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Review Articles

Estimated Acrylamide Intake from Coffee Consumption in Latin America

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Abstract: The presence of acrylamide in foods such as coffee can pose risks to human health. Coffee consumption and production in Latin America have increased in recent years. According to the FAO, world coffee consumption is divided into five groups of countries according to average yearly per capita consumption: (i) between 8.0 kg and 12 kg; (ii) between 4.1 kg and 8.0 kg; (iii) between 2.4 kg and 4.5 kg; (iv) between 0.8 kg and 2.4 kg; and (v) less than 0.8 kg. In this work, the countries of Latin America are divided into three groups according to annual per capita coffee consumption: group 1: between 4.1 kg and 8.0 kg (Brazil, Argentina, Colombia and Costa Rica); group 2: between 2.4 kg and 4.5 kg (Guyana, French Guyana, Honduras, Suriname, Uruguay and Venezuela); and group 3: between 0.8 kg and 2.4 kg (Bolivia, Chile, Cuba, El Salvador, Ecuador, Guatemala, Haiti, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico and Dominican Republic). There are great differences in the consumption of acrylamide-forming foods among populations from different countries. The literature shows a range from 0.5 to 4.21 μg of acrylamide per 300 mL of coffee and the World Health Organization recommends a maximum daily limit for acrylamide intake of 1 μg/kg bw. Thus, coffee is a beverage that contributes greatly to acrylamide intake in almost all population groups. From the calculated data on acrylamide intake in Latin America, it was possible to estimate the daily intake in the region's countries. According to the maximum limit set by the WHO of 1 μg acrylamide per day per bw, for people in the countries of group 1, coffee makes a large contribution to the intake of acrylamide. Thus, there should be focus on reducing the levels of acrylamide in foods, since they are the predominant sources of this substance for some populations.

Keywords: *Coffea Arabica*, *Coffea Canephora*, Coffee Production, Food Safety

Introduction

Acrylamide has attracted concern by public authorities all over the world (Zhang *et al*., 2005; Friedman, 2003). It is a chemical compound (Fig. 1) used to synthesize polyacrylamide. Its chemical structure was first identified in fried potatoes and it began to be studied in 2002 by Swedish scientists. Various studies have been conducted to determine the origin of acrylamide in foods. The previously known sources, such polyacrylamides and heating of organic matter, have been discarded. Some processed foods have been identified since then as the main sources of this substance in the human diet. The potential routes of human exposure to acrylamide are ingestion, skin contact and inhalation. One of the oral exposure routes is via drinking water contaminated by polyacrylamide flocculants used in water treatment.

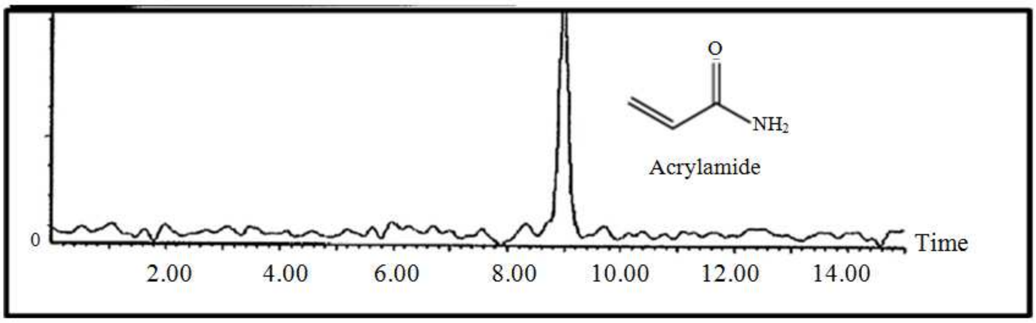

Fig. 1. The chemical structure of acrylamide and its chromatogram Source: Michalak, *et al*. 2013; Rosa *et al*., 2012

