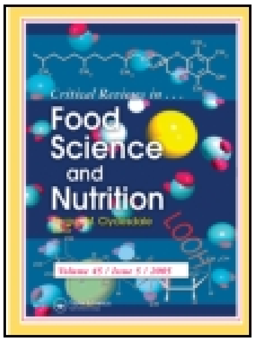

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Effect of Processing on Mycotoxin Content in Grains

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Mycotoxins that commonly occur in cereal grains and other products can contaminate finished processed foods on account of their high toxicity. The mycotoxins that are commonly associated with food grains include aflatoxins, ochratoxin A, fumonisins, deoxynivalenol, and zearalenone. Various food-processing operations include sorting, trimming, cleaning, cooking, baking, frying, roasting, flaking, and extrusion that have variable effects on mycotoxins. The nature of the processing operation viz. physical, chemical, or thermal plays an important role in this; usually, the processes that utilize the higher temperatures have greater effects on mycotoxin dissipation. In general, the processes are known to reduce mycotoxin concentrations significantly, but do not eliminate them completely. However, roasting and extrusion processing result in lowest mycotoxin concentrations, since these involve higher temperatures. It is observed that very high temperatures are needed to bring about high reduction in mycotoxin concentrations, approaching acceptable background levels. The treatment with chemicals like ammonia, bicarbonate, citric acid, or sodium bisulfite is also effective in resulting in significant decline in mycotoxin concentrations.

Keywords Mycotoxins, processing, reduction, chemicals, acceptable

INTRODUCTION: MYCOTOXINS, TYPES, TOXIC EFFECTS, AND DECONTAMINATION

Cereal grains generally become contaminated by molds while in the field and during storage and some of these molds are known to produce mycotoxins. Mycotoxins are secondary metabolites of moulds that exert toxic effects on animals and humans (Peraica et al., 1999).

Toxigenic molds are known to produce one or more of these toxic secondary metabolites. It is well established that not all molds are toxigenic and not all secondary metabolites from molds are toxic. Examples of mycotoxins of greatest public concern from health and agroeconomic significance include aflatoxins (AF), ochratoxins (OT), trichothecenes, zearalenone (ZEN), fumonisins (F), tremorgenic toxins, and ergot alkaloids. These toxins account for millions of dollars annually in losses worldwide in terms of added cost on human health, animal health, and discarded agricultural products (Shane, 1994; Vasanthi and Bhat, 1998). Factors contributing to the presence or production of mycotoxins in foods or feeds include storage, environmental, and ecological conditions and often most of these factors are beyond human control (Hussein and Brasel, 2001).

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The toxic effect of mycotoxins on animal and human health is referred to as mycotoxicosis (Peraica et al., 1999). It is characterized as food or feed related, noncontagious, nontransferable, noninfectious, and nontraceable to microorganisms other than fungi. Clinical symptoms of mycotoxicosis usually subside upon removal of contaminated food or feed (Robb, 1990). There are over 300 mycotoxins that have been isolated and chemically characterized (Betina, 1984). The review of the published literature on the subject indicates that research has mainly focused on those forms that cause significant injuries to humans and their farm animals. These include AF, OT, trichothecenes, ZEN, F, and ergot alkaloids. There have also been recent concerns over other toxins such as citrinin and sterigmatocystin.

Mycotoxins that adversely affect human or animal health are found mainly in post-harvest crops such as cereal grains or forages. These toxins are produced by saprophytic fungi during storage or by endophytic fungi during plant growth. Mycotoxins are generally lipophilic (except for FB) and therefore, they tend to accumulate in the fat fraction of plants and animals. In general, mycotoxins are categorized by fungal species, structure, and (or) mode of action. However, it should be noted, that a single species of fungi may produce one or several mycotoxins and individual mycotoxins may be produced by different fungal species. For example, AFs are produced by several fungal species, exhibit numerous structural variations, and have different modes of action depending on the target animal (Eaton et al., 1994).

Table 1 Mycotoxins and their occurrence in commodities

Mycotoxin	Food commodity
Aflatoxins	Maize, peanuts, milk
Ochratoxins	Wheat, coffee bens, raisins
Zearalenone	Maize
Deoxynivalenol (DON, vomitoxin)	Wheat, barley, maize
Fumonisins	Maize

Source: Bullerman and Bianchini, 2007.

The severity of mycotoxicosis depends on the toxicity of the mycotoxin, the extent of exposure, age, and nutritional status of the individual and possible synergistic effects of other chemicals to which the individual is exposed (Peraica et al., 1999). Table 1 classifies the mycotoxins of concern and the commodities in which they may be present. Examples of fungal species and mycotoxins of biological and economical significance in animal agriculture are presented (D'Mello and MacDonald, 1997) in Table 2.

