Estimating the social costs of the impacts of fungi and aflatoxins in maize and peanuts

A.S.G. Lubulwa and J.S. Davis*

Abstract

This paper first describes five important potential impacts of fungi and aflatoxins in maize and peanuts, namely:

- quality deterioration in the agricultural products;
- spoilage of the agricultural products;
- mutagenic and carcinogenic effects on humans who consume aflatoxin-contaminated food over a long time-period;
- livestock health and productivity effects arising from the use of aflatoxin-contaminated feedstuffs; the emphasis is on increases in mortality rates and reductions in feed to weight conversion ratios for chickens, ducks, egg layers, and pigs; and
- the loss of export markets due to aflatoxin regulations restricting international trade in aflatoxin-contaminated grains.

Next, the paper describes the approach for estimating the social costs of these impacts and then estimates the social costs of aflatoxins in Indonesia, Philippines and Thailand. The social cost of the spoilage effects of fungi and aflatoxins is estimated using a product wastage economic model, and is equal to the surplus lost by producers and consumers as a result of fungal attack and aflatoxin contamination of maize and peanuts. The social cost of human health effects of aflatoxins is estimated as the value of lost productive capacity due to premature death and morbidity from aflatoxin-related primary liver cancer. The social costs to the livestock sector of aflatoxins are estimated as the change in producer and consumer surplus from the increase in costs to livestock producers as a result of using aflatoxin contaminated feed. These social costs are summarised in tabular form below.

The total annual social cost, in Indonesia, Philippines and Thailand, due to aflatoxins in maize in 1991 was about $A319 million. Indonesia incurred 62% of this cost, Philippines 27% and Thailand incurred 11% of the cost. The total annual social cost of aflatoxins in peanuts in 1991 was about $A158 million — Indonesia incurred 84% of this cost, Thailand incurred 13% and Philippines 3% of the cost. These estimates do not include the cost from loss of foreign markets which for these commodities in these countries are not expected to be substantial at this time.

Estimates of the 1991 annual social costs of aflatoxins in Indonesia, Philippines and Thailand ($A million)

Sector	Impact of aflatoxin considered	Parameter used in social cost estimation	Total for three countries		
			Maize	Peanuts	Maize and peanuts
Grains sector households	Product spoilage effects	Change in wastage rates and postharvest costs	$70.9	$36.8	$107.7
	Human health effects	The cost of premature death due to aflatoxin-related primary liver cancer	$112.7	$73.2	$185.9
	Human health effects	The cost of disability due to aflatoxin-related primary liver cancer	$63.8	$41.5	$105.3
Poultry	Increased mortality rates and reduced feed to weight conversion	Reduction in the unit cost of production when the aflatoxin content of feed is reduced	$28.9	$2.5	$31.4
Hen eggs	Increased mortality rates and reduced feed to weight conversion	Reduction in the unit cost of production when the aflatoxin content of feed is reduced	$6.6	$0.6	$7.2
Pig meat	Increased mortality rates and reduced feed to weight conversion	Reduction in the unit cost of production when the aflatoxin content of feed is reduced	$36.2	$3.1	$39.3
Total			$319.1	$157.7	476.9

* ACIAR, GPO Box 1571, Canberra ACT 2601, Australia.

Introducton

Fungi are a diverse[1] group of organisms ranging from simple single cells through to complex structures. However, yeast and moulds are often the fungi responsible for food spoilage (Robinson 1983).

Extensive research has identified the most important physical and chemical factors which influence grain damage by fungal growth. Of these, environmental conditions, temperature, humidity, oxygen and carbon dioxide tensions seem to play a decisive role in determining fungal growth and toxin production (FAO 1983). Pitt and Hocking (1991) have indicated that the dominant factor is water activity — a chemical concept quantifying the relationship between moisture in foods and the ability of micro-organisms to grow on them. Pitt and Hocking conclude that 'Dry a product quickly and keep it dry' remains the most effective method for ensuring fungi do not invade stored products.

When products are not dry while in storage, fungi attack them and fungal growth leads to reduction in the quantity and weight of grains, deterioration in quality of produce for processing and in food value and the production of aflatoxins.

Why focus on aflatoxins?

There are five mycotoxins that occur often in food as follows (GASGA 1993):

Mycotoxin	Main commodity affected	Fungal source
Deoxynivalenol/ nivalenol	Wheat, maize, barley	*Fusarium graminearum, culmorum, crookwellense*
Zearalenone	Maize, wheat	*Fusarium graminearum, culmorum, crookwellense*
Ochratoxin	Barley, wheat	*Aspergillus ochraceous, Penicillium verrucosum*
Fumonisin	Maize	*Fusarium moniliforme*
Aflatoxin B_1, B_2, G_1, G_2	Maize, peanuts	*Aspergillus flavus, A. parasiticus*

Appendix A gives examples of other commodities that are susceptible to fungal attack, and lists the fungi that are often responsible for damage and quality deterioration of grains. The focus of this paper, however, is on a sub-set of mycotoxigenic fungi producing aflatoxins in grains.

Lillehoj (1987) provides some descriptive details about aflatoxins. While aflatoxins are not the only mycotoxins in foods and feed, they are the more important mycotoxins not only in the countries that are included in this study, but in the rest of Asia, Africa and Latin America. For example, Van Egmond (1991) notes that:

> At the time of writing there were about 60 countries that had specific regulations or detailed proposals for regulations on mycotoxins. Most of the existing mycotoxin regulations concern aflatoxins and, in fact, all countries with mycotoxin regulations have tolerances for aflatoxins in foods and/or animal feedstuffs.

Appendix B gives some information on current aflatoxin regulations in selected countries.

Why focus on maize and peanuts in Indonesia, Philippines and Thailand?

Amongst commodities susceptible to fungal attack and aflatoxin contamination, maize and peanuts are by far the most important in monetary value (Pitt 1993). Pitt and Hocking[2] estimate that about 90% of aflatoxins in Indonesia, Philippines and Thailand come from maize and peanuts. Maize and groundnuts have each a wide range of different uses as foods and feedstuffs. Reddy et al. (1992) provided the following summary of the multiple uses of groundnuts:

> The groundnut plant comprises approximately 10 percent roots, 45 percent vines and leaves, and 45 percent pods. The roots and nodules add 125–178 kilograms of nitrogen per hectare to the soil through nitrogen fixation. The vines and leaves are used as green, dry or silage fodder and as fertiliser and fuel. Groundnut husk constitutes about 13 percent of the whole plant and is put to several uses. The whole seed, which constitutes 32 percent of the total mass of the plant, is used for oil and food. The groundnut oil is mainly used for cooking, and in industry for the preparation of several domestic products. The protein rich cake or meal after oil extraction is usually fed to livestock or used as fertiliser. However, in recent years, with proper processing, the meal is being utilised for making products such as hot cakes, biscuits, and baby or invalid foods.

The economic and social costs of using aflatoxin-contaminated maize and peanuts depend on how consumers of these products use them in the different countries. Appendix C provides some information on both the production and usage of maize and peanuts in Indonesia, Philippines and Thailand.

Outline of the paper

The next section introduces five potential impacts of fungi and aflatoxins. The paper then describes an approach for estimating the social costs of these impacts. Finally, the paper presents estimates of the welfare costs of aflatoxins in Indonesia, Philippines and Thailand and draws some conclusions.

Five Potential Impacts of Fungi and Aflatoxins in Agriculture

This section identifies from the scientific literature five potential impacts of fungi and aflatoxins, namely:

- quality deterioration in the agricultural products;
- spoilage of the agricultural products;
- mutagenic and carcinogenic effects on humans who consume aflatoxin-contaminated food over a long time-period;
- livestock health and productivity effects arising from the use of aflatoxin-contaminated feedstuffs; the emphasis is on increases in mortality rates and reductions in feed to weight conversion ratios for chickens, ducks, egg layers, and pigs; and
- the loss of export markets due to aflatoxin regulations restricting international trade in aflatoxin-contaminated grains.

[1] As an indication of the diversity of fungi, in 1991–92, analysis of 1328 samples from field, farm, storage, and retail sources in Indonesia and the Philippines led to the isolation and identification of approximately 6800 fungi (see ACIAR 1992). Samples comprised mainly maize, peanuts, rice (both paddy and milled), beans of various types, with smaller numbers of cashews, kemiri nuts, and spices.

[2] Dr John Pitt and Dr Ailsa Hocking, CSIRO Division of Food Science and Technology, North Ryde, Sydney, personal communication, 14 January 1994.

The purpose of this section is to:

- highlight the importance of each of the five potential impacts of fungi and aflatoxins; and
- summarise the empirical evidence of each gleaned from the scientific literature.

Product quality impacts of fungi and aflatoxins

Grades of produce

Total aflatoxins (B_1, B_2, G_1 and G_2) in µg/kg of product can give an indication of some of the quality attributes of the product. Using data from ACIAR project PN8806 (see ACIAR 1989, 1990, 1991, 1992, 1993) on the levels of aflatoxin contamination in peanuts and maize in Southeast Asia, it is possible to identify three distinct quality grades of produce:

- high quality produce — this is produce which contains no more than 50 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/ kg of product;
- medium quality produce — this is produce containing more than 50 µg of aflatoxins but the level of aflatoxin contamination is less than or equal to 300 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/kg of product;
- low quality produce — this is produce which contains more than 300 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/ kg of product

The category of high quality produce includes almost aflatoxin-free produce containing no more than 5 µg of aflatoxins/kg of product. In many countries the limit of 5 µg/kg of product is applicable to baby food products (see Appendix B). This is also the limit proposed by the European Community for dairy feeds. The reason for such a low limit for dairy feeds is to do with aflatoxin M_1 in milk products. The accepted upper limit for aflatoxin M_1 is 0.05 µg/kg of product. The conversion ratio of aflatoxin B_1 in feed to aflatoxin M_1 in milk is 100:1. Thus the acceptable limit in dairy feeds to meet this standard is 5 µg/kg of dairy feeds.

The upper limit of 50 µg of total aflatoxins (B_1, B_2, G_1 and G_2) per one kilogram of product for high quality produce is arbitrary but it is consistent with the literature on aflatoxin regulations specifying maximum acceptable levels of aflatoxin contamination in foods and feedstuffs. Appendix B lists these limits for selected countries. Different countries have different limits. In 1991, for peanuts, maize and maize products, the maximum value for the acceptable level of aflatoxin contamination was 50 µg/kg of product (see Table B.1 and Table B.2 in Appendix B).

The upper limit of 300 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/kg of product for the medium quality product is also arbitrary. The United States has a limit of 300 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/kg of product for feedstuffs for adult beef cattle , sheep and goats.

In terms of aflatoxin contamination, products that contain more than 300 µg of total aflatoxins (B_1, B_2, G_1 and G_2)/kg of product are low quality products. Such products contain more than 10 times the levels of aflatoxins acceptable in some western countries and more than 60 times the levels of aflatoxins acceptable in western countries with the lowest aflatoxin tolerance levels.

Tiongson and Gacilos (1990) give some support for the approach of using postharvest aflatoxin contamination levels to define grades of farm-level output when they conclude that:

> No definite pattern of increase in the incidence of aflatoxin was observed among different stages of operation. This suggests that the grain may reach substantial level of aflatoxin contamination even at the start of off-farm operation depending on the degree by which the grains were earlier predisposed to *Aspergillus flavus* infection and to on-farm conditions that favour aflatoxin formation during the pre harvest stages of the crop.

Table 1 summarises the relevant data on the quality of maize and peanuts in Indonesia, Philippines and Thailand. The data in Table 1 may be conservative compared to results from other studies. For example, in the case of the Philippines, Agaceta et al. (1993) collected 200 poultry feeds, 300 hog feeds and 100 prawn feeds from different feed mills and farms in Luzon, Visayas and Mindanao and found that 63% of poultry feeds, 61% of swine feeds and 52% of prawn feeds contained more than 50 µg of aflatoxins/kg of feed.

Instead of treating maize (corn) as a homogenous product, this paper treats maize as three different products depending on levels of aflatoxin contamination. Similarly, peanuts (groundnuts) are three different products, where each peanut product line corresponds to different levels of aflatoxin contamination.

Price versus quality

Tiongson and Gacilos (1990) observed an inverse relationship between the price of maize grits and aflatoxin content in the Philippines — that is the lower the level of aflatoxin content, the higher was the price of maize grits.