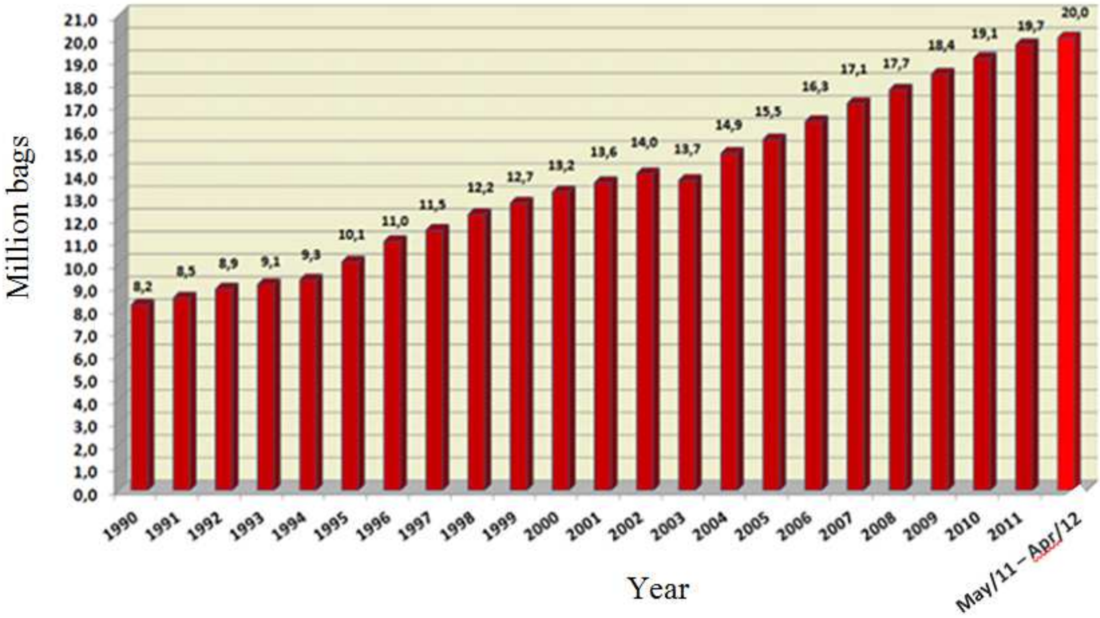

Fig. 2. Evolution of domestic coffee consumption in Brazil Source: ABIC (2012)

Certain workers are at particular risk of exposure, such as those engaged in heavy construction (including tunnels), coal mining, flocculant manufacturing and acrylamide manufacturing (Alves *et al*., 2010; Arisseto and Toledo, 2008; Neri, 2004; Felsot, 2002; Reynolds, 2002).

The presence of acrylamide in food such as coffee can pose risks to human health. Potential toxicological risks in foods are related not only to the presence of its precursors, asparagine and reducing sugars, but also to the concentrations of these compounds in the raw material, which can vary significantly between different species, cultivation practices and processing methods (Dias, 2008). Besides this, acrylamide has been considered neurotoxic and carcinogenic. It forms in carbohydrate-rich foods when they are fried, baked or roasted above 120°C (Arisseto and Toledo, 2008). According to the World Health Organization (WHO), the recommended daily limit for intake of acrylamide is 1 µg/kg bw, or 60 µg, assuming body weight of 60 kg (WHO, 2005; SNFA, 2002).

Coffee is one of the most important beverages in the world because of its flavor and caffeine content. Since its consumption is high, it is important to study not only the chemical composition of the beans, but also the chemical changes during coffee roasting, because this can result in changes in quantity and quality of these pyrolysis products (Rosa *et al*., 2012; Dias, 2008).

World coffee consumption is increasing, particularly because of its growing popularity in China and India, two major consumers of tea. Additionally, coffee shops around the world are helping to spread consumption and creating demand for specialty coffees (Pardo *et al*., 2007).

The acrylamide content of coffee seems to depend not only on the botanical species but also to the type of processing. A comparison between the two most economically important species, *Coffea arabica* and *C. canephora*, showed that *C. canephora*, known as robusta, has a higher level of acrylamide, probably due to increased presence of asparagine in the green beans (Medeiros *et al*., 2011; Lantz *et al*., 2006).