MYCOTOXIN TYPES

Aflatoxins

(A-flavus-toxins) are the most studied group of mycotoxins and are produced by different species of the genus *Aspergillus*. They were initially isolated and identified as the cause of the Turkey X disease (i.e., hepatic necrosis) in 1960 (Asao et al., 1963). AFs [AFB1 and AFB2], [AFG1 and AFG2], and [AFM1 and AFM2; metabolites found in milk]) are dihydrofuran or tetrahydrafurano moieties fused to a coumarin ring. There are over 20 isolated AF derivatives produced by several fungal species. For example, *Aspergillus flavus* produces AFB1 and AFB2 whereas *A. parasiticus* produces AFB1, AFB2, AFG1, and AFG2 (D'Mello and MacDonald, 1997). Variations in the magnitude of toxicity exist among AF. For example, AFB1 is the most toxic in both acute and chronic aflatoxicoses whereas AFM1 (i.e., a metabolite in milk) is as acutely hepatotoxic as AFB1 but not as carcinogenic (Carnaghan et al., 1963).

Table 2 Fungal species and their mycotoxins of concern

Fungal species	Mycotoxin
Apergillus flavus, A. parasticus	Aflatoxin
A. ochraceus, Penicillium viridicatum, and P. cyclopium	Ochratoxin A
Fusarium culmorum, F. graminearum, and F. sporotrichioides	Deoxynivalenol
F. sporotrichioides and F. poae	T-2 toxin
F. sporotrichioides,, F. graminearum, and F. poae	Diacetoxyscirpenol
Fusarium culmorum, F. graminearum, and F. sporotrichioides	Zearalenone
F. proliferatum and F. verticillioides	Fumonisins
Acremonium coenophialum	Ergopeptine alkaloids
A. lolii	Loitrem alkaloids

Source D'Mello and MacDonald, 1997.

Ochratoxins

OTs are metabolites of both *Aspergillus* and *Fusarium* species which are chemically described as 3,4-dihydromethylisocoumarin derivatives linked with an amide bond to the amino group of L-β-phenylalanine (Cole and Cox, 1981). These compounds are known for their nephrotoxic effects (renal damage) in poultry (Lanza et al., 1980; Manning and Wyatt, 1984). They also are acutely toxic in rats (Wannemacher et al., 1991) and mice (Carlton and Tuite, 1977) and may promote tumors in humans (Krogh, 1978). Ochratoxin A (OTA,) is the most toxic compound of this group. It was first isolated from *A. ochraceus* (van der Merwe et al., 1965) and was later shown as a secondary metabolite of *Penicillium* species in temperate climates (Smith and Ross, 1991).

Trichothecenes

Trichothecenes are compounds containing sesquiterpene rings characterized by a 12, 13-epoxy-trichothec-9-ene nucleus. They have different constituents on positions 3, 4, 7, 8, and 15 of the molecule. Trichothecenes are mainly produced by several *Fusarium* species (e.g., *F. sporotrichioides*, *F. graminearum*, *F. poae*, and *F. culmorum*) and can be produced by members of other genera such as *Myrothecium* (Tamm and Breitenstein, 1984) and *Trichothecium* (Jones and Lowe, 1960). Trichothecenes include T-2 toxin, diacetoxyscirpenol (DAS), deoxynivalenol (known as DON or vomitoxin), and nivalenol. Both T-2 toxin and DAS are the most toxic and are soluble in nonpolar solvents (e.g., ethyl acetate and diethyl ether) whereas DON and its parent compound nivalenol are soluble in polar solvents such as alcohols (Trenholm et al., 1986).

Zearalenone

ZEN is a phytoestrogenic compound (Diekman and Green, 1992) known as 6-(10-hydroxy-6-oxo-*trans*-1-undecenyl)-β-resorcylic acid μ-lactone. It is a metabolite primarily associated with several *Fusarium* species (i.e., *F. culmorum*, *F. graminearum*, and *F. sporotrichioides*) with *F. graminearum* being the species most responsible for the estrogenic effects commonly found in farm animals (Marasas, 1991). Alcohol metabolites of ZEN (i.e., α-zearalenol and β-zearalenol) are also estrogenic (Cheeke, 1998).