Cardino-Bermundo et al. (1991) concluded that moisture content and colour of the commodity determines the price of maize grain in the Philippines. Bottema and Altemeier (1990) and Wattanutchariya et al. (1991) indicate that these two factors (moisture content and colour) are the most important two factors in grain price formation in Indonesia and Thailand. In these countries the grain trader (middleman) measures the two factors through sensory evaluation and visual observation.[3] Generally local grain traders and processors do not use laboratory equipment, like moisture testers, to measure grain attributes. The trader discounts wet or discoloured grain by deducting a certain percentage off the gross weight of grain. Alternatively the trader deducts a percentage off the market price to get the price per unit weight of wet or discoloured grain. The discounts increase with the wetness of grain. Cardino-Bermundo et al. (1991) observed the following discounts in the Philippines:

- for skin dry produce, traders reduced the gross weight or the per unit weight price by a factor ranging from 5 to 10% depending on the level of dryness;
- for wet grain traders reduced the weight or price of produce by a factor ranging from 15–20%; and
- for damaged grain traders reduced the gross weight or the unit price of the produce by a factor ranging from 30–50%

[3] Dr John Pitt and Dr Ailsa Hocking, CSIRO, North Ryde, Sydney (pers. comm. 14 January 1994) noted that (a) visual observation is a very poor and unreliable way to tell whether a product contains aflatoxins or not, (b) current pricing regimes do not capture aflatoxin content of products, (c) traders may have price differentials for other attributes of grains but those price differentials are not likely to reflect aflatoxin content. On the basis of these expert observations, the rest of the paper, while differentiating grains by aflatoxin content, does not introduce aflatoxin-related grain-price differentials. The paper uses the average prices for maize and peanuts.

Table 1. The aflatoxin content of maize and peanuts in Indonesia, Philippines and Thailand. (Percentage of sample tested which had the level of aflatoxin contamination in column 2 of the table.)

Commodity grades	Aflatoxin $B_1 + B_2 + G_1 + G_2$ content (µg/kg)	Indonesia Maize[a]	Indonesia Peanuts[a]	Philippines Maize[a]	Philippines Peanuts[a]	Thailand Maize[a]	Thailand Peanuts[a]
Almost aflatoxin free – high quality (1)	µg/kg ≤ 5	68	44	44	67	53	64
High quality (2)	5 < µg/kg ≤ 10	2	1	9	5	0	4
High quality (3)	10 < µg/kg ≤ 50	8	10	27	6	18	7
High quality – total	µg/kg ≤ 50	78	55	80	78	71	75
Medium quality	50 < µg/kg ≤ 300	18	12	14	6	15	14
Low quality (1)	300 < µg/kg ≤ 1000	3	11	5	9	11	7
Low quality (2)	1000< µg/kg ≤ 5000	1	17	1	4	4	3
Low quality (3)	5000 < µg/kg ≤ 10000	0	4	0	2	0	0
Low quality (4)	µg/kg exceed 10000	0	1	0	1	0	0
Low quality – total	µg/kg exceed 300	4	33	6	16	14	11
Total percentage	Not applicable	100	100	100	100	100	100
Total number of samples	Not applicable	96	215	146	81	108	94
Total production	'000 t (1991)	6445[b]	1056[c]	4677[b]	35[d]	4035[b]	163[c]

Sources: [a] ACIAR (1989, 1990, 1991, 1992 and 1993)
[b] CIMMYT (1992)
[c] FAO (1992)
[d] Bureau of Agricultural Statistics (1993)

The pricing regime for grains that Cardino-Bermundo et al. (1991) observed,[4] does not take into account the level of aflatoxin contamination in the grains. Table 2 shows farmgate prices for maize and peanuts in Indonesia, Philippines and Thailand. In the analysis the price of maize and peanuts is the same irrespective of the level of aflatoxin contamination of the grain.

Table 2. The farmgate price of maize and peanuts in Indonesia, Philippines and Thailand ($A/t, 1991)

Country	Maize[a]	Peanuts[b]
Indonesia	170	667
Philippines	253	667
Thailand	137	667

[a] CIMMYT (1992) reports prices in US dollars. These prices are converted to Australian dollars assuming an average 1991 exchange rate of $A1 = $US0.7.
[b] Rao (1993, Table 5.3). This is the international price for groundnuts in shell. National prices are not available, and when they are available, it is often not clear whether they refer to groundnuts in shell or to groundnuts after they are shelled.

Product spoilage effects of fungi and aflatoxins

It is possible for fungi to so adversely affect the sensory characteristics (such as taste, odour, texture, colour), the nutritional value and functional properties of grains that the grains become unacceptable as food or feed. In such cases, the farmer or the grain handler has to discard the grain as waste implying that some of the farm-level production of food or feed does not reach the retail market. Spoilage of food and feed between the farm sector and the retail sector affects the retail prices of these products. This paper explicitly takes into account these product spoilage effects in estimating the impact of fungi and aflatoxins.

FAO (1983) uses the term 'damage' to indicate the physical or mechanical spoilage of a food grain; it may reflect partial deterioration of a food on the basis of a subjective judgement but not necessarily the loss in weight. Fungi and aflatoxins lead to product damage or spoilage in three different ways:

- fungi lead to discoloration and to deterioration in the physical appearance of grains which not only lowers product quality but often makes the product unacceptable for consumption as food or feed and thus of no commercial value;
- storage fungi change the fat acidity of grains — fatty acids contribute to characteristic off-odours and rancidity (unpleasant stale smell or taste) of stored commodities; and
- invasion of seeds by storage fungi drastically reduces germinability of the seed (FAO 1983).

Spoilage rates due to fungi and aflatoxins are described by probability functions. The probability that the spoilage rate takes a particular value is a function of various factors including: the variety of the product (e.g. yellow maize versus white maize), the time and method of harvest, the period and method of storage, the storage temperature, the moisture content, the drying method prior to storage and so on (see Maize Quality Improvement Research Centre 1992). Thus estimates of spoilage rates, in a mathematical statistics sense, are expected spoilage rates.

Current estimates[5] suggest that traders and users of maize and peanut grain in Indonesia, Philippines and Thailand throw away about 5% of the grain because of fungi and aflatoxin contamination. This estimate is consistent with the estimate by Ren-Yong et al. (1992) who used systems analy-

[4] Cardino-Bermudo et al. (1991) note that this scheme does not provide adequate incentives for dried maize; the price differential between dried and wet maize is not enough to cover the cost of mechanical drying. Farmers then tend to produce more wet, poor quality grain than would be the case under a pricing scheme with a larger premium for dry grain.

[5] Dr John Pitt and Dr Ailsa Hocking, CSIRO, North Ryde, Sydney (pers. comm. 14 January 1994).

sis to estimate various postharvest losses in the grains sector and concluded that in China the postharvest spoilage rate due to aflatoxins in the grains sector was about 3.6%.

Human health effects of aflatoxins

When people ingest food containing aflatoxins they may suffer two major types of effects.

- The acute effects of high, short-term exposure to aflatoxins in humans may lead to fatal aflatoxicosis, with jaundice for example, and may play a role in kwashiorkor, and Reye's syndrome (Bhat 1989, 1991). Such acute outbreaks of disease are preventable if countries introduce and adhere to tolerances to aflatoxins in foods (Kuiper-Goodman 1991).
- The chronic mutagenic, carcinogenic effects have long latency periods. They include primary liver cancer, Indian childhood cirrhosis — a liver disorder in India correlated with breast milk and baby food contaminated with aflatoxin, and chronic gastritis (Bhat 1989, 1991).

This paper deals with the most important of these effects — the development of primary liver cancer. Estimates of the numbers of primary liver cancer cases attributable to aflatoxins in maize and peanuts consumed in Indonesia, Philippines and Thailand give an indication of the human health effect of maize- and peanut- related aflatoxicosis in these three countries.

The weight of evidence with respect to carcinogenicity is against aflatoxins. An FAO/WHO Expert Committee (WHO 1987) urged reduction of the intake of aflatoxin B_1 to the lowest practical level so as to reduce the potential for harm. The International Agency for Research on Cancer (IARC 1976, 1987) reviewed aflatoxin B_1 and concluded that aflatoxin B_1 is a human carcinogen.

A number of studies[6] have established a strong correlation between ingestion of aflatoxins and the incidence of primary liver cancer. Most of these have been population-based[7] correlation studies. Since data in these studies are collected on populations rather than individuals, it is not possible to determine the exposure to aflatoxins of individuals who have the disease (Kuiper-Goodman 1991). Furthermore, it appears that primary liver cancer can have a multi-factorial origin. Factors like alcohol (Bulatao-Jayme et al. 1982) and hepatitis B virus (Croy and Crouch 1991) appear to have a synergistic effect on the incidence of primary liver cancer. As well, genetic differences, social economic status, sex and age of the individual may play a role. However, Kuiper-Goodman (1991) has argued that hepatitis B virus is not a confounding factor unless its distribution in the various study populations is uneven. He concludes that it cannot be presumed *a priori* that all the older studies in which hepatitis B virus status of individuals was not measured are invalid.

This paper adopts a population-based correlation approach. The aim is to provide indicative estimates of the human health effects of aflatoxins measured in terms of the number of primary liver cancer cases attributable to aflatoxins in maize and peanut. More accurate estimates need to take into account the confounding factors in the discussion above and must be individually based.

Estimating the human health effects of aflatoxins in terms of primary liver cancer, requires data on human exposure to aflatoxins. Information in Table 1 and Appendix C provides a starting point in exposure assessment. Table 1 gives details on the distribution of aflatoxins in maize and peanuts in Indonesia, Philippines and Thailand. Appendix C indicates the extent to which people in the three countries use maize and peanuts.

Livestock health and productivity impacts of aflatoxins

Using feed which contains aflatoxins leads to a number of negative effects on susceptible livestock and poultry. CAST (1989) notes that:

> The impact of fungal toxins upon animals extends beyond their obvious effect in producing death in the wide variety of animals that are likely to consume mycotoxin-contaminated grains or feeds. The economic impact of lowered productivity, reduced weight gain, reduced feed efficiency, less meat and egg production, greater disease incidence because of immune system suppression, subtle damage to vital body organs, and interferences with reproduction is many times greater than that of immediate morbidity and death.

A typical field case of aflatoxicosis is marked not by mortality but by a decline in productivity with no visible disease symptoms (Hamilton 1987).

Losses that result from using contaminated grain as feed are difficult to measure for various reasons including the following:

- The consequences of aflatoxicosis depend on the dose of aflatoxin, the length of feeding toxic diets and the age at first exposure to the toxin (Rao and Reddy 1989).
- Subtle effects due to using aflatoxin-contaminated feed do not produce clinical symptoms of toxicity (Nichols 1987). These effects include reduced growth rate, reduced feed efficiency, the infertility syndrome in swine and cattle, the loss of quality in animal products — examples include milk with aflatoxin M_1 because dairy cattle are fed on aflatoxin-contaminated feed, chicken carcasses condemned or downgraded because of the broiler bruising syndrome or the pale bird syndrome. Since aflatoxicosis often occurs in these subtle ways, proper diagnosis is dependent on keen observation and good production records. Unfortunately proper diagnosis is often not made.
- The effects of aflatoxins change when there are other aflatoxins in the feed. Feed mixtures may include mycotoxins other than aflatoxins and some of these have additive or synergistic effects with the aflatoxin (Pier 1987).
- Aflatoxins do not occur uniformly in feed. While the presence of moulds can be an indication that aflatoxins may be present, the degree of visible mould infestation is not necessarily an indication of the level of toxin production in the feed or food. Moreover, mouldiness may not be apparent after milling or processing.

The rest of this section discusses the impacts of aflatoxin-contaminated feed on each livestock group which is susceptible to aflatoxicosis.

Poultry meat and egg production

Smith et al. (1971) point out that aflatoxicosis in chicken is characterised by poor growth rates, inefficient feed conversion and increased mortality rates. Among the results

6 See Shank et al. (1972a–e) on aflatoxicosis and primary liver cancer in Thailand. CAST (1989) discusses studies of aflatoxin poisoning in western India, Uganda, Taiwan, Thailand and Kenya. Peers et al. (1976, 1987) studied aflatoxicosis in Swaziland. Yeh et al. (1989) deal with hepatitis B virus and primary liver cancer in China, while Bulatao-Jayme et al. (1982) correlate exposure to aflatoxin and the incidence of primary liver cancer in the Philippines.

