamide levels can also be decreased by optimizing temperature and duration [69]. On the other hand, details regarding Kolo's acrylamide level and reduction technique are lacking. Therefore, research into the mechanisms that contribute to the creation of the acrylamide level in Kolo is necessary.

5.6. *Street foods*

Street food consumption like fried potato chips is on the rise globally, with street vending servings as a significant employment and income source in developing nations [70]. Particularly for kids and teenagers, potato products like French fries and crisps are among the main sources of acrylamide ingestion on a regular basis. A sample of 36 potato crisps from 16 producers yielded an average of 740 μg/kg and a median of 592 μg/kg of acrylamide [71]. On the other hand, analysing two batches from 18 companies, the study assesses the acrylamide concentration of commercial potato crisps in Spain since 2004 and finds an average of 630 μg/kg is reported [72]. The typical amount of acrylamide in baby food varies, but for infants 6–12 months old, the exposure is predicted to be at least 0.41–0.62 μg/kg bw/day. But research has indicated that the acrylamide content of their foods is reported at an average of 2.10–4.42 μg/kg bw/day, which is higher than the exposure estimated for the total Polish population [73]. In many rapidly developing nations, such as China, the consumption of street foods and fast foods is now considered a sign of modernity and has become a popular habit. According to Teferi (2020) [74], millions of people enjoy the good, inexpensive, and convenient meals that street vendors offer every day. Street vendors frequently sell takeout, junk, and fast food. Because of urbanization and poverty, street food is a major component of the urban food distribution system in developing nations, where it is consumed by 2.5 billion people every day [74]. People increasingly prefer to buy street foods in crowded places including streets, schools, train stations, and entertainment venues [75]. The safety of street food has emerged as a significant public health problem leading authorities and experts to increase awareness.

The health and safety of street meals may be impacted by street sellers' ignorance of potential food dangers, their poor food handling techniques, and the lack of consumer understanding of these risks. The street food industry is constantly related to food

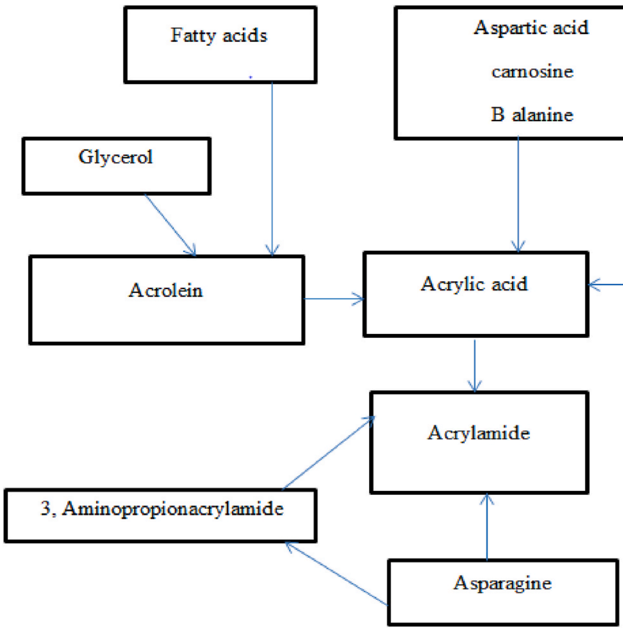

Fig. 2. Formation of acrylamide route in fatty Foods [78].

safety, because trash and filthy waste were visibly adjacent to the stalls, 85 % of vendors in Africa served goods like fish, fruit salads, roasted maize, and chips in an unsanitary manner [76]. The WHO defines food safety as a public health concern that aims to shield consumers from the hazards of acute or chronic food poisoning and food-borne illnesses [75]. Even though numerous research outputs reported about microbial hazards as food safety issues [75,76], health risks due to chemical processing contaminants or acrylamide due to firing of oil and combination of high temperature and time during preparation of foods have been also reported [77]. As indicated in Fig. 2 below, acrylamide is produced not only from starch-based food but also it can be produced in fatty foods due to acrylic acid and asparagine. Acrylamide can also be formed due to lipid oxidation during heating process of foods. Research has shown that acrolein in fatty meals can also create acrylamide when asparagine is free; acrolein contributes its carbonyl group, which encourages significant amounts of asparagine to be converted into acrylamide [66]. Similarly, acrolein, aspartic acid, carnosine, B-alanine, and pyruvic acid have all been shown in certain investigations to undergo various reactions that lead to the conversion of acrylic acid to acrylamide [18].