Fumonisins

Fumonisins (B1 and B2) are cancer-promoting metabolites of *F. proliferatum* and *F. verticillioides* that have a long-chain

Table 3 Effect of processing on Mycotoxin reduction

S. No.	Commodity	Mycotoxin	Processing	Percent dissipation	Explanation	Reference
1.	Corn muffins	Aflatoxin B1	Baking	13	Baking involves high temperature which causes destruction of mycotoxins.	Stoloff and Trucksess, 1981
2.	Bread and cookies	Deoxynivalenol	Baking	24–71%		El-Banna et al., 1983; Scott et al., 1983;
				35%		
3.	Cookies	Deoxynivalenol	Baking	35%		Young et al., 1984
4.	French and Vienna bread	Deoxynivalenol	Baking	41% and 56%		Samar et al., 2001
5.	Corn muffins	Fumonisin	Baking at (175°C and 200°C)	16 and 28%		Jackson et al., 1997
6.	Biscuits	Ochratoxin	Baking	75%		Subirade, 1996
7.	Rice	Aflatoxin B1	Ordinary cooking	34%	Cooking involves high temperature and boiling in water which are both responsible for destruction and dissipation of mycotoxins.	Park et al., 2005; Park and Kim, 2006
8.	Wheat	Aflatoxin B1	Heating at 150 and 200°C	50% and 90%		Hwang and Lee, 2006
9.	Rice	Aflatoxin B1	Cooking in excess water	87.5%		Hussain and Luttfullah, 2009
			Ordinary cooking	84.0%		
			Microwave cooking	72.5%		
10.	Chinese noodles	Deoxynivalenol	Boiling	49%		Nowicki et al., 1988
11.	Japanese noodles	Deoxynivalenol	Boiling	40%		Nowicki et al., 1988
12.	Oatmeal	Ochratoxin	Autoclaving	74%		Trenk et al., 1971
13.	Rice	Ochratoxin	Autoclaving	86–87.5%		Trenk et al., 1971
14.	Beans	Ochratoxin	Autoclaving	84%		Milanez and Leitao, 1996
15.	Rice	Aflatoxin B1	Cooking in excess water	86.6%		Hussain and Luttfullah, 2009
			Ordinary cooking	83.0%		
			Microwave cooking	82.4%		
16.	Beans	Ochratoxin	Washing, soaking, and cooking	50%		Iha et al., 2009
17.	Corn flakes	Fumonisins B1 and B2	Extrusion cooking, gelatinization, and cornflaking	30–55%		Meister, 2001
				20–65%		
				6–35%		
18.	Peanut meal	Aflatoxin	Extrusion cooking	23–66%	Extrusion cooking generally decreases the mycotoxins levels at rates depending on type of extruder, the type of screw, the die configuration, the initial mycotoxin concentration, the barrel temperature, the screw speed, the moisture content of the raw material, and the use of additives (Castells et al., 2005)	Cheftel, 1989
19.	Cereals	Aflatoxin	Extrusion cooking	95%		Castells et al., 2005
20.	Corn flour	Deoxynivalenol	Extrusion cooking	95%		Cazzaniga et al., 2001
21.	Wheat flour dough	Aflatoxin	Fermentation	50%	Fermentation is an effective process to reduce the mycotoxin content due to enzymatic breakdown	Scott, 1991
22.	Tortilla chips	Fumonisins	Frying	67%	High temperature frying causes reduction in fumonisin content but DON is heat stable hence its reduction is low during frying.	Jackson et al., 1997

(Continued on next page)

Table 3 Effect of processing on Mycotoxin reduction *(Continued)*

S. No.	Commodity	Mycotoxin	Processing	Percent dissipation	Explanation	Reference
23.	Corn	Ochratoxin	Wet milling	96% (germ) and 49% (grits)	During milling process, the contamination level does not decrease. In fact it is a redistribution of the contaminant: more in the fractions richer in bran and less in the flour.	Wood, 1982
24.	Wheat	Deoxynivalenol	Milling	24–48%		Lee et al., 1987
25.	Wheat	Deoxynivalenol	Milling	77%		Visconti et al., 2004
26.	Rice	Aflatoxin B1	Parboiling	300% increase	The steeping (precooking/soaking) process in commercial parboiling appears to increase susceptibility of rice grains to fungal infection. So the aflatoxin content in grains increased considerably with the increase in duration of soaking.	Bandara et al., 1991
27.	Wheat	Deoxynivalenol	Sorting	74%	Mycotoxin infected kernels can be separated by contaminated ones through sorting.	Scott et al., 1983
28.	Wheat	Deoxynivalenol	Cleaning	6 to 19%	Cleaning can also be used to remove scab infested wheat and barley kernels.	Abbas et al., 1985
29.	Corn	Fumonisin	Cleaning	26–69%		Sydenham et al., 1994
30.	Cornmeal	Fumonisins	Roasting (218°C for 15 min)	100%	Roasting being a high temperature treatment causes destruction of mycotoxins. The process is dependent on the type and temperature of roasting	Castelo et al., 1998
31.	Pistachio	Aflatoxin	Roasting (150°C and 120 min)	95%		Yazdanpanah et al., 2005
32.	Coffee bean	Aflatoxin	Roasting	42 to 56%		Soliman, 2002
33.	Coffee bean	Ochratoxin	Roasting	13–93%		Pérez de Obanos et al., 2005
34.	Corn	Deoxynivalenol	Autoclaving at 121°C for one hour with 8.33% aqueous sodium bisulphate	95%		Young et al., 1987
35.	Parboiled rice	Aflatoxin	10 ppm calcium hypochlorite (bleach) to soaking water	Appreciable		Bandara et al., 1991
36.	Peanut meal	Aflatoxin	Extrusion cooking in presence of 2–2.5% ammonium hydroxide	87% reduction		Cheftel, 1989
37.	Sorghum flour	Aflatoxin	Extrusion cooking with aqueous lactic or citric acid	Citric acid (92%) and aqueous lactic acid (up to 67%)		Méndez-Albores et al., 2008