7 Exceptions include Bulatao-Jayme et al. (1982) and Yeh et al. (1989). Yeh et al. (1989) collected data on 7917 men residing in five different areas for a period of 3.8 years. However, the study estimated at the population level dietary aflatoxin levels for 4 out of 5 areas on the basis of market sample analyses.

they report are the following which relate to the differences in growth rates, feed conversion and mortality rates for 50 chickens over a period of 21 days:

Aflatoxins affect the following variables	Without aflatoxins in feed	With aflatoxins in feed (10 ppm)
Mean body weight after 21 days	363 g	195 g
Feed consumed/weight gain	1.73	2.23
Mortality rates	0/50	12/50

Aflatoxicosis seems to almost halve the chicken's growth rate, to reduce feed conversion efficiency by about 30% and to increase mortality rates. Hamilton and Garlich (1971) and Huff at al. (1975) demonstrated that aflatoxicosis in laying hens causes an enlarged fatty liver and a decrease in egg production — fewer and smaller eggs are produced. The decrease in egg production does not occur immediately after aflatoxin is introduced in the diet but rather occurs after a 10 to 14 days' lag period.

There are other effects of aflatoxicosis in the poultry and egg production sector not taken into account in this paper because, in the literature, there is inadequate quantification of their magnitude. For example, Boulton et al. (1979) conclude that layers exposed to dietary aflatoxins at the time of Newcastle Disease vaccination may not be adequately vaccinated and that more frequent vaccination may be required. Wyatt (1979) discusses the following additional effects of aflatoxicosis in the poultry and egg production sector: increased condemnation or downgrading of carcasses, poor pigmentation of poultry products which reduces their sale value, altered immunity which increases susceptibility to disease and interference with the birds' normal processes of absorption, digestion and utilisation of nutrients.

Pig production

The toxicity of aflatoxins has been reported in suckling piglets, growing and finishing swine and breeder stock (CAST 1989). Table 3 takes into account three impacts of aflatoxicosis in the hog sector: increased mortality rates, decreased weight gain and decreased feed conversion efficiency. The effects of aflatoxins in pigs are varied, and may be more or less pronounced, depending upon the age of the animal, diet, concentration of aflatoxins and length of exposure. Swine appear to be resistant to dietary levels of aflatoxins up to 300 ppb fed from time of weaning to marketing (CAST 1989). Buhatel and Salajan (1977) provide the following results on the possible impacts of aflatoxicosis weight gain and feed conversion efficiency in the pig sector.

Aflatoxins affect the following variables	Without aflatoxins in feed	With aflatoxins in feed (300 ppm)
Body weight at start (kg)	8.0	8.5
Final body weight (kg)	24.5	15.1
Mean daily weight gain (kg)	0.183	0.073
Percent	100%	40%
Mean daily feed intake (kg)	0.440	0.440
Feed/weight gain	2.40	6.00
Percent	100%	251%

Wilson et al. (1984) reported mortality rates of 10% in herds of 200 or more swine and 28% in herds with 20 to 50 pigs. In Wilson et al. (1984) 30–45% of the pigs in the sampled herds were visibly ill from consuming grain with aflatoxin levels greater than 350 ppb.

Beef cattle

Hsieh (1979) grouped the effects of mycotoxicosis in beef cattle into four major groups:

- the lethal effects — that is, consuming aflatoxins in sufficiently high concentration will lead to death of cattle;
- the sublethal mycotoxicoses — aflatoxins interfere with the immune system of cattle which make them more susceptible to disease; aflatoxins also lead to reduced weight gain and reduced feed conversion efficiency;
- carcinogenic effects ; and
- mutagenic and teratogenic effects.

In the animal production industry, because there is rapid turnover of animals, the first two groups of effects are of greater concern than the carcinogenic and mutagenic effects which are longer-term chronic effects. The effects of aflatoxins on the rate of growth and on the feed-conversion efficiency of beef cattle are complex as demonstrated by the results of a U.S. study by Keyl and Norred (1979). The feed/weight gain ratio deteriorated from 5.7, for cattle given feed containing no aflatoxins, to 6.1, 6.3, 6.5 and 6.6 with feed containing 100, 300, 700 and 1000 ppb aflatoxin, respectively.

The study focused on young animals and the negative effects of aflatoxins are clear and one directional as the level of aflatoxins increase. However Keyl and Norred (1979) report results from another study involving older animals with weights of 700 pounds at the start of the experiment. The effects of aflatoxicosis in older animals was non-linear. In the experiment 15 animals (the control) consumed aflatoxin-free feedstuffs and another 15 animals consumed feed containing 700 ppb of aflatoxins. In the first 30 days of the experiment aflatoxicosis led to a reduction in weight gain. After another 30 days (that is, by day 60), the trend had reversed and there was no statistically significant difference between the average daily weight gain of animals in the control group and those in the group feeding on aflatoxin-contaminated feed.

Cow milk

Patterson and Roberts (1977) list the following effects of aflatoxicosis in the dairy industry: loss of condition or general malaise of dairy cattle, drop in milk yields, failure of calves to thrive, scouring (a kind of diarrhoea in cattle) with or without haemorrhage, failure of cows to conceive and secondary aflatoxicosis — the transfer of toxins, particularly aflatoxin M_1, from dairy cattle to people. In the context of dairy calves, Neathery et al. (1980) observed non-linear relationships between the average daily weight gain over time in the presence of aflatoxins in diet. In an experiment lasting three weeks the following changes were observed.

Time	Average daily body weight changes without aflatoxins in feed (kg/day)	Average daily body weight changes with 0.093 mg/kg of aflatoxins in feed (kg/day)
Week 1	0.714	0.535
Week 2	0.952	–0.292
Week 3	0.996	0.276
Average over 3 weeks	0.887	0.173

Table 3 summarises conservative estimates reported in the literature on aflatoxicosis in livestock. The estimates of economic costs in the livestock sector will depend on the parameter values in Table 3.

Table 3. Livestock health and productivity impacts of aflatoxins

Livestock	Type of impact	Impact with high quality feed Aflatoxin $B_1+B_2+G_1+G_2$ in the following range $0 \leq \mu g/kg \leq 50$	Impact with medium quality feed Aflatoxin $B_1+B_2+G_1+G_2$ in the following range $50 < \mu g/kg \leq 300$	Impact with low quality feed Aflatoxin $B_1+B_2+G_1+G_2$ in the following range $\mu g/kg > 300$
1. Poultry and egg production	1.1 Deaths per year chickens (%)	9[a]	12[a]	14[a]
	1.2 Deaths per year: ducks (%)	12[b]	28[b]	no data
	1.3 Average weight of a bird (kilograms)	4.4[e]	3.3[d]	2.2[c]
	1.4 Feed/weight gain ratio	2.9[h]	3.4[g]	3.8[f]
	1.5 Egg weight /bird feed ratio	2.9	2.96[j]	3.05[i]
2. Hogs	2.1 Deaths per year (%)	1.5[l]	1.5[l]	28[k]
	2.2 Average weight of a pig (kg)	75[n]	75[n]	54[m]
	2.3 Feed consumed to weight gain ratio	2.4[n]	2.4[n]	6.0[n]
3. Beef cattle	3.1 Deaths per year (%)	No data[o]	No data[o]	No data[o]
	3.2 Live weight gain in an animal (t)	0.223[q]	0.212[q]	0.156[p]
	3.3 Feed consumption/ weight gain	5.7[r]	6.3[r]	6.6[r]
4. Cow milk	4.1 Deaths per year (%)	No data[o]	No data[o]	No data[o]
	4.2 Milk production index	100[s]	86[s]	72[s]
	4.3 Feed consumption/ milk produced	5.7[r]	6.3[r]	6.6[r]

Notes:

a From Shane (1991). The values for high quality feed correspond to Shane's standard values for these parameters. This figure includes condemned carcasses. A 3% and 5% increase in mortality rates is associated with medium quality feed and low quality feed correspondingly.
b Hetzel et al. (1984).
c Wu et al. (1991). This is the average weight for Thailand and Philippines chickens.
d This is an estimate of body weight of chicken fed on medium quality feedstuff. It is based on estimates in notes (c) and (e).
e Based on Smith et al. (1971) where presence of aflatoxins halves the growth rate of chicken.
f Wu et al. (1991) feed/gain ratio for Thai native chickens.
g Estimated from notes (f) and (h).
h Based on Smith et al. (1971).
i CAST (1989) estimates that aflatoxicosis could lead to a reduction of 5% in egg production in laying hens.
j By interpolation between the results for the high quality and low quality feed.
k Estimate from Wilson et al. (1984). This is the mortality rate for smaller herds in Georgia, USA and is used here on the assumption that Southeast Asian pig herds tend to be small.
l From CAST (1989) This is the overall mortality rate for hog producers in the Southeastern United States and may be low in the case of Southeast Asia.
m Average of pig carcasses in Indonesia, Philippines and Thailand from data in FAO (1992).
n Based on Buhatel and Salajan (1977) and CAST (1989)
o An extensive literature has not uncovered any reference to increased mortality rate as a major problem in the cattle beef sector. Thus there are no estimates of the effect of aflatoxicosis on beef cattle mortality rates. Hamilton (1987) notes that a typical field case of aflatoxicosis is marked not by mortality but by a decline in productivity with no visible disease symptoms.
p FAO (1992). The assumption is that the current situation in Southeast Asia is such that beef cattle producers use low quality (highly mycotoxin-contaminated) feedstuff.
q Based on Keyl and Norred (1979) and FAO (1992) – Keyl and Norred (1979) suggest that animals on aflatoxin-free diet and those on diets containing 300 ppb of aflatoxins are about 1.43 times and 1.36 times respectively, the weight of animals on diets containing 1000 ppb of aflatoxins.
r Based on Keyl and Norren (1979)
s From CAST (1989)

International trade implications of aflatoxins

Many countries have aflatoxin regulations that restrict international trade in food and feed with unacceptable levels of aflatoxin contamination (see Appendix B). On the other hand, unrestricted international trade is possible with respect to produce which contain internationally acceptable levels of aflatoxins.

There is extensive literature on the economics of protection in international trade dealing with various aspects of the two traditional approaches to protection:

- pure quotas — quantitative restrictions specifying the maximum amount of a commodity a country can export to another country; and
- tariffs — taxes on imports or exports.

For example, using results from Anderson and Neary (1992), it is possible to define shadow prices for aflatoxin regulations and estimate welfare costs of these aflatoxin regulations to the three Southeast Asian countries (Indonesia, Philippines and Thailand).

Table 4 summarises the major implications of aflatoxin contamination of grains for trade in grains. From Table 1 and Appendix B, the major implication is that 22% of Indonesian maize, 20% of maize from Philippines and 29% of maize from Thailand would be unacceptable for export to a number of major export markets which enforce aflatoxin regulations. Similarly 45% of Indonesian peanuts, 22% of peanuts from Philippines and 25% of peanuts from Thailand would be unacceptable for export to a number of major export markets which enforce aflatoxin regulations.

Table 4. International trade implications of aflatoxins for maize and peanut products in Indonesia, Philippines and Thailand

Grain grades	Aflatoxin $B_1 + B_2 + G_1 + G_2$ content (µg/kg)	Per cent of output in Indonesia, Philippines and Thailand in the grade	Per cent of output in Indonesia, Philippines and Thailand in the grade	Comment
		Maize	Peanuts	
High quality	µg/kg ≤ 50	71– 80%	55–78%	Per cent of total produce which satisfies aflatoxin regulations in Appendix B
Medium quality	50 < µg/kg ≤ 300	6–14 %	6–14 %	Per cent of total output in the medium quality grade. This output does not satisfy aflatoxin regulations in Appendix B and so cannot be freely internationally traded
Low quality	µg/kg exceed 300	4–14 %	11–33 %	Per cent of total output in the low quality grade. This output also does not satisfy aflatoxin regulations in Appendix B and so cannot be freely internationally traded

While this paper notes that there are international trade implications of aflatoxin contamination of maize and peanuts, it does not estimate the cost from loss of foreign markets which for these commodities in these countries are not expected to be substantial at this time.

Evaluating the Impacts of Fungi and Aflatoxins: Modelling Issues

A flow chart representation of the impacts of aflatoxins

Figure 1 presents a schematic representation of the different impacts attributable to ingesting maize and peanuts containing aflatoxin. At the farm-level, outputs of maize and peanuts are homogeneous products — that is before aflatoxins contaminate the products. Though Figure 1 does not show it, the supply of maize and peanuts as food is treated separately from the supply of maize and peanuts as feed.

