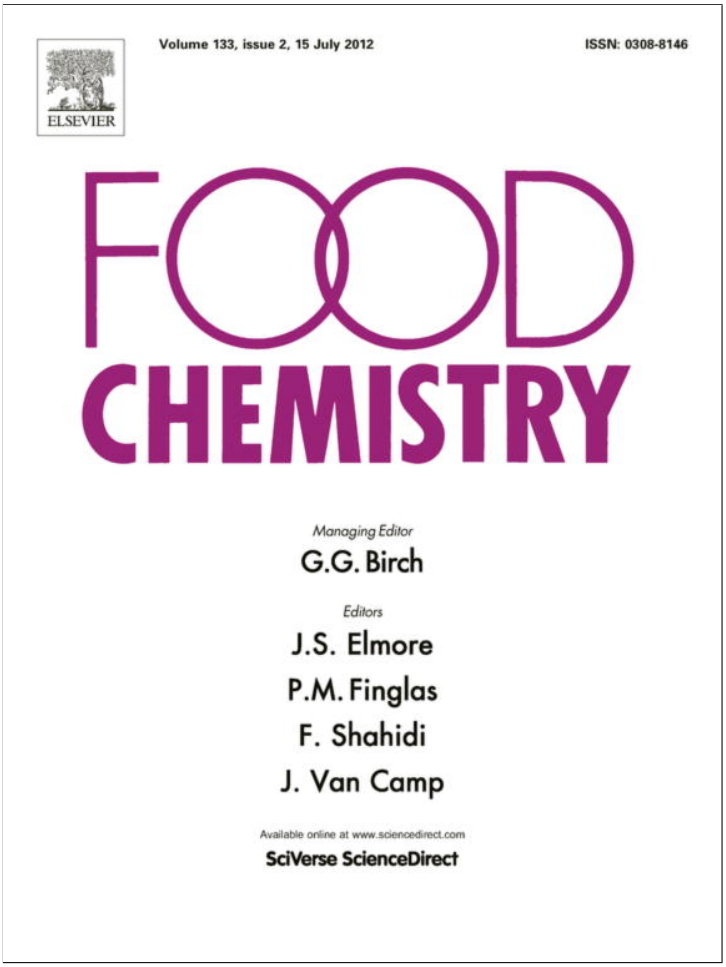

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Acrylamide in Caribbean foods – Residual levels and their relation to reducing sugar and asparagine content

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ABSTRACT

The acrylamide levels in commercial and homemade Caribbean foods were determined by pre-derivatisation of acrylamide to 2-bromopropenamide and analysed by gas chromatography with mass spectrometric (GC/MS) detection. Over 100 Caribbean food samples were analysed for the presence of acrylamide. These samples include: biscuits, breakfast cereals, banana chips and home-prepared foods: breadfruit; *Artocarpus altilis*, banana fritters, and dumplings. The limit of detection (LOD) for the GC/MS method was found to be dependent on the type of column used for the GC/MS analysis. The DB-1701 and the DB-VRX columns gave LODs of 20 and 4 μg/kg, respectively. Acrylamide has not been found in raw foods or foods which have been cooked by boiling. Its content in all other foods had concentrations in the range, 65–3640 μg/kg. The relationship between acrylamide levels and precursor concentration as well as the health implications of our findings are discussed.

1. Introduction

Acrylamide (AA, CAS number 79-06-1), (CH_2=CH–CO–NH_2), a white, odourless, toxic, crystalline compound is produced mainly for the synthesis of the non-toxic polyacrylamide, which is used as a flocculant in water treatment, and as a binder in pulp and paper processing (Acrylamide Analytical Methods Working Group Backgrounder, 2002). AA affects the nervous system even at low levels, causing hallucinations and drowsiness (Acrylamide, http://www.arb.ca.gov/toxics/toc/factshts/acrylami.pdf). Human health effects associated with consumption of small amounts of AA over long periods of time are not known. However, recent studies have suggested that women who eat chips or crisps appear to be at an increased risk of developing ovarian cancer ('Burnt foods' linked to cancers, 2007). Chronic exposure results in neurotoxicity in animals and humans, and AA has been found to be carcinogenic to laboratory animals. As a result, it was classified by the I.A.R.C. (International Agency for Research on Cancer) as a Group 2A: a possible human carcinogen (I.A.R.C, 1987).

