Preparation of South African maize porridge: effect on fumonisin mycotoxin levels

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The estimated levels of fumonisin exposure in South African communities that consume maize as their staple diet have previously been based on the analysis of raw maize collected from subsistence farmers, rather than on analysis of traditionally cooked food. During the preparation of a typical South African stiff porridge, fumonisin levels in naturally contaminated maize meal were reduced during cooking. A mean reduction in fumonisin B_1 levels of 23% was observed, with a correlation coefficient between the levels in uncooked meal and cooked porridge of $r = 0.90$ ($P < 0.01$). A survey of available maize consumption data from around the world indicated that the highest levels of maize consumption are found in the general Mexican population and in the rural population of the Transkei region of South Africa.

Introduction

The fumonisin mycotoxins are secondary metabolites produced primarily in maize by the fungus *Fusarium verticillioides* (Sacc.) Nirenberg (formerly *F. moniliforme* Sheldon) and a few related species.[1] Although a number of different fumonisins have been isolated from culture, the most abundant analogue is fumonisin B_1 (FB_1), with lesser amounts of fumonisins B_2 (FB_2) and B_3 (FB_3) being known to occur naturally.[2] FB_1 has been linked to various disease syndromes in animals, such as leukoencephalomalacia in horses[3] and pulmonary oedema in swine.[4] Concern over the effects on human health due to exposure to these mycotoxins arises primarily from the carcinogenic properties of these toxins. FB_1 is a cancer initiator and strong cancer promoter and is hepatocarcinogenic in rats.[5] The carcinogenic properties of FB_1 have recently been confirmed by the National Toxicology Programme (NTP) study, which demonstrated FB_1 to be nephrocarcinogenic in male rats and hepatocarcinogenic in female mice.[6] The fumonisins have also been associated with the high incidence of human oesophageal cancer in the Transkei region of the Eastern Cape Province of South Africa,[7] and in Linxian County, Henan Province and Cixian County, Hebei Province, China.[8–10] A role for fumonisin exposure as a risk factor for primary liver cancer in Haimen, Jiangsu Province, China, has also been suggested.[11] In 1993, the International Agency for Research on Cancer declared the 'toxins produced by *F. moniliforme*' to be possibly carcinogenic to humans (class 2B carcinogens).[12] More recently, concerns have also been expressed concerning the possible role of fumonisins in the aetiology of neural tube defects in populations that consume high levels of maize.[13]

The carcinogenic properties of fumonisins have led to considerable interest in their occurrence and international concern over the possible exposure of human populations. A risk assessment prepared for the Nordic Council of Ministers recommended an upper tolerable intake for fumonisins of 1 μg/kg body weight/day based on a lowest observed effect level (LOEL) for toxic (non-carcinogenic) effects in animals.[14] The Scientific Committee on Food of the European Commission evaluated toxicity and carcinogenicity studies on FB_1 and has recommended a tolerable daily intake (TDI) of 2 μg/kg body weight/day based on a no observed adverse effect level (NOAEL) in rodent studies and a safety factor of 100.[15] Based on similar considerations in which nephrotoxicity in rats was taken as the most sensitive toxic effect of pure FB_1, the recent 56th meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) determined a group provisional maximum tolerable daily intake (PMTDI) for FB_1, FB_2 and FB_3, alone or in combination, of 2 μg/kg body weight/day.[16] Recommendations have been made in a few countries regarding the setting of tolerance limits for fumonisins in maize. An official tolerance limit for combined FB_1 and FB_2 has been set at 1 mg/kg in Switzerland[17], while a recommendation of a maximum level of 3 mg/kg has been made by the French Council of Public Hygiene.[18] The U.S. Food and Drug Administration (FDA) has published draft guidance levels for industry in which total fumonisin (combined FB_1, FB_2 and FB_3) levels should not exceed 2 mg/kg in degermed dry-milled corn products and 4 mg/kg in whole or partially degermed dry-milled corn products.[19, 20] Although these levels are designed to protect consumers in developed countries where maize consumption is low, much lower tolerance levels of 200 μg/kg would be required to protect subsistence farming communities that consume maize as a staple diet in developing countries.[21]

Maize is the staple food cereal grown and consumed by the rural subsistence farming communities of the Transkei region of the Eastern Cape Province of South Africa. Although it is known through analysis of uncooked home-grown maize that the rural Transkei population is exposed to fumonisin mycotoxins[7], this study was undertaken to investigate the extent by which this exposure may be reduced after the traditional preparation of a South African stiff porridge, a typical and common meal consumed by these communities (Fig. 1). In addition, estimates of the maize consumption in Transkei are compared with consumption figures reported in various other countries.

Materials and methods

Samples and chemicals. Three South African commercial brands of maize meal were purchased from 10 different retail outlets. FB_1, FB_2 and FB_3 were isolated from *Fusarium verticillioides* MRC 826 culture material in the PROMEC Unit, Tygerberg, South Africa.[22] All other reagents and solvents were analytical grade from Merck (Darmstadt).