hydrocarbon unit (similar to that of sphingosine and sphinganine) which plays a role in their toxicity (Wang et al., 1992). Fumonisin B1 (FB1) is the most toxic and has been shown to promote tumor in rats (Gelderblom et al., 1988) and cause equine leukoencephalomalacia (Marasas et al., 1988) and porcine pulmonary edema (Harrison et al., 1990). The naturally co-occurring aminopentol isomers (formed by base hydrolysis of the ester-linked tricarballylic acid of FB1) have been suggested to exert toxic effects due to their structural analogy to sphingoid bases (Humpf et al., 1998).

ADVERSE EFFECTS OF MYCOTOXINS ON NONRUMINANTS

Early studies on the effects of acute aflatoxicosis indicated various toxicities in different animal species (Wogan, 1966). In monogastrics, variable responses have been shown with all mycotoxins (Cheeke, 1998). For example, pigs have been shown to be very sensitive to T-2 toxin, DON (Friend et al., 1992), and ZEN (Biehl et al., 1993). Poultry is also adversely affected by both T-2 and DON but is very resistant to the estrogenic effects of ZEN (Cheeke, 1998). Various degrees of mycotoxicoses from natural sources occur in different animal species because of the wide range of feed ingredients used and the difference among and within species. So, on account of their toxic effects to animal and human health it is necessary to devise suitable strategies that reduce or eliminate these toxic compounds from food. "Mycotoxin detoxification" refers only to postharvest treatments designed to remove, destroy (decontaminate), and ultimately reduce the toxic effects of mycotoxins (detoxify) (Riley and Norred, 1999).

FOOD PROCESSING AND DISSIPATION OF MYCOTOXINS

Commonly used processing techniques provide a means to address this concern in food safety. Food processing covers all physical, chemical, or biological processes undergone by raw grains in the formation of food products. Several studies have been conducted on the fate of mycotoxins during food processing all over the world in the last 20 years (Hazel and Patel, 2004).

Food processes that have been covered in these studies included sorting, trimming, cleaning, milling, cooking, baking, frying, roasting, canning, flaking, alkaline cooking, and extrusion. This paper discusses the effect of common food-processing techniques on the mycotoxin reduction in the food grains. The food processes reviewed in this chapter include sorting, trimming and cleaning, baking, cooking, frying, roasting, extrusion cooking, corn flake processing, and also treatment with chemicals like ammonia, sodium bisulfite, citric acid, and sodium hydroxide (Table 3).

The application of heat to cook and preserve products is the basis of all thermal processes. These processes include ordinary cooking, frying, baking, roasting canning, and extrusion cooking.

Baking

Baking is the technique of prolonged cooking of food by dry heat normally in an oven. It is primarily used for the preparation of bread, cakes, pastries and pies, tarts, and quiches. It is also used for the preparation of baked potatoes; baked apples; baked beans (Kaushik et al., 2009).

Aflatoxins—In a study on corn muffins made from cornmeal naturally contaminated with AFs, 87% of the initial amount of AF B1 in the cornmeal was found to be still present in the baked muffins (Stoloff and Trucksess, 1981).

DON—Baking regular bread, cookies, and biscuits gave variable reductions in deoxynivalenol of 24–71% in bread and a 35% reduction in cookies and biscuits, but baking Egyptian flat bread gave no reduction of deoxynivalenol (El-Banna et al., 1983; Scott et al., 1983; Scott, 1984). Cookies preparation by baking using a standard commercial recipe decreased DON (0.28–0.44 mg/kg) level by up to 35% (Young et al., 1984). Baking by an approved method of the American Association of Cereal Chemists did not destroy DON (0.52–0.31 mg/kg), but the effect on its concentration in the samples analyzed varied, the reduction ranging from 19% to 69% (Abbas et al., 1985). During baking of French and Vienna bread on pilot scale the fermentation at 50°C resulted in respective reductions of 41% and 56% in the DON (150 mg/kg) content (Samar et al., 2001).