During the postharvest stages, fungi and aflatoxins in peanuts and maize lead to at least five impacts. Figure 1 indicates the five most important impacts.

In Figure 1, the first impact of fungi and aflatoxins is product spoilage. Some of the farm-level output does not reach the retail market due to the product spoilage effects of fungi and aflatoxins.

The second impact in Figure 1 is that fungi and aflatoxins lead to qualitative changes in maize and peanuts. In the postharvest stages of maize, there are three types of maize, where the level of aflatoxin contamination is the basis for defining grades of produce. Similarly there are three types of peanuts. The three grades are: high quality, corresponding to produce containing less than 50 µg of aflatoxins/kg of produce, medium quality, corresponding to produce containing between 50 and 300 µg of aflatoxins, and low quality, produce containing more than 300 µg of aflatoxins/kg of produce. The quantity of aflatoxins in a grain is thus treated as a characteristic of a grain and used to define the grades of maize and peanuts. This is a special case of the characteristics approach (Lancaster 1966, Ladd and Suvannunt 1976, Lubulwa 1983, 1989, and Unnevehr 1986).

Ingestion of maize and peanut containing aflatoxins over long periods leads to loss of life due to primary liver cancer. This is the third impact of fungi and aflatoxins in Figure 1. A reduction in aflatoxin contamination of maize and peanuts is likely to lead to a reduction in the number of primary liver cancer cases as households consume less of the produce containing aflatoxins in excess of 50 µg/kg of product.

The fourth category of impacts takes into account the livestock health and productivity impacts of fungi and aflatoxins in the livestock sectors. Table 3 indicated that farmers that use feed containing aflatoxins incur two main losses. First, livestock feeding on aflatoxin-contaminated feedstuffs have higher mortality rates than livestock feeding on high quality feed. Second, livestock feeding on aflatoxin-contaminated feedstuff are inefficient in their utilisation of feed.

The remaining part of this section discusses the estimation of the costs arising from these impacts of fungi and aflatoxins. There are different approaches to the estimation of the costs of fungi and aflatoxins. These approaches are briefly reviewed and one of them is selected for use in this paper.

An overview of economic models which can be used in estimating the social cost of aflatoxins

Possible approaches to the estimation of the social costs of aflatoxins include the following:

- a general equilibrium approach that models impacts of aflatoxins in the whole economy;
- a multi-sector model which models impacts of aflatoxins in the industries most affected; and
- a set of separate single sector or single industry partial equilibrium models.

The information requirements of each of these approaches is different, with the first approach being the most demanding, and the last approach requiring the least amount of information.

A general equilibrium approach that models impacts of aflatoxins in the whole economy

This approach recognises the economy wide implications of aflatoxins. Lower marginal productivity of labour in the production functions reflect the increased morbidity, the immunosuppressive and other human health effects of aflatoxins. Similarly cost functions in the livestock sectors reflect the higher costs of production associated with aflatoxin contamination of feed. On the demand side it would be possible to model the changes in product quality due to aflatoxins. This type of model would also capture the implications of removal of aflatoxin contamination in one feed for other feeds. Removal of aflatoxins then leads to changes in prices and quantities of all products and factor inputs which have a direct or indirect linkage to sectors where aflatoxin contamination occurs. A comparison of the welfare before and the welfare after the removal of aflatoxins generates a measure of the social cost of fungi and aflatoxins. Just et al. (1982) discuss the economic theory of welfare measurements in a general equilibrium context. However, this approach requires a considerable amount of information. For example, it may require a computable general equilibrium model of the whole economy.

A multi-sector model which models impacts of aflatoxins in the industries most affected

This is a special case of the general equilibrium approach. The analysis focuses on a few important sectors and all the other sectors in the economy are treated as one sector producing a composite commodity. A model by Martin and Alston (1993) falls in this category.

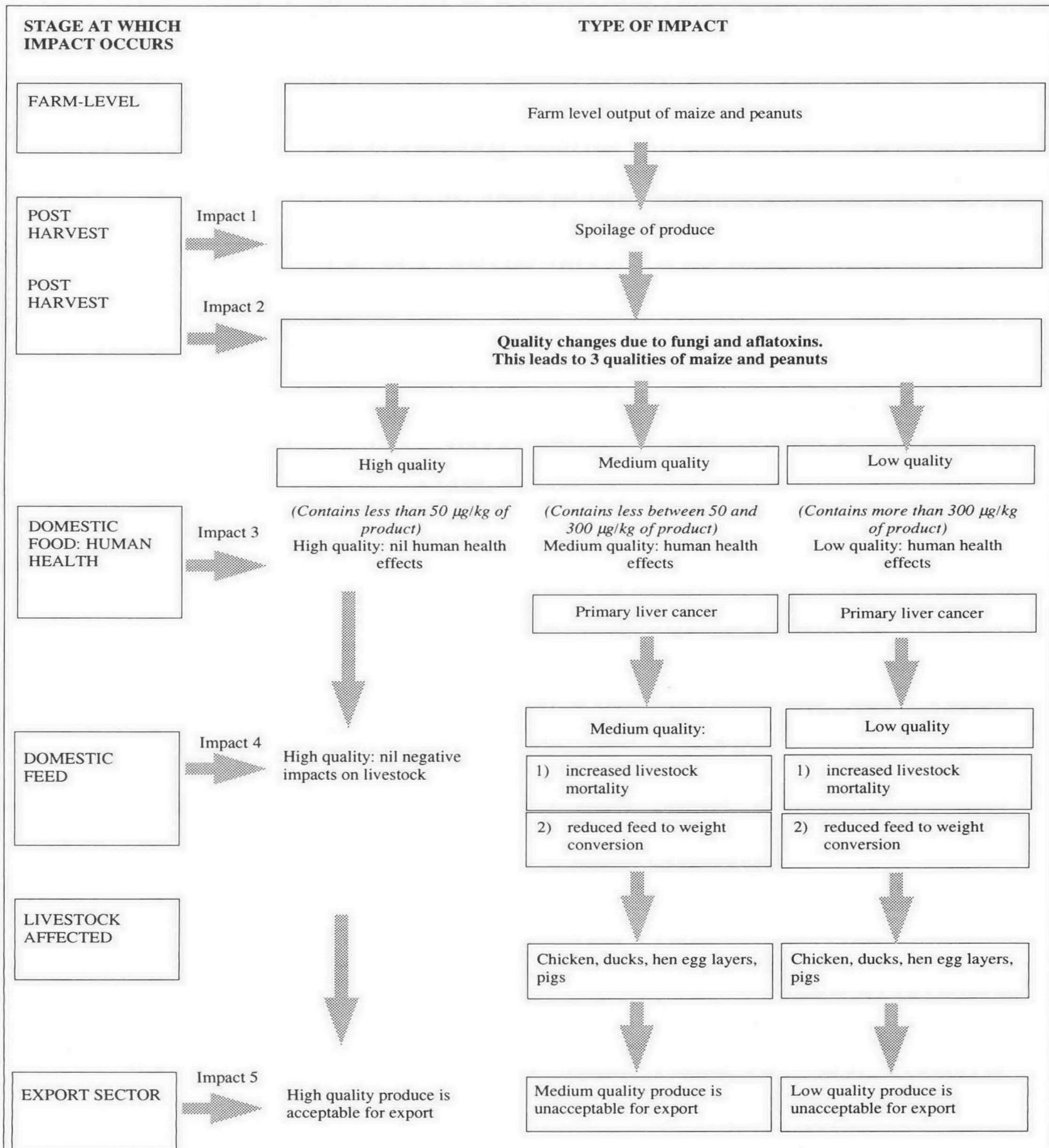

Fig. 1. A schematic representation of the impacts of fungi and aflatoxins.

A set of separate single sector or single industry partial equilibrium models

This approach uses a set of single industry or sector partial equilibrium models. The social costs of aflatoxins are estimated for each industry or sector separately, then the costs in the separate industries or sectors are added up to give the total cost of aflatoxins. The estimates of social costs under this approach approximate the estimates under the general equilibrium approach according to Just et al. (1982) who conclude that :

> Rather comprehensive applied welfare analysis is possible. Depending on empirical conditions, all of the private social welfare effects of a proposed new or altered government policy can be measured completely, at least in an approximate sense, in a single market, which is thereby distorted or in which a distortion is altered. If the policy introduces or alters several distortions, approximate measurement of all private effects is possible by considering the changes sequentially in the respective markets they affect directly.

This is the approach adopted in this paper and estimates the social cost of aflatoxins in the following major segments.

- To estimate the social costs of the product spoilage effects of aflatoxins (impact 1 in Figure 1) in the maize and peanuts food sectors a product wastage economic model is used. Fungi and aflatoxins affect both the food and feed sectors and so the total output of maize and peanuts is the basis for estimating the cost of product spoilage effects.
- The social costs of quality changes in products due to aflatoxins (impact 2 in Figure 1) are reflected in the costs of human health effects and the livestock productivity impacts of aflatoxins.
- The cost of the human health effects (impact 3 in Figure 1) of consuming aflatoxin-contaminated maize and peanuts is equal to the monetary value of productive capacity lost due to premature death and increased morbidity from primary liver cancer attributable to the ingestion of aflatoxin-contaminated maize and peanuts. Only that part of maize and peanut output used as food is relevant in estimating costs of human health effects of aflatoxins.
- The social cost of aflatoxins in the livestock sectors (impact 4 in Figure 1) is equal to the increase in the cost of producing livestock as a result of using aflatoxin-contaminated feed. Only that part of maize and peanut output used as feed is relevant in estimating the livestock productivity impacts of aflatoxins.
- The costs due to restrictions on trade in aflatoxin-contaminated products (impact 5 in Figure 1) are not estimated.

The presence of fungi and aflatoxins in products leads to quality changes in those products. With respect to the analysis of the impacts of quality change, this paper takes heed of Alston (1990) who notes that:

> The approach most commonly used in the literature is to introduce an ad hoc shift in demand for the product induced by changes in quality. Technical change that leads to a change in product quality is a change in supply conditions not demand conditions and it would be better to model it as such.

The remaining part of this paper provides more detail on how the social costs were estimated.

Evaluating the Impacts of Fungi and Aflatoxins: the Economic Models

A model to evaluate the social costs of the product spoilage effects of fungi and aflatoxins

The annual cost of the product wastage effects of fungi and aflatoxins is equal to the annual economic surplus that households and producers forego in Indonesia, Philippines and Thailand as a result of product spoilage effects of fungi and aflatoxins. This estimate depends on the values of the own price demand and supply elasticities, the postharvest costs with and without aflatoxins, and the reduction in spoilage rates assumed.

For grain sector h, where h = maize, peanuts, the total annual economic surplus foregone in the sector, ΔES_h, is given by:

$$\Delta ES_h = \Delta PS_h + \Delta CS_h \qquad (1)$$

ΔCS_h is the annual economic surplus households forego, and ΔPS_h is the annual economic surplus producers of a grain forego as a result of aflatoxin-related product spoilage.

$$\Delta CS_h = (P_{rh} - P_{rh}')\, Q_{rh} + 0.5[(P_{rh} - P_{rh}')\,(Q_{rh}' - Q_{rh})] \qquad (2)$$

$$\Delta PS_h = (P_{fh}' - P_{fh})\, Q_{fh} + 0.5[(P_{fh}' - P_{fh})\,(Q_{fh}' - Q_{fh})] \qquad (3)$$

where:

P_{rh}', Q_{rh}'	are the equilibrium retail price and the retail quantity of grain h after the removal of aflatoxins.
P_{rh}, Q_{rh}	are the retail price and quantity of grain h before the removal of aflatoxins from the grain.
P_{fh}'	is the farmgate price of grain h after the removal of aflatoxins
P_{fh}	is the farmgate price of grain h before the removal of aflatoxins respectively;
Q_{fh}'	is the farm-level output of grain h after the removal of aflatoxins and
Q_{fh}	is the farm-level output of grain h before the removal of aflatoxins, respectively.

The model assumes a linear farm-level supply function. Similarly the retail demand function is linear. This model uses the following parameters:

a_h	is the intercept of the supply function of grain h;
b_h	is the slope of the supply function of grain h;
c_h	is the intercept of the demand function of grain h;
d_h	is the slope of the demand function of grain h;
δ_h	is constant representing spoilage rate of grain h before the removal of aflatoxins;
$\delta_h + \delta_{h1}$	is equal to zero and is the spoilage rate of grain h after the removal of aflatoxins;
M_h	is the postharvest cost of grain h; and
m_{h1}	is the change in the postharvest cost of grain h after the removal of aflatoxins.