Studies have shown that AA is found in foods that are cooked at temperatures above 100 °C (Friedman, 2003). Therefore, foods, which are prepared by methods other than boiling have the potential to contain AA, which is formed by heat-assisted chemical reactions, namely the Maillard reaction, that occur when foods are heated above 100 °C. The amount of AA that is formed is directly related to the quantities of precursors (reducing sugars and amino acids, namely asparagine) that are present within the foods. Higher levels have been found in foods from plant sources than foods from animal sources. Some of the highest levels have been found in potato products such as French fries, and potato chips but very low levels have been found in meats (Friedman, 2003).

Research and quantification of AA in various food products is being conducted in countries such as Sweden, UK, and USA (Friedman, 2003; Nemoto, Takatsuki, Sasaki, & Maitani, 2002; Swedish National Food Administration, 2002) but so far, only one paper has been published on the AA content in foods from the Caribbean (Bent, Maragh, & Dasgupta, 2007). The Caribbean diet consists of high amounts of starchy foods, some of which are cooked (frying, roasting, and baking) at high temperatures, so the need to assess the levels of AA in these foods is of great importance. As a result we embarked on a study to determine the levels of AA in various Caribbean foods. Over one hundred frequently consumed home-made and commercial Caribbean foods were analysed for their AA content by the GC/MS technique.

2. Materials and methods

2.1. Chemicals and standards

AA (electrophoresis grade), $^{13}C_3$-labelled AA (Analar grade) were purchased from Aldrich. Ethyl acetate and all other solvents used were of HPLC or GC grade and were obtained from Fisher

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Chemicals (Fairlawn, NJ, USA). Deionised water was prepared in house using a Labconco Water Pro PS deioniser (Labconco Water Corporation, Kansas City, MO, USA). All AA stock and working solutions were prepared in water. Potassium bromide (KBr), potassium bromated ($KBrO_3$), hydrobromic acid (HBr), anhydrous sodium sulphate (Na_2SO_4), sodium thiosulphate ($Na_2S_2O_3$), potassium hexacyanoferrate(II) trihydrate, and zinc acetate dihydrate were either Analar or GPR grade and obtained from BDH Laboratories (Poole England). Triethylamine (TEA) was obtained from Sigma–Aldrich (Fairlawn, NJ, USA).

Standards were prepared by modifying several methods (Andrawes, Greenhouse, & Draney, 1987; Hamlet, Jayaratne, & Sadd, 2004; Nemoto et al., 2002) and were prepared as such. 100 mg/l AA standards were prepared daily in deionised water. A suitable portion was transferred to a conical flask, acidified to pH 1 with HBr, and brominated with a BrO_3^-/Br^- mixture (Br_2 is generated *in situ* upon acidification). The excess bromine was decolourised with 1 mol/dm^3 $Na_2S_2O_3$ and the reaction mixture was transferred to a separatory funnel. The 2,3-dibromopropionamide was extracted with 3 × 10 ml portions of ethyl acetate and collected into a dry beaker containing 1 g anhydrous Na_2SO_4. The mixture was filtered through a packed silica column for further cleanup and the filtrate collected into a 100-ml RB flask. The beaker was rinsed with 2 × 2 ml portions of ethyl acetate and the combined extracts were transferred to the packed column (5 × 1 cm) with diatomaceous earth as packing material. The column was further washed with 3 × 1 ml portions of ethyl acetate and the washings collected into the flask. 100 μl of TEA were added and the standard concentrated to dryness on a rotary evaporator (Büchi Rotavapor R-200 Bath 490; Labortechnik A.G., Flawil, Switzerland) then reconstituted to 5.00 ml with ethyl acetate. Serial dilutions of the standard mixture were performed and used to prepare standards within the working range of 100 μg/l to 10 mg/l. A portion of each standard was transferred to an amber GC autosampler vial for analysis. The data obtained from each set of standards were used to generate calibration plots, which were used to quantify AA as 2-bromopropenamide (2-BPA). Standard solutions were prepared from modified methods.

A 56.8 mg/l $^{13}C_3$-AA standard was prepared in deionised water. A portion of this was brominated to yield a $^{13}C_3$ 2-BPA standard which was diluted and used to prepare suitable calibration standards.