Preparation of stiff maize porridge. A typical South African stiff porridge was prepared from each commercial maize meal sample according to the traditional recipe of Ms Somdyala (PROMEC Unit, Tygerberg, unpublished data) by boiling 870 ml water, adding a teaspoon of salt and 500 g meal. The mixture was stirred until the porridge thickened and then left to simmer for 20 minutes.

Determination of fumonisins. The moisture content of each commercial maize meal and prepared maize porridge was measured by drying a sample (100 g) to constant weight in an oven at 60°C for 48 hours. Each maize meal and porridge sample was analysed for FB_1, FB_2 and FB_3 by the method of Sydenham *et al.*[23] In brief, a test portion (20 g) was extracted by homogenizing for 3 minutes with methanol/water (70:30, 100 ml). The samples were centrifuged, filtered and the pH was adjusted to approximately

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Fig. 1. Traditional way of cooking maize porridge in a three-legged iron pot in rural Transkei, South Africa.

6.0. An aliquot (10 ml) of each extract was cleaned-up on a strong anion exchange (SAX) solid phase extraction cartridge. The purified extract was dried under nitrogen at 60°C and fumonisins determined by HPLC with precolumn derivatisation with *o*-phthaldialdehyde (OPA). Analytical recoveries were determined in triplicate by spiking samples with FB_1, FB_2 and FB_3 standards at levels of 1000 μg/kg. Mean recoveries of fumonisins from maize meal were 74 ± 1.0% for FB_1, 67 ± 0.6% for FB_2 and 64 ± 2.5% for FB_3 and from maize porridge were 86 ± 1.5% for FB_1, 73 ± 4.2% for FB_2 and 75 ± 3.1% for FB_3. In order to compare the two series of samples, analytical results were corrected for recovery.

Results and discussion

Analytical results for the determination of fumonisins in commercial maize meal and the corresponding stiff porridge prepared by the above recipe are shown in Table 1. A significant ($P < 0.01$) correlation ($r = 0.90$) was observed between the levels in the original meal and those in the corresponding porridge. In general, fumonisin levels were shown to be affected by the cooking process and a mean reduction of 23% was observed in

Table 1. Fumonisin levels in commercial maize meal and maize porridge. Results are on a dry basis and corrected for recovery.

Maize sample*	Moisture (%)	FB_1 (µg/kg)	FB_2 (µg/kg)	FB_3 (µg/kg)
Meal A1	8	146	21	16
Porridge A1	62	108	22	n.d.**
Meal A2	8	93	16	14
Porridge A2	64	106	26	13
Meal A3	10	118	18	23
Porridge A3	68	88	n.d.	n.d.
Meal A4	7	59	n.d.	n.d.
Porridge A4	60	79	n.d.	n.d.
Meal B1	10	491	110	77
Porridge B1	64	337	82	39
Meal B2	9	332	81	53
Porridge B2	66	203	56	27
Meal B3	10	196	40	17
Porridge B3	66	121	8	5
Meal B4	13	246	45	n.d.
Porridge B4	63	133	32	16
Meal C1	5	174	46	25
Porridge C1	50	47	8	n.d.
Meal C2	7	157	31	16
Porridge C2	65	159	42	23

*Letters refer to commercial brands, numbers to retail outlets.
**n.d.: Not detected (<10 µg/kg).

FB_1 levels over all of the samples tested. Nevertheless, it is clear that the cooking of a traditional South African dish of maize porridge does not constitute a decontamination procedure and that the communities reliant on maize as their staple diet are indeed at risk of fumonisin exposure in their daily consumption of this porridge. A previous study conducted in India showed negligible fumonisin loss during the preparation of a single maize porridge and an 11.9% reduction in fumonisin levels during the preparation of a sorghum porridge.[24] Preparation of polenta (an Italian porridge usually made from maize meal) has also been shown to cause a reduction in fumonisin contamination, i.e., FB_1 levels were reduced by 8% (range 2–23%) and FB_2 levels by 20% (range 5–27%).[25] Although the total removal of fumonisins is not achieved, the reduction in levels may be considered together with that associated with the milling of commercial maize[26] to represent a meaningful reduction in exposure in communities cooking commercial maize meal. Such an additive benefit is not available in rural subsistence communities in which the hand grinding of home-grown maize is common and in which no separation of the more contaminated products such as bran occurs.

