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# Aflatoxin and Food Safety: Recent South American Perspectives

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## CONTENTS



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## ABSTRACT

South America (SA) is predominantly a tropical and subtropical continent and provides environmental conditions favorable for fungus growth on food crops, especially the species *Aspergillus flavus* and *A. parasiticus*. Depending on the grain and weather conditions in certain regions of SA, high levels of aflatoxins (AFLs) can be produced during harvesting or storage. That is a real problem in most of the continent. South American economies rely upon government policies to address issues of food safety. As expected, the exporting countries must comply with the standards and regulations that are implemented by the importing country. Thus, the highest quality and safest commodity food products are sold internationally. Conversely, food for internal consumption does not meet the same high quality standards compared with exports. Some SA governments have established food safety guidelines and regulations for AFL control in national food supplies. Research is currently being conducted to determine the levels of naturally occurring AFLs in a range of locally processed foods. These countries include: Brazil, Argentina, Colombia, Venezuela, and Uruguay, the main grain exporting countries in SA. Most contaminated food commodities in SA include peanut and peanut products, followed by corn. The regions most affected by AFL contamination in SA include mainly the peanut-producing countries of northern SA as well as Brazil, Argentina, Uruguay, and Paraguay. Aflatoxin contamination of feeds and foodstuffs seems greater in Colombia and Ecuador. On the other hand, AFLs in corn is high in Venezuela. This review summarizes work published on AFLs throughout the previous decade. While most of the research has been performed in

Brazil, Argentina, and Uruguay, other SA countries including Colombia and Venezuela also have played an important role in AFL research. Conversely, few studies on AFLs have been performed in Bolivia, Chile, Ecuador, and Peru, and no studies have been done in French Guyana, Guyana, Paraguay, and Suriname. There is a lack of data on the SA population exposure to AFLs, either using biomarkers or by evaluating the incidence of hepatocellular carcinoma (HCC) and its relation to AFLs in SA diets.

*Key Words:* Aflatoxins; South America; Food safety.

## I. INTRODUCTION

Food safety in the South American (SA) continent and its relation to mycotoxins is quite broad and diversified. This continent has a wide range of differences including geographical location, climate, soil, types of agricultural commodities, and cultural habits, among others. Differences in economies have lead to diverse tolerance levels and differences in the way that individual countries may regulate food contaminated with mycotoxins. Several of the countries lack regulations or even minimal monitoring programs. Governments and scientists of major grain producing countries in SA (Brazil, Argentina, Colombia, and Venezuela) are well aware of problems associated with some mycotoxins. These are the countries with the most data published in the literature. Less developed SA countries such as Bolivia, French Guyana, Guyana, Paraguay, Peru, and Suriname lack resources and funding to monitor levels of mycotoxins in foods. What really leads SA countries to take mycotoxins seriously is the export of commodities and the use of grains for feeding animals by the meat industry. Conversely, the cause of SA refusing batches of imported grains is not always due to levels of mycotoxin contamination, but the price of the commodity. Therefore, food consumed by the SA populace is not always the safest, and left unchecked, such consumption could have adverse health effects because of exposure to the population. Most of the published data report aflatoxins (AFLs = $AFB_1$, $AFB_2$, $AFG_1$, and $AFG_2$) contamination in peanuts and corn and their products, but some staple foods, such as black beans and rice, also are monitored in some of the countries, as well as wheat, coffee, Brazil nuts, and aflatoxin $M_1$ ($AFM_1$) in milk. Animals exposed to AFL-contaminated feed may be taken into consideration as well, since some SA countries have high levels of AFL residues in meat liver and milk products. It is important to emphasize that, due to their high grain production and export, some

SA countries have implemented control measures to reduce the levels of AFLs. By implementing training programs, good harvesting practices, grain-drying procedures, and emphasizing the adverse effects on public health, levels of AFLs and toxigenic fungi have decreased considerably in recent years.

## A. Grain Production

South America has a high grain production sector. Brazil, Venezuela, and Argentina are the main general exporting countries with 57.8, 29.5, and 26.7 billion free on board (F.O.B.), respectively, followed by Chile, Colombia, Peru, Ecuador, and Uruguay (18.5, 12.3, 7.3, 4.8, and 2.24 billion F.O.B.), respectively (Nationmaster, 2003). They are corn, coffee, soybean, and rice mainly produced in Brazil, Argentina, Colombia, and Venezuela. Peanuts are produced in Argentina, Brazil, Suriname, Chile, Paraguay, Venezuela, and Uruguay.

## B. Patterns of Diet and AFL-Related Food

Central America and SA are the seventh largest consumers of cereal products internationally and the sixth largest consumers of milk internationally (Table 1). According to the World Cancer Research Fund and American Institute for Cancer Research (WCRF/AICR) (1997), most South American countries have middle-income economies. The continent has three dominant food cultures: in 1) Indo-America, along the mountains (Colombia, Ecuador, Peru, and Bolivia), the traditional staple foods are maize, beans and potatoes; 2) Tropi-America (Venezuela and north of Brazil), traditional diets contain a large proportion of starchy roots and tubers (cassava, yam) apart from beans and rice; and 3) Temperate prairies of SA, diets are in animal foods but are otherwise Mediterranean in nature, therefore including cereals. Table 2 shows that the diets of most countries in SA are based on cereals and other starchy foods (WCRF/AICR, 1997). In Brazil and Paraguay, rice and beans are a relatively important stable part of the diet; while in Uruguay and Argentina, rice, beans, and wheat are significant. Clearly, diets of these SA countries include cereals that can be contaminated by AFL when exposed to factors that allow growth of fungi. Starchy roots are often a source of fungal growth in Paraguay, Bolivia, and Colombia. Foods that can be indirectly contaminated with AFLs, because they are obtained from animals fed with $AFB_1$-contaminated feed, include: beef, pork, chicken, liver, eggs, and milk. Thus, AFLs may be found in starchy foods (cereal, pulses, roots), high

*Table 1.* Consumption of some major food groups worldwide as percentage of total energy.

| Country | Cereals (%) | Other starchy food (%) | Vegs and fruits (%) | Meat (%) | Milk and dairy products (%) |
|---|---|---|---|---|---|
| Australia and New Zealand | 26.2 | 6.5 | 8.6 | 34.5 | 15.1 |
| Caribbean | 37.3 | 15.1 | 11.5 | 10.8 | 8.6 |
| Central and South America | 43.1 | 12.9 | 5.0 | 13.6 | 9.4 |
| China | 73.3 | 10.8 | 5.0 | 15.1 | 1.4 |
| Eastern Europe | 38.2 | 7.9 | 7.9 | 20.1 | 12.9 |
| India | 67.1 | 5.8 | 5.0 | 1.43 | 8.6 |
| Asia (low income) | 75.6 | 7.2 | 4.3 | 2.9 | 5.0 |
| Asia (middle income) | 58.2 | 7.9 | 8.6 | 9.4 | 2.9 |
| North Africa | 62.7 | 5.8 | 8.6 | 5.0 | 5.8 |
| North and Central Europe | 22.7 | 11.5 | 9.35 | 25.9 | 15.8 |
| Oceania | 27.6 | 51.1 | 17.9 | 10.8 | 0.7 |
| South Europe | 28.0 | 7.9 | 11.5 | 28.1 | 15.1 |
| Sub-Saharan Africa | 48.4 | 45.3 | 2.9 | 5.8 | 5.0 |
| USA and Canada | 24.4 | 6.5 | 10.1 | 26.6 | 15.8 |

Source: WCRF/AICR, 1997 (modified by Scussel, 2003).

protein foods (beef, chicken, liver), and alcoholic beverages of a typical SA diet.

