1. Introduction

One of the most important food safety aspects in foods and feeds made of cereal grains today is contamination with mycotoxins. Attempts at regulating mycotoxin levels in foods are a long way from being fully effective or are not always the best way to address the problem. Very often the extent of 'the problem' is not very well known, either because the toxicology of the mycotoxin is imperfect, or the level of exposure of consumers is not very clear. This thesis is an attempt to look at some of these issues concerning grain and grain products in South Africa, and the mycotoxins that are of interest.

1.1. What are mycotoxins?

Mycotoxins are chemicals that are sometimes - certainly not always - produced by fungi occurring in food and feed. Particular fungi produce specific mycotoxins. Under a given set of environmental conditions, specific fungi often dominate in particular food crops, either during the growing stage, and/or after harvest. Mycotoxins can be considered as natural toxic substances that can adversely affect human and animal consumers, including causing cancer in some cases. Some mycotoxins also adversely affect plants and/or micro-organisms. One of the best-known mycotoxins is penicillin, used as an antibiotic for treatment against disease organisms.

Mycotoxins have probably been present in food and feed since early in the history of of humankind. Some of their effects have been known for hundreds of years. The technology to detect and chemically characterize them has only really developed in the last 40 years, particularly since 1980. Very small quantities of many of the important mycotoxins can now be detected and accurately measured in foods and feeds. In addition to those already known, many others are known to exist, but have not yet been chemically characterized. Scientists are now identifying toxic compounds in food faster than the information can be processed. However, to maintain perspective, it must be remembered that these substances have always been there, that humans have always been eating the food in which they occur and in the case of many substances, only the dose makes the poison.

1.2. Where do mycotoxins come from in grain?

Fungi that infect growing crop plants, or foodstuffs in storage, produce mycotoxins. However, mycotoxins are not necessarily produced at all times when fungi are actively growing on grain, dead plant material, or in live plants. The range of environmental conditions, especially the humidity and temperature, under which a fungus will produce a mycotoxin, is generally much narrower than the range in which fungal growth can take place. Thus, the presence of a fungus, even at a high infection rate, does not necessarily mean that there will also be mycotoxins present. In addition, there are large differences between different strains of a given fungal species in their ability to produce mycotoxins. On the other hand, mycotoxins that have been produced by a fungus can remain in plant materials long after all signs of fungal infection have disappeared.

Theoretically, preventing fungal infection of the growing plant or the stored commodity can prevent mycotoxin contamination of food. In practice, however, mycotoxins in food are unavoidable, because fungi are ubiquitous and there is no cost-effective way available to prevent fungal infection of crops in the field. The only real prospect of achieving this is to develop plant varieties that are resistant to fungal infection, either through conventional plant breeding or through genetic modification. In storage, fungal growth can be limited by storing grain as dry and as cool as possible. Reliable moisture measurement in stored grain is essential to this end, since changes as small as 0.5% in the moisture content of cereal grains can have a significant effect on fungal growth and the production of mycotoxins.

About 100 000 fungi have been identified, of which over 400 are considered potentially toxic. About 20 of these produce toxic compounds - or families of compounds - which cause problems in one or more parts of the world (De Koe, 1993). A handful predominates in grain crops in South Africa. These, together with the most important mycotoxins that each produces if conditions are suitable, are given below:

In maize

Fungal species	Main mycotoxins produced	Reference
Fusarium verticillioides (Previously known as *F. moniliforme*)	Fumonisins (FBs)	Gelderblom *et al* (1988); Thiel *et al* (1991a); Marasas (2001); JECFA (2002)
Fusarium subglutinans	Moniliformin (MON)	Kriek *et al* (1977); Marasas (2001)
Fusarium graminearum	Deoxynivalenol (DON), or nivalenol (NIV), zearalenone (ZEA)	Marasas *et al* (1984a); Marasas (2001)
Aspergillus flavus	Aflatoxins	IARC (1993); JECFA (1998)
Penicillium spp	OA, Citrinin (CIT), Patulin (PAT)	Scott (1994)
Stenocarpella maydis	Unidentified, causing diplodiosis in cattle and sheep	Rabie *et al* (1985a); Kellerman *et al* (1985)
Stenocarpella macrospora	Diplosporin	Gorst-Allman *et al* (1983)
Alternaria alternata	Alternariol monomethyl ether (AME)	Visconti & Sibilia (1994)

In wheat

Fungal species	Main mycotoxins produced	Reference
Alternaria alternata	AME	Visconti & Sibilia (1994)
Eurotium spp	Sterigmatocystin	Scott (1994)
Fusarium graminearum	DON or NIV, ZEA	Marasas *et al* (1984a); Marasas (2001)
Fusarium crookwellense	NIV, ZEA	Marasas *et al* (1984a); Marasas (2001)
Fusarium culmorum	DON, ZEA	Marasas *et al* (1984a); Marasas (2001)
Fusarium equiseti	Diacetoxyscirpenol (DAS)	Marasas *et al* (1984a)
Penicillium spp	CIT, OA, penicillic acid	Scott (1994)
Aspergillus flavus	Aflatoxins	IARC (1993); JECFA (1998)