Though many studies conclude that baking resulted in loss in DON content in contrast several studies also reported that baking did not cause appreciable decline in DON content. Baking for 30 min at 205°C did not destroy DON (4.1 mg/kg) (Scott et al., 1983). Similarly baking for 30 min at 170°C did not affect DON (0.17 mg/kg) content (Tanaka et al., 1986). Also baking for 14 min at 210°C had no significant effect on DON (0.09–2.99 mg/kg) levels (Lancova et al., 2008). Even baking Egyption bread for 2 min at 350°C) did not reduce DON (El-Banna et al., 1983). A recent study has demonstrated that DON level in bread was not reduced as a chemical compound but that the biological toxicity was significantly reduced. This fact indicates the possibility that a new complex is produced in bread during cooking such as DON-binding protein or DON-binding carbohydrate has less cytotoxicity than DON itself (Sugita-Konishi et al., 2006).

Fumonisins—Castelo et al. (1998) found that corn-muffin mix artificially contaminated with 5 μg/g of FB1 and naturally contaminated corn-muffin mix showed no significant losses of fumonisins upon baking. In another study, baking corn muffins at 175°C and 200°C resulted in 16% and 28% reductions of fumonisin, respectively. At both temperatures, losses of FB1 were greater at the surface than at the core of the muffins (Jackson et al., 1997).

Ochratoxin—It is stable during bread baking, with no loss or reduction of the concentration of OT (Subirade, 1996; Scudamore et al., 2003). However, baking of biscuits resulted in about two-thirds of the toxin being destroyed or immobilized (Subirade, 1996). It is clear from the above discussion that the losses of mycotoxins during baking are low and also variable depending on the toxin and the duration of treatment.

Cooking

Cooking is the act of preparing food for eating by the application of heat. It encompasses a vast range of methods depending on the customs and traditions, availability and the affordability of the resources (Kaushik et al., 2009). Several studies in the literature report on effect of cooking on mycotoxin dissipation.

Aflatoxin—Ordinary cooking of rice contaminated with AF B1 showed an average reduction of 34%. Pressure cooking resulted in greater reduction (78–88%) (Park et al., 2005; Park and Kim, 2006). In another study, the boiling of corn grits gave 28% reduction in AFs. The level of AFB_1 in dried wheat decreased to 50% and 90% by heating at 150 and 200°C (Hwang and Lee, 2006). When three forms of cooking were compared for reduction in AFB1 levels (Hussain and Luttfullah, 2009). It was found that highest mycotoxin reductions were observed when the rice samples were cooked in excess water (87.5% for AFB1), followed by normal cooking (84.0%) and microwave cooking (72.5%).

DON—Chinese noodles contaminated with DON (12.5 mg/kg) on boiling for 10 min and draining for 5 min showed 49% reduction of DON level. While the same process in Japanese noodles caused reduction of 40% in DON level after boiling (Nowicki et al., 1988).

Fumonisins—Fumonisin B1 (FB1) is a fairly heat stable compound that is stable at boiling temperatures. No loss of FB1 was observed when *Fusarium verticillioides* culture material was boiled in water for 30 min and dried at 60°C for 24 h (Alberts et al., 1990). However, at higher temperatures some reduction may be observed.

Ochratoxin—Autoclaving of oatmeal (with 50% water) gave a 74% reduction in OT, while autoclaving dry oatmeal or rice cereal gave greater losses of 86–87.5% (Trenk et al., 1971). The effect of cooking on the reduction of ochratoxin A (OA) content in beans (*Phaseolus vulgaris L.*), variety "*Carioca*," was evaluated after inoculating with spore suspensions of *Aspergillus alutaceus Berk. & Curt*. (formerly *A. ochraceus Wilh.*) NRRL 3174, an ochratoxigenic strain. After 10 days, samples were taken, analyzed for their OA content, and then cooked under pressure, with and without previous soaking. It was observed that cooking caused a substantial reduction in the levels of OA (up to 84%). This effect was even more pronounced when the bean grains were soaked in the water for 12 h before cooking under pressure, at 115°C, for 45 min (Milanez and Leitao, 1996). Among three forms of cooking, it was found that highest mycotoxin reductions were observed when the rice samples were cooked in excess water (86.6% for OTA), followed by normal cooking (83.0%) and microwave cooking (82.4%) (Hussain and Luttfullah, 2009).

Based on these results it is evident that greater losses in contents of AF and OT were observed on cooking. DON levels showed lesser decline as a result of cooking and Fumonisins seem to be stable at lower temperatures during cooking that have been investigated.