## C. Regulation

Due to social and economic concerns, some SA countries have addressed food safety issues and established a maximum residue level (MRL) for AFLs and other mycotoxins. Table 3 shows the MRL for AFLs established by Mercosul countries (southern area of SA trade that comprises Argentine, Brazil, Paraguay, and Uruguay) as well as for Suriname, Venezuela, Peru, and Colombia. The Mercosul countries have established MRLs for total AFLs ($AFB_1 + AFB_2 + AFG_1 + AFG_2$) of 20 μg/Kg for all food products that contain either peanuts or corn. Furthermore, the

*Table 2.* Consumption of some major food groups in South America as percentage of total energy.

| SA[a] Regions | Country | Cereals (%) | Other starchy food (%) | Vegs and fruits (%) | Meat (%) | Milk and dairy products (%) |
|---|---|---|---|---|---|---|
| *Eastern* | Brazil | 34.9 | 19.8 | 6.9 | 17.6 | 13.5 |
| *Northern* | Colombia | 33.1 | 32.3 | 5.8 | 17.6 | 12.3 |
| | Ecuador | 35.9 | 21.3 | 4.8 | 12.7 | 15.2 |
| | French Guyana | 31.5 | 13.5 | 13.8 | 43.6 | 16.4 |
| | Guyana | 49.0 | 15.1 | 4.8 | 13.3 | 15.8 |
| | Suriname | 50.8 | 7.8 | 6.4 | 17.0 | 11.1 |
| | Venezuela | 51.8 | 14.1 | 3.7 | 13.9 | 11.7 |
| *Southern* | Argentina | 31.5 | 12.0 | 9.0 | 44.9 | 18.1 |
| | Chile | 46.5 | 9.4 | 10.1 | 20.0 | 12.9 |
| | Uruguay | 34.6 | 9.4 | 7.4 | 38.2 | 35.7 |
| *Western* | Bolivia | 42.8 | 32.3 | 7.4 | 24.9 | 4.7 |
| | Paraguay | 31.0 | 41.2 | 11.1 | 31.5 | 7.0 |
| | Peru | 46.4 | 21.4 | 6.9 | 15.2 | 10.5 |

Source: WCRF/AICR, 1997 (modified by Scussel, 2003).
[a]South America.

Mercosul countries have established MRLs on milk products of 0.5 μg/Kg (natural) and 5.0 μg/Kg (powdered). Each country that belongs to Mercosul also has its own regulations. For example, Argentina allows only 5 μg/Kg of $AFB_1$ in peanuts, corn, and related products (Brazil, 1996; Fonseca, 2003). A zero tolerance for $AFB_1$ is mandated in all baby food products. It seems that Colombia, Suriname, Venezuela, and Uruguay should modify their MRL for AFLs, which remains high (30 μg/Kg) for cereal, peanuts, and related food products.

### D. Aflatoxin Exposure in South American Population

Without governmental policies and thresholds to regulate AFL levels in food supplies, the human population in SA is exposed continuously to these mycotoxins. Although there are some data suggesting that exposure to food contaminated with AFL can lead to hepatocellular carcinoma (HCC), there is a lack of published data on acute and chronic human aflatoxicosis outbreaks in SA communities. Although the data are scarce or nonexistent, AFL exposure remains an important issue concerning food safety and public health. Safety assessment needs to be addressed by SA countries since data suggest that long-term exposure might lead to HCC development or other diseases (Van Rensberg, 1977). An Argentina study performed by Lopes et al. (1997) showed 0.47 ng/mL (Limit of detection LDC = 250 pg/mL) $AFB_1$ in one of 13 blood samples from donors with hepatic diseases.

Evaluation of AFL exposure by measuring toxin levels in contaminated food can be difficult to interpret and to draw conclusions from, due to the heterogeneous distribution of AFLs. Additionally, dietary intake of a given food can be highly variable and unreliably reported. Genetic variability in $AFB_1$ metabolism may also influence the level of exposure at the individual level. Therefore, an alternative for evaluating AFL exposure is to estimate levels using specific biological markers (biomarkers) based on an understanding of the metabolism of the compound. For $AFB_1$, these include aflatoxin-N7-guanine ($AFB_1$-N7-gua) in the urine, or aflatoxin-albumin ($AFB_1$-alb) in the blood. Using the $AFB_1$-alb biomarker assay approach, a study was carried out by Haas et al. (2003) to assess the level of exposure to $AFB_1$ in a Brazilian population. A blood sample was taken from urban residents (n = 50; aged 18–52) in 1999 at the Blood Center of Antonio Carlos de Camargo Hospital, Sao Paulo. Serum albumin was extracted and digested, and $AFB_1$-alb adduct levels were determined by enzyme linked immunosorbent assay (ELISA). $AFB_1$-alb adducts were detected in 31/50 (62%) samples [range was from 0 to 57.3 pg $AFB_1$-lys adducts/mg of blood albumin (pg/mg)]. The mean level for those

*Table 3.* Aflatoxin regulation for foods consumed by humans in countries of South America.

| Country | Food | | Aflatoxin | |
|---|---|---|---|---|
| | Raw | Products | Type | MRL[a] (μg/Kg) |
| Argentina | – | Baby food | $AFB_1$ | Zero |
| | Peanuts | Peanut products ($AFB_1$: 5 μg/kg) | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Corn | Corn products ($AFB_1$: 5 μg/kg) | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | – | Soy meal | $AFB_1$ | 30 |
| | Milk | Milk powder | $AFM_1$ | 0.05 |
| | – | Milk products | $AFM_1$ | 0.5 |
| Brazil[b,c] | Peanuts (With/without hull-peel) | Peanut (toasted, roasted) | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | | Peanut butter | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Corn (Whole/broken/smashed) | Corn flours (Whole/no germ) | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Milk | – | $AFM_1$ | 0.5 |
| | Milk | Milk powder | $AFM_1$ | 5.0 |
| Colombia | Foods | Foods | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Cereal (sorghum, millet) | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 30 |
| | Oilseeds | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 10 |
| | Sesame seeds | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |

| | | | | |
|---|---|---|---|---|
| Mercosul[d] | Peanuts (With/without hull-peel) | Peanut (toasted, roasted) Peanut butter | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Corn | Corn flour (whole/no germ) | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | – | Cornmeal | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | Milk | – | $AFM_1$ | 0.5 |
| | – | Milk powder | $AFM_1$ | 5.0 |
| Peru | All foods | All foods | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 10 |
| Suriname | Peanuts | Peanut products | $AFB_1$ | 5 |
| | Pulses | – | $AFB_1$ | 5 |
| | Corn | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 30 |
| Uruguay | Peanuts | Peanut products | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 30 |
| | Food and spices | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 20 |
| | – | Soy products | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 30 |
| | – | Dried fruits | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 30 |
| | Cocoa | – | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 10 |
| | – | Baby food | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 3 |
| | Milk | Milk products | $AFM_1$ | 0.5 |
| Venezuela | – | Rice flour | $AFB_1 + AFB_2 + AFG_1 + AFG_2$ | 5 |

[a]Maximum residue level.
[b](Brazil, 1996).
[c](Brazil, 2000).
[d](Fonseca, 2003).

individuals that tested positive was 14.9 pg/mg. Males had the two highest levels measured at 57.1 and 57.3 pg/mg. The levels in this study were similar to those observed in the Philippines (Tan et al., 1995). This was the first study from SA that determined exposure of $AFB_1$ on individuals using the biomarker approach. These data warrant further investigation of both the sources and consequences of exposure to this potent toxin in Brazil and other SA countries.

