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FW11032 Dietary Exposure to Aflatoxins: Risk Estimates and Proportionality of Exposure Source

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Scientific Interpretive Summary

This SIS is prepared by MPI risk assessors to provide context to the following report for MPI risk managers and external readers

The New Zealand Mycotoxin Surveillance Program 06-14 Report Series

FW11032 Dietary Exposure to Aflatoxins: Risk Estimates and Proportionality of Exposure Source

These reports are the outputs of MPIs ongoing mycotoxin surveillance programme. The nine reports form a series detailing the research undertaken over the last eight years to characterise and quantify the risk to the New Zealand public through the presence of mycotoxins in the food supply.

The nine reports are:

- Risk Profile: Mycotoxin in Foods 2006
- Aflatoxins in Maize Products 2008
- Aflatoxins and Ochratoxin A in Dried Fruits and Spices 2009
- Aflatoxins in Nuts and Nut Products 2010
- Dietary Exposure to Aflatoxins 2011
- Ochratoxin A in Cereal Products, Wine, Beer and Coffee 2011
- Trichothecene Mycotoxins in Cereal Products 2014
- Dietary Exposure to Ochratoxin A and Trichothecene Mycotoxins 2014
- Risk Profile: Mycotoxin in Foods 2014

<u>Dietary Exposure to Aflatoxins 2011</u>

As recognised liver carcinogens there was a priority in undertaking an exposure assessment for aflatoxins (AF) in the New Zealand diet.

Following three previous reports that had surveyed foods deemed at high risk of contamination to derive occurrence data there was now a sufficient understanding of levels in New Zealand foods from which to undertake and accurate exposure assessment.

This report details the two methodologies utilised to provide estimates of aflatoxins in the New Zealand diet, and the comparison of the resulting exposure estimates against health based guidance values.

Exposure values for New Zealanders from AF are presented for various age groups. The report notes exposure is deemed to be consistent with that reported in other developed countries. Spices were the predominant contributor, followed by nuts and nut products.

Risk estimates based on this exposure showed that there is a very low risk to public health. An estimated lifetime risk from the mean levels of AF for developing primary liver cancer was approximately one in a million.

DIETARY EXPOSURE TO AFLATOXINS: RISK ESTIMATES AND PROPORTIONALITY OF EXPOSURE SOURCE

Client Report FW11032

by

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DIETARY EXPOSURE TO AFLATOXINS: RISK ESTIMATES AND PROPORTIONALITY OF EXPOSURE SOURCE

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as part of overall contract for scientific services

Client Report FW11032

by

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May 2011

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Aflatoxins are toxic secondary metabolites produced by three species of *Aspergillus* mould: *A. flavus, A. parasiticus* and *A. nomius.* The major toxicological impact of aflatoxins on humans and animals is an increase in primary liver cancer (hepatocellular carcinoma).

Information on the prevalence and concentration of aflatoxins in foods available in New Zealand was collated and combined with information on consumption of these foods and the body weights of consumers to give estimates of dietary exposure to aflatoxins. Two food consumption models were used: simulated typical diets, to produce a deterministic estimate of aflatoxin exposure, and dietary recall information from the national nutrition surveys (dietary modelling), to give estimates of the distribution of aflatoxin exposure. Estimates were derived for a range of age-gender groups. Due to the high proportion of left-censored ('not detected') results for the analysis of aflatoxins in foods, exposure estimates were determined as a range (lower-upper bound).

Mean deterministic exposure estimates for total aflatoxins ranged from 0.19-0.21 ng/kg body weight/day for an adult female to 0.46-0.54 ng/kg body weight/day for a 5-6 years child. Aflatoxin B1 accounted for more than 80% of total aflatoxin dietary exposure. Exposure estimates were consistent with estimates from other developed countries and much lower than estimates from developing countries. Spices contribute the greatest proportion to overall aflatoxin exposure, followed by nuts and nut products. However, the predominance of spices in the exposure calculation is mostly due to a single very high concentration of aflatoxins (225 mg/kg total aflatoxins) detected in a sample of curry powder.

Mean estimates of dietary total aflatoxin exposure from dietary modelling were generally lower than deterministic estimates and ranged from 0.09-0.11 ng/kg body weight/day for an adult female to 0.030-0.036 ng/kg body weight/day for a 5-6 years child. Estimates of dietary total aflatoxin exposure at the 95th percentile level were also determined and ranged from 0.35-0.44 ng/kg body weight/day for an adult female to 0.62-1.11 ng/kg body weight/day for a 5-6 years child. Dietary modelling also concluded that spices were the major contributor to aflatoxin exposure.

Risk estimates were calculated using cancer potency factors derived by the FAO/WHO Joint Expert Committee on Food Additives (JECFA) and estimates of mean lifetime aflatoxin B1 exposure for New Zealanders. Risk estimates suggest that dietary exposure to aflatoxins in New Zealand would result in a negligible contribution to the burden of primary liver cancer (<1 cancer/10 years).

1 INTRODUCTION

1.1 Mycotoxin Surveillance Programme (MSP)

The Mycotoxin Surveillance Programme (MSP) involves investigation of food safety issues associated with mycotoxins in the New Zealand food supply.

As with other activities of the Ministry of Agriculture and Forestry (MAF), activities in this area are directed on the basis of risk. The risk profile of mycotoxins in the New Zealand food supply (Cressey and Thomson, 2006) is viewed as a starting point for this process. The risk profile identified a number of issues to be investigated or clarified. With respect to aflatoxins, the risk profile found consistent reports (reported in more than one study) of aflatoxins associated with the following foods:

- Peanuts and peanut products
- Corn/maize
- Dried fruits, particularly figs
- Spices, particularly pepper, chilli and cayenne, ginger, paprika and nutmeg
- Tree nuts

Aflatoxins in maize products were the focus of the MSP in the 2007-2008 year (Cressey and Jones, 2008), while aflatoxins in dried fruits and spices were considered in 2008-2009 (Cressey and Jones, 2009). During 2009-2010, the MSP continued analysis of the presence of aflatoxins in foods through analysis of nuts (groundnuts/peanuts and tree nuts) and nut products (Cressey and Jones, 2010).

1.2 Aflatoxins

1.2.1 Hazard identification

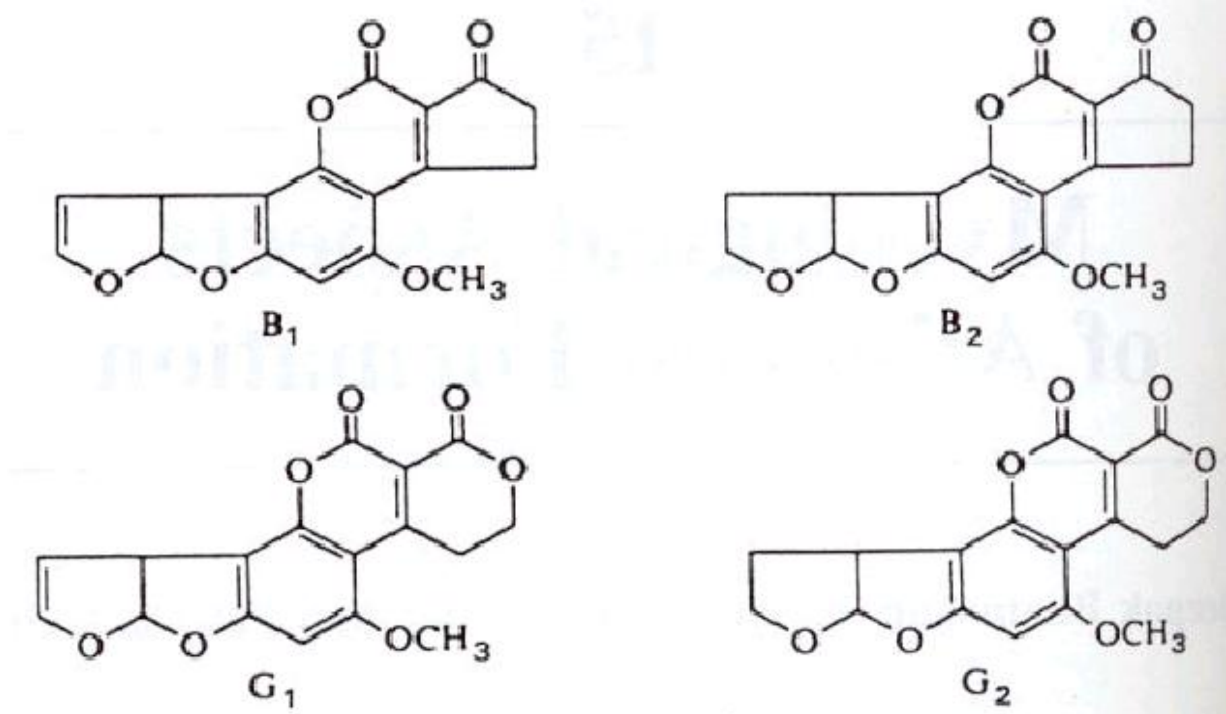
Aflatoxins are secondary metabolites produced by three species of *Aspergillus* mould: *A. flavus*, *A. parasiticus* and *A. nomius* (JECFA, 1998). *A. flavus* occurs in all tropical and subtropical regions and is particularly associated with peanuts and other nuts, maize and other oilseeds. *A. parasiticus* is less widely distributed and is usually only associated with peanuts (Pitt and Tomaska, 2001). *A. nomius* is closely related to *A. flavus*, but little information is available on its host range (Kurtzman *et al.*, 1987).

1.2.1.1 Structure and nomenclature

While the aflatoxins comprise a group of about 20 related compounds, the four major naturally-occurring compounds are aflatoxins B_1, B_2, G_1 and G_2. The ‘B’ and ‘G’ refer to the blue and green fluorescent colours produced by these compounds under UV light, while the subscripts ‘1’ and ‘2’ refer to major and minor components respectively (Pitt and Tomaska, 2001). The ‘2’ compounds are dihydro derivatives of the major (‘1’) metabolites. Chemical structures are shown in Figure 1. Aflatoxins M_1 and M_2 are hydroxylated metabolites of the respective ‘B’ aflatoxins produced when ruminant animals consume aflatoxin-contaminated feed. The ‘M’ aflatoxins may be excreted in milk (Pitt and Tomaska, 2001). Aflatoxins are fat soluble (lipophilic).

Reference to 'aflatoxins' or 'total aflatoxins' can be taken to refer to the sum of B and G aflatoxins.

Figure 1: Structure of aflatoxins



Reproduced from Eaton and Groopman (Eaton and Groopman, 1994)

1.2.1.2 Occurrence

A. flavus produces only 'B' aflatoxins (AFB_1 and AFB_2), with only about 40% of isolates producing toxins. *A. parasiticus* produces both 'B' (AFB_1 and AFB_2) and 'G' (AFG_1 and AFG_2) aflatoxins, with virtually all isolates producing toxins (Klich and Pitt, 1988). The situation for *A. nomius* appears to be similar to that for *A. parasiticus.*

Aflatoxin B_1 is the most commonly occurring aflatoxin in foods and is also the compound which has been most thoroughly studied in toxicological studies.

A. flavus occurs widely in the environment, but *A. parasiticus* is considerably less common. However, some regional specificities exist and *A. parasiticus* is commonly isolated from peanuts in the United States, South Africa and Australia.

Fungal infection and consequent aflatoxin contamination can occur in field crops prior to harvest or during post-harvest storage if the moisture content of the crop exceeds critical values for fungal growth (JECFA, 1998). Fungal growth and subsequent toxin production are favoured by factors which place the host plant under stress such as high temperature, drought, and high insect activity.

Aflatoxin contamination is most commonly associated with peanuts and peanut products, dried fruit, tree nuts, spices, figs, crude vegetable oils, cocoa beans, maize, rice, cottonseed and copra (JECFA, 1998). Consumption of aflatoxin-contaminated feed by animals can lead to occurrence of aflatoxins (mainly the hydroxylated metabolite AFM_1) in meat, eggs and milk.

Most of these crops are not grown in New Zealand. Surveillance of fungal infections of New Zealand grown grain found no *Aspergillus* species (Sayer and Lauren, 1991). This is consistent with expert opinion, that aflatoxigenic species of *Aspergillus* are unlikely to occur in New Zealand (Pitt JI, Mycologist, Food Science Australia, personal communication; 1999).

1.3 Current Project

While information on the prevalence and concentrations of aflatoxin contamination in foods is useful, estimation of the risks associated with aflatoxin contamination in different foods requires combination of this information with food consumption information to provide estimates of dietary exposure. The current project has objectives:

- To estimate dietary aflatoxin exposure in New Zealand, including estimates of the distribution of exposure.
- To use currently available cancer potency factors to determine the excess cancer risk associated with aflatoxin exposure in New Zealand.
- To determine the proportionality of different dietary sources of aflatoxins to the overall risk.

2 METHODS, RATIONALES AND ASSUMPTIONS

For dietary exposure to chemicals, exposure can be defined as:

$$E_i = \frac{\Sigma Q_{i,k} \times C_{i,k}}{bw_i}$$

Where E_i is the exposure of individual *i* to some chemical at some specified point in time, $Q_{i,k}$ is the amount of food *k* consumed by individual *i*, $C_{i,k}$ is the concentration of the chemical of interest in food *k* consumed by individual *i* and bw_i is the body weight of individual *i*. For deterministic (point) estimates of exposure these parameters (concentration, food consumption and body weight) are represented by population averages or selected percentiles. For dietary modelling, food consumption and body weight will be represented by actual reported values for an individual on one particular day or on several days, depending on the structure of the dietary survey.