2.2. Acrylamide recovery

Boiled samples were prepared in deionised water until fork-tender and air-dried, 100–200 ml of deionised water were added to the boiled samples and the samples homogenised with a hand-blender (Braun Handblender MR310, Braun Inc., Lynnfield, MA, USA). All other samples were homogenised in a household spice mill.

Ten grams homogenised food samples were weighed into stoppered 250 ml conical flasks and spiked with 3.00 ml of a 2.84 mg/l $^{13}C_3$-AA standard solution. Fifty millilitres deionised water were added followed by 1 ml each of Carrez I (potassium hexacyanoferrate(II) trihydrate), and Carrez II (zinc acetate dihydrate) solutions prepared at 136 and 267 g/l, respectively. The samples were agitated for 10 min then filtered under suction. Fifty millilitres of filtrate were subjected to bromination and reconstituted to 5 ml with ethyl acetate. A portion was transferred to an amber GC autosampler vial for quantification by GC/MS. All samples were analysed in triplicate.

2.3. Samples for testing

Commercial foods, including: banana-, potato-, and plantain-chips, breakfast cereals, breads, patties, meat- and vegetable-loaves, coffee (ground and instant), cocoa powder, biscuits (cookies and crackers), and pastry were obtained from local supermarkets. Roasted breadfruit (roasted in an open flame on a gas stove), ackee (boiled, then sautéed with sliced onions, escallions, garlic and other seasonings), and banana fritters (prepared from over-ripe bananas, flour, sugar, and water, made into a fritter batter and fried in vegetable oil until golden brown) were obtained from a home-kitchen. Festival mix, whole wheat, and white flour were obtained from a local supermarket and used to prepare fried dumplings in the laboratory.

2.4. Preparation of fried dumplings

One cup of each of white and whole wheat flour was mixed with a tablespoon of baking powder and a pinch of salt into separate bowls. Festival (a type of deep-fried dumpling, indigenous to Jamaica) was prepared from a store bought mix. The festival mix was prepared as instructed on the package. Water was added to each bowl and the dumpling mixes kneaded into a dough, and rolled into small balls of dough each weighing about 10 g. They were deep-fried in 5 l of vegetable oil in batches of 30 g each (to prevent temperature variation) at 175 ± 2 °C in an electric deep fryer (Eastern Electric 5 Quart Deep Fryer, Cooker, Steamer). Each batch was fried for 2 min on each side then removed from the fryer and placed on absorbent paper to remove the excess oil. Images of the final products were taken with a digital camera. The settings were: auto mode; picture quality: good (1200 × 900 pixels) (Kodak EasyShare CX7430 Zoom Digital Camera, Eastman Kodak Company, Rochester, NY, USA). The samples were then defatted and the AA content determined by GC/MS.

2.5. Extraction of acrylamide from food samples

The peel of the roasted breadfruit was scraped to remove the excess charcoal. The inner core (inedible portion) was removed and the fruit sliced. Both the fruit and the peel were analysed for their AA content.

Samples were defatted by soxhlet extraction prior to AA extraction where necessary and homogenised using a household spice mill. These samples were re-homogenised prior to AA extraction. 5–20 g portions of homogenate (depending on sample size) were weighed into separate 250 ml conical flasks and 30.00–200.00 ml deionised water added. The samples were then treated successively with 1 ml each of the Carrez solutions. Samples were agitated for 10 min by a Mistral Multi-Mixer wrist action shaker (Lab-Line Instruments Inc., IL, USA) followed by filtration or centrifugation (IEC Medispin) for 15 min (depending on viscosity and volume of liquid present after extraction). Samples were then prepared for GC/MS analysis.

For GC/MS analysis, a portion of the extract was brominated and extracted with ethyl acetate as described above. Samples were reconstituted to 1 ml with ethyl acetate in an autosampler vial. All experiments were done in triplicate.