The purpose of this review is to summarize recent literature published over the previous decade (after 1993) on the natural occurrence of AFLs in SA. This information serves as an indicator of the current research effort and the various areas of interest in the countries across the continent. Due to the small quantity of SA data published in English-language journals, which do not represent the real data produced in that continent, data published in journals of Spanish or Portuguese language, some good quality data published in the Latin American (LA) Mycotoxicology Conference Proceedings, and official data obtained from SA private and governmental accredited laboratories of mycotoxin analysis are presented here. In order to maintain regional perspectives, this review has been subdivided into the geographical areas of northern (Ecuador, Colombia, French Guyana, Guyana, Suriname, Venezuela), southern (Argentina, Chile, and Uruguay), eastern (Brazil—a major region by itself), and western (Bolivia, Peru, and Paraguay) SA. I am going to start the discussion with the eastern region, as most AFL data are from that region.

## II. CLIMATE

AFLs are produced by *Aspergillus flavus* Link and *A. parasiticus* Speare. The optimal thermal conditions for growth of these fungi are from 36° to 38°C, while maximum toxin production occurs between 25° and 27°C. Fungal growth in storage facilities is favored by relative humidity above 85%. Since suitable conditions for their growth and toxin production occur in most areas of SA, AFL contamination of food is problematic in most parts of the continent. Variable climate conditions and the specific type of commodity can also lead to differences and prevalence of fungal species in the regions, and therefore the toxins produced (Shephard, 2003). Climate in SA is quite diversified with equatorial and tropical climates to the north and west, and subtropical and temperate climates in the center and south of the continent. South America contains areas of dense forests, deserts, and prairies, making part of it an excellent ground for crops but also for fungi growth. Considering variations in temperature and relative humidity, AFLs as well as other mycotoxins, such as deoxynivalenol (DON), $T_{-2}$ toxin, fumonisins (FBs), and zearalenone (ZEA) produced by *Fusarium* spp., occur in the southern region of SA, including southeast and southern Brazil. An exception would be the dry climate (semi-arid in the north and arid in the south) of Argentina, north of Chile, and the sea coast of Peru.

### A. Droughts and Food Supply

Food safety with its emphasis on food quality is an issue that must be balanced by food security and sufficiency of supply. There are areas where food shortages are caused by recurrent climate variations such as drought or too much rain leading to crop spoilage by fungi and/or AFL contamination (fungus stress). Many subsistence-farming communities in SA depend upon consumption of homegrown crops, irrespective of their quality. This especially happens in countries such as Peru, Bolivia, Suriname, or Paraguay that have lower income (lack of information or regulations, laboratories for mycotoxin analysis, and/or monitoring programs). Droughts during winter 2003 in a number of countries of southern SA have reduced staple food supplies. The reality for rural subsistence farmers, extensive for all SA countries, is that, irrespective of food quality, lack of economic alternatives frequently means that all food produced must be consumed by the local community. This leads to $AFB_1$ exposure. In addition, even with adequate crops, poor traditional storage facilities can lead to fungal deterioration of crops. Considering the above, it is not surprising that fungal contamination of SA staple foods is an area of major concern for food safety experts.

## III. NATURAL OCCURRENCE OF AFLATOXINS IN SOUTH AMERICAN COUNTRIES

### A. Country of Eastern South America

#### 1. Brazil Agriculture and Mycotoxins

Brazil is the fifth largest country (8,551,996 $Km^2$) and the largest country in SA. It has one-third of the world's total tropical rain forests and the four main climate zones (Equatorial, Tropical, Sub-tropical, and Temperate) are represented within. Therefore, this climate diversity offers optimal conditions of temperature and moisture for different species of fungi growth and types of mycotoxins to be produced. Moreover, Brazil soil is very rich in organic matter, allowing a large area for production of grain and other food commodities. In fact, Brazil has the greatest economic potential of SA and is the main exporter of agricultural products, including soybean, coffee, corn, sugar, and cocoa.

Brazil is divided into five regions (North, Northeast, Centralwest, South, and Southeast). The North and Northeast regions have average temperatures of 26°C and rainfall greater than 2500 mm/year. The Centralwest and Southeast regions have dry winters, wet summers and rainfall from 1000 to 1500 mm/year. On the other hand, the South region has milder temperatures and rainfall of 1500 to 2000 mm/year. It has four very well-defined seasons and balanced amounts of rainfall throughout the year. In fact it has a climate similar to Argentina and Uruguay (SA southern region).

Brazil's well-developed commercial farming sector is located mainly in the South and Centralwest regions, where most grain (corn and soy) production is produced for export (Conab, 2003). There are also agricultural cooperatives throughout these regions that have high quality grain/farming equipment and storage facilities to be shared by the members. This leads to excellent grain handling and good storage practices. Prevention and control procedures to reduce mycotoxin formation in crops are very well established by the cooperatives.

Nevertheless, mycotoxin contaminated foods are present, especially during drought or other stress conditions such as flood or high insect proliferation in the field. The major concern in Brazil is still the AFLs. Peanuts are the main crop affected. The prevalence of AFL contamination in corn is lower. Other mycotoxins such as ochratoxin A (OTA), ZEA, DON, and FBs are known to contaminate corn, beans, and wheat in Brazil. However, depending on the Brazilian region, their occurrence varies. Some regions must monitor AFLs and OTA contamination in crops, but also some *Fusarium* toxins. Conversely, in the southern region of Brazil, *Fusarium* toxins (FBs, trichothecenes, and ZEA) are the biggest concern. However, AFL contamination is constantly being monitored for food in the South.

As far as Brazilian laboratory accreditation and monitoring programs are concerned, the Brazilian Agriculture Ministry (MA) has established laboratory accreditation for AFL analysis. The MA's reference laboratory is located in the state of Minas Gerais (MG). For a laboratory to be accredited, it must meet several criteria set by the reference laboratory. This includes practices and procedures related to methodology, safety, reference standard handling, sampling procedures, and staff training. Monitoring programs have been carried out throughout the country by the MA (Brazil, 1997) and the Ministry of Health (MH) through the Sanitary Vigilance Agency.