Expressing P_{fh}', P_{rh}', Q_{hf}' and Q_{hr}' as functions of the prices, quantities and supply and demand parameters before the removal of aflatoxins gives the following equations:

$$Q_{fh}' = [1/(\delta_h + \delta_{h1})]Q_{rh}' \qquad (4)$$

$$P_{fh}' = (\delta_h + \delta_{h1})P_{rh}' - (M_h + m_{1h}) \qquad (5)$$

$$P_{rh}' = [c_h + b_h(\delta_h + \delta_{h1})(M_h + m_{h1}) - a_h(b_h\delta_h + \delta_{h1})]/[b_h(\delta_h + \delta_{h1})^2 + d_h] \quad (6)$$

$$Q_{rh}' = [c_h b_h(\delta_h + \delta_{h1})^2 - b_h d_h(\delta_h + \delta_{h1})(M_h + m_{h1}) + a_h d_h(\delta_h + \delta_{h1})]/[b_h(\delta_h + \delta_{h1})^2 + d_h] \quad (7)$$

A derivation of these equations is in Davis and Lubulwa (1994). In equations (1) to (7) the product wastage economic model distinguishes between farm-level output and retail output for maize and peanuts. This model recognises that some of the farm-level output of maize and peanut does not reach the retail market due to the spoilage effects of fungi and aflatoxins. The product spoilage effects of fungi and aflatoxins mean that retail supply is lower and retail prices may be higher than they would be without the spoilage effects.

Pitt and Hocking (pers. comm., January 1994) estimated that δ_h is 0.05, that is, about 5% of the farm supply of maize and peanuts in Indonesia, Philippines and Thailand is spoilt as a result of fungal attack and aflatoxin contamination. The removal of aflatoxins means that $\delta_h + \delta_{h1}$, is equal to zero. IFPRI (1993) estimated postharvest costs for maize in Indonesia to include \$A21/t in transport costs, \$A9/t in handling costs and \$A13/t of other costs. Thus M the postharvest cost for grain is about \$A 43/t of grain.

The estimates of a, b, c and d, the supply and demand function parameters depend on demand and supply own price elasticities. Estimates of own price supply elasticity for maize range from 0.35 (Gardiner et al. 1989) to 0.61 (Carambas 1993). Similarly the estimates of the own price elasticity of supply for peanuts range from 0.3 (ACIAR Economic Evaluation Unit Database) to 0.37 (Gardiner at al. 1989). In this paper the own price supply elasticity of maize is 0.61 and that for peanuts is 0.37. In addition this paper uses the own price demand elasticity of maize of –0.5 (ACIAR Economic Evaluation Unit Database) and an own price elasticity of peanut –0.8 (Parton and Piggot 1987).

Estimates of the cost of the product wastage effects of fungi based on equations (1) to (7) are given in Table 10.

Evaluating the costs of the human health effects of aflatoxins

There are two main approaches to the study of disease in a community. One approach estimates disability-adjusted life years lost due to premature death and increased morbidity. Examples of this approach include World Bank (1993). The aim in computing life years lost is to give some impression of the nature and degree of ill health in a community. This approach does not generally produce a monetary cost of disease. A second approach estimates the monetary cost of disease. Examples of this approach include Crowley et al. (1992). This paper uses the second approach because it generates a meaningful, though partial, monetary measure of the cost of disease. It is partial because it does not cover all impacts of disease. For example, it does not incorporate the effects of disease on quality of life or human suffering, for which satisfactory measures are still being developed (Crowley et al. 1992).

Disease leads to the following categories of cost (see Crowley et al , 1992):

- the cost of mortality which relates to the cost of productive capacity lost when people die prior to reaching the end of their productive life;
- the cost of morbidity which relates to value of production loss resulting from hospitalisation and the cost of health care services consumed when an individual is sick;
- the costs incurred by governments and hospitals in the provision of medical services for individuals suffering from primary liver cancer; and
- the cost of intangibles — pain, suffering, anxiety and reduction in quality of life.

In this paper, the cost of the human health effects of fungi and aflatoxins include only the first two categories of the cost of primary liver cancer. The estimation of the costs in the third category requires data on the number and lengths of visits made by primary liver cancer patients to hospitals, medical centres and medical facilities, the type of medical personnel that attended them, the drugs and other pharmaceutical products prescribed and whether they were hospitalised or not. This category was excluded mainly because the data needed to enable their estimation is not available. The last category was excluded because at this time, there are no satisfactory monetary measures of the intangible cost of disease.

Determining the value of life can be controversial. On one extreme is the assumption that the value of an individual life is infinite. This assumption, however, is not helpful (BTCE 1993). This paper assumes that human life has a finite value. There are two main methods for determining the finite value of life (Crowley et al. 1992):

- the human capital approach; and
- the willingness to pay.

The human capital method equates the value of life with the present value of expected future earnings. The willingness to pay method uses contingency valuation surveys to ask people how much they would be willing to pay to avoid different levels and types of risks. The willingness to pay approach is inappropriate when people surveyed cannot perceive the risk whose cost they are asked to assess. In the case of aflatoxin-related primary liver cancer deaths in the Southeast Asian region it is not clear that people consuming aflatoxin-contaminated maize and peanuts realise the risk they face from aflatoxin-related primary liver cancer. This paper uses the human capital approach to estimate the cost of life.

Estimating the cost of premature death due to aflatoxin-related primary liver cancer

The cost, ΔES_{1Hj}, of premature death from consuming aflatoxin-contaminated grain j, is equal to the economic surplus foregone by households (sector H) as a result of consuming aflatoxin-contaminated grains and is given by equation (8)

$$\Delta ES_{1Hj} = \Sigma_i(\Sigma_g D_{jig} L_g) \quad (8)$$

where:

D_{jig}	is the number of people dying of primary liver cancer prematurely at age g due to the consumption of grain j of grade i.
L_g	is the unit cost of a life of someone dying prematurely at age g,
i	(high quality, medium quality, low quality),
j	(maize, peanuts).

The unit cost of life for a person dying at age g is estimated using the functions in equations (9) to (11) which define the present value of an annuity:

$$L_g = \{\pi[(1 + \xi)^{\psi} - 1]/(\xi)\}[1/(1 + \xi)^{\psi}] \quad (9)$$

$$\pi = GNP/12 \quad (10)$$

$$\psi = 12(\Omega - \Gamma) \quad (11)$$

where:

π	is an estimate of the monthly wage;
GNP	is the nation's Gross National Product;
ξ	is the interest rate per month;
ψ	is the number of months of life lost due to premature death
Ω	is the country's average life expectancy measured in years
Γ	is the age at death due to primary liver cancer.

The number of people dying of aflatoxin-related primary liver cancer at age g are given by the following equation:

$$D_{jig} = (E_g[C_{ji}-A]N_{ji}) \qquad (12)$$

where:

E_g	is the percentage of the population dying of cancer at age g as estimated by World Bank (1993);
C_{ji}	is the estimated incidence of primary liver cancer per 100 000 of population attributable to the consumption of aflatoxin-contaminated grain j of grade i;
A	is the background risk of primary liver cancer per 100 000 of population;
N_{ji}	is the number of people exposed to aflatoxins from grain j of grade i.

The incidence of primary liver cancer attributable to the consumption of aflatoxin-contaminated grain j of grade i is given by the following equation:

$$C_{ji} = A + BZ_{ji} \qquad (13)$$

where:

Z_{ji}	is the dose of aflatoxins measured as nanograms of aflatoxins/kg body weight per day attributable to the consumption of grain j of grade i. Kuiper-Goodman (1991) reports that on the basis of ecological studies in Kenya, Swaziland, Thailand, and Mozambique, the values of A and B in equation (13) are 2.2 and 0.106, respectively, for males and females combined.

The estimates of aflatoxin dosage are given by the following equation:

$$Z_{ji} = [\rho_j(1-\alpha_j)\beta_{ji}F_{ji}Q_{jr}]/(N_{ji}WR_{ji}) \qquad (14)$$

where:

ρ_j	is the proportion of grain j used as food,
α_j	is the proportion of grain j consumed fresh (about 18% of total output of maize and peanuts according to Rosegrant et al. (1987).
β_{ji}	is the proportion of grain j which is of grade i.
F_{ji}	is the average quantity of aflatoxin B1, B2, G1 and G2 in a kilogram of grain j of grade i. Qjr is the retail quantity of grain j,
N_{ji}	is the number of people exposed to aflatoxins from grain j.
W	is the average body weight of individuals exposed to aflatoxins. The average body weight is about 50 kilograms (see Haddad and Bouis 1991).
R_{ji}	is the number of days in a year when individuals are exposed to aflatoxins from grain j of grade i.
Q_{ji}	is the quantity consumed of grain j of grade i

Table 5 summarises the estimates of the incidence of primary liver cancer per 100 000 of population in Indonesia Philippines and Thailand.

The age distribution of disability-adjusted life years lost due to non communicable diseases estimated by World Bank (1993) makes it possible to disaggregate by age the number of primary liver cancer cases. This distribution, which is E_g in equation (10) is as follows:

Age at death group	Proportion of primary liver cancer cases in age category (E_g)
0–4	0.203
5–14	0.112
15–44	0.271
45–49	0.200
60+	0.214

Source: Derived from World Bank (1993)

The mid-points of the age groups in the age distribution of primary liver cancer gives estimates of the age at death for individuals in the different age at death groups. The Far Eastern Economic Review (1993) reported the average life expectancy, in 1991, in Indonesia, Philippines and Thailand to be 60 years, 65 years and 69 years respectively. The difference between the national average life expectancy and the age at death of primary liver cancer patients gives an estimate of the number of productive life years lost. The Far Eastern Economic Review (1993) also reported that the 1991 per capita gross national product was US$610, US$730, US$1570 for Indonesia, Philippines and Thailand, respectively.

Using these data and equation (9) leads to the following unit costs of life:

Age group	Unit cost of life, L_g ($A)		
	Indonesia	Philippines	Thailand
0–4	1528	1886	4144
5–14	11389	14302	31687
15–44	13528	17220	38449
45–59	6162	9891	24729

Table 10 summarises the costs of premature death in Indonesia, Philippines and Thailand estimated using equations (8) to (12).

Estimating the cost of disability due to aflatoxin-related primary liver cancer

Equations (8) to (12) estimate the monetary value to premature deaths arising from the consumption of aflatoxin-contaminated maize and peanuts. World Bank (1993) estimated that in the Other Asia and Islands region (includes Indonesia, Philippines and Thailand), for 113 million disability-adjusted life years lost due to premature death, there are 63.7 million disability-adjusted life years lost due to disability and morbidity. Thus the ratio of disability related life years lost to premature death related life years lost is equal to 0.56. Using this ratio and the cost of premature deaths due to aflatoxins yields an estimate of the cost of morbidity, ΔES_{2Hj}, attributable to the consumption of aflatoxin-contaminated grain h. ΔES_{2Hj} is given by the following equation:

Table 5. The incidence of cancer (per 100 000 of population); estimates of the number of primary liver cancer cases due to aflatoxins in maize and peanuts and related data: Indonesia, Philippines and Thailand

	Maize – high quality	Maize – medium quality	Maize – low quality	Peanut – high quality	Peanut – medium quality	Peanut – low quality	Total
Indonesia							
Per capita consumption of aflatoxins per day by source in nanograms ($Z_{ji}W$)	108	1739	1436	14	213	2173	5683
Aflatoxin dosage in nanograms/kg body weight per day (Z_{ji})	2	35	29	0.28	4	43	114
Incidence of liver cancer/ 100000 of population by source of aflatoxin (C_{ji})	0.23	3.69	3.04	0.03	0.45	4.61	12.05
Primary liver cancer deaths ($D_{ji}i$)[a]	426	6889	5686	55	84	8609	22509
Philippines							
Per capita consumption of aflatoxins per day by source in nanograms ($Z_{ji}W$)	57	700	1114	2	10	99	1982
Aflatoxin dosage in nanograms/ kg body weight per day (Z_{ji})	1	14	22	0.04	0.20	2	40
Incidence of liver cancer/ 100000 of population by source of aflatoxin (C_{ji})	0.12	1.48	2.36	0.004	0.02	0.21	4.20
Primary liver cancer deaths (Dji)[b]	76	933	1486	2	13	132	2642
Thailand							
Per capita consumption of aflatoxins per day by source in nanograms ($Z_{ji}W$)	3	40	137	7	94	274	554
Aflatoxin dosage in nanograms/ kg body weight per day (Z_{ji})	0.05	0.79	2.74	0.14	1.88	5.48	11.08
Incidence of liver cancer/ 100000 of population by source of aflatoxin (C_{ji})	0.01	0.08	0.29	0.02	0.20	0.58	1.17
Primary liver cancer deaths (Dji)[c]	3	48	166	9	114	332	672

Notes:

a Estimated using the equation by Kuiper-Goodman (1991) and assuming that Indonesia's population, in 1991, was about 187 million people.

b Estimated using the equation by Kuiper-Goodman (1991) and assuming that Philippines' population , in 1991, was about 63 million people. The total incidence per 100 000 population of malignant neoplasm in the Philippines is 35.5 (National Statistical Coordination Board, The Republic of Philippines, 1991). Thus the estimated incidence of primary liver cancer due to aflatoxin in maize and peanuts is about 12% of the total incidence of malignant neoplasm in Philippines.

c: Estimated using the equation by Kuiper-Goodman (1991) and assuming that Thailand's population , in 1991, was about 57 million people. The total incidence per 100 000 population of malignant neoplasm in the Thailand is 20.2 (National Statistical Office, Thailand (1992) Thus the estimated incidence of primary liver cancer due to aflatoxin in maize and peanuts is about 6% of the incidence of malignant neoplasm in Thailand.

$$\Delta ES_{2Hj} = 0.56(\Delta ES_{1Hj}) \qquad (15)$$

where:

ΔES_{1Hj} is the economic surplus foregone due to premature death from aflatoxin-related primary liver cancer.