Combined Treatments

Generally food grains are processed using a blend of processing treatments which include washing, soaking followed by cooking. A combination of washing and boiling treatments given to barley resulted in successive losses in the mycotoxin content. The initial levels of NIV in unwashed barley were 0.347 ppm which after washing treatment became 0.152 ppm, 0.066 ppm, respectively, after first and second washings and boiled barley contained only 0.060 ppm (Oh-Kyung et al., 2004). Dried beans were washed with water for 2, 60, or 120 min, soaked in water for 60, 120 min, or 10 h, and cooked for 60 or 120 min. The combination of the three treatments eliminated about 50% of the toxin from whole beans. It was concluded that discarding the washing, soaking and cooking in water leads to a significant reduction in OTA contamination in dried beans (Iha et al., 2009).

Therefore it can be concluded that a set of processing treatments are effective in eliminating a large proportion of mycotoxins from food grains.

Corn Flake Processing

The effect of corn flake processing on AF and fumonisins has been widely studied (Castelo, 1999; De Girolamo et al., 2001; Meister, 2001).

Aflatoxins—Cooking the grits containing AFs, with and without sugars resulted in 64–67% reduction of AF. After toasting the flakes with and without sugar the reductions in AF ranged from 78% to 85% (Lu et al., 1997).

Ochratoxin—OT was also reduced by the corn flake process (Aish et al., 2004).

Fumonisin—Castelo (1999) found that corn flake processing without sugars resulted in 53.5% and 48.7% losses in FB1 content after cooking and toasting, respectively, whereas processing in the presence of glucose gave 86–89% reduction. The stability of fumonisin B1 and B2 in the corn flake process was studied (De Girolamo et al. 2001), and it was found that about 60–70% reduction in fumonisin content occurred during the entire process, and only 30% of those losses were attributed to the extrusion step, where the material was subjected to 70–170°C for 2–5 min. In another study, Meister (2001) evaluated the effects of extrusion cooking, gelatinization, and cornflaking on the stability of fumonisins B1 and B2, and reported that cooking extrusion and gelatinization were able to reduce fumonisin levels to 30–55%, while cooking the grits for flaking reduced contamination to 20–65%, and roasting the flakes reduced fumonisin content to 6–35%. Losses of FB1 in the presence of sucrose, maltose and high fructose corn syrup were similar to reductions in corn flakes made without sugars. While reductions of fumonisins during corn flake manufacture occurred, the presence of so-called "hidden" or "masked" fumonisins (protein bound) has been reported in commercial corn flake samples obtained from retail outlets (Kim et al., 2003).

Significant losses in AFs and fumonisin content have been reported in studies in literature. It is important to note that cornflaking in the presence of sugars significantly reduces the mycotoxin content.

Extrusion Cooking

Extrusion cooking is one of the fastest growing food-processing operations in recent years due to several advantages over traditional methods. Apart from its main goal of improving the quality of intermediate and final processed products, it may incidentally also improve safety because of the potential to reduce mycotoxin levels in cereals (Castells et al., 2005).

Aflatoxin—Hameed (1993) showed that extrusion reduced the AF content by 50–80%. Cheftel (1989) reported similar results when peanut meal was subjected to extrusion cooking (23–66% reduction). Ninety five percent decline in AF content has been reported during extrusion cooking of cereals (Castells et al., 2005).

DON—When corn flour was experimentally contaminated with DON (at 5 mg/kg), extrusion experiments (employing three variables (moisture/temperature and sodium metabisulphite addition)) was found to reduce DON under all conditions assessed (Accerbi et al., 1999). Wolf-Hall et al. (1999) demonstrated that spiked DON was stable in extruded corn grits and pet foods, and in autoclaved cream style corn, a 12% decrease in DON was observed. The authors concluded that DON was stable at the temperatures and pressures used in these processes. However, a significant drop occurred in the wheat after soaking in the presence of sodium bisulphite. Samples of corn flour experimentally contaminated with DON (5 ppm) were extruded. The process was found to be effective for the reduction of DON content (higher than 95%) under all the conditions assessed (Cazzaniga et al., 2001). Lower reduction (55%) was observed for deoxynivalenol, during extrusion cooking of cereals (Castells et al., 2005).

Extrusion cooking generally decreases the mycotoxins levels at rates depending on different factors such as the type of extruder, the type of screw, the die configuration, the initial mycotoxin concentration, the barrel temperature, the screw speed, the moisture content of the raw material, and the use of additives (Castells et al., 2005).

Fermentation

Fermentation is a simple process during which the enzymes hydrolyze most of the proteins to amino acids and low molecular weight peptides; starch is partially converted to simple sugars which are fermented primarily to lactic acid, alcohol, and carbon dioxide (Pardez-Lopez et al., 1991).