## 2. Aflatoxins in the Brazilian Diet

There has been a large amount of research in Brazil concerning AFLs and other mycotoxin food contamination as it relates to human health. Studies include the identification of various toxigenic fungi genera and species, mapping of different crop regions, method development, and agronomic and storage practices to reduce AFL contamination. Aflatoxins are currently being monitored in several different foods (apart from peanuts and corn), as well as $AFM_1$ in milk. Most data reported on mycotoxins are focused in the southeastern and southern regions of Brazil. Mainly this data is on processed peanuts and corn but also beans, rice, wheat, Brazil nuts, dried fruits, and other commodities. However, most of the data has been obtained from peanuts, corn, and milk due to Brazilian regulatory policies on these foods.

(a) Peanuts: most of Brazil's peanut production comes from the state of São Paulo (SP) (Fonseca et al., 1998). Table 4 shows data obtained for AFL contamination from the South and Southeast regions of Brazil for commercialized raw and processed peanuts. The percentage of positive samples varied from ca. 8% to 80% of total samples, irrespective of the harvesting year. Levels ranged from 2 to 16,862 μg/Kg. The high level detected in peanut commercialized in Rio Grande do Sul (RS) corresponded to a single sample (Mallman, 2000). These data show that AFL contamination in peanuts and peanut products in Brazil is still a serious problem. Occasionally, disturbingly high levels of AFL were identified in peanuts from SP and RS. High AFL levels in peanuts suggest that more adequate control measures need to be introduced. São Paulo has improved its agricultural practices for harvesting, storing, and processing peanuts in order to reduce contamination. It is important to emphasize that most of the peanut products in the South region came from SP, but that these same products were packed and commercialized in the southern states of RS, SC, or Parana (PR). The most recent data collected for quantifying levels of AFLs were obtained from official and private laboratories that monitor commercialized foods in Brazil.

(b) Brazilian staple foods: the country's main dietary staples include rice and black beans (*Phaseolus vulgaris* L.), but also processed wheat and corn. Although some AFLs have been detected in all of these commodities, the occurrence is not as frequent as for peanuts, and levels of contamination are less (Table 5). In fact, the most prevalent mycotoxin in black beans is OTA (Costa,

*Table 4.* Aflatoxin contamination in raw and processed peanuts commercialized in different Brazilian regions.

| Brazilian | | | | | Positive sample (µg/Kg) | | | |
|---|---|---|---|---|---|---|---|---|
| Region | State | Year | Aflatoxins | Positive/total sample | Range | Mean | Detection | References |
| Southeast | SP | 94 | $AFB_1 + AFG_1$[a] | 32/66 | 28–997 ($B_1$) 14–149 ($G_1$) | NA | TLC | Brigido et al., 1995 |
| | SP | 90–96 | $AFB_1 + AFG_1$ | 279/1115 | 63–948 | NA | TLC | Fonseca et al., 1998 |
| | SP | 95–96 | $AFB_1 + AFG_1$ | 41/80 | 1099 (max) | 266 | TLC | Freitas and Brigido, 1998 |
| | SP | 90–91 | $AFB_1 + AFG_1$ | 205/316 | 4–195 | NA | TLC | Freitas and Baldolato, 1992 |
| | SP | NA | $AFB_1 + AFG_1$ | 3/25 | 2–1000 | NA | TLC | Miranda, 1996 |
| | SP | 96–97 | AFLs | 53/108 | 29–1178 | NA | TLC | Oliveira et al., 1998 |
| | SP | 94 | $AFB_1 + AFG_1$ | 142/321 | 5–2440 | 305 | TLC | Sabino et al., 1999a |
| | SP | 95–97 | AFB1 + AFG1 | 62/137 | 5–536 | NA | TLC | Sabino et al., 1999b |
| | SP | NA | AFLs | 9.6/10 | 0.2–44.7 | NA | TLC | Stefanovitz et al., 1996 |
| | SP | NA | $AFB_1 + AFG_1$ | 51/99 | 8–2152 | NA | HPLC | Sylos et al., 1996 |
| | SP | NA | AFL | 8/30 | 5–233 | NA | TLC | Sylos, 2000 |
| | SP | NA | AFLs | 209/272 | $2 \geq 22$ | NA | TLC | Vieira et al., 1996 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Southern | RS | NA | AFLs | 36/59 | 805 (max) | NA | TLC | Baldissera et al., 1992 |
| | RS | 97 | AFLs | 36/213 | 3.2–25.6 | NA | TLC | Pitch et al., 1998 |
| | RS | 86–00 | AFLs | 43/524 | 584–16862 | NA | HPLC | Mallmann, 2000 |
| | RS | 98–99 | AFLs | 63/210 | 5–2227 | NA | TLC | Nordin, 2000a |
| | RS | 97–00 | AFLs | 157/544 | 3–6018 | NA | TLC | Nordin, 2000b |
| | SC | 97 | AFLs | 5/72 | $2^b$–53 | NA | TLC | Costa and Scussel, 1998 |
| | SC | 97–98 | AFLs | 12/131 | 57–127 | NA | TLC | Costa and Scussel, 1999a |
| | SC | 98–00 | AFLs | 72/246 | $2^b$–74 | NA | TLC | Costa and Scussel, 1999b |
| | SC | 00–02 | AFLs | 17/147 | $2^b$–120 | NA | TLC | Costa et al., 2002 |
| | SC | 98–99 | AFLs | 16/106 | 33.4–127.3 | NA | TLC | Scussel et al., 1999 |
| | SC | 01–03 | $AFB_1 + AFG_1$ | 19/214 | $2^b$–641 | 221.2 | TLC | Scussel et al., 2003 |
| Others | FD | 85–95 | $AFB_1 + AFG_1$ | 89/450 | < 10–600 | NA | TLC | Silva et al., 1996 |
| | PE | 89–91 | $AFB_1 + AFG_1$ | 21/43 | 25–518 | NA | TLC | Colaço et al., 1994 |

Note: AFLs: aflatoxins ($AFB_1 + FB_2 + AFG_1 + AFG_2$), FD Federal District, AM: Amazonas, SP: São Paulo, PR: Paraná, RJ: Rio de Janeiro, MG: Minas Gerais, SC: Santa Catarina, GO: Goiás, PE: Pernanbuco, RS: Rio Grande do Sul, BA: Bahia, MG/S: Mato Grosso do Sul, TLC: thin layer chromatography, HPLC: high-performance liquid chromatography, NA: data not available.

[a]Brazilian regulation up to 1996 = $AFB_1 + AFG_1$ (30 μg/Kg).

[b]LDQ: 2 μg/kg (limit of quantification).