Evaluating the livestock health and productivity impacts of aflatoxins

The livestock health and productivity cost of aflatoxins is equal to the welfare gains to producers and consumers of livestock as a result of removing aflatoxins in maize and peanut feed. For each grade i, of maize or peanut feed, the social cost of aflatoxins in a livestock sector h is estimated by the following equation:

$$\Delta ES_{ijh} = k_{ijh}V_{oijh} + \varepsilon\sigma V_{oijh}k_{ijh}{}^{\wedge 2}/ 2{*}P_o(\varepsilon + \sigma), \qquad (16)$$

where:

k_{ijh} is the absolute change in the unit cost of livestock j fed on grain feed h of quality i as a result of using aflatoxin-free feed instead of aflatoxin-contaminated feed

V_{oijh} is the 'with aflatoxin' level of livestock output j from grain feed h of grade i;

ε is the own price elasticity of supply of a livestock product;

σ is the own price elasticity of demand of a livestock product;

P_{oj} is the price of the livestock product h.

The output of livestock j before the removal of aflatoxins is given by:

$$V_{oijh} = \theta_{jh}(1 - \alpha_h)\beta_{hi}Q_{jrh}/\mu_{jih} \qquad (17)$$

where:

θ_{jh} is the proportion of grain h used as feed in livestock sector j,

α_j is the proportion of grain feed h consumed fresh (about 18% of total output of maize and peanuts according to Rosegrant et al. 1987),

β_{hi} is the proportion of grain h which is of grade i,

Q_{jrh} is the retail quantity of grain h, and

μ_{jih} is the feed to weight conversion ratio for feed h and grade i in livestock sector j.

The cost of aflatoxin-contaminated grain feed h of grade i used to produce V_{oih} is equal to:

$$T_{ojih} = \theta_{jh}(1 - \alpha_j)\beta_{ji}Q_{jr}P_{jr} \quad (18)$$

The cost of feed per tonne of livestock h when feed is contaminated with aflatoxins is given by equation (19):

$$\gamma^0 = T_{ojih}/V_{ojih} \quad (19)$$

The livestock output when livestock producers use feed without aflatoxins is given by equation (20)

$$V_{1ijh} = [\theta_{jh}(1 - \alpha_j)\beta_{ji}Q_{ji}/\mu_j^*](1 + t_{ijh}) \quad (20)$$

where:

- μ_j^* is the feed to weight conversion ratio for livestock j when feedstuffs do not contain aflatoxins, and
- t_{ijh} is the reduction in mortality rates in livestock sector j attributable to a change from feed h of quality i to aflatoxin free feed.

The cost of feed per tonne when feed is aflatoxin free is given by equation (21).

$$\gamma^1 = T_{ojih}/V_{1ijh} \quad (21)$$

The estimate of k_{ijh} is given by equation (22):

$$k_{ijh} = \gamma^0 - \gamma^1 \quad (22)$$

These estimates are given in Tables 6, 7 and 8 for poultry, the hen eggs and pig meat sectors.

Substituting the estimates of k_{ijh} in Tables 6, 7 and 8 into equation (16) for the different grades of feed gives the social cost of using the different grades of feed in livestock sector h. These costs are summarised in Table 10. Table 9 gives the livestock prices and elasticities used in the estimation of the social costs of aflatoxins in the livestock sector.

Beef cattle, dairy cattle and goats

The analysis does not include beef cattle, dairy cattle and goats among livestock that are susceptible to maize- and peanut-related aflatoxin contamination in Indonesia, Philippines and Thailand. Livestock producers in these countries do not use maize and peanut feed in the production of beef, cow milk and goat meat. Defining primary feedstuffs as ingredients that form 70 to 80% of a feeding system Devendra (1990) provides the following information on primary feedstuffs in these sectors.

Livestock	Indonesia	Philippines	Thailand
Beef cattle, dairy cattle and goats			
Primary feedstuff	Cassava leaves Cassava pomace Maize stover Rice straw Rice bran	Cassava leaves Cassava pomace Maize stover Rice straw Rice bran	Cassava leaves Cassava pomace Maize stover Rice straw Sugarcane tops and bagasse

Estimates of the Social Costs of Fungi and Aflatoxins

Table 10 summarises the social costs of aflatoxins in maize and peanuts in Indonesia, Philippines and Thailand. The total annual cost, in Indonesia, Philippines and Thailand, due to aflatoxins in maize in 1991 was about $A319 million. Indonesia incurred 62% of this cost, Philippines 27% and Thailand incurred 11% of the cost. The total annual cost of aflatoxins in peanuts in 1991 was about $A158 million — Indonesia incurred 84% of this cost, Thailand incurred 13% and Philippines 3% of the cost.

The annual cost, in Indonesia, Philippines and Thailand, of premature death and increased morbidity due to the incidence of aflatoxin-related primary liver cancer was $A291 million. This was followed by the annual cost of $A108 million due to the product spoilage effects of fungi and aflatoxins in the maize and peanut sectors in the three countries. The annual cost of livestock productivity impacts of fungi and aflatoxins in 1991 was about $A77 million.

Amongst the livestock sectors, the pig meat sector incurred the highest cost — over $A39 million, followed by the poultry (chicken and duck) sector which incurred an annual cost of $A31 million and the hen eggs sector which incurred an annual cost of $A7 million.

Conclusion

This paper has discussed five important impacts of fungi and aflatoxins in maize and peanuts. It has suggested a way to estimate the annual social costs of these impacts and Table 10 summarises these costs. In the estimation of costs in the food and feed sectors, the two sectors have been analysed separately. This was to ensure that there is no double counting of benefits between the two sectors.

The costs of human health and livestock productivity effects are dependent on the data in Table 1. These data are the best available data on aflatoxin contamination in maize and peanuts which are also consistent across the three countries (Indonesia, Philippines and Thailand).

The cost of human health effects does not include the additional costs that countries incur in order to provide for hospital and medical services to those suffering from primary liver cancer. Neither does it cover the cost of intangibles (pain and suffering, anxiety and reduction in quality of life) associated with the incidence of primary liver cancer.

The paper assumes that the distribution of aflatoxins in maize and peanuts is the same for food as for feed. If the distribution of aflatoxins shows a higher percentage of food in the low quality grade compared to that for feed, then the cost in Table 10 will understate the human life cost and overstate the livestock costs, and vice versa.

There is insufficient data on the joint occurrence, in food and feed, of aflatoxins with other mycotoxins in the three countries. The paper assumes that maize and peanuts contain only aflatoxins, or that if other mycotoxins are present they do not lead to synergistic effects on the incidence of cancer or on the feed utilisation efficiency of livestock. In those cases where maize and peanuts contain other mycotoxins the cost estimates in Table 10 are lower than the true cost of aflatoxins.

In conclusion, the costs in Table 10 are likely to be on the lower bound of the total costs attributable to fungi and aflatoxins in maize and peanuts in Indonesia, Philippines and Thailand.

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Table 6. Indonesia: The differences in estimated livestock output and costs of maize and peanut feedstuffs under the 'with aflatoxin' and 'without aflatoxin' scenarios

	Maize – high quality	Maize – medium quality	Maize – low quality	Peanut – high quality	Peanut – medium quality	Peanut – low quality
Poultry meat output (t)						
With aflatoxin (V_{oijh})	143 354	28 127	5 610	3 449	642	1 579
Without aflatoxins	143 354	33 082	7 351	3 449	752	2069
Including death rates (V_{1ijh})	143 354	34 074	7 719	3 449	775	2 173
Cost of feed (T_{ojih}) ('000, $A)	$93 132	$21 492	$4 776	$7 472	$1 630	$4 483
Change in unit cost (k_{ijh})–$A	$0	-$131	–$233	$0	$437	–$776
Hen egg output (t)						
With aflatoxin (V_{oijh})	113 716	25 710	5 545	2 792	579	1 592
Without aflatoxins	113 716	26 242	5 832	2 792	609	1 675
Including death rates (V_{1ijh})	113 716	27 030	6 123	2 792	627	1 759
Cost of feed (T_{oijh}) ('000, $A)	$73 877	$17 048	$3 788	$6 049	$1 319	$3 629
Change in unit cost (k_{ijh})–$A	$0	–$32	–$65	$0	–$108	–$215
Pig meat output (t)						
With aflatoxin (t)	98 933	22 831	2 029	2 381	520	572
Without aflatoxins	98 933	22 831	5 074	2 381	520	1 429
Including death rates (V_{1ijh})	98 933	22 831	6 418	2 381	520	1 807
Cost of feed (T_{oijh}) ('000, $A)	$53 192	$12 275	$2 727	$4 270	$931	$2 562
Change in unit cost (k_{ijh})–$A	$0	$0	$919	$0	$0	–$3 066

Table 7. Philippines: The differences in estimated livestock output and costs of maize and peanut feedstuffs under the 'with aflatoxin' and 'without aflatoxin' scenarios

	Maize – high quality	Maize – medium quality	Maize – low quality	Peanut – high quality	Peanut – medium quality	Peanut – low quality
Poultry meat output (t)						
With aflatoxin (V_{oijh})	203 130	30 320	11 627	371	24	58
Without aflatoxins	203 130	35 548	15 235	371	29	76
Including death rates (V_{1ijh})	203 130	36 614	15 997	371	29.4	80
Cost of feed (T_{oijh}) ('000, $A)	183 433	32 100	13 757	802	61	164
Change in unit cost (k_{ijh})–$A	0	–182	–323	0	–437	–776
Hen egg output (t)						
With aflatoxin (V_{oijh})	177 739	30 474	12 675	324	24	63
Without aflatoxins	177 739	31 104	13 330	324	25	67
Including death rates (V_{1ijh})	177 739	32 037	13 997	324	26	70
Cost of feed (T_{oijh}) ('000, $A)	160 504	28 088	12 037	702	54	144
Change in unit cost (k_{ijh})–$A	$0	–45	–90	0	–108	–215
Pig meat output (t)						
With aflatoxin (t)	562 487	98 435	16 875	1 026	79	84
Without aflatoxins	562 487	98 435	42 187	1 026	79	210
Including death rates (V_{1ijh})	562 487	98 435	53 366	1 026	79	266
Cost of feed (T_{oijh}) ('000, $A)	420 368	73 564	31 527	1 839	141	377
Change in unit cost (k_{ijh})–$A	0	0	–1 278	0	0	–3066

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Table 8. Thailand: The differences in estimated livestock output and costs of maize and peanut feedstuffs under the 'with aflatoxin' and 'without aflatoxin' scenarios