In grain sorghum and sorghum malt

Fungal species	Main mycotoxins produced	Reference
Alternaria alternata	AME	Bosman *et al* (1991); Visconti & Sibilia (1994)
Phoma sorghina	Tenuazonic acid?[1]	Rabie & Lübben (1984)
Fusarium verticillioides	FB?	Rabie & Lübben (1984)
Fusarium thapsinum	MON	Marasas *et al* (1984a);

		Marasas (2001); Leslie & Marasas (2001)
Fusarium subglutinans	MON?	Rabie & Lübben (1984)
Fusarium chlamydosporum	Not known	Rabie & Lübben (1984)
Fusarium andiyazi	Not known	Marasas *et al* (2001); Marasas (2001)
Aspergillus flavus	Aflatoxins?	Rabie & Lübben (1984)
Rhizopus spp	Rhizonin A and unknown mycotoxins	Rabie *et al* (1985b)
Epicoccum spp	Not known	Bosman *et al* (1991)
Gonatobotrys spp	Not known	Bosman *et al* (1991)
Cladosporium spp	Not known	Bosman *et al* (1991)

[1]? – It is unclear whether the relevant mycotoxin occurs naturally in the particular crop plant in South Africa.

Some of the mycotoxins mentioned above rarely occur in South Africa, or are generally considered relatively harmless, and were therefore not included in the study.

The fungi listed above are not host specific, but environmental conditions in specific crops in specific countries are often more suitable for fungal growth or mycotoxin production than in other crops or in other countries.

1.3. Purpose of the study

The broad purposes of the study were:

- To report on the occurrence of certain mycotoxins in grain and grain products in South Africa, compared with other countries;
- To weigh the evidence on their effects or suspected effects on the health of test animals, and human and animal consumers;
- To determine where statutory measures might be needed to regulate their presence in food and to propose practical measures that can work in the South African grain storage and trading system;
- To consider means other than legislative regulation to deal with any real problem;
- To consider the practical application of a regulatory system.

The study is based on an analysis of the knowledge available in the published scientific literature, and surveys of mycotoxins in maize carried out by the South African Maize Board, which existed between 1939 and 1997 to administer a marketing scheme for maize. The information was used to address a number of specific objectives, listed below. First, the abstracts, or full papers of more than 1 500 published papers, a few selected textbooks, conference proceedings and web pages were obtained that deal with the mycotoxins involved, and related issues. The references, with authors, title, source, keywords and a hyperlink where appropriate, were incorporated in a database to enable quick and easy searches for papers on any given topic. Each objective was then dealt with individually. Lastly, this thesis was compiled from the results of the analyses of data related to each of the various objectives.

1.4. Objectives

Based on the broad purposes of the study, specific objectives were formulated. The objectives were to:

- Gather information on regulatory/advisory/recommended maximum tolerable levels (MTLs) of AFLA, FBs, DON, ZEA, NIV, T-2, MON, DAS and AME in maize, wheat and grain sorghum and their products intended for human and animal consumption in the USA, Europe, Canada, Australia, Japan, Africa, China and other Asian countries. More specifically, the grains and grain products the indicated MTL applies to, whether the MTL indicated is regulatory, advisory, or recommended, the known effects of each mycotoxin on humans and animals, and which mycotoxins are considered to be carcinogens, and which are not, needed to be indicated.

- Overview categories of carcinogens of the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) and of the mycotoxins considered being carcinogens.

- Overview the relationship between the FBs and oesophageal cancer (OC) in SA, China, France, Iran & USA.

- Overview other factors implicated in OC.

- Overview toxicological studies with the mycotoxins listed above in humans and animals.

- Overview the aetiology of liver, kidney and brain cancer in SA in relation to the occurrence of the mycotoxins listed above.

- Overview the aetiology of Neural Tube Defects in SA in relation to the occurrence of the mycotoxins listed above.

- Overview the occurrence of mycotoxins in SA grains, grain products, and the possible risks of natural levels to consumers.

- Estimate the highest MTLs that can be allowed in SA for the mycotoxins listed above, without jeopardizing the safety of consumers.

- Discuss the probable implications of existing and newly proposed MTLs for the local grain milling industry, and for major grain trading partners on international trade in grains and grain products, with reference to naturally occurring levels of the mycotoxins listed above.

- Overview available test methods for the mycotoxins listed above in grains and grain products.

- Recommend test methods, sampling methods and testing procedures to be considered for adoption by the grains industry in South Africa, together with MTLs for the mycotoxins listed above.