Studies show that frying meals at high temperatures, especially using vegetable oils, greatly increases the amount of acrylamide formation. Varying cooking temperatures and times significantly affect the amount of acrylamide formation because starchy fatty foods also undergo the formation of acrylamide [79]. Due to the reusing of oil during food cooking acrylamide is produced and known to cause cancer [80]. Moreover, acrylamide has been shown to have neurotoxic, genotoxic, and carcinogenic effects [81] and other similar reports showed that a range of symptoms, including central and peripheral neuropathy and genetic abnormalities in both human and animal subjects, indicate the neurotoxic, carcinogenic, genotoxic, and reproductive health consequences of acrylamide [78]. Generally, asparagine and reducing sugars in bread, biscuits, and potato chips undergo a Maillard reaction that produces acrylamide, and growing attention has been directed towards acrylamide due to its extensive global public health threat [82].

5.7. Bread

Baking is another popular cooking technique that also plays a role in the production of acrylamide. The Maillard reaction occurs when high oven temperatures are applied to carbohydrate-rich meals like bread, pastries, and cookies. These meals contain reducing sugars and amino acids, especially asparagine, which combines to undergo intricate chemical reactions that result in the synthesis of acrylamide. The likelihood of acrylamide production increases with increasing baking time and temperature. Thus, it is essential to precisely regulate baking parameters, such as temperature and time, in order to reduce the amount of acrylamide in baked products [17]. Different research indicates, the main precursor of acrylamide formation in bread is the reaction of asparagine with reducing sugars while baking and the level of acrylamide is expected to be toxic for human health [45,55,83]. According to Esposito et al. (2020) [84], from Two hundred Italian baked product, the content of acrylamide ranged from 31 to 454 μg/kg for bread and products thereof and from 204 to 400 μg/kg for the sweets category. The exposure data did not show any neurotoxic health concern. Levels of acrylamide shouldn't go over Soft bread: 100 μg/kg, morning cereals: 300 μg/kg, and cookies, crackers, and crisp bread: 400 μg/kg [79].

Baked products show noticeable levels of acrylamide and among them, bread and similar products could be a significant source of dietary exposure to acrylamide for consumers due to the high quantity that is ingested every day by consumers. The formation of acrylamide during the baking process of bread can be influenced by many factors, such as moisture content, pH, temperature, and time [84]. Furthermore, baked foods are mostly consuming by infants due to such reasons infants exposed by acrylamide and causes for different health threats. There is a danger that baked foods could be one of the main human sources of acrylamide, and this raises the possibility of cancer [19]. Biscuits significantly contribute to daily acrylamide intake in Western diets due to high consumption, low moisture content, and thermal treatment. The biscuits made of rye, teff, and oats showed the highest concentration 2144, 1559, and 1424 μg/kg, respectively [85]. All these indicated that cereal products are the main contributors of acrylamide when they are exposed to high temperature. The amount of acrylamide in foods made from cereals varies depending on the type and extent of the thermal treatment, the food matrix, and precursor levels [79]. The Polish population's exposure to acrylamide in food was assessed using data from the 'household food consumption and anthropometric survey in Poland. The mean acrylamide content ranged from 11 to 3647 μg/kg, with bread being the main source [86]. This indicates that biscuits and other infant foods are vulnerable to acrylamide formation and need the effort to protect against this harmful chemical [87].