	Maize – high quality	Maize – medium quality	Maize – low quality	Peanut – high quality	Peanut – medium quality	Peanut – low quality
Poultry meat output (t)						
With aflatoxin (V_{oijh})	267 320	48 171	40 227	3 422	545	383
Without aflatoxins	267 320	56 476	52 711	3 422	639	502
Including death rates (V_{1ijh})	267 320	58 170	55 342	3 422	658	527
Cost of feed (T_{oijh}) ('000, $A)	146 739	31 001	28 934	7 415	1 384	1 087
Change in unit cost (k_{ijh})–$A	0	–111	–196	0	–437	–776
Hen egg output (t)						
With aflatoxin (V_{oijh})	178 213	36 888	33 412	2 247	411	313
Without aflatoxins	178 213	37 651	35 141	2 247	419	330
Including death rates (V_{1ijh})	178 213	38 780	36 898	2 247	432	346
Cost of feed (T_{ojih}) ('000, $A)	97 826	20 667	19 289	4 868	908	714
Change in unit cost (k_{ijh})–$A	0	–27	–55	0	–108	–215
Pig meat output (t)						
With aflatoxin (t)	146 824	31 019	11 580	1 921	359	113
Without aflatoxins	146 824	31 019	28 951	1 921	359	282
Including death rates (V_{1ijh})	146 824	31 019	36 623	1 921	359	356
Cost of feed (T_{ojih}) ('000, $A)	66 699	14 091	13 152	3 445	643	505
Change in unit cost (k_{ijh})–$A	0	0	–777	0	0	–3 066

Table 9. Prices and own price elasticity values for livestock in Indonesia, Philippines and Thailand

Variable	Units	Value
Poultry meat		
Price of poultry meat	World price $A/t	973[a]
Supply elasticity		0.5[b]
Demand elasticity		–1.3[c]
Hen eggs		
Price of hen eggs	World price $A/t	1 141[a]
Supply elasticity		0.35[d]
Demand elasticity		–1.3[c]
Pig meat		
Price of pig meat	World price $A/t	1 537[a]
Supply elasticity		0.45[b]
Demand elasticity		–1.1[c]

Sources: [a] FAO (1992); [b] Gardiner et al. (1989); [c] Bouis (1984); [d] Henneberry (1986, Appendix VI – Own-price supply elasticity, Asian and African countries).

Table 10. Estimate of the annual social costs of fungi and aflatoxins in Indonesia, Philippines and Thailand (Million $A, 1991)

Sector and impact of aflatoxins	Parameters used in estimation of welfare change	Indonesia maize	Indonesia peanuts	Philippines maize	Philippines peanuts	Thailand maize	Thailand peanuts	Total for three countries Maize	Total for three countries Peanuts	Total mazie and peanuts
Maize and peanut sectors										
Product spoilage effects	Change in wastage rates and postharvest costs	58.0	32.1	12.5	1.0	0.4	3.7	70.9	36.8	107.7
Household sector										
Human health effects	The cost life due to pre-mature death from primary liver cancer	84.3	61.6	23.5	1.4	4.9	10.2	112.7	73.2	185.9
Human health effects	The cost of disability and morbidity due to aflatoxin-related primary liver cancer	47.7	34.9	13.3	0.8	2.8	5.8	63.8	41.5	105.3
Poultry sector										
Increased mortality rates and reduced feed to weight gain conversion efficiency	Reduction in unit cost of production	5.2	1.8	9.9	0	13.8	0.6	28.9	2.5	31.4
Hen egg sector										
Increased mortality rates and reduced feed to weight gain conversion efficiency	Reduction in unit cost of production	1.2	0.4	2.5	0	2.9	0.1	6.6	0.6	7.2
Pig meat sector										
Increased mortality rates and reduced feed to weight gain conversion efficiency	Reduction in unit cost of production	2.1	2.3	24.4	0.3	9.7	0.5	36.2	3.1	39.3
Country total		198.5	133.1	86.2	3.5	34.4	20.9	319.1	157.7	476.9
Country total as a percentage of the total for three countries		62.0	84.4	27.0	2.3	11	13.3	100	100	

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Appendix A. Fungi and Commodities They Affect

Commodity	Field fungi	Spoilage fungi	Mycotoxigenic fungi
Cashews (aflatoxin-high-risk)	Cladosporium cladosporioides; Nigrospora oryzae	Chaetomium spp	Aspergillus flavus**
Cassava and sweet potato	Lasiodiplodia theobromae; Nigrospora oryzae; Phoma sp.		
Copra (aflatoxin-high risk)	Nigrospora oryzae	Chaetomium spp; A. tamarii	Aspergillus flavus**
Maize (aflatoxin-high risk)	Nigrospora oryzae; Cuvularia pallescens; C. lunata; C. clavata; Lasiodiplodia theobromae; Bipolaris maydis; Arthrinium phaeospermum; Rhizopas oryzae; Phoma herbarum; Rhizoctonia solani	Aspergillus niger; Chaetomium spp; Penicillium citrinum*; P. funiculosum*; A. wentii	Aspergillus flavus**; Fusarium moniliforme**; F. semitectum
Peanuts (aflatoxin-high risk)	Cladosporium cladosporioides; Lasiodiplodia theobromae; Pestalotiopsis guepinii	Aspergillus niger; Penicillium pinophilum*; Chaetomium spp.	Aspergillus flavus**
Rice (aflatoxin-high risk)	Bipolaris maydis; Fusarium semitectum; Cladosporium cladosporioides; Nigrospora oryzae; Curvularia lunata; C. genticulatus; C. oryzae; C. eragrostidis; C. pallescens; Phoma sp; Colletotrichum sp.		Altenaria padwickii; A. alternata; A. longissima
Sorghum	Bipolaris maydis; Fusarium semitectum; Cladosporium cladosporioides; Nigrospora oryzae; Curvularia lunata; C.pallescens; Phoma sp; Setosphaeria rostrata	Aspergillus niger; Eurotium chevalieri; E. rubrum; Chaetomium sp.	Aspergillus flavus**; Fusarium moniliforme; Penicillium citrinum; Alternaria longissima; A. alternata
Soybeans	Arthrinium phaeospermum; Lasiodiplodia theobromae; Fusarium semitectum; Cladosporium cladosporioides; Nigrospora oryzae; Curvularia lunata; C.pallescens; Phoma sp; Epicoccum nigrum; Pestalotiopsis guepinii	Aspergillus niger; A. wentii; A. restrictus; A. penicillioides; Eurotium rubrum; Eupen. cinnamopurpureum; Chaetomium sp.	Aspergillus flavus; Fusarium moniliforme; Penicillium citrinum Alternaria alternata
High sugar foods (confectionery, dried fruits and jams)		A. restrictus; Eurotium species; A. candidus; Wallemia sebi; Xeromyces bisporus; Chrysosporium species; Eremascus species; Zygosaccharomyces rouxii	
Dried meats and meat products		A. restrictus; Eurotium species; A. candidus; Wallemia sebi	
Animal products (milk, cheese)			
Dried seafood products		Polypaecilum pisce; Basipetospora halophila; Aspergillus species; Eurotium species; A. wentii	

Source: Champ et al. (1991).

Notes: * in the table denotes that a fungus is common in South East Asia and ** very common.
F. moniliforme is the source of fumonisin, a toxin known to be responsible for severe diseases in some animals, and suspected (but not proven) to be involved in human oesophageal cancer in parts of China and southern Africa.

Appendix B. Aflatoxin Regulations

Table B.1. Aflatoxin limits (μg/kg) for selected commodities by major (western) importing country (1991)

Country	Aflatoxins	All human foods	All baby food	Milk[c]	Peanuts	Nuts, seeds cereals	Maize and maize products	Feeds for dairy and young cattle and pigs[e]	Feedstuffs for pigs and poultry	Feedstuffs for beef cattle, sheep, goats (not young)
USA	Aflatoxin	20[a]	20[a]	0.5[a]	20[a]	20[a]	20[a]	20[a]	20[a]	300[a]
	$B_1+B_2+G_1+G_2$			Aflatoxin M_1						
Japan	Aflatoxin B_1	10[b]	10[b]	Not specified	10[b]	10[b]	10[b]	10[b]	20[b]	20[b]
				Aflatoxin M_1						
European	Aflatoxin	5[a] to 30[a]	5[a]	Not specified	5[a] to 50[a]	1[a] to 30[a]	5[a] to 50[a]	10[a,f]	20[a,f]	50[a,f]
Community	$B_1+B_2+G_1+G_2$			Aflatoxin M_1				10[a,g]	30[a,g]	50[a,g]
					200[a,d]		200[a,d]	5[a,h]	10[a,h]	20[a,h]
Belgium	Aflatoxin B_1	5[a]	5[a]	0.1[a]	5[a]	5[a]	5[a]	5[a,h]	10[a,h]	20[a,h]
				Aflatoxin M_1						
Denmark	Aflatoxin	NS	NS	Not specified	10[a]	10[a]		5[a,h]	10[a,h]	20[a,h]
	$B_1+B_2+G_1+G_2$			Aflatoxin M_1						
France	Aflatoxin									
	$B_1+B_2+G_1+G_2$	10[a]	5[a]	0.2[a]	0.1[a]	5[a]	10[a]	5[a,h]	10[a,h]	20[a,h]
				Aflatoxin M_1	(nut pastes)					
Germany	Aflatoxin B_1	NS	NS	0.05[a]	5 [a,i]	5[a,i]		5a,h	10[a,h]	20[a,h]
				Aflatoxin M_1	2[a,j]	2[a,j]				
	Aflatoxin									
	$B_1+B_2+G_1+G_2$	NS	NS		10[a,i]	10[a,i]		5[a,h]	10[a,h]	20[a,h]
					4[a,j]	4[a,j]				
Greece	Aflatoxin B_1	NS	NS		1[a]	1[a]	1[a]	5[a,h]	10[a,h]	20[a,h]
	Aflatoxin	NS	NS	Not specified	5[a]	5[a]	5[a]	5[a,h]	10[a,h]	20[a,h]
	$B_1+B_2+G_1+G_2$			Aflatoxin M_1						
Ireland	Aflatoxin B_1	5[a]						5[a,h]	10[a,h]	20[a,h]
	Aflatoxin			Not specified				5[a,h]	10[a,h]	20[a,h]
	$B_1+B_2+G_1+G_2$	30[a]		Aflatoxin M_1						
Italy	Aflatoxin	NS		Not specified				5[a,h]	10[a,h]	20[a,h]
	$B_1+B_2+G_1+G_2$			Aflatoxin M_1	30[a]	30[a]	30[a]			
Luxembourg	Aflatoxin B_1	NS		Not specified	5[a]			5[a,h]	10[a,h]	20[a,h]
				Aflatoxin M_1						
Netherlands	Aflatoxin B_1	5[a]		0.05[a] Milk	50[a]			5[a,h]	10[a,h]	20[a,h]
				0.2[a] Cheese						
				Aflatoxin M_1						
Portugal	Aflatoxin B_1	20[a]	5[a]	Not specified						
				Aflatoxin M_1	25[a]			5[a,h]	10[a,h]	20[a,h]
Spain	Aflatoxin B_1	5[a]			5[a]	5[a]	5[a]	5[a,h]	10[a,h]	20[a,h]
Britain	Aflatoxin	10[a]		Not specified				5[a,h]	10[a,h]	20[a,h]
	$B_1+B_2+G_1+G_2$			Aflatoxin M_1	10[a]	10[a]	10[a]			

Notes:
NS denotes that the aflatoxin limit is not specified. However, some countries rely instead on general food legislation that prohibits the introduction or receipt for commerce of food containing substances injurious to health (Van Egmond 1991).
(a) From Gilbert (1991).
(b) From Van Egmond (1991).
(c) When dairy cattle are fed feedstuff containing aflatoxin B_1, some of this toxin is converted by the animal into aflatoxin M_1 in milk. In some countries (e.g. U.K.) the absence of specific regulations for aflatoxin M_1 in milk is because of a belief that if the animal-feed regulations for aflatoxins are obeyed, then aflatoxin M_1 should not be detectable in milk at a limit of detection of 0.05 μg/kg. (See Gilbert 1991).
(d) This limit applies if the buyer is a European Community registered manufacturer.
(e) The acceptable level of aflatoxins for dairy has to be set at such a level that it does not lead to detectable levels of aflatoxin M_1 in milk products.
(f) This is the pre-1991 limit for complete feedstuffs. The pre-1984 limit for these feedstuffs was 20 μg/kg of product.
(g) This is the pre-1991 limit for complementary feeds.
(h) This limit applies to both complete and complementary feedstuff since 1991.
(i) Pre-1991 limits.
(j) Limits from May 1991.