2.1 Aflatoxin Concentration Data

Recent data are available on the concentration of aflatoxins in foods consumed in New Zealand (Cressey and Jones, 2008;2009;2010). Compared to earlier surveys of aflatoxins in foods available in New Zealand (Lake *et al.*, 1991; Stanton, 1977;1999;2000), these surveys usually contained greater sample numbers and achieved lower limits of detection. A comparison of aflatoxin surveys carried out in New Zealand is included in Appendix 1.

2.1.1 Reporting of aflatoxin concentrations. Chemical entity reported

Recent surveys determined the concentrations of the four major aflatoxins (B1, B2, G1, G2) and the total (the sum of the four major aflatoxins). The early study of Stanton (1977) only determined aflatoxin B1, while the latter two studies by the same author only reported total aflatoxin (Stanton, 1999;2000). The 1991 study reported concentrations of individual and total aflatoxins (Lake *et al.*, 1991).

Recent aflatoxin exposure assessments have varied in the way they handle aflatoxin concentration data, with some calculating exposure to aflatoxin B1 (Bakker *et al.*, 2009; Coffey *et al.*, 2009) only, while others calculate exposure to total aflatoxins (Kumagai *et al.*, 2008; Leblanc *et al.*, 2005; Soubra *et al.*, 2009) or both aflatoxin B1 and total aflatoxins (Sugita-Konishi *et al.*, 2010).

Most of the available toxicity data relates to aflatoxin B1 and the cancer potency factors derived by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) relate only to aflatoxin B1 (JECFA, 1998). The current exercise will determine exposure both in terms of aflatoxin B1, to allow utilisation of JECFA cancer potency factors for risk assessment, and as total aflatoxins, to allow estimation of the magnitude of exposure not due to aflatoxin B1 and to allow comparison to studies using this approach.

2.1.2 Food classification

In order to analyse aflatoxin concentration data it is necessary to define food descriptions or food groups to allow meaningful aggregation of aflatoxin data. For the current exercise, foods analysed under the Mycotoxin Surveillance Programme were aggregated into the groupings outlined in Table 1.

Table 1: Food aggregation groupings for aflatoxin concentration data

Food group description	Includes
Peanuts and peanut products	
Peanuts	Raw, roasted or blanched peanuts, with or without addition of salt or other flavouring
Peanut butter	Peanut butters and peanut spreads, salted or unsalted
Peanut sauce	Peanut or satay sauces
Peanut confectionery	Chocolate-coated peanuts, peanut containing chocolate bars, peanut crisps, peanut candy
Tree nuts and tree nut products	
Almonds	Almonds or almond butters, sliced or unsliced, salt or unsalted
Brazil nuts	Brazil nuts or Brazil nut butters, sliced or unsliced, salt or unsalted
Cashews	Cashews or cashew butters, sliced or unsliced, salt or unsalted
Pistachios	Pistachios or pistachio butters, shelled or in-shell, sliced or unsliced, salt or unsalted
Mixed nuts	Combination of two or more nut species
Spices	
Capsicum-based spices	Chilli powder, cayenne pepper, paprika
Curry powder	Curry powder and other spice mixtures
Ginger, ground	Ginger, ground
Pepper (black, white)	Pepper (black, white)
Maize-containing foods	
Bakery products	Bread, biscuits, cakes and bakery mixes containing maize
Breakfast cereals, cornflakes	Cornflakes
Breakfast cereals, other	Non-cornflake breakfast cereals containing maize
Corn chips	Corn chips and corn crackers
Maize meal/polenta	Maize meal/polenta and any other ground maize products
Pasta, maize-based	Pasta, maize-based
Popcorn	Popcorn
Snack foods	All extruded or otherwise formed maize based snack foods
Dried fruits	
Dates	Dates
Dried apricots	Dried apricots
Dried vine fruits	Raisins, sultanas and currants
Dried figs	Dried figs
Prunes	Prunes
Foods containing components from more than one category	
Mixed nuts and fruit	Combination of two or more nut species and dried fruit
Snack bars	All snack bars, including those containing maize, peanuts, tree nuts and dried fruit

While chilli powder, cayenne pepper and paprika were analysed as individual foods in the Mycotoxin Surveillance Programme, these spices are all derived from *Capsicum anuum* and the aflatoxin concentrations observed in the three spice types were within a similar range; not detected to 5.0 mg/kg total aflatoxin for cayenne pepper, not detected to 8.5 mg/kg total aflatoxin for chilli powder and 0.2-3.5 mg/kg total aflatoxin for paprika. Import data, which provides a crude estimate of the amount of spice consumed by New Zealanders, aggregates all three spice types under HS code 0904200900 (Spices; fruits of the genus *Capsicum* or *Pimenta*, dried, crushed or ground)[1].

2.1.3 Use of aflatoxin concentration data in exposure assessment

Exposure to aflatoxins is of concern due to their known carcinogenicity and the potential for exposure to increase the population risk of developing primary liver cancer (JECFA, 1998). In this context, the parameter of interest is the chronic, habitual/usual level of exposure. In the absence of more detailed information, it must be assumed that individuals within the population will be exposed to the complete distribution of aflatoxin concentrations in a particular food over time. Therefore, the most appropriate parameter of the distribution of aflatoxin concentrations for calculation of chronic exposure is the mean or expected value. This is consistent with the conclusions of JECFA (1998).

2.1.4 Treatment of 'not detected' (left censored) data

Left censorship refers to the situation where the distribution of observed results is truncated at the left hand end due to the limitations of measurement technologies. The data set for aflatoxins in New Zealand foods contains a high proportion of left-censored (non detected) data. This may include both true zero and true very low concentration data.

2.1.4.1 Statistical approaches

A number of techniques are available for estimating statistics for a data set believed to contain positive, but left censored values (Baccarelli *et al.*, 2005; Clarke, 1998; Helsel, 2005;2006; Hewett and Ganser, 2007; Huybrechts *et al.*, 2002; Kuttatharmmakul *et al.*, 2000; Kuttatharmmakul *et al.*, 2001; She, 1997; Singh and Nocerino, 2002; Tressou, 2006). These include:

- Deletion – removing not detected results from the data set
- Substitution – assigning a defined value (e.g. half the limit of detection) to all left censored values
- Assumption of an underlying (parametric) distributional form and use of statistical techniques, such as maximum likelihood estimation (MLE) to determine the parameters of the censored underlying distribution
- Use of non-parametric techniques, based on Kaplan-Meier survival analysis techniques, to estimate summary statistics for the censored data.

Appendix 2 contains a comparison of mean aflatoxin concentrations for a range of aflatoxin-containing foods available in New Zealand. Calculations were carried out for a range of

[1] http://www.stats.govt.nz/infoshare/TradeVariables.aspx?DataType=TIM. Accessed 12 October 2010.

methods (details in Appendix 2) and based on three different assumptions about the nature of the left censored values:

- All left-censored values are true zeros;
- No left-censored values are true zeroes; or
- Half of left-censored values are true zeroes.

Methods used to calculate estimates for the mean concentration value were:

- Substitution (ND = 0, LOD/2 or LOD);
- Maximum likelihood estimation (MLE), assuming that samples were drawn from a lognormally distributed population (Helsel, 2005);
- Regression on order statistic (ROS), a probability plot method that also assumes lognormality in the underlying data (Helsel, 2005); and
- Non-parametric Kaplan-Meier (KM), a method that makes no assumptions about the underlying distribution (Helsel, 2005).

The latter three methods were applied using the Nondetects and Data Analysis (NADA) package for R[1]. The MLE, ROS and KM techniques were not consistently reliable with the small datasets and the high proportion of censored data often present in the data associated with the current project. Where estimates were clearly nonsensical (e.g. estimate of mean higher than any quantified value), they were not included in the data summary in Appendix 2.

2.1.4.2 Assumptions

For the current study it was assumed that, where aflatoxins were not detected in any sample of a particular food type, the observed results represent true zero concentration. For example, the mean concentration of aflatoxin B1 and total aflatoxin in almonds was assumed to be zero.

The statistical approaches to estimating means of censored data sets (MLE, ROS and KM) were not able to produce consistently sensible estimates for the small data sets included in the current study. It was decided to use the WHO GEMS/Food conventions for left censored data sets (WHO GEMS/Food-Euro, 1995), specifically:

- When 60% or less of data are censored, the mean was calculated using a value of half the limit of detection for values below the limit of detection; and
- When more than 60% of data are censored two estimated of the mean are calculated; one assuming that all values less than the limit of detection are true zero values (lower bound) and one assuming that all values less than the limit of detection are true non-detects with values equal to the limit of detection (upper bound)

Adoption of these conventions means that all estimates of dietary exposure will be represented by an interval, rather than a single value.

[1] http://www.r-project.org/

2.2 Food Consumption Information

Two food consumption data resources were used for the current project.

2.2.1 New Zealand Total Diet Survey (NZTDS) simulated typical diets

In the 2009 NZTDS, simulated 'typical' diets were developed for eight selected sub-sets of the New Zealand population: - young male 19-24 years, adult male 25 years and over, adult female 25 years and over, adolescent male 11-14 years, adolescent female 11-14 years, child 5-6 years, child 1-3 years, and infant 6-12 months.

Fourteen day simulated 'typical' diets were created for each of the population subgroups listed above. These were based on the NZTDS Food List which identified the foods most commonly consumed by the New Zealand population. Other foods were added to the list for specific population groups such as children and infants, as well as a number of foods identified as high risk for contaminants and pesticides, such as oysters, mussels and lambs liver. Fourteen day consumed food quantities were converted to daily consumed food quantities. It should be noted that this does not imply that all foods are eaten every day. Some foods would only be eaten once in the fourteen day period, while others may be consumed every day.

Construction of the simulated diets was based on the most recently available research on food consumption patterns. The main data sources were the National Nutrition surveys conducted for adults 15 and over years of age (Russell *et al.*, 1999) and children 5-14 years of age (Ministry of Health, 2003) and recent surveys of dietary habits of young children (Soh *et al.*, 2002). This enabled an estimate of the amount of each specific food from the NZTDS food list to be included in each 'typical' diet. Diets were then created that would resemble an average consumer in each of the selected groups. In some situations industry sectors were contacted to confirm consumption patterns that may have changed since the adult nutrition survey was conducted in 1997. In constructing the simulated 'typical' diets, the following guidelines were used: serving sizes at any meal would be realistic, the diets would be representative of the given population, and each diet has all appropriate foods from the NZTDS Food List in it (i.e. children's diets do not contain alcohol).

Simulated typical diets support estimation of deterministic (point) estimates of dietary exposure.

2.2.1.1 Use of simulated typical diets for aflatoxin exposure assessment

For the purpose of estimating dietary exposure to aflatoxins, the NZTDS Food List is deficient in two respects when compared to the food list in Table 1; it does not include any tree nuts or tree nut products and it does not explicitly include spices. It also contains an abbreviated selection of dried fruits, with only dried vine fruits (raisins/sultanas) and prunes being included.

In deciding what aflatoxin concentration should be applied to NZTDS Food List descriptors two possible approaches suggest themselves:

- Literal. The most appropriate concentration is applied to the food e.g. the mean aflatoxin concentration of prunes is combined with the consumption estimate for prunes; or
- Representative. A food such as prunes is taken to be representative of a wider range of related foods for which aflatoxin concentration data are available, such as dried apricots, dates and figs.

Table 2 lists foods from the NZTDS Food List that may contain aflatoxins and proposes literal and representative matches to the food group descriptors given in Table 1.

Table 2: Matching of NZTDS simulated typical diet foods to aflatoxin food descriptors

NZTDS food	Aflatoxin food descriptor(s)	
	Literal	**Representative**
Cornflakes	Breakfast cereals, cornflakes	Breakfast cereals, cornflakes
Muesli	Breakfast cereals, other	Breakfast cereals, other
Peanut butter	Peanut butter	Peanut butter, peanut sauce
Peanuts, whole	Peanuts	Peanuts, almonds, Brazil nuts, cashews, pistachios, mixed nuts, peanut confectionery
Prunes	Prunes	Prunes, dates, dried apricots, figs
Raisins/sultanas	Dried vine fruits	Dried vine fruits
Snack bars	Snack bars	Snack bars
Snacks, flavoured	Snack foods	Snack foods, corn chips

Deterministic exposure estimates were calculated using both approaches, to assess the sensitivity of exposure to this variable. Under the representative approach the contribution of different foods to a composite aflatoxin concentration was considered to be equal.

2.2.1.2 Treatment of spice consumption

Simulated typical diets used in the NZTDS do not include spices as a specific food item. However, several foods in the food list could reasonably be expected to contain spices or list spices in their ingredients list. These are; Chinese dish, Indian takeaway, instant noodles, salad dressing, baked beans, tomato sauce, canned spaghetti, meat pie, and pizza. However, for many of these products, although spices are listed in the ingredients, no valid means of identifying the spices present or the quantity present suggests itself. Recipes from standard sources were used to suggest a typical spice for some recipe types and a typical proportion (e.g. Chinese dish, Indian takeaway). Where recipe information could not be located a general source on usage of spices in foods was used[1] and a nominal (0.5% by weight) proportion of spice was assigned to each relevant food. Where the spice-containing food was a proportion of another food (e.g. tomato sauce in canned spaghetti), an estimate of spice content was made to reflect the proportion of the ingredient food and its spice component in the composite food. Allocations are summarised in Table 3.