The formation of acrylamide in coffee occurs rapidly with the beginning of the roasting process and then slows as it approaches the maximum level (Alves *et al*., 2010). The acrylamide content in brewed coffee is highly variable, ranging from 0.5 to 4.21 μg per 300 mL of coffee (Pedreschi *et al*., 2011).

The amount of acrylamide found in roasted coffee is relatively low compared to the potential formation resulting from the abundant presence of asparagine and reducing sugars (Dias, 2008). One factor that can contribute to relatively high levels of acrylamide is the number of defective and immature beans used in commercial production systems. Immature coffee beans contain significantly higher levels of free asparagine compared with mature ones (Guenther *et al*., 2007).

Coffee Consumption

Coffee Consumption in Brazil

Brazil's coffee consumption continues to increase. In the period between May 2011 and April 2012, ABIC recorded consumption of 19,975 million bags, an increase of 3.05% over the previous corresponding period (May 2010 to April 2011), was 19,383 million bags (Fig. 2). This increase was due to (i) growth of consumption outside the home, (ii) new and innovative products in the market, (iii) improved quality; and (iv) expanded supply of differentiated products (ABIC, 2012). Brazil is the world's leading coffee producer, with a market share of approximately 35% (MAPA, 2012).

Brazilians are consuming more cups of coffee per day and diversifying the forms of drinking during the day, consuming espressos, cappuccinos and other combinations with milk in addition to the coffee brewed by filtering in homes (ABIC, 2012).

Brazil's per capita consumption remains one of the highest in the world. The champions of consumption, however, are still the Nordic countries-Finland, Norway and Denmark-with a volume of around 13 kg/per capita/year (IBGE, 2012). Given the current low price of coffee arabica, differentiation has been an important alternative to increase competitiveness. The increasing concern with food safety and sustainability of agriculture are prompting growers to produce coffee with higher value (Arisseto *et al*., 2009).

According to Pereira *et al*. (2014) in Brazil, beverages contributed roughly 17% to total energy intake and caloric coffee beverages were the most commonly consumed beverage, regardless of age group.

Coffee Consumption in Latin America

Coffee consumption in Latin America has increased in recent years along with production. In Argentina, for example, coffee consumption is growing, especially of coffee in capsules, which increased by 30% (FAOSTAT, 2012).

In times of sharp decline in international coffee prices, big volumes produced and uncertainty about consumer demand in traditional markets, Brazil stands out as one of the emerging countries where sales continue to expand, a trend they should continue in the coming years (Anese *et al*., 2010).

Colombian coffee producers intend to open franchised coffee shops in Brazil and in other countries, as are already the case in the United States, Mexico and some countries in Europe. With this Colombian marketing action, coffee consumption in Latin American countries should increase, particularly of specialty coffees (for which Colombia is known). For example, in Brazil specialty coffees only account for 4% of the market (ABIC, 2012).

According to the FAOSTAT (2012), world coffee consumption is divided into five groups of countries according to average yearly per capita consumption: (i) between 8.0 kg and 12 kg; (ii) between 4.1 kg and 8.0 kg; (iii) between 2.4 kg and 4.5 kg; (iv) between 0.8 kg and 2.4 kg; and (v) less than 0.8 kg (FAOSTAT, 2012). Further according to data from the FAOSTAT (2012), the countries of Latin America are divided into three groups according to annual per capita coffee consumption: group 1: between 4.1 kg and 8.0 kg (Brazil, Argentina, Colombia and Costa Rica); group 2: between 2.4 kg and 4.5 kg (Guyana, French Guyana, Honduras, Suriname, Uruguay and Venezuela); and group 3: between 0.8 kg and 2.4 kg (Bolivia, Chile, Cuba, El Salvador, Ecuador, Guatemala, Haiti, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico and Dominican Republic).