*Table 5.* Aflatoxin contamination in raw and processed food commercialized in different Brazilian regions.

| Brazilian Region | State | Commodity | Year | Aflatoxins | Positive/ total sample | Positive sample (μg/Kg) Range | Mean | Detection | References |
|---|---|---|---|---|---|---|---|---|---|
| Southeastern | MG | Corn | 92–93 | AFLs | 0/40 | NA | NA | TLC | Nicacio et al., 1995 |
| | SP | Corn | 91 | AFLs | 1/30 | 500 | NA | TLC | Pozzi et al., 1995 |
| | SP | Organic and morning cereals | 91 | AFLs | 0/103 | NA | NA | TLC | Soares and Furlanni, 1996a |
| | SP | Wheat | 90 | AFLs | 0/20 | NA | NA | TLC | Furlong et al., 1995a |
| | SP | Wheat, products | 91 | AFLs | 0/38 | NA | NA | TLC | Soares and Furlanni, 1996b |
| Southern | SC | Beans | 97–98 | $AFB_1$ | 4/72 | 2[a] | 2 | TLC | Costa, 2000 |
| | SC | Corn | 01–02 | AFLs | 1/30 | 18 | NA | TLC | Costa et al., 2002 |
| | SC | Corn | 01–03 | AFLs | 7/84 | 2–256.4 | 38.6 | TLC | Labmico, SC, 2003 |
| | RS | Corn | 86–97 | AFLs | 1273/2460 | NA | 36.2 | TLC | Santurio et al., 1997 |
| | SC | Dried fruits | 03 | AFLs | 3/90 | 2–6 | 3.3 | TLC | Robert et al., 2004 |
| \| | RS | Beans | 97–00 | AFLs | 2/100 | 21–38 | 29.5 | TLC | Nordin, 2000 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | RS | Corn products | 97–00 | AFLs | 59/296 | 3.18–67 | NA | TLC | Nordin, 2000 |
| | RG | Corn for feed | 93–94 | $AFB_1$ | 1/115 | 10 | 10 | TLC | Nordin and Luchese, 1998 |
| | RG | Sorghum | 93–03 | AFLs | NA/804 | 60–146 | 0–96 | TLC | Labmic, RS, 2003 |
| | PR | Wheat and wheat flour | 03 | AFBs | 0/38 | ND | NA | TLC | Birck et al., 2003 |
| | RS | Wheat | 88–90 | AFLs | 0/16 | NA | NA | TLC | Furlong et al., 1995b |
| Others | Several states[a] | Beans | 96–97 | AFLs | 92/481 | 53.4/160.3 | NA | TLC | Scussel et al., 1997 |
| | FD | Beans/rice/corn/wheat/feed | 85–95 | $AFB_1AFG_1$ | 0/114 | NA | NA | TLC | Silva et al., 1996 |
| | SP PR MGS MG GO | Corn | 93–94 | $AFB_1$ | 97/292 | 2–89 | NA | TLC | Gloria et al., 1997 |
| | | Corn | 93–94 | $AFB_2$ | 33/292 | 1–17 | NA | TLC | Gloria et al., 1997 |
| | | Corn | 93–94 | $AFG_1$ | 13/292 | 2–85 | NA | TLC | Gloria et al., 1997 |
| | | Corn | 93–94 | $AFG_2$ | 7/292 | 1–6 | NA | TCL | Gloria et al., 1997 |
| | AM | Feed | 95 | AFLs | 0/60 | NA | NA | TLC | Oliveira et al., 1997 |
| | FD | Nuts | 85–95 | $AFB_1AFG_1$ | 1/117 | 1200 | 1200 | TLC | Silva et al., 1996 |

Note: AFLs; aflatoxins ($AFB_1 + FB_2 + AFG_1 + AFG_2$), AM: Amazonas, BA: Bahia, AC: Acre, FD: Federal District, GO: Goiás, MGS: Mato Grosso do Sul, MG: Minas Gerais, PR: Paraná, RJ: Rio de Janeiro, RS: Rio Grande do Sul, SC: Santa Catarina, SP: São Paulo, PE: Pernanbuco, TLC: thin layer chromatography, HPLC: high-performance liquid chromatography, NA: data not available.

[a]LDQ: 2 μg/kg (limit of quantification).

[a]BA CE (Ceara) GO MG MGS PR RS SC SP states.

2000). Brazilian corn has less AFL contamination compared with peanuts, too. Most reports suggest levels ranging from 2 to 256.4 μg/Kg. Only one sample out of 30 from SP was contaminated with 500 μg/Kg of AFLs (Pozzi et al., 1995). In a recent survey, 84 corn samples were collected from supermarkets in SC for AFL analysis. Only seven were contaminated with AFLs with a maximum of 256.4 μg/Kg) and a mean of 38.6 μg/Kg (Labmico, 2003). Wheat contamination has always been reportedly lower than peanuts contamination. The detected reported levels were shown to be 38 μg/Kg in both 1990 and 2003 (Birck et al., 2003; Soares and Furlanni, 1996b).

(c) Milk and dairy products: when corn and other AFL-contaminated crops are used for feeding dairy cattle, $AFB_1$ will be metabolized to $AFM_1$. Levels of $AFM_1$ have been identified in cows' milk ranging from 0.073 to 2.920 μg/Kg ($MRL_{Brazil}$: 0.5 μg/Kg). Therefore, AFLs and $AFM_1$ are currently being monitored in cow silage/feeds and in milk to assure milk quality for the Brazilian population. As shown in Table 6, the state of MG reported that cheese from the city of Belo Horizonte had maximum $AFM_1$ levels of 6.920 μg/Kg (Prado et al., 2000). In contrast, milk analyzed in SC in 2001 and 2003 did not contain $AFM_1$ up to the limit of quantification LOQ (0.005 μg/Kg). These data suggest that high quality silage and feed are being used to feed milking cows in this region of Brazil.

(d) Brazil nuts: Brazil nuts are an important product for the northern economy of Brazil (especially for the states of Acre, Amazon, Para, and Macapa). However, there are some constraints on their export when sold in shells, due to AFL contamination. Studies have been carried out to evaluate AFL contamination and to assess the risk points prior to harvesting or processing of Brazil nuts. Cartaxo et al. (2003) studied the occurrence of filamentous fungi and AFL contamination of Brazil nuts in shell. Nuts were collected from dense rain forest in the state of Acre after pods fell naturally from trees and analyzed for fungi and AFLs. *Aspergillus flavus* and *A. niger* were the predominant species throughout the harvesting period (90 days). Although fungus was detected, no AFL contamination was observed, suggesting that environmental conditions in the forest are not suitable for toxin production. However, the presence of fungi indicates the need for rigorous quality control of temperature and humidity, especially during transport and storage of in-shell Brazil nuts. However, when