2.6. GC/MS analysis

Analysis of AA was done using a modified version of the method used by Tareke, Rydberg, Karlsson, and Tornqvist (2002) on a HP 6890 gas chromatograph coupled to a HP 5973 mass spectrometer attached to an autosampler. Initially, the separation was performed using a DB-1701 capillary column (30 m × 0.53 mm i.d. × 250 μm film thickness; Agilent Technologies, Palo Alto, CA, USA). The operating conditions for the GC/MS were: oven temperature: 65 °C for 3 min then ramped to 150 °C at 15 °C/min and held for 0.5 min then ramped to 250 °C at 50 °C/min; electron ionisation (70 eV); splitless mode; injector temperature 250 °C; He (>99% purity)

carrier gas, flow rate 1.3 ml/min; solvent delay time 7 min; runtime 11.17 min; injection volume 2 μl. The chromatographic column was changed to a DB-VRX capillary column (20 m × 0.18 mm i.d. × 1 μm film thickness; Agilent Technologies, Palo Alto, CA, USA) operating conditions were as stated above. SIM ions for 2-BPA: 70, 106, 133, 149; SIM ions for $^{13}C_3$ 2-BPA: 73, 108, 136, 152. All solutions were injected in triplicate.

2.7. Statistical analysis of data

The data obtained from the analysis of 2-BPA standard solutions were used to generate calibration plots using the Microsoft Excel 2000 software. These calibration plots were then used to quantify the levels of AA within the food samples as well as the relative standard deviation (RSD) associated with the results.

3. Results and discussion

3.1. Optimisation of GC/MS method

Various existing GC/MS methods were examined to determine which was best suited to quantify AA in Caribbean foods based on equipment availability. The GC/MS method that was developed proved to be ideal for the analysis of AA. The initial method in which the DB-1701 column was used, a LOD of 20 μg/kg was obtained. The LOD was lowered to 4 μg/kg when the column was replaced with the DB-VRX column which emphasises the importance of using a column, which provides good resolution. Since there is no allowable limit yet established for AA in foods it is crucial that if AA is present within a sample, it can be quantified (Tareke et al., 2002; Weiβhaar, 2004).

Andrawes et al. (1987) reported on the possibility of the thermal degradation of the 2,3-dibromopropionamide to the monobromo derivative, 2-BPA, within the GC and that the process is inconsistent. This was tested and confirmed by GC/ECD (results not shown). As a result the AA in all samples and standards were converted to 2-BPA prior to GC/MS analysis.

The calibration plots ($R^2 > 0.992$) for 2-BPA analysed by GC/MS using a DB-1701 column have been found to be linear (Fig. 1). These plots show instrument variation over different days, and emphasise the need for daily calibration to test instrument variability. The error bars indicate the precision of triplicate injections.

The AA recovery in foods was ⩾83%. The recoveries are: banana: 83 ± 5%, breadfruit: 93 ± 5%, potato: 105 ± 10%, ackee: 83 ± 1%, bread: 100 ± 6%, cocoa powder: 102 ± 8%, coffee (ground): 104 ± 4%, and coffee (instant): 92 ± 4%.

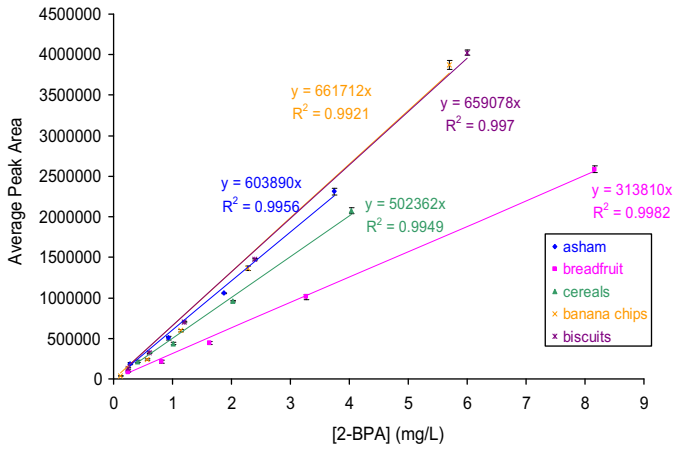

Fig. 1. Calibration plots used to quantify AA in foods.

Fig. 2 is an overlaid GC/MS chromatogram analysed on the DB-1701 column which shows the 2-BPA standard solution eluting with a retention time of 7.40 min. The presence of a peak with a corresponding retention time as seen for the roasted breadfruit and spiked samples, and a match of the mass spectrum of the analyte, is proof that AA is present. The figure shows tailing especially at the lower 2-BPA concentrations. As a result, higher standard concentrations had to be used to obtain the linear calibration range and larger sample masses in order to quantify the AA content in the samples. The inset shows a $^{13}C_3$ 2-BPA standard analysed on the DB-VRX column. The peak shape and resolution were vastly improved which resulted in an improvement of the LOD by a factor of 5.