[1] http://www.spiceadvice.com/usage/chart.html

Fowles *et al.* used imported quantities of spice to calculate a per capita figure for spice consumption (Fowles *et al.*, 2001). Per capita import figures for 2009 (see Appendix 3) were used to "reality check" spice consumption estimates derived for the simulated typical diets. Estimates were not derived for pepper, as no aflatoxins were detected in this spice type in surveys carried out in New Zealand. Results of this analysis are summarised in Table 3.

Table 3: Estimation of spice consumption by allocation of spices to NZTDS simulated diet foods

	Chilli powder/cayenne pepper/paprika	**Ginger, ground**	**Curry powder**
Food		*Proportion of spice in food*	
Chinese dish		0.01	
Indian takeaway			0.01
Instant noodles	0.005		
Salad dressing	0.005		
Baked beans			0.005
Tomato sauce	0.005		
Spaghetti, canned	0.0025*		
Meat pie			0.005
Pizza	0.0003*		
Population group		*Estimated spice consumption (g/day)*	
Adult male	0.23	0.13	0.29
Adult Female	0.15	0.13	0.20
Young Male	0.26	0.14	0.48
Teenage Boy	0.20	0.09	0.25
Teenage Girl	0.23	0.07	0.22
Child	0.15	0.00	0.10
Toddler	0.10	0.00	0.07
Infant	0.05	0.00	0.04
Weighted average	**0.19**	**0.11**	**0.24**
Per capita imports	**0.19**	**0.09**	**NA**

* Based on tomato sauce content of dish
NA Not available

These allocations of spice consumption to NZTDS foods were used for deterministic exposure assessment of aflatoxins.

2.2.2 National Nutrition Survey (NNS) records

Periodic national nutrition surveys are carried out in New Zealand. The most recent are the 1997 National Nutrition Survey (97NNS) covering adult New Zealanders, aged 15 years and over (Russell *et al.*, 1999) and the 2002 National Children's Nutrition Survey (02CNS) covering New Zealand children aged 5-15 years (Ministry of Health, 2003).

These two surveys contain two sources of information of potential value in informing estimates of food consumption:

- 24-hour dietary recall records (24HDR). These include a complete listing of all foods consumed by an individual during one 24-hour period. Days of the week and time of year are randomised across the survey to avoid bias due to these factors. The 97NNS contains 24HDR records for 4,636 respondents and the 02CNS contains 24HDR records for 3,275 respondents.
- Qualitative Food Frequency Questionnaire (QFFQ). The questionnaire asked respondent to estimate how frequently they consume a list of defined foods. This list is not exhaustive and reflects particular issues being investigated at the time of the survey.

While the 24HDR records provide a very good record of the food intake by an individual on a particular day, this is not the same as the individual's habitual long-term food intake and may include consumption of foods rarely eaten by the individual or exclude foods commonly eaten by the individual. This will usually mean that any exposure estimate based on 24HDR records will not be a true representation of habitual exposure for an individual. While the mean of exposures derived in this manner are likely to be good estimates of the true mean, it is expected that the variability in dietary exposure derived from 24HDR records will be greater than the true population habitual exposure variability, as it will include both between person variability (inter-person) and within person variability (intra-person) (Dodd *et al.*, 2006; Hoffmann *et al.*, 2002; Nusser *et al.*, 1996). Between person variability is the parameter of interest for risk assessment associated with chronic exposure, as is the case for aflatoxins.

For the 97NNS and 02CNS, 24HDR dietary information was collected on a second day for approximately 15% of respondents. These duplicate days can be used to estimate intra-person variability and correct the overall estimate of exposure variability to only represent inter-person variability (Dodd *et al.*, 2006; Hoffmann *et al.*, 2002; Nusser *et al.*, 1996). However, the correction process does not work well when the dataset contains a high proportion of zero exposure days. This is the case for aflatoxin exposure, as aflatoxins are not present in dietary staples in New Zealand. Approximately half of adult daily exposure estimates and a third of child exposure estimates represented zero exposure days and the statistical correction for intra-person variability was not possible.

2.2.2.1 Mapping of NNS foods to aflatoxin containing foods

The NNSs contain over 4000 unique food descriptors. In order to estimate the aflatoxin concentration of each of these foods it is necessary to map the foods for which aflatoxin concentrations are available (Table 1) to the list of unique NNS food descriptors. Three situations arise:

- The food description in Table 1 is sufficiently similar to the NNS food descriptor to allow direct application of the determined aflatoxin concentration;
- The NNS food is unrelated to any food in Table 1 and is unlikely to contain aflatoxins; or
- The NNS food is similar to or contains (as part of a recipe) one of the foods in Table 1.

The bulk of the mapping effort relates to the third situation. Appendix 4 outlines the methodology used to determine the amount of aflatoxin-containing food in a recipe, while

Table 4 identifies the range of foods and recipes that were identified as needing to be mapped to the list of aflatoxin-containing foods.

In addition to these processes it was necessary to apply a standard set of assumptions to the mapping process. These included:

- Aflatoxins were assumed not to be present in dried fruits other than those included in Table 1 (e.g. dried apple);
- If no suitable recipe information was available, but a food was known or strongly suspected of containing a particular spice, it was assumed that the spice content of recipes was 0.5%;
- While the recipe is a secret, it was assumed that the coating of Kentucky Fried Chicken included *Capsicum*-based spices;
- Bakery products (e.g. biscuits, cakes) described as containing nuts were mapped to 'Mixed nuts', except where a specific nut type (e.g. peanut brownies) was identified

Table 4: Mapping of foods for which aflatoxin information was available to national nutrition survey foods

Food group description	Includes
Peanuts and peanut products	
Peanuts	Peanuts, raw and roasted (dry or honey roasted), salted or unsalted; peanut-containing bakery products
Peanut butter	Peanut butter, smooth and crunchy; peanut butter and jelly spread
Peanut sauce	Satay (peanut) sauces; satay dishes (meat or vegetables with satay sauce); stir fry recipes using satay sauce
Peanut confectionery	Chocolate-coated peanuts; peanut-containing chocolate bars (e.g. Snickers); peanut-containing blocks of chocolate, peanut-containing lollies
Tree nuts and tree nut products	
Almonds	Almonds, raw or roasted, whole, ground or slivered; chocolate-coated almonds
Brazil nuts	Brazil nuts, chocolate-coated Brazil nuts
Cashews	Cashews, raw and roasted, salted or unsalted; chicken and cashew nut recipe
Pistachios	Pistachios, raw and roasted, salted or unsalted
Mixed nuts	Mixed nuts; nuts, type not specified; nut-containing bakery products, type not specified
Spices	
Capsicum-based spices	Various recipes
Curry powder	Various recipes
Ginger, ground	Various recipes
Pepper (black, white)	Not mapped, did not contain aflatoxins
Maize-containing foods	
Bakery products	Cornbread
Breakfast cereals, cornflakes	Cereal, flakes, corn, with or without fruit
Breakfast cereals, other	Cereal, muesli, toasted or untoasted; cereal, puffed, corn
Corn chips	Corn chips or crisps; nachos

Food group description	Includes
Maize meal/polenta	Corn meal or flour; polenta; burritos, enchiladas, tacos or tortillas
Pasta, maize-based	No appropriate food descriptors identified
Popcorn	Not mapped, did not contain aflatoxins
Snack foods	All maize-based snack foods (e.g. Burger rings, Cheezels, etc.)
Dried fruits	
Dates	Dates; date scones
Dried apricots	Dried apricots; apricots, cooked from dry
Dried vine fruits	Raisins; sultanas; currants; mixed fruit; fruit mince; fruit-containing bakery products, fruit type not specified
Dried figs	Dried figs; figs, cooked from dry
Prunes	Prunes, dried; prunes, cooked; plums, dried
Foods containing components from more than one category	
Mixed nuts and fruit	Nuts, mixed with dried fruit; trail mix/scroggin; chocolate filled with fruit and nut; fruit and nut-containing bakery products
Snack bars	All snack bars, including muesli bars, nut bars, cake bars, cornflake bars and rice bubble bars

2.3 Body Weights

For deterministic exposure estimates, based on the NZTDS simulated diets, mean body weights as used in the NZTDS were employed. Values used are summarised in Appendix 5. The dietary modelling approach generates an estimate of aflatoxin exposure for each respondent in the 97NNS or 02CNS and the corresponding actual body weights are used in this approach.

2.4 Quantification of Uncertainty

Inputs to the exposure assessment will have a degree of uncertainty associated with them (Cullen and Frey, 1999). In some cases techniques exist to allow quantification of this uncertainty, allowing the definition of credible intervals around outputs parameters of the exposure assessment. For the current exercise, two sources of uncertainty were assessed:

- Aflatoxin measurement uncertainty; and
- National nutrition survey sampling uncertainty.

2.4.1 Measurement uncertainty

Measurement uncertainty can be viewed as made up of two components:

- A fixed uncertainty associated with ‘near zero’ measurements. This uncertainty is usually expressed in terms of a limit of detection.
- A variable uncertainty associated with quantifiable values. This uncertainty is usually expressed in terms of a coefficient of variation, where the uncertainty is proportional to the measured value.

These two components of uncertainty have been incorporated into a model for use in analytical chemistry (Rocke and Lorenzato, 1995). This model can be expressed as:

Where x is the measured value, μ is the true value, and η and ε are the variable and near zero (fixed) analytical uncertainties. The uncertainty terms are assumed to be normally distributed with means equal to zero and variances σ_η^2 and σ_ε^2.

The method coefficient of variation and the limit of detection were used to derive estimates for σ_η and σ_ε, respectively. Simulation analysis (@Risk, 100,000 iterations) was used to determine the impact of this measurement uncertainty on mean lower and upper bound estimates of the concentration of total aflatoxins and aflatoxin B1 in surveyed foods. The uncertainty distributions for concentration values were then used to assess the impact of measurement uncertainty on mean and percentile estimates of dietary aflatoxin exposure. However, given the complexity of the latter model, it was only feasible to run simulations for a relative small number of iterations (n = 100). Replicate runs of 100 iterations were run for some scenarios and demonstrated that this number of iterations was sufficient to achieve convergence and stability in summary statistics of exposure.

2.4.2 Sampling uncertainty

Dietary modelling exposure estimates are based on responses provided by participants in the 1997 National Nutrition Survey and the 2002 National Children's Nutrition Survey. These participants represent a sample of the New Zealand population and estimates of dietary exposure to aflatoxins, based on their responses, will include uncertainty associated with this sampling process.

Sampling uncertainty in exposure estimates was quantified using a non-parametric bootstrap method (Efron and Tibshirani, 1986). For a data set of n samples, (x_1, x_2, ...x_n), it is possible to create B bootstrap samples, (x_1^*, x_2^*, ...x_n^*), where each x_i^* is a random sample, with replacement from the original n samples. For each of the B bootstrap samples the statistic of interest (e.g. mean) can then be calculated. The distribution of the B estimates of the statistic represents the bootstrap estimate of uncertainty in that statistic.

Each of the bootstrap samples must be the same size as the original sample. Caution should be exercised in applying this method for small samples. However, the nutrition surveys contain sufficient participants and corresponding estimates of exposure that this is not an issue. While no definitive rules exist, it is generally considered that B=50-200 is sufficient to gain a good estimate of uncertainty. In the current study, 1,000 bootstrap samples were generated to ensure stability of the uncertainty estimates.

While the data sets used to estimate mean concentration values will also include sampling errors, the samples are too small in most cases to allow application of the bootstrap method.

2.5 Risk Assessment

2.5.1 Measure of exposure

Risk assessments carried out for aflatoxins have considered lifetime average exposures to aflatoxin B1 (Henry *et al.*, 1998). Exposures determined in this study are segmented by age and, in some cases, gender. Therefore, it is necessary to use these segmented estimates to estimate lifetime average exposures. Table 5 shows the mapping used for this exercise for the Total Diet and the Dietary Modelling approaches and the corresponding weighting factors to convert the segmented exposure estimates to a lifetime average exposure estimate. Separate estimates were derived for males and females. For example, the aflatoxin exposure estimate derived for a 11-14 years female has been taken to be representative of the wider age interval of 11-18 years. While some of these decisions are arbitrary, it should be noted that the lifetime exposure estimate will be heavily weighted towards the adult exposure assessment, due to the long period spent in the adult time period.