Table B2. Aflatoxin limits (μg/kg) for selected commodities in Southeast Asia (1991)

Country	Aflatoxins	All human foods	All baby food	Milk	Peanuts	Nuts, seeds cereals	Maize and maize products	Complete feedstuffs for dairy cattle and young cattle, pigs and birds	Complete feedstuffs for pigs and poultry	Complementary feedstuffs for cattle, sheep and goats (not young)
Burma (Myanmar)	Aflatoxin B_1+B_2+G_1+G_2	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Cambodia	Aflatoxin B_1+B_2+G_1+G_2	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Indonesia	Aflatoxin B_1+B_2+G_1+G_2	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Laos	Aflatoxin B_1+B_2+G_1+G_2	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Malaysia	Aflatoxin B_1+B_2+G_1+G_2	35[b]	35[b]	Limits may not exist[a]	35[b]	35[b]	35[b]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Philippines	Aflatoxin B_1	20[b]		Limits may not exist[a]	20[b]	20[b]	20[b]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Singapore	Aflatoxin B_1+B_2+G_1+G_2	Zero[b]	Zero[b]	Limits may not exist[a]	Zero[b]	Zero[b]	Zero[b]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Thailand	Aflatoxin B_1+B_2+G_1+G_2	20[b]		Limits may not exist[a]	20[b]	20[b]	20[b]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]
Vietnam	Aflatoxin B_1+B_2+G_1+G_2	Zero[b]		Limits may not exist[a]	Zero[b]	Zero[b]	Zero[b]	Limits may not exist[a]	Limits may not exist[a]	Limits may not exist[a]

(a) A literature search to date has not revealed the existence of regulations specifying aflatoxin limits in these. However, this literature search has been limited to literature in English (see Van Egmond 1991). Thus it is possible that these regulations exist in the official languages of these countries.

(b) Information from Van Egmond (1991).

Appendix C. Data on Maize, Peanuts and Selected Livestock Sectors in Indonesia, Philippines and Thailand

Table C.1 Indonesia: Supply of and demand for maize (corn) and peanuts (groundnuts) in 1991

Row number	Variable	Maize (corn)		Peanuts (groundnuts)	
	Supply side				
S1	Area harvested ('000 ha)	3 037[a]		628[g]	
S2	Yield (t/ha)	2.1[a]		1.7[g]	
S3	Production ('000 t)	6445[a]		1056[h]	
S4	Imports ('000 t)	0[b]		53[i]	
S5	Total supply = S3+S4 ('000 t)	6445		1109	
	Demand side	'000 t	(Percent of S3)	'000 t	(Percent of S3)
D1	Seeds	129[c]	(2.0%)	na[j]	na[j]
D2	Exports	0[b]	(0.0%)	2	(0.20%)[k]
D3	Use as staple food in Indonesia	4834[d]	(75%)[d]	887	(84%)[l]
D4	Use as feed in the poultry meat industry	650[e]	(10%)	22	(2.1%)[m]
D5	Use as feed in the hen eggs industry	516[e]	(8%)	18	(1.7%)[m]
D6	Use as feed in the hog industry	371[e]	(6%)	13	(1.2%)[m]
D7	Other uses – industrial uses (oil, starch, glue, sweeteners)	64	(1.0%)[d]	114	(11%)[n]
	Total (D1–D7)	6445	(100%)	1056	(100%)
W	Spoilage due to fungi and mycotoxins (%)		(5%)f		(5%)[f]

Note: na not available

Sources:

(a) CIMMYT (1992).
(b) Nataredja and Halid (1993, Table 5) shows that in 1990 and 1991 there were neither imports nor exports of maize in Indonesia.
(c) This estimate is based on Labadan (1993) who estimates that seed are about 2% of production.
(d) Piggot et al. (1993).
(e) Based on Piggot et al. (1993) who estimate that feedstuffs are over 20% of the total farm-level production of maize in Indonesia and the relative sizes of livestock industries in Table C.4.
(f) Dr John Pitt and Dr Ailsa Hocking , CSIRO, Sydney, (Personal communication, 14 January 1994)
(g) FAO (1992, Table 38 on groundnuts in shell).
(h) FAO (1992, Table 38 on groundnuts in shell). This is an estimate by FAO based on unofficial information.
(i) On the basis of Fletcher et al. (1992), imports are about 5.3% of production in Indonesia. Indonesia has been an importer of peanuts since 1979 (Piggot et al. 1993).
(j) Not available. Fletcher et al. (1992) includes seeds in the other use category.
(k) From Fletcher et al. (1992) exports are about 0.2% of total maize production in Indonesia.
(l) Fletcher et al. (1992). Bottema and Altemeier (1990) notes that groundnut is primarily used for snacks, and consumption is about 2.5 kilograms per capita per year.
(m) Fletcher et al. (1992) estimated that about 5% of Indonesia's peanuts was used as crushed peanut cake meal feed for livestock . Table C.4 gives livestock production figures.
(n) Fletcher et al. (1992).

Table C2. Philippines: supply of maize (corn) and peanuts (groundnuts) in 1991

Row number	Variable	Maize (corn)		Peanuts (groundnuts)	
	Supply side				
S1	Area harvested ('000 ha)	3 699[a]		45[g]	
S2	Yield (t/ha)	1.3[a]		1.80[g]	
S3	Production ('000 t)	4677[a]		35[h]	
S4	Imports ('000 t)	348[b]		9[i]	
S5	Total supply = S3+S4 ('000 t)	5025		44	
	Demand side	'000 t	(Percent of S3)	'000 t	(Percent of S3)
D1	Seeds	94[c]	(2%)[c]	na[j]	na[j]
D2	Exports	0[b]	(0%)[b]	0[k]	0k
D3	Use as staple food in Philippines	842	(18%)[d]	28[k]	(80%)[k]
D4	Use as feed in the poultry meat industry	898	(19.2%)[e]	1.7	(4.8%)[l]
D5	Use as feed in the hen eggs industry	786	(16.8%)[e]	1.5	(4 2%)[l]
D6	Use as feed in the hog industry	2057	(44.0%)[e]	3.8	(11%)[l]
D7	Other uses – industrial uses (oil, starch, glue, sweeteners)	0	0[e]	0	(0%)[l]
	Total (D1–D7)	4677	(100%)	35	(100%)
W	Spoilage due to fungi and mycotoxins (%)		(5%)[f]		(5%)[f]

Sources:

(a) CIMMYT (1992). Labadan (1993) indicates that white corn forms 61% and yellow corn forms 39% of national production of corn in Philippines. White corn takes up 72% and yellow corn 28% of area harvested. Yield per hectare is higher for yellow corn at 1.75t/ha compared to 1.08t/ha for white corn (Labadan 1993, Tables 3, 4 and 5).

(b) Labadan (1993, Table 8). Labadan (1993) notes that importation has been allowed in the past to alleviate maize shortage in Philippines Exports are zero.

(c) This is an estimate based on Labadan (1993) who estimates seeds to be about 2% of production .

(d) Labadan (1993, Table 9). This table shows there has been a rapid decline in the percentage of maize used as food in the Philippines, from 48% in 1980 to 41% in 1985 to 18% in 1991. White maize variety is the only variety used for food. In the Table 18% share of total maize used as food is equivalent to about 45% of white maize produced in Philippines

(e) Labadan (1993, Table 9). One hundred percent of yellow maize and 55% of white maize is used as feed. The percentages of maize used as feed in the different livestock sectors are estimated using the relative sizes of livestock industries in Table C.4 and Labadan's estimate that feeds form about 80% of total demand for maize in the Philippines. Labadan (1993) estimates that a complete or mixed feed for hogs or poultry contains 50% ground maize. Rebong (1992) states that as much as 60% maize may be used to compound an animal feed. Hogs and chicken need to eat about 3 kilograms of quality feeds to produce 1 kg of live weight.

(f) John Pitt and Ailsa Hocking, Personal communication, 14 January 1994

(g) See Domingo (1992). The figure is for 1987.

(h) Bureau of Agricultural Statistics (1991). Production has dropped from 43 000 t (see Domingo 1992) the average for the period 1980–1987.

(i) Fletcher et al. (1992) estimated that the Philippines imported groundnuts equal to about 25% of their average production in the period 1980 to 1989. There were no exports.

(j) Not available. Fletcher et al. (1992) included seeds in the other use category.

(k) Fletcher et al. (1992)

(l) John Pitt and Ailsa Hocking, CSIRO, Sydney, Personal communication, 14 January 1994 estimated that the pattern of use of peanuts as feed in the poultry and pig meat sector in Philippines is probably the same as in Thailand with feed forming 20% of total production.

Table C3. Thailand: supply of maize (corn) and peanuts (groundnuts) in 1991

Row number	Variable	Maize (corn)		Peanuts (groundnuts)	
	Supply side				
S1	Area harvested ('000 ha)	1644[a]		119[h]	
S2	Yield (t/ha)	2.5[a]		1.4[h]	
S3	Production ('000 t)	4035[a]		163[h]	
S4	Imports ('000 t)	0[b]		0[i]	
S5	Total supply = S3+S4 ('000 t)	4035		163	
	Demand side	'000 t	(Percent of S3)	'000 t	Percent of S3
D1	Seeds	17[c]	0.4%[c]	na	nai
D2	Exports	1170[d]	30%[d]	10	(6%)[i]
D3	Use as staple food in Thailand	40[e]	1%[e]	103	(63%)[i]
D4	Use as feed in the poultry meat industry	1328[f]	33%[f]	16	(9.9%)[j]
D5	Use as feed in the hen eggs industry	887[f]	22%[f]	11	(6.5%)[j]
D6	Use as feed in the hog industry	605[f]	15%[f]	7.5	(4.6%)[j]
D7	Other uses – industrial uses (oil, starch, glue, sweeteners)	0	0	16	(10%)[i]
	Total (D1–D7)	4035	100%	163	(100%)
W	Spoilage due to fungi and mycotoxins (%)		(5%)[g]		(5%)[g]

Sources:
(a) CIMMYT (1992).
(b) Thailand is a net exporter of maize.
(c) Wattanutchariya et al. (1991).
(d) CIMMYT (1992). Note though in 1960 exports were 95% of Thailand's maize production, by 1985 this had dropped to 56% of total production and by 1991 the export share in total production of maize in Thailand had dropped to less than 30% (see Wattanutchariya et al. 1991, Table 4.20). Wattanutchariya et al. (1991) argue that aflatoxin contamination resulting from improper postharvest handling has contributed to the reduction in the demand for Thai maize on the world market. There has also been a shift in the countries that buy Thai maize from those with strict mycotoxin regulations to those with less stringent mycotoxin regulations (see Arunthong 1987).
(e) Human consumption of maize in Thailand is close to zero. Mekvanich (1992) estimates that the feed industry in Thailand consumes up to 70% of the country's maize production.
(f) The percentages of maize used as feed in the different livestock sectors are estimated using the sizes of livestock industries in Table C.4 and the earlier estimate that feeds form 69.7% of total demand for maize in Thailand.
(g) Dr John Pitt and Dr Ailsa Hocking, CSIRO, Sydney, Personal communication, 14 January 1994.
(h) FAO (1992, Table 38 on groundnuts in shell). See also Lampang (1993).
(i) Fletcher et al. (1992). The estimates were for the period 1980 to 1989. They included seeds in the other use category. In the case of human consumption, Shank (1971) notes that groundnuts can be a significant source of dietary aflatoxins and that in Thailand most groundnuts are eaten between meals usually away from home.
(j) Based on Fletcher et al. (1992) estimate that about 21% of Thai peanut is used as crushed peanut cake meal feed for livestock plus Table C.4.

Table C4. Outputs of selected livestock industries affected by fungi and mycotoxins (1991)

Countries	Units	1 Poultry meat	2 Hen eggs	3 Pig meat	4 Total
Indonesia					
Production[a]	'000 t	498[b]	400[b]	275[b]	1173
Share in output of livestock sectors vulnerable to mycotoxins	Proportion	0.42	0.34	0.24	1.0
Philippines					
Production[a]	'000 t	302	267	690	1259
Share in output of livestock sectors vulnerable to mycotoxins	Proportion	0.24	0.21	0.55	1.0
Thailand					
Production[a]	'000 t	717	474[b]	340[b]	1531
Share in output of livestock sectors vulnerable to mycotoxins	Proportion	0.47	0.31	0.22	1

a The data for 1991 is from FAO (1992, Table 96 (Pig meat), Table 97 (Poultry meat), Table 103 (Hen eggs).
b denotes FAO estimate.