***Table 6.*** Aflatoxin contamination in milk, milk products, and eggs commercialized in different Brazilian states.

| Brazilian | | | | | | Positive sample (μg/Kg) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | State | Commodity | Year | Aflatoxins | Positive/ total sample | Range | Mean | Detection | Reference |
| Southeast | MG | Cheese | 00 | $AFM_1$ | 56/75 | 0.020–6.920 | 0.62 | HPLC | Prado et al., 2000 |
| | SP | Cheese, yogurt | 90 | $AFM_1$ | 0/66 | ND | ND | HPLC | Sylos and Rodriguez-Amaya, 1996 |
| | RJ | Egg | NA | $AFB_1$ | 2/120 | 2–5 | 3 | TLC | Fraga et al., 1996 |
| | RJ | Egg | NA | $AFM_1$ | 0/120 | ND | ND | TLC | Fraga et al., 1996 |
| | SP | Milk (pasteurized) | 92 | $AFM_1$ | 4/52 | 0.073–0.370 | 0.156 | HPLC | Sylos and Rodriguez-Amaya, 1996 |
| | SP | Milk *in natura* | 92–93 | $AFM_1$ | 0/144 | ND | ND | TLC | Correa et al., 1997 |
| | SP | Milk powder (disolved) | 92–93 | $AFM_1$ | 33/300 | 0.100–1.000 | 0.270 | ELISA | Oliveira et al., 1997 |
| South | RS | Milk *in natura* | 95–96 | $AFM_1$ | 11/240 | 0.198–2.920 | NA | HPLC | Mallman et al., 1997 |
| | RS | Milk *in natura* (tetrapack) | 95–96 | $AFM_1$ | 3/35 | 0.197–0.418 | NA | HPLC | Mallman et al., 1997 |
| | SC | Milk *in natura*[b] | 01 | $AFM_1$ | 0[a]/20 | ND | ND | HPLC | Labmico, SC, 2003 |
| | SC | Milk *in natura* (tetrapack) | 03 | $AFM_1$ | 0[a]/25 | ND | ND | HPLC | Seo et al., 2003 |

Note: MG: Minas Gerais, RJ: Rio de Janeiro, RS: Rio Grande do Sul, SC: Santa Catarina, SP: São Paulo, TLC: thin layer chromatography, HPLC: high-performance liquid chromatography, ELISA: enzyme linked immunesorbent assay, ND: not detected, NA: data not available.

[a]LDQ: 0.5 ppb.

[b]Tetrapack carton and polyethelene bags LDQ: 2 μg/kg (limit of quantification).

*Table 7.* Aflatoxin contamination in tree nuts commercialized in different Brazilian states with respective LOD and LOQ.

| | | Sample | | | Positive samples (μg/Kg) | | | Detection (μg/Kg) TLC | | Detection (μg/Kg) HPLC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree nuts[b] | State | Total | Year | Range | Mean | > LOQ[b] | < LOQ | LOD | LOQ | LOD | LOQ | References[a] |
| Brazil nuts | | | | | | | | | | | | |
| In shell | MA | 120 | 02[a] | 8.0/686 | 171.4 | 30 | ND | 2.0 | 2.0 | – | – | Nutricon, 2003[c] |
| | SP | 164 | 01–03 | 1.0/1.076 | 179 | 148 | 16 | < 1 | ≥ 1 | – | – | Esalq, 2003[d] |
| Shelled | RS | 14 | 00–03 | ND | ND | ND | ND | 5 | 5 | – | – | Cientec, 2003[d] |
| | SC | 63 | 03 | ND | ND | ND | ND | 2 | 2 | – | – | Labmico, 2003[d] |
| Almond | SP | 09 | 01–03 | 27.5/27.5 | 27.5 | 1 | 8 | < 1 | ≥ 1 | | | Esalq, 2003[d] |
| Hazelnuts | RS | 04 | 01–02 | ND | ND | ND | ND | 5 | 5 | – | – | Labmic, 2003[d] |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cashew nut | SP | 23 | 02–03 | 2.0/8.0 | 4.4 | 11 | 12 | < 1 | ≥ 1 | – | – | Esalq, 2003[d] |
| Walnuts | RS | 14 | 93–03 | 3.0 | 0.8 | 2 | 12 | – | – | – | 1 | Labmic, 2003[d] |
| Pecan | RS | 13 | 00 | ND | ND | ND | ND | 5 | 5 | – | – | Cientec, 2003[d] |

[a]Accreditated laboratory data. ND: not detected, LOQ: limit of quantification, LOD: limit of detection, ND: not detected, MA: Amazon, RS: Rio Grande do Sul, SC: Santa Catarian, SP: São Paulo.

[b]Brazil nut samples: (a) from MA state were (in shell) collected in the Amazon forest and analyzed prior to processing (vapor shelling) for export.
(b) from other states were (without shell and peeled) collected from supermarkets and commercialized in Brazil (packed in plastic containers).
(c) other tree nuts (with shell and peel except for cashew nuts) collected from supermarkets and commercialized in Brazil (packed in plastic bags).

Sampling: [c]Brazil, MAPA, 1998. [d]Randomly from supermarkets.

$AFL = AFB_1 + AFB_2 + AFG_1 + AFG_2$.

Brazil nuts are shelled, AFLs are seldom detected as shown in Table 7 (Scussel et al., 2004).

### 3. Population Exposure vs. Staple Food

Cancer is the second leading cause of death in Brazil. Hepatocellular carcinoma (HCC) is the eighth most common cancer in the world and represents ca. 4% of death in Brazil (FOSP, 2003). However, there is a lack of proper registry for cases of cancer in several regions of Brazil, suggesting that the real situation could be worse. In a study carried out by the Brazilian Institute of Cancer, from a total 2066 HCC cases registered (1981 to 1985), 166, 110, and 45 cases were from PR, RS, and SC states, respectively (South region of Brazil). On the other hand, 608 registered cases were from the state of SP (Southeast region) (INCA, 1991, 2003). As far as Brazilian data reported internationally (by IARC) is concerned, only a few data are available, and they are from three Brazilian states (Para, Goias, and RS), being 7/6, 42/34, and 117/83 cases of HCC for males/females, on a total of 2093/2794, 3095/3702, and 5436/5865 cases of cancer registered in their respective capital cities: Belem, Goiania, and Porto Alegre (Parkin et al., 1997).

Brazil has an internationally recognized reputation for AFL contamination in foods, especially peanuts and to a lesser extent, their products. However, only one report in literature has been cited concerning the levels of Brazilian population exposure to $AFB_1$ and its relations to HCC. Haas et al. (2003) reported a mean level of 14.9 pg of $AFB_1$-Lys/mg using blood samples collected from individuals during the ''Fiestas juninas'' (winter parties where main foods consumed are made with peanuts and corn). These observations in Brazil were similar to those in the Philippines, using the $AFB_1$ biomarker ($AFB_1$-alb adducts) detection method.

A relationship between $AFB_1$ and hepatitis virus (HBV) in the etiology of HCC has been reported (Wild et al., 1993, 1995). Major risk factors for HCC in high-risk areas are chronic infection with HBV and dietary exposure to AFLs. Hepatitus virus infection can alter hepatic metabolism of AFL, leading to increased DNA damage for a given level of exposure. The potency of $AFB_1$ as a hepatocarcinogenic agent increases some thirty-fold in the presence of HBV. A survey on type and incidence of hepatic disease (cirrosis, hepatitis, and HCC) cases in children and adults, registered in the cancer reference hospital Joana de Gusmao located in SC, was carried out by Haas and Scussel (1999). Incidence of cirrhosis and hepatitis corresponded to 46% and 40% of the cases, respectively, while the number of reported HCC cases was 14%. Sixty-four percent of the hepatitis cases were caused by virus infection while 22% were autoimmune. The virus A and B hepatitis (HAV and HBV) was 7.1% and 21.4% of the total virus cases, respectively. Although the HCC incidence in SC has been low in relation to other HD studies between 1980 and 1997, the authors emphasize that the hepatitis virus had a high participation, especially by HBV infection. In adults, the incidence of hepatitis and of HCC were lower (14.3 and 11.7% of cases). Apart from HBV that could lead to HCC in the SC populace, one should take into account diet and possibility of $AFB_1$ contamination. The populace of the southeast and southern regions of Brazil consumes large quantities of peanut snacks and a sort of hard peanut paste (pacoquinha) that is preferred by children—the most sensitive group to $AFB_1$ toxic effects.