Some studies have demonstrated that fumonisins are heat-stable mycotoxins.[27–29] In addition, studies on shelled maize and pelleted feed samples showed that drying these commodities at 50°C had no influence on the levels of fumonisin contamination.[30] The fumonisins that are apparently lost during the preparation of porridge could have been rendered analytically unavailable to extraction either by binding to the starch matrix or by the formation of various sugar adducts such as *N*-(carboxymethyl)-FB_1[31] and *N*-(1-deoxy-D-fructose-1-yl)-FB_1.[32] Although recent data suggest that the formation of these soluble adducts is relatively small,[32] they have been detected in both maize and processed maize products.[31,33]

The recent setting of a PMTDI by JECFA has highlighted the potential exposure of various world communities to fumonisins.[16] The most important fungi producing fumonisins are the maize pathogens, *F. verticillioides* and *F. proliferatum* (Matsushima) Nirenberg. Hence, apart from other minor sources, the overwhelming origin of exposure to fumonisins remains the consumption of maize or maize products. The conduct of adequate exposure assessments requires knowledge of maize intakes in a wide spectrum of communities and special risk groups. Table 2 summarizes published figures for maize consumption in various countries. Maize consumption is generally highest in rural subsistence farming communities and lowest in countries of the developed world where maize products represent a minor component of a varied diet. In the Transkei region of South Africa, maize represents both the staple cereal grown on a subsistence level and also the predominant food consumed, either as home-grown maize or shop-bought meal. Previous workers have estimated that individual maize consumption in the Transkei is as high as 460 g per person per day.[34] This figure was not based on direct measurement, but estimated from published total carbohydrate intakes obtained from 24-hour dietary recall investigations conducted in 1977 on lactating mothers in both urban and rural areas in the Ciskei region of South Africa, an area geographically adjacent to the Transkei with a culturally similar population.[35] Based on the assumption of maize representing 85% of carbohydrate intake and the average carbohydrate contents of raw maize or raw maize meal, an estimated consumption of 460 g can be determined.

These figures are in total contrast to those in Canada[36], the European Union[37], the Netherlands[38], Sweden[39] and Switzer-

Table 2. Maize consumption in various countries.

Country	Maize product	Population	Maize consumption (g/person/day)	Reference
Argentina	Maize meal	Adult males (26–55 yr)		41
		All persons	20	
		Maize eaters	250	
		Adult females (26–55yr)		
		All persons	11.5	
		Maize eaters	215.3	
Argentina	Maize and its products	General	76	49
	Maize flour		15.2	
Brazil	Maize meal	Urban	2–12	50
		Rural	11–39	
	Dried maize	Urban	1	
		Rural	1–22	
Canada	Maize, dried maize, maize meal, flour, semolina	All persons (adults)	2.6	36
		Eaters only (adults)	36	
China	Maize	Linxian County	79.3	51
European Union	Maize	General	7	37
Mexico	Maize	General	510	43
	Maize	General	250	44
	Maize	General	389	52
	Maize as tortillas	Women on Texas–Mexico border	90	13
Netherlands	Maize	All persons	3	38
		Maize eaters	42	
		High risk (e.g. celiac disease)	162	
South Africa	Maize	Transkei	460	34
		Urban	267	53
Sweden	Maize products	General	2.9	39
		High consumers (95th percentile)	7.5	
Switzerland	Maize	General	4	40

land,[40] where maize consumption among the general population is no higher than 7 g per person per day (Table 2). However, data for a country as a whole can disguise the risk of certain subgroups in the general population who consume relatively more maize. It has been estimated in The Netherlands that people with celiac disease or gluten intolerance could consume up to 162 g maize per person per day if their total cereal intake is from maize products.[38] Figures published in certain countries distinguish between the average consumption for the population as a whole and the average consumption by those who are classified as actual maize eaters. This difference can be seen in the data from Canada[36] and Argentina,[41] in which maize eaters are exposed to over 10 times the levels reported for the population as a whole. Global figures for cereal consumption drawn up by the World Health Organization in the form of Global Environment Monitoring System (GEMS)/Food Regional Diets indicate average total cereal consumption in the African diet to be 318.4 g/person/day, of which maize accounts for 106.2 g/person/day.[42] Clearly, vast regional dietary differences exist in Africa, but this maize consumption represents over double the consumption calculated for any of the four other regional diets and is in contrast to the European regional diet of 8.8 g maize/person/day within a total cereal intake of 226.3 g/person/day.

In addition to the Transkei region of South Africa, it is clear that various South and Central American communities also have high levels of maize consumption (Table 2). In particular, one reference from Mexico reports consumption as high as 510 g/person/day, which is considerably more than the Transkei estimates.[43] Traditional cooking procedures for maize also vary between countries. Although the porridge prepared above is a typical African dish, maize is consumed in Mexico primarily as tortillas following nixtamalization (lime treatment) of the meal[43,44], as polenta in Italy[25] and southern Brazil[45], and as grits in the southern United States.[46] The process of nixtamalization with alkali leads to a reduction in fumonisin levels by hydrolysis, although animal studies have suggested that toxic effects are not entirely removed by this process.[47]

It is generally recognized that risk assessment of mycotoxins has two main components, that is, hazard assessment and exposure assessment.[48] International concerns over fumonisin exposure and the consequent hazard assessment have resulted in the establishment of the PMTDI of 2 μg total fumonisins/kg body weight/day by JECFA.[16] Accurate and comprehensive exposure assessments require detailed knowledge of maize consumption in various populations, however, and further studies on this aspect of risk assessment are still required.

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