Fermentation of wheat flour dough reduced detectable AF by approximately 50% (Scott, 1991). Alcohol fermentation of barley reduced mycotoxin concentration by 100% (from 16.32 ppm became ND). The ferment waste produced from alcohol fermentation indicated a low concentration of mycotoxins because of fermentation activity and a decomposition ratio of major mycotoxins in waste showed the order of DON > NIV > ZEA (Oh-Kyung et al., 2004). Therefore, fermentation of cereals is an effective process to reduce the mycotoxin content which occurs due to enzymatic breakdown.

Frying

Frying is the cooking of food in oil or another fat. This takes several forms, from *deep-frying*, where the food is completely immersed in hot oil, to *sautéing* where food is cooked in a frying pan where there is only a thin coating of oil. Frying is the fastest way to cook, as it is the most efficient way to transfer heat into the food. Despite using liquid oil, frying is considered to be a dry cooking method as water is not used in the cooking process and ideally the cooking oil will not be absorbed by the food (Tannahill, 1995).

Frying corn masa at 140–170°C (0–6 min) gave no reduction of fumonisins; while frying tortilla chips at 190°C (15 min) resulted in a 67% reduction of fumonisin (Jackson et al., 1997). In contrast frying (15 min at 169°C, 2.5 min at 205°C, and 1.0 min at 243°C) of wheat containing DON (1.2 mg/kg) did not result in significant reduction of DON (Samar et al., 2007). High temperature frying, therefore, causes reduction in fumonisin content but DON is heat stable hence its reduction is low during the process of frying.

Milling

Milling is one of the oldest forms of food processing. It is the process of crushing of grains to prepare flour. Wet milling of corn resulted in reductions of OT levels in germ and grits of 96% and 49%, respectively (Wood, 1982). Dry milling on soft wheats containing DON (2.0 mg/kg) in US and Canada revealed that DON was distributed throughout all fractions of the milled grains; bran and shorts (Hart and Braselton, 1983). Experiments in Japan on wheat with DON (0.17 mg/kg), cocontaminated with NIV and ZON milled with a Bühler experimental mill showed that 60% of DON remained after milling. And the DON content in bran was 2.7 times of that in the original wheat (Tanaka et al., 1986). Similar work in Korea showed wheat milling (Bühler test mill) resulted in 24–48% reduction of DON in flour fractions (initial DON level 0.068mg/kg) intended for human consumption (Lee et al., 1987).

The level of DON in cleaned wheat was 77% of that in uncleaned wheat when the original DON content ranged from 0.3 to 13.1 mg/kg (Visconti et al., 2004). In contrast, the adverse effect of milling on wheat flour was found in experiments in Italy and Switzerland where the initial level of DON was undetermined but consequent to modern milling DON level became 0.36 mg/kg (Palpacelli et al., 2007) and DON contents in break flour, reduction flour, shorts, bran were 16.2, 16.9, 84.4, and 122.0 mg/kg, respectively (Gärtner et al., 2008).

In spite of the differences noted among the studies a fact which is common is that the bran has higher level of DON. The DON content in bran was manifold of that in the original wheat (Tanaka et al., 1986; Tanaka et al., 1999; Visconti et al., 2004; Gärtner et al., 2008).

So regarding the deoxynivalenol level during milling process, it is important to mention that the contamination level does not decrease. In fact, it is a redistribution of the contaminant: more in the fractions richer in bran and less in the flour. Taking into account that the bran fractions are also used for human consumption, it is obvious that milling cannot be considered as an efficient decontamination step. (Israel-Roming and Avram, 2010).

Parboiling

Parboiling is a cooking technique in which food is partially cooked in boiling water but is removed before it is completely cooked. The process is beneficial as cooking time is reduced when parboiled ingredients are added to a recipe.

AF contents in inoculated rice produced by commercial parboiling (AFB1 60–92 mg/kg) were significantly higher than that in inoculated 'cottage' processed rice (AFB1 12–29 μg/kg). The steeping (precooking/soaking) process in commercial parboiling appears to increase the susceptibility of rice grains to fungal infection. AF content in grains increased considerably with the increase in duration of soaking (Bandara et al., 1991). Hence parboiling does not appear to be a favorable process for AF decontamination.

Preliminary Sorting, Trimming, and Cleaning

The steps of sorting, trimming, and cleaning may reduce mycotoxin concentrations in commodities; however, these operations may not completely remove all of the contamination. The initial condition of the grain, or commodity, and extent of the contamination will have an effect on cleaning efficiency.