## B. Countries of Southern South America

The countries of the SA southern region also are called countries of the Southern Cone and are the major exporters of beef and grain. Their terrains consist of desert, grasslands, temperate forests, and glaciers. Argentina and Uruguay have mild winters and regular rainfall throughout the year.

Argentina and Uruguay: several studies have been published on mycotoxins in Argentina and Uruguay. However, there is still a lack of results on the real AFL exposure on the populace in the southern regions of those countries. Contamination with *Fusarium* toxins on agricultural crops including wheat, corn, sunflower seeds, and soybean is a major concern in these two countries. Peanuts contaminated with AFLs grown for export also are an issue, especially in Argentina. Although Uruguay is smaller compared to the main SA agricultural countries, it has been investigating mycotoxins in a temperate climate environment. These include esporodesmins, cyclopiazonic acid, and Ergot toxins. Uruguay also monitors AFLs throughout the country. Table 8 shows data from the southern region for several commodities. Data reported by Resnik et al. (1996) showed that AFL contamination in the corn crop was greatest in Argentina from 1990 to 1992, reaching a maximum of 200 μg/kg in 1991. Conversely, for the 1994 and 1995 planting seasons in Argentina, no AFL contamination was observed in 30 samples of corn (Gonzales et al., 1999). During the 1993–1995 planting seasons in Uruguay 71 corn samples were analyzed for the presence of AFL and contamination reached maximal level of 20 μg/Kg. Crops such as wheat, barley, soybean, dried fruits, and vegetables had a greater number of samples analyzed than for corn and presented AFL contamination up to the MRL allowed by the Mercosul (20 μg/Kg).

Chile: AFL contamination in foodstuffs and feeds from Chile is not defined yet. There simply has not been a much published data on

*Table 8.* Aflatoxin contamination in raw and processed food from Southern region of the South American continent.

| Country | Commodity | Crop year | Aflatoxin | Positive/ total sample | Positive sample (μg/Kg) Range | Mean | Detection | Reference |
|---|---|---|---|---|---|---|---|---|
| Argentina | Corn[a] | 88,93,94 | $AFB_1$ | 0/682 | ND | ND | TLC | Resnik et al., 1996 |
| | | 90 | $AFB_1$ | 123/491 | 160 (max) | 8 | | |
| | | 91 | $AFB_1$ | 90/288 | 200 (max) | 9 | | |
| | | 92 | $AFB_1$ | 94/349 | 30 (max) | 4 | | |
| Argentina | Corn[b] | 94–95 | AFLs | 0/30 | ND | ND | TLC | Gonzales et al., 1999 |
| Argentina | Polenta[e] | 96 | $AFB_1$ | 65/135 | tr-24 | NA | TLC | Garbini et al., 1997 |
| Argentina | Cornmeal, flakes[c] | 97 | AFLs | 0/38 | ND | NA | TLC | Solovey et al., 1999 |
| Chile | Several food | 97–00 | AFLs | 46/201 | 0.2–268 | NA | HPTLC | Vega et al., 2000 |
| Chile | Peanuts | 01–03 | AFLs | 2/466 | 1.3–17 | NA | HPTLC | Vega, 2003 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Uruguay[d] | Wheat | 93–95 | AFLs | 29/123 | $2 \geq 20$ | NA | TLC | Pineiro et al., 1996 |
| | Barley, malt | 93–95 | AFLs | 12/137 | $2 \geq 20$ | NA | | |
| | Rice, soybean, meat prods | 93–95 | AFLs | 0/140 | ND | NA | | |
| | Corn | 93–95 | AFLs | 1/71 | < 20 | NA | | |
| | Oilseeds | 93–95 | AFLs | 9/80 | $2 \geq 20$ | NA | | |
| | Dried fruits | 93–95 | AFLs | 6/157 | 2–20 | NA | | |
| | Dried vegetables | 93–95 | AFLs | 2/100 | 2–20 | NA | | |
| | Cocoa beans | 93–95 | AFLs | 3/91 | $2 \geq 20$ | NA | | |
| | Milk | 93–95 | $AFM_1$ | 7/22 | $2 \geq 20$ | NA | TLC | Pineiro et al., 1996 |
| | Butter | 93–95 | $AFM_1$ | 0/14 | ND | ND | TLC | |

Note: AFLs, aflatoxins ($AFB_1$ $FB_2$ $AFG_1$ $AFG_2$), TLC: thin layer chromatography, HPTLC: high-performance thin layer chromatography, NA: data not available, ND: not detected.

[a]Buenos Aires, Santa Fe.

[b]Buenos Aires, Cordoba, Santa Fe.

[c]Buenos Aires, Santa Fe.

[d]Various regions of the country.

[e]Hard porridge made with corn flour and hot water.

*Table 9.* Aflatoxin contamination in raw and processed food from Northern region of the South American continent.

| Country | Commodity | Crop year | Aflatoxin | Positive/ total sample | Positive sample (μg/Kg) Range | Mean | Detection | Reference |
|---|---|---|---|---|---|---|---|---|
| Colombia | Feedstuff | 95–96 | $AFB_1$ | 39/154 | 1–66 | 11 | HPLC | Cespedes and Diaz, 1997 |
| | | 95–96 | $AFB_2$ | 13/154 | 1–10 | 8 | | |
| Colombia | Feed | 95–96 | $AFB_1$ | 19/46 | 2–23 | 7 | HPLC | Cespedes and Diaz, 1997 |
| | | 95–96 | $AFB_2$ | 2/46 | 1–2 | 2 | | |
| Colombia | Corn | 02 | $AFB_1$ | 38/300 | 103 (max) | NA | HPLC | Diaz, 2003 |
| Ecuador | Feed (milking cows) | 00 | AFLs | 25/39 | 21–320 | NA | NA | Lucio et al., 2000 |
| Venezuela | Peanuts | 97 | | 9/54 | | | TLC | Carrara et al., 1997 |
| | Canned | | AFLs | 2/16 | NA | 9 | | |
| | Toasted in shell | | AFLs | 2/16 | NA | 28.5 | | |
| | In bags | | AFLs | 3/15 | NA | 23 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Toasted with sugar | | AFLs | 2/7 | NA | 4 | | |
| | Butter | | AFLs | 11/15 | tr-91 | NA | | |
| Venezuela | Sorghum | NA | $AFB_1$ $AFB_2$ $AFG_1$ | 31/47 | 0.375–2.5 | NA | TLC | Meléndez and Martinez, 1996 |
| Venezuela | Corn | 96 | $AFB_1$ | 2/20 | NA | NA | TLC | Loreto and Martinez, 1997 |
| | Rice | 96 | AFLs | 0/20 | ND | NA | TLC | |
| Venezuela | Corn[a] | 95–96[b] | AFLs | NA | 0–931.7 | NA | ELISA | Mazzani et al., 1997 |
| | | 95–96[c] | AFL | NA | 508–908 | NA | ELISA | |

Note: AFLs; aflatoxins ($AFB_1 + FB_2 + AFG_1 + AFG_2$), tr = traces (no LDC reported), ELISA: enzyme linked immunosorbent assay, TLC = thin layer chromatography, HPLC: high-performance liquid chromatography, NA: data not available, ND: not detected.
[a]Various cities.
[b]Sabana Larga.
[c]Sabana Para.

mycotoxins from Chile. Research projects that investigate AFL-producing fungi and their toxigenicity, as well as environment stress to Chilean crops, would provide insight as to whether AFL contamination of foodstuffs is an issue in this country.