Table 5: Mapping of Total Diet and Dietary Modelling age-gender groups to the full period of life expectancy, New Zealand males and females

Group	Mapped to (Male)	Weighting factor[1] (Male)	Mapped to (Female)	Weighting factor[1] (Female)
Total Diet				
Infant (6 months)	0 years	0.013	0 years	0.012
Toddler (1-3 years)	1-3 years	0.038	1-3 years	0.036
Child (5-6 years)	4-10 years	0.089	4-10 years	0.085
Female (11-14 years)			11-18 years	0.097
Male (11-14 years)	11-18 years	0.102		
Male (19-24 years)	19-24 years	0.076		
Female (25+ years)			19+ years	0.770
Male (25+ years)	25+ years	0.683		
Dietary Modelling				
Child (5-6 years)	0-10 years	0.140	0-10 years	0.133
Female (11-14 years)			11-18 years	0.097
Male (11-14 years)	11-18 years	0.102		
Male (19-24 years)	19-24 years	0.076		
Female (25+ years)			19+ years	0.770
Male (25+ years)	25+ years	0.683		

[1] Based on a life expectancy for a New Zealand male of 78.8 years and for a New Zealand female of 82.7 years (http://search.stats.govt.nz/search?w=life%20expectancy)

Weighting factors were also applied to 95th percentile exposure estimates for the individual age-gender group to give a 95th percentile lifetime exposure for males and females. However, this exercise assumes that individuals in the high exposure category will remain in that category throughout their life. The validity of this assumption is uncertain.

2.5.2 Measure of response

The major toxicological impact of aflatoxins on humans and animals is an increase in primary liver cancer (hepatocellular carcinoma).

2.5.3 Dose-response relationship

A number of estimates of cancer potency for aflatoxin B1 have been derived from human epidemiological data (Bowers *et al.*, 1993; Hoseyni, 1992; Qian *et al.*, 1994; Wang *et al.*, 1996; Wu-Williams *et al.*, 1992; Yeh *et al.*, 1989). Estimates of cancer potency have also been derived from studies in test animals (Henry *et al.*, 1998). However, it was concluded that there is currently insufficient understanding of the differences in metabolism between humans and animals to use animal cancer potencies in human risk assessment (Henry *et al.*, 1998).

JECFA reviewed cancer potency estimates and chose separate central tendency estimated potencies and ranges for $HBsAg^+$ (hepatitis B surface antigen positive) and $HBsAg^-$ individuals (Henry *et al.*, 1998). The potencies are expressed in terms of an expected increase in the incidence (per 100,000 population) of primary liver cancer per ng aflatoxin B1/kg body weight/day. Potency values of 0.3 cancers/year/100,000 (uncertainty range 0.05-0.5) and 0.01 cancers/year/100,000 (uncertainty range 0.002-0.03) were derived for $HBsAg^+$ and $HBsAg^-$ individuals, respectively.

These estimates of cancer potency have been used in subsequent aflatoxin risk assessment (Lee *et al.*, 2009; Liu and Wu, 2010; Shephard, 2008; Sugita-Konishi *et al.*, 2010) and will be used in the current study.

In calculating population risks, JECFA adopted an approach of using the proportion of $HBsAg^+$ individuals in a population to derive a population cancer potency according to the formula:

$$\text{Population cancer potency} = 0.3p + 0.01(1-p)$$

Where p is the proportion of $HBsAg^+$ individuals in the population.

It has been estimated that there are approximately 67,000 New Zealanders with chronic hepatitis B (Gane, 2005). The current estimates of the New Zealand population are approximately 4.4 million[1], suggesting a value for p of 0.015 and a population cancer potency of 0.014 cancers/year/100,000 (uncertainty range 0.002-0.037).

[1] http://www.stats.govt.nz/

3 RESULTS AND DISCUSSION

3.1 Deterministic Exposure Assessment

3.1.1 Estimated dietary exposure

Table 6 summarises deterministic estimates of dietary exposure to total aflatoxins and aflatoxin B1. These estimates are based on a literal mapping of foods for which aflatoxin concentration was available to total diet foods (see Table 2). Use of a representative mapping where, for instance, the concentration of aflatoxins in prunes was replaced by the mean concentration of aflatoxins in prunes, dates, dried apricots and figs (see Table 2) resulted in a slight increase in exposure estimates for younger age groups and a slight decrease for adult age groups.

Table 6: Estimated aflatoxin (total and B1) dietary exposure for various New Zealand population subgroups, based on a total diet (deterministic) method

Age-gender group	Estimated dietary aflatoxin exposure, lower bound – upper bound, ng/kg body weight/day	
	Aflatoxin, total	Aflatoxin B1
Infant (6 months)	0.28 – 0.32	0.23 – 0.28
Toddler (1-3 years)	0.37 – 0.43	0.31 – 0.37
Child (5-6 years)	0.46 – 0.54	0.37 – 0.45
Female (11-14 years)	0.29 – 0.32	0.25 – 0.28
Male (11-14 years)	0.34 – 0.37	0.28 – 0.32
Male (19-24 years)	0.38 – 0.40	0.33 – 0.35
Female (25+ years)	0.19 – 0.21	0.17 – 0.19
Male (25+ years)	0.24 – 0.26	0.21 – 0.23

Exposure estimates in Table 6 confirm that aflatoxin B1 is the major contributor to total aflatoxin exposure, accounting for more than 80% of total aflatoxin exposure across all age and gender groups.

Table 7 summarises estimates of dietary aflatoxin exposure from other countries for comparison with the estimates in this report.

Table 7: Overseas estimates of dietary aflatoxin exposure[1]

Country	Cohort description	Estimated dietary aflatoxin exposure, mean (95th percentile) (ng/kg body weight/day)		Reference
		Total	Aflatoxin B1	
Australia	Toddler, 2 years	0.2 (0.3)		(Marro, 1996)
	Girl, 12 years	0.1 (0.2)		
	Boy, 12 years	0.3 (0.5)		
	Adult female	0.2 (0.3)		
	Adult male	0.2 (0.2)		
Australia	Toddler, 2 years	1.6 (1.9)		(Hardy, 1998)
	Girl, 12 years	1.0 (1.5)		
	Boy, 12 years	2.4 (3.8)		
	Adult female	1.2 (1.9)		

Country	Cohort description	Estimated dietary aflatoxin exposure, mean (95th percentile) (ng/kg body weight/day)		Reference
		Total	Aflatoxin B1	
	Adult male	1.1 (1.8)		
Belgium	Average inhabitant		0.2	(SCOOP, 1997)
China	Standard man, 18-45 years		0-10	(Chen and Gao, 1993)
France	Adult		1.3	(SCOOP, 1997)
France	Adult, 15+ years	0.12 (0.35)		(Leblanc *et al.*, 2005)
	Child, 3-14 years	0.32 (0.89)		
Germany	Adult		0.03	(SCOOP, 1997)
	Child		0.3	
Korea	Adult		1.2-5.8	(Park *et al.*, 2004)
Korea	Whole population		0.64 (2.5)	(Ok *et al.*, 2007)
Korea	Adult, 20+ years		0.06-0.36	(Lee *et al.*, 2009)
Lebanon	Teenager, 14-18 years	1.3-3.8 (3.1-6.5)		(Soubra *et al.*, 2009)
	Child, 8-13 years	1.5-4.4 (3.5-7.7)		
Netherlands	Adult		0.37	(SCOOP, 1997)
Netherlands	Children		0.1	(Bakker *et al.*, 2009)
Sweden	Adult	0.8 (2.1)		(Thuvander *et al.*, 2001)
United Kingdom	Adult		0.03	(SCOOP, 1997)

[1] Information in this table is largely restricted to national estimates of aflatoxin exposure. Studies in sub-populations with high exposure to aflatoxins have estimated much higher aflatoxin exposures, up to 2,000 ng/kg body weight/day for aflatoxin B1.

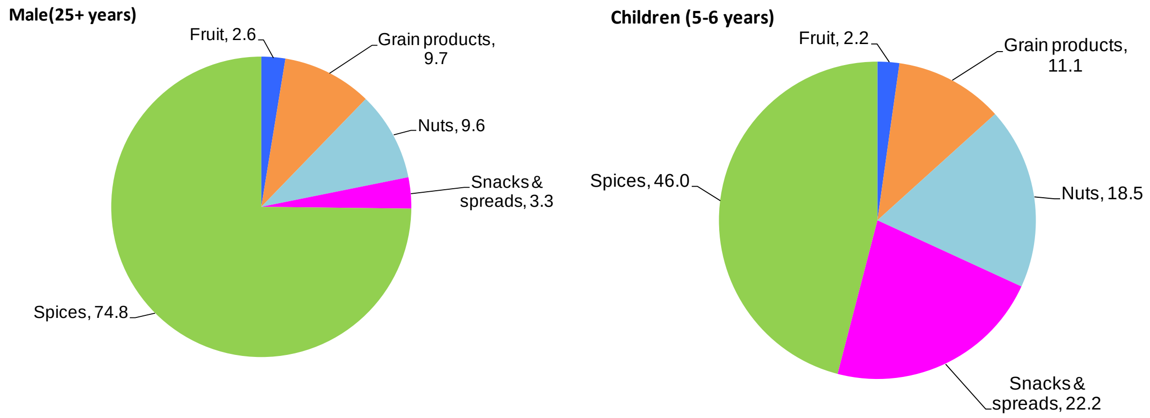
Estimates from the current study are generally consistent with estimates for other developed countries, although the European SCOOP initiative produced very low estimates of dietary aflatoxin exposure for adults in Germany and the United Kingdom (both 0.03 ng/kg body weight/day). The United Kingdom contributors noted that they did not consider the indications of total intake to be valid.

Studies on dietary exposure to aflatoxins have often included a very limited range of foods in the exposure assessment. For example, a recent Japanese study based their assessment on only peanut butter and bitter chocolate (Kumagai *et al.*, 2008), while Australian total diet studies have generally only included one or two foods likely to contain aflatoxins (Food Standards Australia New Zealand, 2002; Hardy, 1998; Marro, 1996).

3.1.2 Contributing foods

Figure 2 shows the proportional contribution of different food groups to estimated total aflatoxin exposure for an adult male and a 5-6 years old child (the group with the highest exposure on a per kilogram body weight basis). Figures are based on upper bound estimates of exposure to total aflatoxins. The contribution of food groups to total aflatoxin and aflatoxin B1 exposure for all age-gender groups are included in Appendix 6.

Figure 2: Contribution of food groups to upper bound estimates of total aflatoxin dietary exposure for adult males (25+ years) and children (5-6 years) from total diet



Exposure estimates for both age-gender groups are dominated by the contribution from spices. Further analysis revealed that this was almost entirely due to the contribution to dietary aflatoxin exposure from curry powder. This contribution was, in turn, almost entirely due to one analytical result in the original data set – a sample of curry powder containing 225 mg/kg total aflatoxin (202 mg/kg aflatoxin B1). Exclusion of this single analytical result would result in estimates of dietary aflatoxin exposure shown in Table 6 being reduced by as much as 75%. However, there is no valid reason to exclude this analytical value from the exposure calculation, as it is unknown whether curry powder is commonly contaminated with such high concentrations of aflatoxins.

The food group contributing the second greatest amount to dietary aflatoxin exposure is nuts and nut products. Nuts contribute approximately half of the non-spice exposure. The contribution from the snacks and spreads group is due to detection of aflatoxins in snack bars. The original source of the aflatoxins in snack bars is unknown, but may be due to cereal, nut or fruit components present in the bars. However, analysis of label data on the composition of these products suggests that the presence of aflatoxins in snack bars may be largely due to the nut component of these foods.

3.2 Dietary Modelling Exposure Assessment

3.2.1 Estimated dietary exposure

Table 8 summarises the estimated dietary exposure to aflatoxins (total and B1) for various New Zealand population subgroups derived from dietary modelling. As much as possible, population subgroups have been defined to allow easy comparison with results from deterministic modelling of aflatoxin dietary exposure. As dietary modelling allows determination of a range of representative dietary intakes, Table 8 includes both mean estimates and 95th percentile estimates of dietary exposure.

Table 8: Estimated aflatoxin (total and B1) dietary exposure for various New Zealand population subgroups, based on a dietary modelling method

Age-gender group	Estimated dietary aflatoxin exposure, lower bound – upper bound, ng/kg body weight/day	
	Aflatoxin, total, mean* (95th percentile)	Aflatoxin B1, mean* (95th percentile)
Child (5-6 years)	0.30 – 0.36 (0.62 – 1.11)	0.24 – 0.31 (0.46 – 1.00)
Female (11-14 years)	0.23 – 0.27 (0.73 – 0.94)	0.19 – 0.23 (0.59 – 0.83)
Male (11-14 years)	0.20 – 0.25 (0.51 – 0.88)	0.16 – 0.22 (0.40 – 0.78)
Male (19-24 years)	0.14 – 0.16 (0.60 – 0.62)	0.12 – 0.13 (0.53 – 0.55)
Female (25+ years)	0.09 – 0.11 (0.35 – 0.44)	0.07 – 0.09 (0.27 – 0.37)
Male (25+ years)	0.12 – 0.14 (0.54 – 0.63)	0.10 – 0.12 (0.44 – 0.55)

* Means are weighted using national nutrition survey weights, to align the demographics of the sample set to the New Zealand population

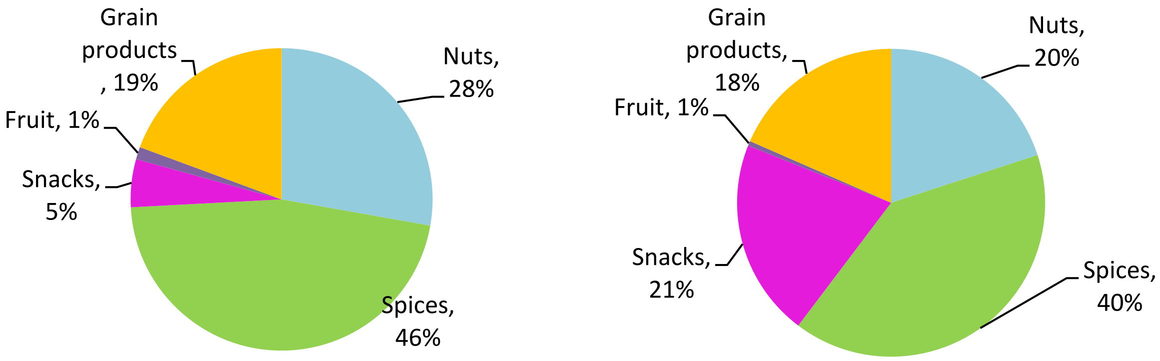
Mean estimates of dietary aflatoxin exposure derived from dietary modelling are consistently lower than the equivalent exposure estimates derived from the deterministic total diet approach. For adults the estimates are approximately half of those derived from the deterministic approach. While 95th percentile estimates of dietary aflatoxin exposure are up to 4.5 times higher than mean estimates, they are still within the range of **mean** estimates reported for developed countries (see Table 7).