3.2. Acrylamide content in Caribbean food

The AA content of some Caribbean food samples is listed in Table 1. The RDS for triplicate analysis of all food samples was <10%, an indication of method precision. The home-made samples were prepared following standard methods of preparation adopted within Caribbean homes. The values obtained vary widely between product type and even within the same product. This indicates variation in the precursor levels and variation in preparation techniques of samples.

Breadfruit is a staple that is widely consumed in the Caribbean. Both the peel and the fruit of the roasted breadfruit were analysed separately for their AA content. The results show that the peel contains approximately three times as much AA as the fruit itself because the peel was in direct contact with the heat source resulting in a much more rapid formation of AA. This may have serious health implications for persons who eat both the roasted peel and the fruit as they are exposed to much higher levels of AA.

Products that are made with whole wheat flour and wheat bran contain over twice as much AA as those made with white flour. Whole wheat flour contains more asparagine (Asn) and reducing sugars (AA precursors) than white flour (Hamlet, Sadd, & Liang, 2007); as a result more AA will be formed in these products. The high levels found in the whole wheat biscuits can be attributed to the fact that ammonium bicarbonate was used in the recipe. Ammonium salts used as leavening agents have been known to increase the AA yield by several orders of magnitude (Biedermann-Brem et al., 2003; Grob, 2005) by either acting as an additional source of nitrogen or by indirectly catalysing the degradation of sugars to produce reactive carbonyls (Grob, 2005). Some of the whole wheat or bran biscuits analysed in this study had AA levels up to twenty times higher than sweet or savoury biscuits.

Unlike cereal products where the asparagine (Asn) levels influence AA formation, it is the reducing sugar content in starchy foods that is the key factor in AA formation. The quantity and composition of sucrose in starchy foods is dependent on cultivar, stage of maturity, occurrence of stress, handling, and storage management practices. Sucrose is the transport form of sugar from leaves to fruit and is the major free sugar in immature fruits (The CIAA acrylamide "toolbox" Review 9, 2006). As the fruit matures, sucrose is converted to, and stored as, starch.

Depending on the food type, different factors affect sucrose content. The higher the sucrose content the more reducing sugars are formed. In the case of potatoes, the tubers are said to be mature when a low soluble sugar level of ⩽1.5 mg/g fresh weight is attained (Stark, Olsen, Kleinkopf, & Love, http://www.cals.uidaho.edu/potatoes/Research&Extension/Author/Stark,Jeff/TuberQuality.pdf; University of Manitoba, 1993). However, stresses such as low temperature, low oxygen, or physical damage usually result in a reversion of starch to glucose. Hence, if potato products are to be prepared at high temperatures they should not be refrigerated.

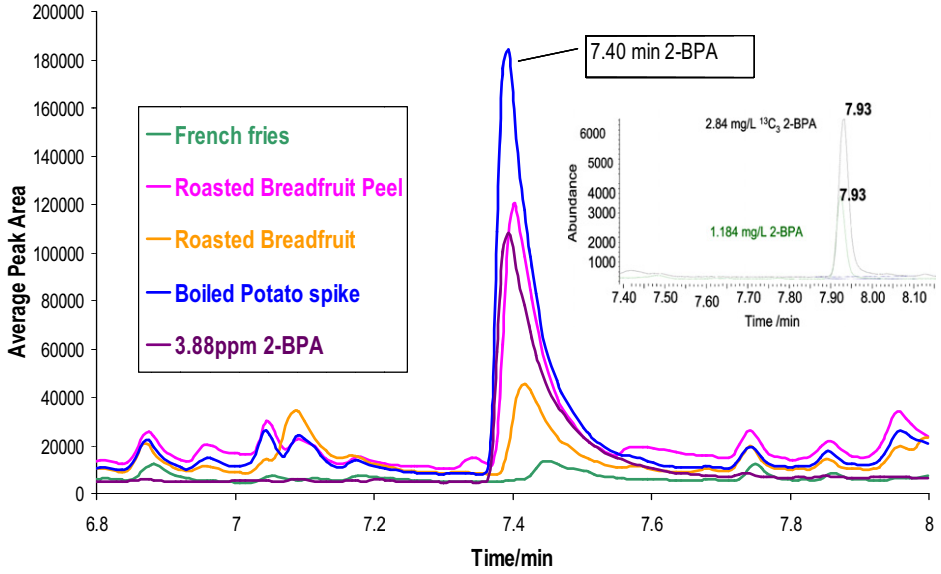

Fig. 2. Overlaid GC/MS chromatograms of AA analysed as 2-BPA in some Caribbean foods analysed on the DB-1701 column. Inset shows the $^{13}C_3$ 2-BPA standard analysed on the DB-VRX column.