### C. Countries of Northern South America

Countries in the SA Northern region are located near the Ecuator. This implies a region of high humidity, with constant rainfalls and hot temperatures throughout the year. The main crops produced in these countries are rice, corn, and coffee. Although rice is produced in all the countries, corn is grown mainly in Colombia, Venezuela, Guyana, and French Guyana. Coffee is the main crop of Colombia and Venezuela. The Northern region has countries of Creole culture such as Colombia and Venezuela, thus beans and rice are their everyday main source of energy. In contrast, in countries of indigenous Inca cultures such as Ecuador, corn is the staple food.

Colombia and Venezuela: from the Northern region of SA, data on mycotoxins has been published only from Colombia and Venezuela. Venezuela carried out work on AFL decontamination with ammonia (Martinez, 2000). Both countries have set standards for AFL contamination in foodstuffs. The Colombian government allows an MRL for AFL of 30 μg/Kg in cereals, 20 μg/Kg in sesame seeds, 10 μg/Kg in oil seeds, and 20 μg/Kg in all other foodstuffs. Venezuela regulates for AFLs in rice, with an MRL of 5 μg/Kg. Table 9 shows levels of AFL contamination in foods as reported by the Columbian and Venezuelan officials. In this study, 300 corn samples were analyzed in Colombia but only 38 were contaminated with AFLs. Diaz (2003) reported a maximum level of 103 μg/Kg in 2003. Colombia also grows peanuts, which contain AFLs. However, this issue seems to be more prevalent in animal feedstuff. Interestingly, feed and feedstuff produced in 1995 and 1996 had relatively low levels of AFL contamination (mean 11 and 8 μg/Kg, maximum 66 and 10 μg/kg for $AFB_1$ and $AFB_2$, respectively) (Cespedes and Diaz, 1997). Aflatoxins were detected in 16.7% of the samples in Venezuela when different peanut-related products (toasted in shell, packed in bags or canned, prepared with sugar and ground as peanut butter) were analyzed. Peanut butter reportedly had the highest levels of AFLs with 91 μg/Kg (Carrara et al., 1997). Venezuela analyzed corn grown in the crop year 1995–1996 for mycoflora and AFLs. Although the authors do not provide information with regards to the total number of samples contaminated, AFL levels for each region surveyed were as follows: 1) region I reported between trace levels to 931.7 μg/Kg; 2) region II reported between 508 to 931.7 μg/Kg, a very high AFL contamination level (Mazzani et al., 1997).

*Table 10.* Aflatoxin contamination in raw and processed food from Western region of the South American continent.

| Country | Commodity | Crop year | Mycotoxin | Positive/ total sample | Positive sample (µg/Kg) Range | Mean | Detection | Reference |
|---|---|---|---|---|---|---|---|---|
| Bolivia | Brazil nuts | | | | | | | |
| | Raw | NA | AFLs | NA/49 | 2.4–8.8 | NA | TLC | Morales and Flores, 1997 |
| | Processed | NA | AFLs | 0/71 | ND | ND | TLC | |
| Bolivia | Milk | NA | $AFM_1$ | 5/40 | NA | NA | HPLC | Gonzales and Morales, 2000 |

Note: AFLs: aflatoxins ($AFB_1 + FB_2 + AFG_1 + AFG_2$), NA: data not available, ND: not detected, TLC: thin layer chromatography, HPLC: high-performance liquid chromatography.

Ecuador, French Guyana, Guyana, and Suriname: Agricultural commodities from this region include rice, corn, cocoa, coffee, and manioc. While AFL or other mycotoxins are probably contaminating their crops, data is very difficult to obtain. A study performed in Ecuador reported AFL contamination in 63% of the samples that were used to feed milking cows (Lucio et al., 1997). The maximum level of AFL reported was 320 μg/Kg. The authors expressed concerns on the possibility that $AFM_1$, transferred via contaminated milk, could expose the public, especially children, and cause health related problems in the future.

### D. Countries of Western South America

These countries are of indigenous culture (Inca) and have corn and potato as their staple food. Paraguay produces peanuts, corn, soybean, and wheat. The most prevalent crops in Peru and Bolivia include coffee, rice, corn, and cocoa. These commodities are considered good substrates for aflatoxigenic fungi growth. Although they are located in a region where climate is suitable for fungal growth, published data are nonexistent or difficult to gather. Bolivia has reported some data on AFL contamination in Brazil nuts and milk (Table 10). Although the number of nut samples wasn't representative of the Bolivians production, a low contamination was detected (Morales and Flores, 1997). No $AFM_1$ was contaminating the 40 milk samples surveyed by Gonzales and Morales (2000). Indeed, these countries are the most impoverished in SA and there are minimal regulations, monitoring programs, and data available to evaluate public exposure levels of AFLs.

## IV. ORGANIZATION OF THE SA MYCOTOXICOLOGY RESEARCH COMMUNITY

It is important to emphasize that the Latin American (LA) scientists working in mycotoxin research organized the Latin American Society of Mycotoxicology (LASM) in 1996. The Society provides a forum on mycotoxins for scientists from Mexico, Central America, and SA, while organizing conferences and promoting mycotoxin training courses, reference laboratories, and harmonization of methodology and sampling plans. All of this is leading to more reliable data from LA. The LASM produces official documents to inform governmental and community sectors on the risks of mycotoxins for human and animal health. Also, it gathers an on-line database at the "LA Mycotoxicology Network Site," where members and nonmembers can share information on LA current publications (http://www.ufrrj.br/slam/).

## V. CONCLUSIONS

This review article shows that some countries of SA (Brazil, Argentina, Uruguay, Venezuela, and Colombia) are addressing the needs of the region by monitoring levels of AFLs in spite of constraints in human and material resources. However, these research activities must be extended to other SA countries as well. Data on AFL exposure using biomarkers have been carried out only in Brazil. Contamination of raw and processed food consumed by the population of SA is a reality. Therefore, the SA scientific community should consider evaluating levels of human exposure to $AFB_1$ by means of biomarkers. This technique seems to provide improved reliability compared with evaluating exposures through AFL detection in food (Van Rensberg, 1977). It is necessary to set regulations and control measurements for AFL for all SA countries in order to protect South Americans' health as well as to promote fair trade at the international level.

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*CONTENTS*



*(continued on inside back cover)*

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