Dietary exposure estimates in Table 8 show a clear trend on decreasing aflatoxin exposure with increasing age. As a general rule, this is what would be expected as the energy intake per unit body weight is highest in childhood and decreases with age.

3.2.2 Contributing foods

Figure 3 shows the proportional contribution of different food groups to estimated total aflatoxin exposure for an adult male and a 5-6 years old child (the group with the highest exposure on a per kilogram body weight basis) based on dietary modelling. Figures are based on upper bound estimates of exposure. The contribution of food groups to total aflatoxin and aflatoxin B1 exposure for all age-gender groups are included in Appendix 6.

Figure 3: Contribution of food groups to upper bound estimates of total aflatoxin dietary exposure for adult males (25+ years) and children (5-6 years) from dietary modelling



Although there are some age group related variations, the analysis of food groups contributing to dietary aflatoxin exposure, assessed by dietary modelling, confirms a relative order of contribution of spices > nuts > cereal products > snacks > fruit. As previously discussed, the single very high result for aflatoxins in curry powder is the dominating factor in this exposure assessment. Exclusion of this single analytical result would decrease estimates of dietary aflatoxin exposure by approximately 30-40%. Peanuts, followed by peanut butter, are the major contributors to exposure from the nut category, while breakfast cereals are the major contributor amongst cereal products.

Pistachios are currently a prescribed food for importation into New Zealand and conditions for importation are specified under an imported food requirement[1]. The current estimate of dietary aflatoxin exposure suggests that pistachios contribute no more than 0.2% of dietary exposure for any age-gender group.

3.3 Uncertainty Assessment

3.3.1 Measurement uncertainty

Appendix 7 lists 95th percentile credible intervals for all concentration values used in the current study, considering measurement uncertainty. These credible intervals were derived by application of the two component uncertainty model for chemical analyses (Rocke and Lorenzato, 1995) and were determined by simulation. Table 9 shows the uncertainty intervals for mean and 95th percentile estimates of dietary exposure for total aflatoxins and aflatoxin B1, derived from dietary modelling. As these statistics are already represented by an uncertainty interval (upper and lower bounded), the credible interval represents the interval between the 2.5th percentile credible limit for the lower bound estimate and the upper 97.5th percentile credible limit for the upper bound estimate.

[1] http://www.foodsafety.govt.nz/elibrary/industry/Imported_Food_Requirements_Peanuts-Sets_Clearance.pdf

Table 9: Uncertainty in summary statistics of dietary aflatoxin exposure estimates (dietary modelling) due to measurement uncertainty

Age-gender group	Estimated dietary aflatoxin exposure, lower bound – upper bound (95th percentile credible interval), ng/kg body weight/day			
	Aflatoxin, total		Aflatoxin B1	
	Mean	95th percentile	Mean	95th percentile
Child (5-6 years)	0.30-0.36 (0.29-0.37)	0.62-1.11 (0.59-1.15)	0.24-0.31 (0.23-0.32)	0.46-1.00 (0.44-1.08)
Female (11-14 years)	0.23-0.27 (0.22-0.28)	0.73-0.94 (0.71-0.98)	0.19-0.23 (0.19-0.24)	0.59-0.83 (0.57-0.86)
Male (11-14 years)	0.20-0.25 (0.19-0.26)	0.51-0.88 (0.48-0.92)	0.16-0.22 (0.15-0.22)	0.40-0.78 (0.39-0.81)
Male (19-24 years)	0.14-0.16 (0.13-0.16)	0.60-0.62 (0.55-0.66)	0.12-0.13 (0.11-0.14)	0.53-0.55 (0.49-0.59)
Female (25+ years)	0.09-0.11 (0.09-0.11)	0.35-0.44 (0.34-0.46)	0.07-0.09 (0.07-0.09)	0.27-0.37 (0.26-0.38)
Male (25+ years)	0.12-0.14 (0.12-0.15)	0.54-0.63 (0.51-0.65)	0.10-0.12 (0.10-0.13)	0.44-0.55 (0.42-0.57)

The credible intervals suggest that measurement uncertainty adds little extra uncertainty to dietary aflatoxin exposure estimates, over and above the uncertainty generated by the high proportion on 'not detected' results in the analytical data. This is not surprising as uncertainty in analytical values will tend to 'average out' during the generation of summary statistics such the mean and the 95th percentile.

3.3.2 Sampling uncertainty

The bootstrap (resampling) method was used to quantify the uncertainty in summary statistics of dietary aflatoxin exposure derived from dietary modelling due to sampling of the national nutrition survey cohort. Results are summarised in Table 10.

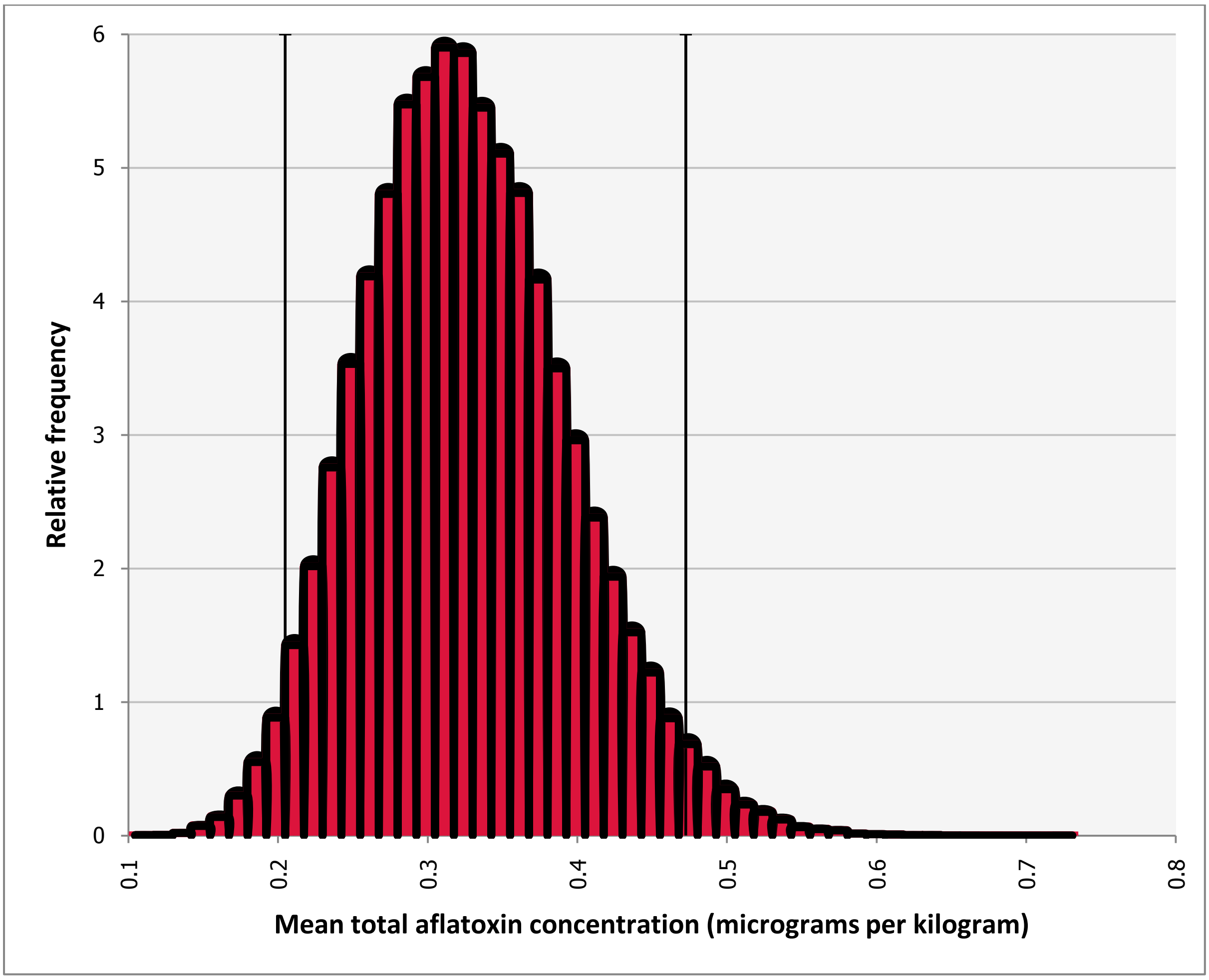
Table 10: Uncertainty in summary statistics of dietary aflatoxin exposure estimates (dietary modelling) due to sampling uncertainty

Age-gender group	Estimated dietary aflatoxin exposure, lower bound – upper bound (95th percentile credible interval), ng/kg body weight/day			
	Aflatoxin, total		Aflatoxin B1	
	Mean	95th percentile	Mean	95th percentile
Child (5-6 years)	0.30-0.36 (0.21-0.48)	0.62-1.11 (0.56-1.27)	0.24-0.31 (0.16-0.40)	0.46-1.00 (0.40-1.24)
Female (11-14 years)	0.23-0.27 (0.16-0.35)	0.73-0.94 (0.43-1.41)	0.19-0.23 (0.13-0.30)	0.59-0.83 (0.37-1.28)
Male (11-14 years)	0.20-0.25 (0.13-0.33)	0.51-0.88 (0.40-1.04)	0.16-0.22 (0.10-0.29)	0.40-0.78 (0.32-0.92)
Male (19-24 years)	0.14-0.16 (0.08-0.24)	0.60-0.62 (0.26-2.34)	0.12-0.13 (0.06-0.20)	0.53-0.55 (0.21-1.29)
Female (25+ years)	0.09-0.11 (0.07-0.14)	0.35-0.44 (0.28-0.52)	0.07-0.09 (0.06-0.11)	0.27-0.37 (0.23-0.43)
Male (25+ years)	0.12-0.14 (0.10-0.17)	0.54-0.63 (0.45-0.69)	0.10-0.12 (0.08-0.15)	0.44-0.55 (0.35-0.60)

The outputs in Table 10 suggest that the uncertainty due to the population sample selected may be quite large, particularly for the determination of high exposure percentiles. This is particularly true when the national nutrition survey cohort for the particular age-gender group is not large. For example, the 24-hour dietary recall component of the 1997 National Nutrition Survey used in the current dietary modelling contained eligible records for 1,622 adult males (25+ years), but only 141 records for young males (19-24 years).

Although the relatively small sample sets do not allow a general analysis of the impact of sampling of foods for aflatoxin analysis on dietary aflatoxin exposure estimation, Figure 4 shows the uncertainty distribution generated by the bootstrap method for the mean concentration of total aflatoxins in peanut butter.

Figure 4: Quantification of uncertainty in the mean value for the total aflatoxin content of peanut butter, due to sampling



The bootstrap analysis suggests that sampling may contribute significantly to uncertainty in the concentration values used to estimate dietary aflatoxin exposure.

3.4 Risk Assessment

Table 11 summarises population risk estimates for males and females, at the mean level of aflatoxin B1 exposure and at the 95th percentile level of aflatoxin B1 exposure, using JECFA cancer potency values (Henry *et al.*, 1998).

Table 11: Cancer risk estimates for New Zealand males and females from dietary exposure to aflatoxin B1

Exposure estimate	Risk estimate (cancers/year/100,000), lower bound-upper bound (uncertainty interval)[1]	
	Male	**Female**
Deterministic total diet approach, mean	0.0034-0.0038 (0.0005-0.0101)	0.0028-0.0032 (0.0004-0.0084)
Dietary modelling approach, mean	0.0018-0.0022 (0.0003-0.0058)	0.0015-0.0019 (0.0002-0.0049)
Dietary modelling approach, 95th percentile	0.0062-0.0089 (0.0009-0.0235)	0.0046-0.0070 (0.0007-0.0184)

[1]Uncertainty intervals relate only to uncertainty in the cancer potency factor

For New Zealand, with a population of approximately 4.4 million, the expected number of primary liver cancer cases per year resulting from the mean level of aflatoxin B1 exposure would be less than 0.1 per year or less than one every 10 years. To place this figure in context, 143 new cases of primary liver cancer were registered in New Zealand in 2007 (the latest year for which reports are available; this equates to a crude rate, based in mid-year 2007 population estimates, of 3.4 new cases/100,000 population)[1]. This suggests that dietary aflatoxin exposure is a negligible contributor to the total burden of primary liver cancer in New Zealand.