Acrylamide Intake in Latin America

Acrylamide Intake Data

The literature reports a range from 0.5 to 4.21 μg of acrylamide per 300 mL of coffee (Pedreschi *et al*., 2011). The WHO recommends a daily maximum limit for acrylamide intake of 1 μg/kg bw/day (WHO, 2005). Thus, coffee contributes greatly to acrylamide intake by people who consume it (Medeiros *et al*., 2011).

Acrylamide Intake from Coffee Consumption

The figures on the estimated intake of acrylamide from coffee are presented in Table 1. The results of the estimated annual intake of acrylamide from coffee consumption were calculated from the formula:

$$y = x * (0.5 \text{ to } 4.21)/0.018$$

where, x is the amount in kg of coffee per person per year consumed and y is the amount of acrylamide intake in micrograms per person per year, reported in Table 1.

Table 1. Coffee Production, Consumption and Acrylamide Intake *Data adapted from ICO (2013) and FAOSTAT (2012)

Country	Coffee production*	Coffee consumption**(kg)	Acrylamide Intake (μg) ***
Brazil	50,826	4.1–8.0	173.61–1461.80
Argentina	-	4.1–8.0	173.61–1461.80
Colombia	9,500	4.1–8.0	173.61–1461.80
Costa Rica	1,700	4.1–8.0	173.61–1461.80
Guyana	5	2.4–4.5	95.83–806.76
French Guyana	-	2.4–4.5	95.83–806.76
Honduras	4,900	2.4–4.5	95.83–806.76
Suriname	-	2.4–4.5	95.83–806.76
Uruguay	-	2.4– 4.5	95.83–806.76
Venezuela	2,300	2.4–4.5	95.83–806.76
Bolivia	115	0.8–2.4	44.44–374.22
Chile	-	0.8–2.4	44.44–374.22
Cuba	828	0.8–2.4	44.44–374.22
El Salvador	1,250	0.8–2.4	44.44–374.22
Ecuador	656	0.8–2.4	44.44–374.22
Guatemala	3,200	0.8–2.4	44.44–374.22
Haiti	325	0.8–2.4	44.44–374.22
Jamaica	-	0.8–2.4	44.44–374.22
Mexico	3,900	0.8–2.4	44.44–374.22
Nicaragua	1,500	0.8–2.4	44.44–374.22
Panama	110	0.8–2.4	44.44–374.22
Paraguay	20	0.8–2.4	44.44–374.22
Peru	4,133	0.8–2.4	44.44–374.22
Puerto Rico	-	0.8–2.4	44.44–374.22
Dominican Republic	550	0.8–2.4	44.44–374.22

*Coffee production per year - (1000 bags) **Estimated coffee consumption per year per person ***Estimated acrylamide intake per year per person

Table 2. Comparison of acrylamide intake by groups of countries in Latin America

Groups	Annual intake of acrylamide*	Daily intake of acrylamide*
1	173.61-1461.80 μg	0.47 μg to 4.00 μg
2	95.83-806.76 μg	0.26 μg to 2.21 μg
3	44.44-374.22 μg	0.12 μg to 1.02 μg

*Intake per person

The results of the estimated daily intake of acrylamide from coffee consumption were calculated from the formula:

$$y = \{[x * (0.5 \text{ to } 4.21)]/0.018\}/365$$

where, x is the amount in kg of coffee per person per day consumed and y is the amount of acrylamide intake in micrograms per person per day, shown in Table 2.

The high consumption of coffee in some countries of Latin America generates concern over the consumption of this substance, since coffee is indicated as one of the main food sources of ingestion.

Daily Acrylamide Intake through Coffee Consumption

From the calculated data on acrylamide intake in Latin America, it was possible to estimate the daily intake of these populations from consuming coffee. The people from the countries in group 1 can ingest 0.47 μg to 4.00 μg of acrylamide daily, while those from group 2 countries take in 0.26 μg to 2.21 μg and those in group 3 countries ingest 0.12 μg to 1.02 μg (Table 2).