Table 1
Data obtained for different Caribbean food samples analysed for AA content.

Food type	Number of samples (*n*)	[AA]/μg/kg	Food type	Number of samples (*n*)	[AA]/μg/kg
Asham	1	450	**Gizzarda**		
Banana (boiled)	1	<4	Shell	1	413
Banana chips (green bananas)	3	100–430	Filling	1	195
Banana chips (ripe bananas)	1	180	Whole pie	1	325
Banana fritters	1	1090	Grater cake	1	612
Bammy (fried)	2	555–560	Meatloaf (white flour)	1	1780
Bammy (un-fried)	2	532–546	Meatloaf (whole wheat)	1	2560
Biscuits (crackers, savoury)	1	150	**Patty (Beef)**		
Biscuits (cookies, sweet)	3	105–120	Crust	1	3612
Biscuits (whole wheat, bran)	2	300–2090	Filling	1	390
Breadfruit (raw)	1	<4	Whole pie	1	2270
Breadfruit (roasted)	2	620–690	**Patty (Chicken)**		
Breadfruit peel (roasted)	2	1780–2210	Crust	1	3010
Breakfast cereals	1	130	Filling	1	440
Breakfast cereals (bran)	2	210–700	Whole pie	1	2270
Bread (white)			**Patty (Vegetable)**		
Crust	2	65–114	Crust	1	3640
Middle	2	56–75	Filling	1	820
Whole Slice	2	70–75	Whole pie	1	3130
Bread (whole wheat)			Peanut Cake	1	500
Crust	2	80–180	Plantain chips	2	120–140
Middle	2	80–95	Potato (boiled)	1	<4
Whole Slice	2	100–150	Potato chips (crisps)	2	105–115
Coconut Biscuit	2	202–240	Potato stix	1	46
Coconut Drops	1	610	Rock Bun	1	300
Dumpling (white flour, fried)	1	2440	Vegetable loaf (white flour)	1	2010
Dumpling (whole wheat, fried)	1	3360	Vegetable loaf (whole wheat)	1	2700
Festival mix (fried)	1	4280			

The analytical data for residual AA in various foods obtained from our studies as well as studies conducted in Europe are listed in Table 2. It is evident from the data that the results from the European studies agree well with our findings. It shows that no AA was detected in boiled or raw foods but is present in potato crisps and chips, which are prepared by frying. Ackee is the national fruit of Jamaica. Boiling the ackees before sautéing removes the AA precursors; as a result no AA was found (Table 1). This confirms that AA is absent from boiled foods and does not occur naturally in foods but is formed as a result of preparation at temperatures above 100 °C.

3.2.1. Acrylamide in grain and starchy products which contain fat

Banana fritters are made from over-ripe bananas which have much higher reducing sugar content than the green variety. Also, sucrose was added to the mix which accounts for the much higher AA content.

Patties, meat- and vegetable-loaves are very affordable foods and highly consumed in the Caribbean, especially in Jamaica, by the lower income earners, which is a considerable percentage of the population. They had to be examined to see how their consumption would affect the daily AA consumption. The patty is a flour pastry that contains various spices and fillings baked inside

Table 2
Comparative data of AA levels in different food products from the Caribbean and various European countries.

Food type	Acrylamide levels (μg/kg)	
	Caribbean	Europe
Biscuits, crackers, toast, bread, crisps	70–2090	<30–3200
Breakfast cereals	115–700	<30–1346
Chocolate Powder	75–330	<50–100
Coffee (powder, instant, ground)	1590–3410	<30–200
Crisps, potato	105–115	170–2287
Potato (boiled, raw)	ND	ND
Poultry, crumbed, battered[a]	440	39–64

[a] Data – adapted from references Friedman (2003) and Tareke et al. (2002).

a shell (flaky pastry). The Jamaican meat- and vegetable-loaves are similar to the patty, however, the pastry used is bread dough. Samples were defatted before AA extraction and analysis. Patties, meat- and vegetable-loaves had some of the highest AA levels of the foods that were analysed. The AA content was in the range 2560–3130 μg/kg.