Expressed in another way, the annual probability of an adult male developing primary liver cancer due to aflatoxin exposure if 1.8-2.2 x 10^{-8}. This equates to a lifetime cancer risk, over a 78 year lifetime of 1.4-1.7 x 10^{-6} or approximately one in a million. For comparison, Thomson and Lake (1995) estimated a cancer risk for an average New Zealander due to dietary exposure to heterocyclic amines of 0.3-0.4 x 10^{-4}, while the cancer risk due to ingestion of polycyclic aromatic hydrocarbons (PAHs) by New Zealanders has been estimated as 7.5 x 10^{-4} (Thomson and Lake, 1994).

Using a similar approach, risk estimates for dietary exposure to aflatoxin B1 in Japan were approximately two orders of magnitude lower than the estimates in Table 11 (0.00004-0.00005 cancer/year/100,000 at the 95th percentile level of exposure (Sugita-Konishi *et al.*, 2010). This appears to be due to the infrequent consumption of foods such as peanut butter and other foods that frequently contain aflatoxins in Japan. In contrast, assessment of cancer risks due to aflatoxin B1 in Africa produced mean risk estimates in the range 0.1-70.1 cancers/year/100,000 (Shephard, 2008).

[1] http://www.moh.govt.nz/moh.nsf/indexmh/cancer-reg-deaths-2007-jun10?Open

Liu and Wu (2010) carried out a global assessment of cancer risk due to dietary exposure to aflatoxin B1, with estimates of cancers per year ranging from a maximum of two for Australia and the USA to a maximum of 27,000 in India.

4 CONCLUSIONS

Aflatoxins may be present in a range of foods consumed by New Zealanders. Estimates of dietary aflatoxin exposure are consistent with estimates in other developed countries. While the choice of calculation method (total diet or dietary modelling) has an impact on the actual estimates of dietary exposure, these differences are small when compared to the differences in exposure between developed and some developing countries.

An analysis of foods contributing to dietary aflatoxin exposure indicates that spices are the major contributor. It should be noted that this conclusion is almost entirely due to a very high concentration of aflatoxins detected in one sample of curry powder. As only five samples of curry powder were analysed, it is not possible to say whether the contamination profile observed for this foods was typical. Apart from the contribution to exposure from this source, most dietary exposure is due to consumption of peanuts and peanut products, breakfast cereals, snack bars and *Capsicum*-based spices (chilli powder, cayenne pepper, paprika). The contribution from snack bars is probably due to the presence of peanuts and other nuts in these products.

Risk estimates, calculated using JECFA cancer potency factors, indicate that dietary exposure to aflatoxins in New Zealand is unlikely to contribute appreciably to the national burden of primary liver cancer. Even assuming that an individual would be at the 95th percentile for aflatoxin exposure for their entire life results in an estimated excess cancer risk for males of 0.0062-0.0089 cancers/year/100,000.

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APPENDIX 1 SURVEYS OF AFLATOXINS IN FOODS AVAILABLE IN NEW ZEALAND

Food	Year of survey	Analytical limit of detection, µg/kg	Aflatoxin B1		Total Aflatoxin	
			Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg	Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg
Peanuts and peanut products						
Peanuts	1977	2-4	2/16 (12.5, 1.6-38.4)	5.5 (5-6)	ND	ND
Peanuts	1991	Not stated	4/10 (40, 12.1-73.8)[1]	67.5 (15-160)	4/10 (40, 12.1-73.8)[1]	92.5 (30-200)
Peanuts	1999	1	NR	NR	1/2 (50; 1.3-98.7)	26
Peanuts	2000	1	NR	NR	0/34 (0, 0.0-10.3)	-
Peanuts	2010	0.1	10/50 (20, 10.0-33.7)	5.2 (0.1-22.7)	10/50 (20, 10.0-33.7)	6.5 (0.1-26.6)
Peanut butter	1977	2-4	0/1 (0, 0.0-97.5)	-	ND	ND
Peanut butter	1991	Not stated	0/3 (0, 0.0-70.8)	-	0/3 (0, 0.0-70.8)	-
Peanut butter	1999	1	NR	NR	6/17 (35.3, 14.2-61.7)	3.7 (1-9)
Peanut butter	2010	0.1	31/75 (41.3, 30.1-53.3)	0.5 (0.1-2.1)	31/75 (41.3, 30.1-53.3)	0.7 (0.1-3.4)
Peanut confectionery[2]	2010	0.1	3/17 (17.7, 3.8-43.4)	1.0 (0.1-2.1)	3/17 (17.7, 3.8-43.4)	1.1 (0.5-2.3)
Peanut sauces	1999	1	NR	NR	12/49 (24.5, 13.3-38.9)	
Peanut sauces	2010	0.1	8/24 (33.3, 15.6-55.3)	2.0 (0.2-8.3)	8/24 (33.3, 15.6-55.3)	2.7 (0.2-10.5)
Tree nuts and tree nut products						
Almonds	1991	Not stated	0/2 (0, 0.0-84.2)	-	0/2 (0, 0.0-84.2)	-
Almonds	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Almonds	2010	0.1	0/10 (0, 0.0-30.9)	-	0/10 (0, 0.0-30.9)	-
Brazil nuts	1991	Not stated	0/1 (0, 0.0-97.5)	-	0/1 (0, 0.0-97.5)	-
Brazil nuts	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-

Food	Year of survey	Analytical limit of detection, µg/kg	Aflatoxin B1		Total Aflatoxin	
			Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg	Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg
Brazil nuts	2010	0.1	1/10 (10, 0.3-44.5)	5.8	1/10 (10, 0.3-44.5)	5.8
Cashews	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Cashews	2010	0.1	0/10 (0, 0.0-30.9)	-	0/10 (0, 0.0-30.9)	-
Coconut, desiccated	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Hazelnuts	2000	1	NR	NR	0/1 (0, 0.0-97.5)	-
Mixed nuts	2010	0.1	12/33 (36.4, 20.4-54.9)	1.6 (0.3-9.0)	12/33 (36.4, 20.4-54.9)	1.7 (0.3-9.7)
Pecans	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Pistachios	2000	1	NR	NR	0/7 (0, 0.0-41.0)	-
Pistachios	2010	0.1	1/20 (5, 0.1-24.9)	0.6	1/20 (5, 0.1-24.9)	0.7
Walnuts	1991	Not stated	0/1 (0, 0.0-97.5)	-	0/1 (0, 0.0-97.5)	-
Walnuts	2000	1	NR	NR	0/4 (0, 0.0-60.2)	-
Spices						
Cayenne pepper	2009	0.1	4/5 (80, 28.4-99.5)	3.7 (2.9-4.8)	4/5 (80, 28.4-99.5)	3.8 (2.9-5.0)
Chilli powder	2009	0.1	4/5 (80, 28.4-99.5)	5.1 (3.5-7.7)	4/5 (80, 28.4-99.5)	5.5 (3.5-8.5)
Curry powder	2009	0.1	5/5 (100, 47.8-100)	41.4 (0.2-202)	5/5 (100, 47.8-100)	46.1 (0.2-225)
Ginger, ground	2009	0.1	4/5 (80, 28.4-99.5)	1.4 (0.3-2.7)	4/5 (80, 28.4-99.5)	2.0 (0.3-3.6)
Paprika	2009	0.1	5/5 (100, 47.8-100)	1.5 (0.2-3.5)	5/5 (100, 47.8-100)	1.7 (0.2-3.5)
Pepper (black, white)	2009	0.1	0/5 (0, 0.0-52.2)	-	0/5 (0, 0.0-52.2)	-
Maize-containing foods						
Bakery products (bread, biscuits)	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-

Food	Year of survey	Analytical limit of detection, µg/kg	Aflatoxin B1		Total Aflatoxin	
			Number of samples positive/ total samples (%, 95% CI)	**Mean of positive results (range), µg/kg**	**Number of samples positive/ total samples (%, 95% CI)**	**Mean of positive results (range), µg/kg**
Bakery products (bread, biscuits)	2008	0.1	1/13 (7.7, 0.2-36.0)	0.6	1/13 (7.7, 0.2-36.0)	0.7
Breakfast cereals, cornflakes	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Breakfast cereals, cornflakes	2008	0.1	1/5 (20, 0.5-71.6)	0.2	1/5 (20, 0.5-71.6)	0.2
Breakfast cereals, other	2000	1	NR	NR	0/23 (0, 0.0-14.8)	-
Breakfast cereals, other	2008	0.1	1/11 (9.1, 0.2-41.3)	0.9	1/11 (9.1, 0.2-41.3)	1.1
Corn chips	2000	1-2	NR	NR	0/12 (0, 0.0-26.5)	-
Corn chips	2008	0.1	0/5 (0, 0.0-52.2)	-	0/5 (0, 0.0-52.2)	-
Cornmeal/polenta	2000	1-2	NR	NR	0/5 (0, 0.0-52.2)	-
Cornmeal/polenta	2008	0.1	0/4 (0, 0.0-60.2)	-	0/4 (0, 0.0-60.2)	-
Extruded snack foods	2000	1-2	NR	NR	0/8 (0, 0.0-36.9)	-
Extruded snack foods	2008	0.1	0/9 (0, 0.0-33.6)	-	0/9 (0, 0.0-33.6)	-
Pasta/noodles	2000	1	NR	NR	0/7 (0, 0.0-41.0)	-
Pasta/noodles	2008	0.1	0/7 (0, 0.0-41.0)	-	0/7 (0, 0.0-41.0)	-
Popcorn	1991	Not stated	0/1 (0, 0.0-97.5)	-	0/1 (0, 0.0-97.5)	-
Popcorn	2000	1-2	NR	NR	0/3 (0, 0.0-70.8)	-
Popcorn	2008	0.1	0/1 (0, 0.0-97.5)	-	0/1 (0, 0.0-97.5)	-

Food	Year of survey	Analytical limit of detection, µg/kg	Aflatoxin B1		Total Aflatoxin	
			Number of samples positive/ total samples (%, 95% CI)	**Mean of positive results (range), µg/kg**	**Number of samples positive/ total samples (%, 95% CI)**	**Mean of positive results (range), µg/kg**
Dried fruits						
Dates	2000	1	NR	NR	0/4 (0, 0.0-60.2)	-
Dates	2010	0.1	0/5 (0, 0.0-52.2)	-	0/5 (0, 0.0-52.2)	-
Dried apricots	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Dried apricots	2010	0.1	1/10 (10, 0.3-44.5)	0.2	1/10 (10, 0.3-44.5)	0.9
Dried vine fruit	2000	0.5-1	NR	NR	0/23 (0, 0.0-14.8)	-
Dried vine fruit	2009	0.1	0/10 (0, 0.0-30.9)	-	0/10 (0, 0.0-30.9)	-
Figs	1991	Not stated	0/3 (0, 0.0-70.8)	-	0/3 (0, 0.0-70.8)	-
Figs	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Figs	2009	0.1	3/10 (30, 6.7-65.3)	1.7 (0.1-3.2)	3/10 (30, 6.7-65.3)	4.2 (0.1-6.7)
Prunes	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Prunes	2010	0.1	1/5 (20, 0.5-71.6)	0.1	1/5 (20, 0.5-71.6)	0.5
Cereals						
Barley	1977	2-4	0/9 (0, 0.0-33.6)	-	ND	ND
Barley	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Millet	1977	2-4	0/1 (0, 0.0-97.5)	-	ND	ND
Rice	1977	2-4	0/5 (0, 0.0-52.2)	-	ND	ND
Rice	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Rye meal	2000	1	NR	NR	0/3 (0, 0.0-70.8)	-
Wheat flour	1977	2-4	0/2 (0, 0.0-84.2)	-	ND	ND
Wheat and wheat flour	2000	1	NR	NR	0/13 (0, 0.0-24.7)	-

Food	Year of survey	Analytical limit of detection, µg/kg	Aflatoxin B1		Total Aflatoxin	
			Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg	Number of samples positive/ total samples (%, 95% CI)	Mean of positive results (range), µg/kg
Oilseeds and oilseed products						
Soy beans and soy flour	1977	2-4	0/2 (0, 0.0-84.2)	-	ND	ND
Soy flour	2000	1	NR	NR	0/1 (0, 0.0-97.5)	-
Soy bean oil	1977	2-4	0/1 (0, 0.0-97.5)	-	ND	ND
Sunflower seed oil	1977	2-4	0/1 (0, 0.0-97.5)	-	ND	ND
Other foods or foods containing components from more than one category						
Pulses, various	2000	1	NR	NR	0/13 (0, 0.0-24.7)	-
Olives	2000	1	NR	NR	0/2 (0, 0.0-84.2)	-
Dried fruit and nuts	2009	0.1	3/19 (15.8, 3.4-39.6)	0.1 (0.1-0.1)	3/19 (15.8, 3.4-39.6)	0.4 (0.1-0.7)
Snack bars	2008; 2010	0.1	4/41 (9.8, 2.7-23.1)	1.4 (0.1-4.8)	4/41 (9.8, 2.7-23.1)	2.1 (0.2-7.7)

[1] Two of the samples in which aflatoxins were detected were from sacks of peanuts that had been rejected at the border and were subsequently destroyed

[2] Stanton (1999) analysed products that were classified as 'peanut confectionery'. However, this category included snack bars and did not provide information to allow separation of data into sub-categories.