The high coffee consumption in some countries makes it a significant potential source of daily exposure to acrylamide, due to the use of roasted coffee beans for brewing. The likelihood of significant levels of acrylamide is high in all types of coffee (Jin *et al*., 2013; Senyuva and Gokmen, 2005). The concentration of acrylamide between arabica and robusta coffee varies with the amount of free asparagine present in the beans, which is slightly higher in the robusta varieties. With this, it is possible to affirm that the presence of acrylamide in robusta coffee is higher than in arabica (Dias, 2008).

Epidemiological Evidence of Risk from Consumption of Acrylamide in Coffee and Strategies to Ameliorate Risk and/or Decontaminate Coffee

Acrylamide, which is widely used worldwide in industry and can be produced by cooking and processing foods, has been found to be harmful to human beings. Brain Creatine Kinase (BB-CK) has been proposed as one of the important targets in the neurotoxicity of acrylamide. Sheng *et al.* (2009) studied the effects of acrylamide on human BB-CK activity, structure and the potential binding sites. Compared to creatine kinase from rabbits, Human Brain Creatine Kinase (HBCK) was fully inhibited at several-fold lower concentrations of acrylamide and exhibited distinct properties upon acrylamide-induced inactivation and structural changes. The highly conserved structure of CKs presented quite dissimilar responses, suggested that the effects of acrylamide might be isoenzyme- and species-specific. The binding sites of acrylamide were proposed to be located at the cleft between the N- and C-terminal domains of CK and the affinities of the multiple sites might account for the slight difference in the sequence and structure of various CKs. This might be the structural basis for the different effects of acrylamide on various CKs. According to the authors, the results provided insight into the inhibitory effects and the possible ligand-binding mechanism of acrylamide on CK (Lu *et al*., 2009).

Pennisi *et al.* (2013) showed that acrylamide-exposed workers presented high prevalence of paresthesia in hands and legs, cramping in legs, poor blood circulation in fingers, skin irritation and peeling of skin on the hands, headache and breathlessness. The acrylamide induced neurotoxicity diminished ATP-ase activity while enhancing activity of acetilcholinesterase and dopamine depletion. Neurotoxicity is characterized by ataxia and skeletal muscle weakness. Numbness in hands and feet, fatigue and sweating of hands and feet are prominent symptoms of intoxication by this substance (Kopp and Dekant, 2009; Lu *et al*., 2009).

The foods that most contribute to consumer exposure to acrylamide are fried potatoes (16 to 30% of total exposure), potato chips (6 to 46%), coffee (13 to 39%), baked products, including cookies and crackers (10 to 20%), and bread and toast (10 to 30%) according to the type of processing used in the manufacture of these products (Dias, 2008).

There are great differences in the consumption of acrylamide-forming foods among populations from different countries besides wide variation in specific population groups (children, adolescents, adults, elderly, men versus women). This wide variation observed in the total levels of acrylamide in the diet in different food categories should stimulate the development of new approaches to reduce the acrylamide content of foods rich in this substance. (Keramate *et al*., 2011; Friedman and Levin, 2008).

According to Friedman and Levin (2008), coffee contributes to acrylamide intake in almost all population groups. This contribution varies demographically and the results indicate that for certain populations the amount of acrylamide received through consumption of coffee should be considered important.

Arisseto and Toledo (2008) conducted a study of the estimated intake of acrylamide in Brazil based on regional average consumption levels. This study showed that intake values of the country's five official regions were Midwest (0.09 μg/kg per day), Northeast (0.11 μg/kg per day), North (0.12 μg/kg per day), Southeast (0.15 μg/kg per day) and South (0.20 μg/kg per day). The foods that contributed most to the Brazilian exposure to acrylamide were fried potatoes, cookies/crackers and breads.

According to the European Food Safety Authority (EFSA) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) a margin of exposure (MOE) of 10000 would indicate low concern, underlining that the relatively low MOE for acrylamide calls for rapid and effective mitigation measures in order to lower consumer exposure (Bolger *et al*., 2010; Seal *et al*., 2008).