6. Acrylamide and health risks in human beings

Exposure to acrylamide has been linked to a considerable increase in ovarian, renal, and endometrial cancers as well as nerve damage, blood adducts, and reproductive issues [49]. According to the authors, the burden of illness approach provides determinant information on population health loss over time by converting risks into morbidity and mortality. Consumption of acrylamide concentrations in West African areas ranged from 0.025 to 14.39 mg/kg, with Ethiopia and Kenya having a higher concentration (7.81 mg/kg) and Ghana and Nigeria having a higher exposure (1.03×10^{-5} mg/kg (bw) per day [49]. Acrylamide consumption ranging from 0.3 to 0.8 μg/kg bw daily, may increase breast and kidney cancer risks [78]. According to studies, 40 g/kg bw/day of acrylamide is considered to be the tolerated daily intake for neurotoxicity and 2.6 g/kg bw/day for carcinogenic effects [68] and this harmful is responsible for chronic and acute diseases [88]. Additionally, it has been suggested that exposure to acrylamide may affect a person's peripheral, central, and autonomic nerve systems, leading to numbness and weakness in the hands, feet, legs, and arms [18]. The central neurological system (CNS) and peripheral nervous system (PNS) are both impacted by the well-known strong neurotoxin acrylamide. The period of exposure and the total exposure dose determine how hazardous the effect will be [89]. For instance, in Ethiopia, there is a record for loss of 26.10 healthy life years per 100,000 people. In contrast to a comparable Danish study, dietary acrylamide induced malignancies resulted in the loss of 1.8 healthy life years per 100,000 people [49]. Therefore, in order to guarantee food safety, infants under one year old should have their foods extensively checked for toxins because of their low body weight and insufficient detoxifying processes [50].

Recently, resources have diminished worldwide, and this is the worst scenario in developing countries, including Ethiopia. In this regard, the paper indicates that safe food processing is the best alternative to mitigate food safety risks by selecting potential foods that are highly vulnerable to acrylamide formations and by showing future directions how such foods will have low food safety risks. Chemical hazards are not much considered as food safety risks but they need more emphasis [90]. According to FDA consumption studies [33], the top eight food products that cause the highest levels of acrylamide intake are brewed coffee, breakfast cereal, toast, soft bread, cookies, and potato chips as indicated in Fig. 3. From this, the highest acrylamide formation is occurred in potato chips followed by, French fries noodle, soup mixes and snack foods. Reducing the amount of acrylamide in food should be a top priority for lawmakers and producers of potato products in order to lessen the negative health impacts of this substance [91]. According to Asogwa & Aremu, (2018) [78], the formation of acrylamide in different foods is reported as, biscuits 10 %, Coffee 2 %, bread 34 % breakfast cereals 5 %, Cocoa products 1 %, and potatoes and products 48 %. WHO estimated that for the general population, including children, the international mean dietary exposure to acrylamide in food is 1 μg/kg bw per day [78]. According to the same article, 4 μg/kg bw per day is considered to be the excessive dietary exposure to acrylamide [31,91–93]. Acrylamide is thought to be genotoxic, there is no safe threshold dose, and since the dangers posed by genotoxic substances are not species-specific, the relative cancer risk observed in animals is extrapolated to humans [31]. The amount of acrylamide in food should be follow the guideline ALARA (As Low As Reasonably Achievable) [36]. Bread, coffee, and French fries are examples of foods high in acrylamide that pregnant women should stay away from since they increase the risk of cancer in both the mother and the fetus [93]. Acrylamide is classified as a neo-formed toxin (NFT), meaning that it may have harmful effects on human health. Accordingly, acrylamide was classified as a potential human carcinogen (Class 2A) by the International Agency for Research on Cancer (IARC) [31]. Given the documented carcinogenic effects of acrylamide in rodents (rats and mice), dietary exposure to acrylamide may therefore have some negative consequences on human health [92]. Furthermore, a few recent epidemiological studies have highlighted the link between consuming acrylamide from food and a higher risk of various cancer types in particular populations [94]. Following dietary ingestion, acrylamide is rapidly absorbed through the digestive system, circulated throughout the body by the bloodstream, and subsequently accumulates in a few organs like heart, thymus, brain, kidneys, and liver [42]. Following repeated exposure to acrylamide, degeneration of peripheral nerve and nerve terminals was detected in certain brain areas (cerebral cortex, hypothalamus, and hippocampus) important to memory, learning, and