NR = Not reported ND = Not detected

APPENDIX 2 ESTIMATES OF MEAN AFLATOXIN CONCENTRATIONS OF FOOD TYPES IN NEW ZEALAND

Total Aflatoxins

	Peanuts	Peanut butter	Peanut sauce	Peanut confectionery	Almonds	Brazil nuts	Cashews	Pistachios	Mixed nuts	*Capsicum*-based spices	Curry powder	Ginger	Pepper (black, white)	Bakery products (maize)	Breakfast cereals, cornflakes	Breakfast cereals, other	Corn chips
Number of samples analysed	50	75	25	17	10	10	10	20	33	15	5	5	5	13	5	11	5
Number of samples with detectable aflatoxins	10	31	8	3	0	1	0	1	12	13	5	4	0	1	1	1	0
Percent left censored	80	59	68	82	100	90	100	95	64	13	0	20	100	92	80	91	100
Mean, positive only values	6.48	0.718	2.74	1.15	0.00	5.83	0.00	0.73	1.75	3.51	46.1	1.98	0.00	0.74	0.22	1.10	0.00
All ND true zero[1]	1.295	0.297	0.875	0.202	0.000	0.583	0.000	0.037	0.635	3.038		1.587	0.000	0.057	0.044	0.10	0.000
All ND true ND																	
Substitution (ND=LOD/2)	1.335	0.326	0.909	0.243	0.050	0.628	0.050	0.084	0.667	3.045		1.597	0.050	0.103	0.084	0.145	0.050
Substitution (ND=LOD)	1.375	0.356	0.943	0.285	0.100	0.673	0.100	0.132	0.699	3.051		1.607	0.100	0.149	0.124	0.191	0.100
MLE		0.446						0.69	2.48	5.670		2.79		0.74	0.078	5.7	
KM	1.370	0.349	1.011	0.586		5.83		0.73	0.810	3.066		1.65		0.74	0.22	1.1	
ROS	1.407	0.339	0.887	0.228		5.83		0.73	0.675	3.084		1.61		0.74	0.22	1.1	
Half ND=0, half true ND																	
Substitution (ND=LOD/2)	1.315	0.312	0.892	0.223	0.025	0.606	0.025	0.060	0.651	3.041		1.592	0.025	0.080	0.064	0.123	0.025
Substitution (ND=LOD)	1.335	0.326	0.909	0.243	0.050	0.628	0.050	0.084	0.667	3.045		1.597	0.050	0.103	0.084	0.145	0.050
MLE																	
KM	1.297	0.300	0.875	0.202					0.635	3.051				0.057	0.044	0.1	
ROS										3.053							

	Maize meal/polenta	Pasta (maize)	Popcorn	Snack foods	Dates	Dried apricots	Dried vine fruits	Dried figs	Prunes	Mixed nuts and fruit	Snack bars
Number of samples analysed	4	7	1	9	5	10	10	10	5	19	41
Number of samples with detectable aflatoxins	0	0	0	0	0	1	0	3	1	3	4
Percent left censored	100	100	100	100	100	90	100	70	80	84	90
Mean, positive only values	0.00	0.00	0.00	0.00	0.00	0.88	0.00	4.19	0.46	0.39	2.13
All ND true zero[1]	0.000	0.000	0.000	0.000	0.000	0.088	0.000	1.26	0.092	0.062	0.208
All ND true ND											
Substitution (ND=LOD/2)	0.050	0.050	0.050	0.050	0.050	0.133	0.050	1.29	0.132	0.104	0.253
Substitution (ND=LOD)	0.100	0.100	0.100	0.100	0.100	0.178	0.100	1.33	0.172	0.146	0.298
MLE						1.64			0.209	0.103	1.02
KM						0.88		1.32	0.46	0.172	0.343
ROS						0.88		1.41	0.46	0.069	0.209
Half ND=0, half true ND											
Substitution (ND=LOD/2)	0.025	0.025	0.025	0.025	0.025	0.111	0.025	1.28	0.112	0.083	0.230
Substitution (ND=LOD)	0.050	0.050	0.050	0.050	0.050	0.133	0.050	1.29	0.132	0.104	0.253
MLE											
KM						0.088		1.26	0.092	0.062	0.208
ROS											

ND = not detects or left-censored values LOD = analytical limit of detection
MLE = maximum likelihood estimation
KM = Kaplan-Meier
ROS = regression on order statistics (probability plot)
[1] Substituting all left-censored data by zero is equivalent to assuming that all these values are true zeros.

Aflatoxin B1

	Peanuts	Peanut butter	Peanut sauce	Peanut confectionery	Almonds	Brazil nuts	Cashews	Pistachios	Mixed nuts	*Capsicum*-based spices	Curry powder	Ginger	Pepper (black, white)	Bakery products (maize)	Breakfast cereals, cornflakes	Breakfast cereals, other	Corn chips
Number of samples analysed	50	75	25	17	10	10	10	20	33	15	5	5	5	13	5	11	5
Number of samples with detectable aflatoxins	10	31	8	3	0	1	0	1	12	13	5	4	0	1	1	1	0
Percent left censored	80	59	68	82	100	90	100	95	64	13	0	20	100	92	80	91	100
Mean, positive only values	5.23	0.481	2.02	0.967	0.00	5.83	0.00	0.63	1.57	3.25	41.4	1.44	0.00	0.55	0.22	0.89	0.00
All ND true zero[1]	1.047	0.199	0.646	0.171	0.000	0.583	0.000	0.032	0.572	2.817		1.150	0.000	0.042	0.044	0.081	0.000
All ND true ND																	
Substitution (ND=LOD/2)	1.087	0.228	0.680	0.212	0.050	0.628	0.050	0.079	0.603	2.823		1.160	0.050	0.088	0.084	0.126	0.050
Substitution (ND=LOD)	1.127	0.258	0.714	0.253	0.100	0.673	0.100	0.127	0.635	2.830		1.170	0.100	0.135	0.124	0.172	0.100
MLE		0.264		0.585				0.328	1.76	5.071		1.739		0.209	0.078	1.79	
KM	1.119	0.249	0.735	0.270		5.83		0.63	0.750	2.845		1.214		0.55	0.22	0.89	
ROS	1.110	0.234	0.653	0.174		5.83		0.63	0.607	2.857		1.174		0.55	0.22	0.89	
Half ND=0, half true ND																	
Substitution (ND=LOD/2)	1.067	0.214	0.663	0.191	0.025	0.606	0.025	0.055	0.587	2.820		1.155	0.025	0.065	0.064	0.104	0.025
Substitution (ND=LOD)	1.087	0.228	0.680	0.212	0.050	0.628	0.050	0.079	0.603	2.823		1.160	0.050	0.088	0.084	0.126	0.050
MLE																	
KM	1.048	0.201	0.647	0.171					0.572	2.817				0.042	0.044	0.081	
ROS																	

	Maize meal/polenta	Pasta (maize)	Popcorn	Snack foods	Dates	Dried apricots	Dried vine fruits	Dried figs	Prunes	Mixed nuts and fruit	Snack bars
Number of samples analysed	4	7	1	9	5	10	10	10	5	19	41
Number of samples with detectable aflatoxins	0	0	0	0	0	1	0	3	1	3	4
Percent left censored	100	100	100	100	100	90	100	70	80	84	90
Mean, positive only values	0.00	0.00	0.00	0.00	0.00	0.21	0.00	1.72	0.10	0.12	1.36
All ND true zero[1]	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.516	0.010	0.018	0.133
All ND true ND											
Substitution (ND=LOD/2)	0.050	0.050	0.050	0.050	0.050	0.066	0.050	0.550	0.060	0.061	0.178
Substitution (ND=LOD)	0.100	0.100	0.100	0.100	0.100	0.111	0.100	0.586	0.100	0.103	0.224
MLE						0.045		3.32		0.073	0.305
KM						0.21		0.579	0.100	0.086	0.260
ROS						0.21		0.624	0.100	0.087	0.135
Half ND=0, half true ND											
Substitution (ND=LOD/2)	0.025	0.025	0.025	0.025	0.025	0.044	0.025	0.534	0.040	0.039	0.156
Substitution (ND=LOD)	0.050	0.050	0.050	0.050	0.050	0.066	0.050	0.550	0.060	0.061	0.178
MLE											
KM						0.021		0.525	0.020	0.022	0.133
ROS											

ND = not detects or left-censored values
LOD = analytical limit of detection
MLE = maximum likelihood estimation
KM = Kaplan-Meier
ROS = regression on order statistics (probability plot)
[1] Substituting all left-censored data by zero is equivalent to assuming that all these values are true zeros.

APPENDIX 3 IMPORTS OF RELEVANT FOODS INTO NEW ZEALAND DURING 2009

Food group description	Imports (2009, tonnes)
Peanuts and peanut products	
Peanuts	5,185
Peanut butter	3,107
Tree nuts and tree nut products	
Almonds	1,633
Brazil nuts	300
Cashews	1,962
Pistachios	119
Spices	
Capsicum-based spices	287
Ginger, ground	134
Pepper (black, white)	416
Dried fruits	
Dates	1,323
Dried apricots	1,586
Dried vine fruits	7,888
Dried figs	162
Prunes	884

APPENDIX 4 PROCEDURE FOR DETERMINING THE PROPORTION OF AFLATOXIN-CONTAINING FOODS IN RECIPES

Sources of recipes

No single standard source for recipes exists. In the absence of such a resource, the recipes used in a database must be selected based on a pre-determined strategy. While such a strategy may be discussed and even criticised, its existence provides a methodology than can be followed for subsequent additions and can be utilised by other parties. The following sources of recipes have been identified:

- New Zealand Food Composition Database. Contains recipes for 272 foods (in the version of Food Files currently held by ESR). Not all of these are true recipes, as some describe how food descriptors have been combined to produce food composition information for other descriptors. Recipes are expressed as the percentage of the ingredient in the food.
- McCance and Widdowson's The Composition of Foods (this is essentially the British equivalent of the food composition database) contains recipes for 103 foods (Holland *et al.*, 1991). Recipes are expressed in terms of the weight of the ingredients plus an estimate of the weight loss upon cooking, where relevant.
- The National Nutrition Survey (Russell *et al.*, 1999) and National Children's Nutrition Survey (Ministry of Health, 2003) 24-hour dietary recall studies include recipes, where these were provided by respondents. These have already been integrated into our working version of the database, but could be used as a resource to define recipes for situations where recipes were not provided by respondents. Recipes are in the form of the weight of the ingredients.
- Recipes used in conjunction with the USDA Nutrient database for nationwide food surveys 2007 is available on-line[1]. Recipes are expressed as percentages of ingredients in final foods.
- Various cookbooks and internet resources. Express ingredients in terms of weights or standard measures.

Yield Factors

For many recipes, particularly cooked recipes, the final weight of the prepared recipe will be different from the sum of the weights of the (uncooked) ingredients. The ratio of these two weights is often referred to as a yield factor. Weight changes during cooking mainly relate to gains or losses in moisture (Bergstrom, 1999).

Unfortunately, the form of the calculations carried out for food composition purposes is opposite to that required for management of recipes in a food consumption database. Our interest is generally in deconvoluting from a cooked composite food to uncooked ingredients. In this case the sum of the weights of the individual ingredients would be expected to be equal to or greater than the weight of the composite food. However, different ingredients will differ in their moisture content and would be expected to lose differing amounts of their initial weights during the cooking process.

[1] http://www.nal.usda.gov/fnic/foodcomp/Data/SurveyNDB7/

Utility of yield factor information will depend on the form of other information available. The following scenarios are envisaged:

- Consumed weight of recipe available. Yield factor available. Ingredient composition available in terms of standard measures. Calculate total weight of ingredients from recipe. Calculate total weight of ingredients from consumed weight and yield factor. Scale weight of ingredients to uncooked weight of prepared food.
- Consumed weight of recipe available. Yield factor available. Percentage figures available for recipe ingredients. If percentage refers to uncooked weight, use consumed weight and yield factor to determine uncooked weight then apply percentages. If percentage refers to cooked weight, then composition of uncooked recipe cannot be determined. However, this scenario is unlikely.

Procedure for Application of Recipes in Food Consumption Datasets

The following procedure is largely based on that of Reinivuo *et al.* (Reinivuo *et al*., 2009), although it has been modified to accommodate different formats of information. The two formats encountered are:

- Classical recipes, where the ingredients are listed in terms of weights or measures; and
- Database recipes, where the ingredients are listed in terms of percentages of the finished recipe.

The procedure is:

- Identify recipe from a source listed in the section 'Source of recipes'. Wherever possible, priority should be given to New Zealand sources. However, priority should be given to systematic sources of recipes over *ad hoc* sources (e.g. choose NZ Food Composition Database recipe before internet recipe).
- If recipe is in the form of percentages, apply directly.
- If recipe is in the form of weights and measures, convert all measures (cups, tablespoons, etc.) to weights using standard weights per measure (see 'CSM' file in the most recent version of Foodfiles held at ESR, currently Foodfiles 2006) or standard volumes of measures and density values for the ingredient. Standard volumes are listed in Attachment 1 and densities of food items can be found in the CSM file in Foodfiles.
- Convert weights to percentages.