In March 2006, the European Commission and the Confederation of EU Food and Drink Industries (CIAA) organized a joint workshop to discuss current knowledge and achievements in the reduction of acrylamide levels (Konings *et al*., 2007). Acrylamide toxic exposure prevention should aim to avoid inhalation, dermal uptake or ingestion of food sources of this substance (Keramat *et al*., 2011). Yuan *et al.* (2014) evidenced that immersing potatoes in a NaCl and citric acid solution had a great influence on acrylamide formation in this food. Optimal immersion treatments can substantially reduce acrylamide content while reasonably retaining the sensory attributes of potato chips. Another way to reduce the formation of acrylamide is to use asparaginase, an enzyme that converts asparagine to aspartic acid. This procedure is used successfully in potato processing, where its application reduces the formation of acrylamide by 90% without causing sensory changes in the product. This strategy can also be used in coffee to reduce acrylamide formation (Dias, 2008; Wilson *et al*., 2006).

According to Claus *et al.* (2008), the most promising way to reduce acrylamide levels in cereal products is the addition of low molecular additives such as polyphenols. Polyphenols are a major contributor to the consumption of brewed coffee and the presence of antioxidants is important for a number of reasons, such as the prevention of lipid oxidation (Jin *et al*., 2013; Farah and Donangelo, 2006).

With the use of asparaginase, preliminary results in laboratory scale showed an acrylamide reduction of about 45%, but the flavor was negatively altered, particularly of arabica coffee beans (Hidalgo *et al*., 2011).

Final Considerations

According to the maximum limit set by the WHO of 1 μg acrylamide per day per bw, for people in the countries of group 1, coffee makes a large contribution to the intake of acrylamide. Thus, the focus should be on reducing the levels of acrylamide in foods, since they are the predominant sources of this substance for some populations.

In recent years, there have been significant advances in the understanding of acrylamide and toxicity, including its formation mechanism and mitigation strategies. Some investigations have focused on the effect of various antioxidants and antioxidative extracts on acrylamide. Despite the presence of acrylamide in all types of roasted coffee, measures can be taken to lessen the formation of this substance and its presence can also be offset by oxidative balance. Polyphenols are a major contributor to the intake of the beverage and the presence of antioxidants is important for a number of factors, such as the prevention of lipid oxidation.

The data found in the literature and the findings in the present study evidence the importance of a balanced diet, as well the development of techniques that can reduce the formation of acrylamide in food sources such as coffee, to guarantee the safety of this important beverage.

Conclusion

The formation of acrylamide in coffee, the presence of its precursors, concentrations of these compounds in the raw material, coffee consumption and production in Latin America and potential toxicological risks to human health has been discussed in this review article. In this work, the countries of Latin America were divided into three groups according to annual per capita coffee consumption: group 1: between 4.1 kg and 8.0 kg (Brazil, Argentina, Colombia and Costa Rica); group 2: between 2.4 kg and 4.5 kg (Guyana, French Guyana, Honduras, Suriname, Uruguay and Venezuela); and group 3: between 0.8 kg and 2.4 kg (Bolivia, Chile, Cuba, El Salvador, Ecuador, Guatemala, Haiti, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico and Dominican Republic). Coffee contributes to acrylamide intake in almost all population groups. From the calculated data on acrylamide intake in Latin America, it was possible to estimate the daily intake in the region's countries. According to the maximum limit set by the WHO of 1 μg acrylamide per day per bw, for people in the countries of group 1, coffee makes a large contribution to the intake of acrylamide. In this way is mandatory to be focus on research to reduce the levels of acrylamide in foods, especially in coffee.

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Author's Contributions

Ana Carolina Vieira Porto: Participated in all steps of this review, analyzed the data and contributed to the writing of the manuscript.

Otniel Freitas-Silva: Designed the research plan and organized the study.

Jeane Santos da Rosa: Coordinated the data-analysis and contributed to the writing of the manuscript.

Leda Maria Fortes Gottschalk: Designed the research plan and organized the study.

Ethichs

The authors have no conflict of interest.

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