Fig. 3 is the digital photograph of the fried dumpling and festival samples. The AA content in whole wheat dumpling was higher than that of white flour dumpling, as was expected. The main ingredients of the festival mix are white flour, cornmeal and sucrose, which accounts for the higher levels of AA than for both types of dumpling, as sucrose is converted to glucose and fructose (AA precursors) on heating and white flour, and cornmeal both contain AA precursors.

In Jamaica, cassava is traditionally made into "bammy," a small cake made from grated, partially-dried cassava inherited from the native Tainos. Bammy is usually baked over an open flame which would yield higher levels of AA as it would be cooked at a high temperature due to the proximity of the heat source. The AA content was comparable in both brands obtained, which implies that the AA precursor content in the tubers used to prepare the bammy used in this study were similar. Frying increased the AA content as expected due to the presence of AA precursors present in the bammy itself and cow's milk in which the samples were pre-soaked before frying; browning was also observed. The presence of browning was an indication of increased AA levels in the fried products.

3.2.2. Caribbean pastry

This category includes foods, which are either sweets or pastries, such as: gizzarda, grater cake, and coconut drops. Gizzarda, grater cake, and coconut drops are all made from ripe coconut. When the coconut is ripe the outer husk is brown and the meat (endosperm) becomes thick and hardened. Gizzarda and grater cake are made from grated, peeled coconut, while coconut drops are made from diced coconut with the peel still attached. These coconut products are made with a lot of added sugar. It is a possibility that the amino acid concentrations were low, which might explain why ripe-banana fritters contained higher levels of AA than all the coconut products.

Of the three coconut products, the gizzarda filling contained the lowest AA levels and that can be attributed to the fact that much less coconut and sugar are used to make the filling than what is used to make grater cake and coconut drops. The filling of the gizzarda is cooked to a lower final temperature than the other two products. Less sugar, both from the coconut and added sugar results in less AA precursors and hence less AA on cooking. As expected, the pastry shell of the gizzarda contained fairly high levels (413 μg/kg) of AA, since the shell is wheat-based and is baked for a long time. The coconut drops had the highest AA content as expected because it requires longer cooking in boiling syrup to soften the coconut (because it is diced with the peel still attached). This occurs at a fairly high cooking temperature and would result in the formation of higher levels of AA.

3.3. Processing conditions

The concentration of AA in food products is directly related to cooking time and temperature. Roasting uses one of the highest cooking temperatures as the food is usually in direct contact with the flame or, in direct contact with a hot surface. In industry, roasting is usually conducted between 300 and 320 °C (Murkovic, 2007) and home roasting can exceed these temperatures by far. It also requires one of the longest cooking times because of poor heat transfer within foods, so a longer time is required to attain roasting temperature. The larger the food item the more time is required for roasting thus forming more AA in the outer section that is closer to the hot surface. There exists a more constant supply of AA precursors so the AA levels will rise steadily as opposed to smaller food items, where this supply is more quickly depleted and the elimination of AA could surpass formation. Products that were roasted (breadfruit, coffee, and asham) contained much higher levels of AA, as expected, than most of the foods that were either baked or fried (Table 1).

Previous studies showed that the AA content in roasted nuts is dependent on the levels of Asn, roasting temperature, and roasting time. It was found that the roasting temperature had a stronger influence on AA formation than roasting time (Amrein et al., 2005, 2007). Since home roasting is often conducted at temperatures above 320 °C it is possible that a higher roasting temperature for the breadfruit contributed to much higher levels of AA than coffee and cocoa products.

Asham is a mixture of roasted corn, roasted peanuts, salt, and sugar which has been finely milled or ground in a mortar. This product contained a high AA content (Table 1) due to the method

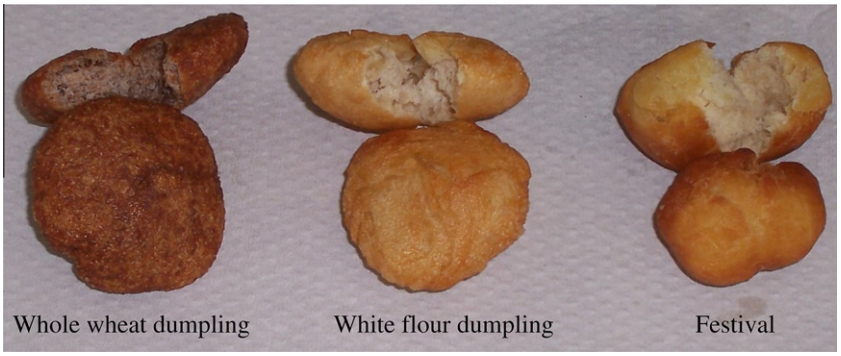

Fig. 3. Digital photograph of fried dough samples (actual size).

of processing. The corn and peanuts, two of the main ingredients in asham were parched.