So, to convert a weight of a final recipe to the weight of its ingredients:

- Take weight of final recipe.
- If recipe is cooked or processed otherwise in a manner that will cause a weight change, apply the inverse of the appropriate yield factor to give the total weight of ingredients. For example, if the final weight is 500 g and yield tables indicate that the recipe loses 9% of its weight through cooking, the weight of the ingredients is 500 x (100/100-9) or 500/0.91. This gives a weight of 549 g.
- Apply percentages determined above to give the weight of ingredients.

<u>Examples</u>

The NNS contains entries for Macaroni cheese (with or without added meat). A common serving size is 506 g. The Food files (New Zealand Food Composition Database) give a percentage recipe for Macaroni cheese:

- Milk, fluid, standard 45
- Macaroni, boiled 36
- Cheese processed 13
- Butter, salted 3
- Flour, wheat, white, standard 3
- Salt 0

European yield tables give a 9% weight loss for macaroni cheese on cooking (Bergstrom, 1999). For a serving of 506 g, the uncooked weight would be 506/0.91 = 556 g. The weight (g) of the uncooked ingredients would be:

- Milk, fluid, standard 250
- Macaroni, boiled 200
- Cheese processed 72
- Butter, salted 17
- Flour, wheat, white, standard 17
- Salt 0

McCance and Widdowson (Holland *et al.*, 1991) gives a recipe for macaroni cheese of:

- 350 ml milk
- 280 g cooked macaroni
- 100 g grated cheese
- 25 g margarine
- 25 g flour
- 0.5 tsp salt

Weight loss is 9.4%. Excluding salt and assuming a density of 1 g/ml for milk, the total weight of ingredients is 780 g, with a cooked weight equivalent of 707 g. For a 506 g serving the scale factor is 506/707 = 0.716. Applying this to the original recipe gives:

- Milk 251
- Cooked macaroni 200
- Grated cheese 72
- Margarine 18
- Flour 18

It appears probably that these two expressions of the recipe for macaroni cheese are from the same primary source.

Using a more challenging source for the recipe (an internet source) of macaroni cheese (ingredients list was truncated for simplicity):

- 2 cups milk
- 2 cups macaroni, cooked
- 2 cups grated cheese
- 2 TB butter
- 2 TB flour

The ‘csm’ file in Foodfiles contains weights of standard measures for foods in the database. Another useful resource is the USDA measurement conversion tables: http://www.ars.usda.gov/Aboutus/docs.htm?docid=9617

For this exercise the following are relevant:

- Milk. CSM gives a weight of 15.5 g/tablespoon for standard, fluid milk. USDA gives a conversion of 16 tablespoons per cup. 2 cups = 500 g
- Macaroni. CSM doesn’t give the weight of a cup of cooked macaroni, but does give a density 0.596 g/ml. Therefore, 2 cups (500 ml) would be expected to weigh 300 g.
- Cheese. CSM gives the weight of a cup of shredded Gruyere cheese as 119 g. This is similar to using the density of cheddar cheese (0.47 g/ml) and the volume of a standard cup (250 ml). Therefore, 2 cups of grated cheese will weigh approximately 240 g.
- Butter. CSM gives the weight of a tablespoon of salted butter as 15 g. Therefore, 2 tablespoons will weigh 30 g.
- Flour. CSM gives the density of standard white flour as 0.489 g/ml. A tablespoon is approximately 15.5 ml giving a weight for 2 tablespoons of flour of 15 g.

Total weight of this recipe is 1085 g, corresponding to a cooked weight (-9%) of 987 g and a conversion factor for a 506 g serving of 506/987 = 0.513. The recipe weights equating to a 506 g serving, based on this recipe are:

- Milk 257 g
- Macaroni 154 g
- Cheese 123 g
- Butter 15 g
- Flour 8 g

These figures differ from those above, but are generally still recognisable.

APPENDIX 5 MEAN BODY WEIGHTS FOR DETERMINISTIC EXPOSURE ASSESSMENT

Age-gender group	Mean body weight (kg)
6-12 month infant	9
1-3 years toddler	13
5-6 years child	23
11-14 years girl	55
11-14 years boy	54
19-24 years young male	78
25+ years female	70
25+ years male	82

APPENDIX 6 CONTRIBUTION OF FOOD GROUPS TO DIETARY AFLATOXIN EXPOSURE

Deterministic Exposure Assessment

Total aflatoxin

Age-gender group	Contribution of food group to estimated dietary exposure (%), based on lower bound – upper bound concentration estimates				
	Spices	Nuts	Grain products	Snacks & spreads	Fruit
Infant (6 months)	80.3 – 69.5	NC	3.8 – 9.3	12.0 – 14.8	4.0 – 6.4
Toddler (1-3 years)	72.5 – 62.9	9.6 – 8.3	6.1 – 13.1	9.2 – 11.4	2.7 – 4.4
Child (5-6 years)	54.3 – 46.0	21.0 – 18.5	5.0 – 11.1	18.3 - 22.2	1.4 – 2.2
Female (11-14 years)	73.6 – 66.6	10.8 – 10.3	3.2 – 6.7	11.5 – 14.9	0.9 – 1.5
Male (11-14 years)	72.3 – 65.3	12.9 – 12.1	3.7 – 8.1	10.5 – 13.6	0.6 – 1.0
Male (19-24 years)	86.6 – 80.6	6.8 – 6.9	4.4 – 9.4	1.7 – 2.2	0.5 – 0.9
Female (25+ years)	80.4 – 72.4	7.4 – 7.3	7.0 – 12.9	3.6 – 4.7	1.6 – 2.7
Male (25+ years)	81.4 – 74.8	9.6 – 9.6	4.9 – 9.7	2.5 – 3.3	1.5 – 2.6

NC = Not consumed

Aflatoxin B1

Age-gender group	Contribution of food group to estimated dietary exposure (%), based on lower bound – upper bound concentration estimates				
	Spices	Nuts	Grain products	Snacks & spreads	Fruit
Infant (6 months)	85.9 – 72.2	NC	4.5 – 10.7	9.1 – 12.9	0.5 – 4.3
Toddler (1-3 years)	77.9 – 65.6	8.0 – 6.7	6.7 – 14.8	7.0 – 9.9	0.4 – 2.9
Child (5-6 years)	53.1 – 44.1	28.8 – 25.0	5.2 – 11.6	12.7 – 17.8	0.2 – 1.4
Female (11-14 years)	72.4 – 64.7	16.4 – 15.4	3.1 – 6.9	8.0 – 12.1	0.1 – 0.9
Male (11-14 years)	71.6 – 63.8	17.1 – 15.9	3.8 – 8.5	7.4 – 11.1	0.1 – 0.6
Male (19-24 years)	81.1 – 75.1	13.6 – 13.4	4.1 – 9.2	1.1 – 1.7	0.1 – 0.5
Female (25+ years)	76.2 – 68.0	15.0 – 14.2	6.2 – 12.5	2.5 – 3.7	0.2 – 1.6
Male (25+ years)	75.5 – 68.8	18.3 – 17.8	4.4 – 9.3	1.7 – 2.6	0.2 – 1.5

NC = Not consumed

Dietary Modelling Exposure Assessment

Total aflatoxin

Age-gender group	Contribution of food group to estimated dietary exposure (%), based on lower bound – upper bound concentration estimates				
	Spices	Nuts	Grain products	Snacks	Fruit
Child (5-6 years)	49.2 – 40.2	23.5 – 21.1	6.7 – 14.3	20.5 – 24.1	0.2 – 0.3
Female (11-14 years)	70.8 – 62.7	15.1 – 14.5	5.3 – 11.6	8.7 – 11.1	0.1 – 0.2
Male (11-14 years)	46.2 – 37.3	29.4 – 25.8	10.0 – 20.2	14.4 – 16.7	0.0 – 0.0
Male (19-24 years)	72.3 – 65.3	18.0 – 17.2	8.2 – 15.5	1.4 – 1.8	0.1 – 0.2
Female (25+ years)	54.4 – 46.4	26.4 – 24.4	11.6 – 20.1	4.2 – 5.3	3.3 – 3.8
Male (25+ years)	54.1 – 46.4	29.9 – 27.8	10.7 – 19.4	4.1 – 5.1	1.2 – 1.3

Aflatoxin B1

Age-gender group	Contribution of food group to estimated dietary exposure (%), based on lower bound – upper bound concentration estimates				
	Spices	Nuts	Grain products	Snacks	Fruit
Child (5-6 years)	54.0 – 42.4	22.3 – 19.7	7.8 – 16.4	15.9 – 21.2	0.1 – 0.2
Female (11-14 years)	74.0 – 64.3	13.8 – 13.2	5.7 – 12.8	6.5 – 9.5	0.0 – 0.1
Male (11-14 years)	50.1 – 38.9	27.5 – 23.7	11.3 – 22.8	11.1 – 14.5	0.0 – 0.0
Male (19-24 years)	74.8 – 66.6	16.1 – 15.4	8.0 – 16.3	1.0 – 1.6	0.0 – 0.1
Female (25+ years)	58.6 – 48.4	25.4 – 23.2	11.6 – 21.4	3.1 – 4.6	1.3 – 2.3
Male (25+ years)	57.5 – 48.0	28.3 – 26.1	10.7 – 20.7	3.0 – 4.4	0.5 – 0.8

APPENDIX 7 AFLATOXIN CONCENTRATION VALUES USED IN THE CURRENT STUDY AND THEIR ASSOCIATED CREDIBLE INTERVALS, CONSIDERING MEASUREMENT UNCERTAINTY

Foodgroup	**Mean Total Aflatoxins, µg/kg (95th percentile credible interval)**		**Mean Aflatoxin B1, µg/kg (95th percentile credible interval)**	
	Lower bound	**Upper bound**	**Lower bound**	**Upper bound**
Peanuts	1.30 (1.24-1.35)	1.38 (1.32-1.43)	1.05 (1.00-1.10)	1.13 (1.08-1.18)
Peanut butter	0.326 (0.29-0.36)	0.326 (0.29-0.36)	0.228 (0.193-0.263)	0.228 (0.193-0.263)
Peanut sauce	0.88 (0.84-0.92)	0.94 (0.90-0.99)	0.65 (0.62-0.68)	0.71 (0.68-0.75)
Peanut confectionery	0.202 (0.190-0.216)	0.285 (0.271-0.297)	0.171 (0.159-0.183)	0.253 (0.240-0.265)
Almonds	0.000	0.000	0.000	0.000
Brazil nuts	0.583 (0.54-0.63)	0.673 (0.63-0.72)	0.583 (0.54-0.63)	0.673 (0.63-0.72)
Cashews	0.000	0.000	0.000	0.000
Pistachios	0.037 (0.033-0.041)	0.132 (0.127-0.135)	0.032 (0.028-0.035)	0.127 (0.122-0.130)
Mixed nuts	0.64 (0.61-0.66)	0.70 (0.67-0.73)	0.57 (0.55-0.60)	0.64 (0.61-0.66)
Capsicum based spices	3.05 (2.96-2.34)	3.05 (2.96-2.34)	2.82 (2.74-2.90)	2.82 (2.74-2.90)
Curry powder	46.1 (42.6-50.0)	46.1 (42.6-50.0)	41.4 (38.2-44.9)	41.4 (38.2-44.9)
Ginger, ground	1.60 (1.51-1.69)	1.60 (1.51-1.69)	1.16 (1.09-1.23)	1.16 (1.09-1.23)
Bakery products	0.053 (0.047-0.059)	0.146 (0.139-0.151)	0.039 (0.034-0.045)	0.132 (0.126-0.136)
Breakfast cereal, cornflakes	0.044 (0.033-0.056)	0.124 (0.112-0.135)	0.044 (0.033-0.056)	0.124 (0.112-0.135)
Breakfast cereal, other	0.100 (0.091-0.110)	0.191 (0.181-0.200)	0.081 (0.073-0.090)	0.172 (0.163-0.180)
Corn chips	0.000	0.000	0.000	0.000
Maize, meal/polenta	0.000	0.000	0.000	0.000
Snack foods	0.000	0.000	0.000	0.000
Dates	0.000	0.000	0.000	0.000
Dried apricots	0.088 (0.079-0.097)	0.178 (0.168-0.186)	0.021 (0.015-0.027)	0.111 (0.105-0.116)
Dried vine fruits	0.000	0.000	0.000	0.000
Figs, dried	1.26 (1.19-1.33)	1.33 (1.26-1.40)	0.52 (0.48-0.55)	0.59 (0.55-0.62)
Prune	0.092 (0.079-0.106)	0.172 (0.158-0.185)	0.010 (0.009-0.031)	0.100 (0.088-0.110)
Mixed fruit and nuts	0.062 (0.056-0.068)	0.146 (0.139-0.151)	0.018 (0.014-0.024)	0.103 (0.097-0.107)
Snack bars	0.208 (0.193-0.224)	0.298 (0.282-0.314)	0.133 (0.124-0.144)	0.224 (0.213-0.233)