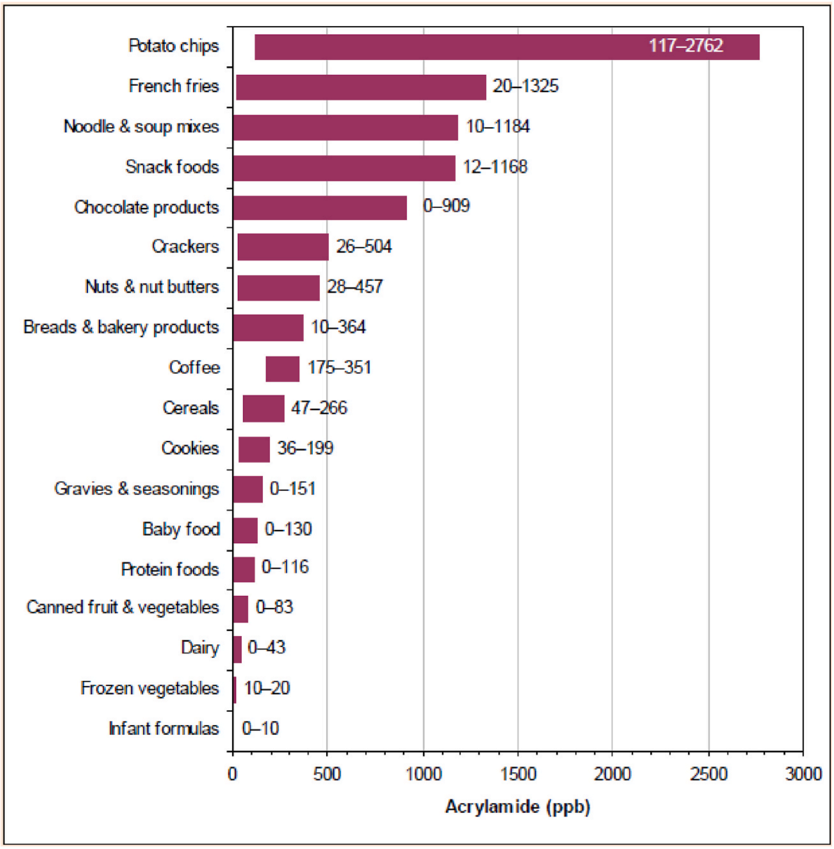

Fig. 3. Ranges of acrylamide in various food products [33].

cognitive functioning [95]. In rats given two distinct doses of acrylamide (50 or 21 mg/kg/day), a study revealed neurotoxic symptoms as ataxia and muscle paresis along with a gradual degradation of nerve terminals in every region of the central nervous system (CNS). Acrylamide appears to cause synaptic dysfunction and degeneration by acting directly on the nerve end sites. Motor, sensory, and autonomic impairments are caused by damage to the peripheral and central nervous systems [16]. In addition, fetal brain tissue treated with acrylamide results in hemorrhagic damage, a decrease in brain-derived neurotropic factors, and degeneration of the neuronal structures. Acrylamide inhibits progenitor neural cell proliferation and differentiation as well as the expression of neural and astrocyte biomarkers, according to in vitro research [96]. Three major theories exist about the mechanism of acrylamide-induced neurotoxicity, despite the fact that the precise pathway is still unclear: neurotransmitter levels can change, kinesin-based rapid axonal transport can be inhibited, and neurotransmission can be directly inhibited [95].

7. Conclusion

Tradition methods that are applied for the processing of food commonly use relatively high temperature and long cooking time for the preparation of foods. This relatively high temperature and long processing time of foods especially in the presence of carbohydrate is highly associated with the formation of acrylamide. During high processing temperature and time, there is degradation of starch and amino acid to form Maillard reactions due to the reaction of free reducing sugars and asparagine. Most traditional foods pass at high temperature and long processing time during cooking, baking, and roasting, which is likely to result in the formation of acrylamide and its adverse health impacts. Furthermore, care must be done during preparing and consuming street foods which is prepared by over fried and starch-based foods or wheat flours. Therefore, understanding the chemical pathways, factors affecting formation in traditional processing, and potential health effects of acrylamide is essential for developing strategies to minimize its presence and promote food safety. Further research and collaboration among the food industry, regulatory authorities, and scientific communities are crucial to address this significant issue.

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Mekuannt Alefe Adimas: Writing – review & editing, Writing – original draft, Conceptualization. **Biresaw Demelash Abera:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Zemenu Tadesse Adimas:** Writing – original draft. **Henock Woldemichael Woldemariam:** Writing – review & editing, Supervision. **Mulugeta Admasu Delele:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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