Peanut drops, better known as peanut cake in Jamaica, is another confection often eaten in the Caribbean, made from parched peanuts. The AA content obtained was 500 μg/kg and is comparable to the value obtained for asham (450 μg/kg). The slightly higher value for peanut cake could be due to additional AA precursors formed by the decomposition of sucrose to reducing sugars on heating, higher levels of AA precursors in the peanut cultivar used, or roasting the nuts at a higher temperature, or for a longer time.

Due to better heat transfer, a shorter roasting time or lower temperature might explain, why the levels found for asham and peanut cake, are lower than for breadfruit. There also exists the possibility that the lower levels found in asham or peanut cake resulted from a higher rate of elimination than formation due to faster depletion of AA precursors than for breadfruit. This can be investigated by sampling at different roasting temperatures and times for peanut and breadfruit.

Studies have shown that the levels of AA in roasted coffee and cocoa are due to the amounts of Asn in the raw product (Murkovic & Derler, 2006; Redgwell, Trovato, & Curti, 2003). The AA content in cocoa products was similar to those reported in previous studies (de Brito, Narain, Garcia, Valente, & Pini, 2002). Three different brands of ground coffee were used (including an espresso), and one brand of instant coffee. The espresso coffee was from South America while all other coffee samples were from Jamaica.

The Jamaican coffee samples were medium roast, while the espresso coffee was dark roast. The results from our findings are in agreement with previous work. Medium roasted ground coffee contained higher levels of AA than dark roast coffee. This could be attributed to the fact that as the roasting temperatures and times increase, the rate of elimination/degradation of AA exceeds the rate of formation (Hamide & Gokmen, 2005; Roach, Andrzejewski, Gay, & Musser, 2004; Taeymans et al., 2004). Instant coffee had the highest levels of AA. Instant coffee is of a lower quality than ground coffee and usually contains higher levels of AA because it is prepared from coffee brew. Since AA is highly water soluble (2155 g/l) it would be efficiently extracted into the coffee brew. Excess water is removed from the coffee brew by freeze-drying and small water-soluble coffee granules are formed. This process concentrates the coffee flavour and increases the concentration of other water soluble components, such as AA. Therefore, a serving of instant coffee (2 g) contains higher levels of AA (3410 μg/kg) than a serving of coffee from coffee grounds (5 g), (1590–2370 μg/kg).

The AA content in the coffee samples were higher than previously reported values (Roach et al., 2004; Taeymans et al., 2004). However, the AA content in coffee is not only related to the cultivar and processing conditions but also to storage conditions. As storage temperature and time increase, the levels of AA decrease possibly by binding with components, such as sulphur compounds, present within coffee. It is uncertain as to the freshness, storage conditions, and the roasting process of the coffee used in this study. These parameters may be investigated by sampling at different roasting temperatures and times as well as different storage temperatures and times for Jamaican coffee.

4. Conclusion

Quantification of AA in foods is still a very active area of research. Attempts are being made to minimise the levels of AA in foods by pre- and post-treatment methods. This is the first comprehensive study reported from the Caribbean to quantify the levels of AA in foods indigenous to the region as well as foods commonly consumed in the region. This study provides vital data from a third world region, the Caribbean, to add to the AA food database. It is also the aim of this research to increase public awareness to this food toxin with the hope that individuals will recognise the importance of food quality, and modify eating habits and preparation techniques to minimise AA exposure.

Much of the data is comparable for the AA content in foods common to both the Caribbean and Europe, such as breads and biscuits. Our results also agree with previous studies, which indicate that foods from plant sources contain higher levels of AA than foods from animal sources, and boiled and raw foods contained no AA, confirming that AA is not a natural occurrence in foods but is formed during thermal processing at temperatures above 100 °C.

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