DON in cleaned wheat was 4.6 mg/kg, while DON in dockage was 16.7 mg/kg (Scott et al., 1983) when the initial DON content was 7.1 mg/kg in hard red spring Canadian wheat. Reduction in DON levels of up to 74% has been reported after such sorting of grossly contaminated samples. However, many *Fusarium*-infected kernels, which may contain high levels of trichothecenes, can be physically indistinguishable from healthy grains and not removed by sorting; hence, routine grain cleaning can lead to, at best a small (up to 20%) reduction in trichothecene levels (Scott et al., 1984). DON content was decreased by 16% and screening had 4.7-fold higher DON contents than cleaned (combination of screening and air flow) soft US wheat (Seitz et al., 1985). The percent reduction of DON found in the cleaned wheat ranged from 6% to 19% which contained an initial level of DON ranging from 7.9–9.6 mg/kg (Abbas et al., 1985). So, cleaning can also be used to remove scab-infested wheat and barley kernels. Scouring reduced DON level by 22% from an initial content of 12.5 mg/kg (Nowicki et al., 1988). Sydenham et al. (1994) observed that cleaning in corn reduced Fumonisin concentrations by 26–69%. On the other hand, only 2–3% reduction of OTA in barley was achieved by cleaning (Scudamore et al., 2003). Physical cleaning, where mold-damaged kernels, seeds, or nuts are removed from the intact commodity, may result in 40–80% reduction of AFs (Park, 2002).

Roasting

It is a cooking method that uses dry heat, whether an open flame, oven, or other heat source. Roasting can enhance flavor through caramelization and Maillard browning on the surface of the food.

Roasting cornmeal samples both artificially contaminated (5 μg/g of FB1) and naturally contaminated cornmeal samples at 218°C for 15 min resulted in almost complete loss of fumonisins (Castelo et al., 1998). Roasting pistachio nuts at 90, 120, and 150°C for 30, 60, and 120 min reduced the AF content of the nuts by 17–63%, with the reduction being dependent on time and temperature. Treatment of naturally contaminated whole pistachio kernels at 150°C for 30 min significantly reduced level of AFs contamination in samples. Roasting at 150°C and 120 min condition degraded more than 95% of AFB1 in pistachio (Yazdanpanah et al., 2005). The reduction of AFs during coffee bean roasting was also dependent on the type and temperature of roasting with reductions of about 42% to 56% achieved (Soliman, 2002). Roasting coffee gave 13–93% reduction of OT (Pérez de Obanos et al., 2005). Home roasting in electrical oven for 6–10 min reduced mycotoxins by up to 40% but increasing the duration to 15 min resulted in greater reduction to up to 75% (Bokhari and Aly, 2009). Therefore, roasting being a high temperature treatment causes destruction of AFs.

Treatment with Chemicals

Inactivation of AF by chemical treatment appears to offer the most promising and feasible approach. Indications are that two points of the AF molecule are most susceptible to chemical attack: the internal ester of the coumarin moiety and the double bond of the terminal furan (when it is present). Many different chemicals have been applied for the treatment of peanut and cottonseed meals for the inactivation of AF.

These include ozone, hydrogen peroxide, methylamine, sodium hypochlorite, formaldehyde and calcium hydroxide, and ammonia (Anderson, 1982).

DON levels in corn were reduced by as much as 95% by autoclaving at 121°C for one hour with 8.33% aqueous sodium bisulphate (Young et al., 1987). The addition of 10 ppm calcium hypochlorite (bleach) to soaking water appreciably reduced *A. flavus* contamination and subsequent AF content in parboiled rice (Bandara et al., 1991).

Boyaciouglu et al. (1993) examined the effects of bread additives on DON level postbake and has shown that potassium bromate and l-ascorbic acid had no effect, but sodium bisulphite, l-cysteine, and ammonium phosphate resulted in decline of up to 40%. It was also interesting to note that the metabolite isoDON was formed during the process.

Hameed (1993) found that extrusion alone reduced AF content by 50–80%, and with addition of ammonia, either as hydroxide (0.7 and 1.0%) or as bicarbonate (0.4%) the AF reduction achieved became 95%. Cheftel (1989) reported similar results when peanut meal was subjected to extrusion cooking in the absence (23–66% reduction) or presence of 2–2.5% ammonium hydroxide (87% reduction).

Nixtamalization (alkaline cooking) reduced fumonisin B_1 (FB_1) concentrations (50–80%) through a combination of extraction and hydrolysis. DON was significantly reduced due to its instability in alkaline conditions (Voss, 2008).

Corn was processed into tortillas through the process of nixtamalization. Tortillas contained approximately 0.50 ppm of FB(1), plus 0.36 ppm of HFB(1), which represented 18.5% of the initial FB(1) concentration (8.79 ppm). It was concluded that nixtamalization significantly reduced the amount of fumonisin in maize (Dombrink-Kurtzman et al., 2000).

Experimental units (EU) of sorghum flour contaminated with B-AFs (140 ppb) were extrusion cooked with aqueous lactic or citric acid at six different concentrations. Under some conditions, the AF reduction is more effective when using aqueous citric acid (up to 92%), than when using aqueous lactic acid (up to 67%) (Méndez-Albores et al., 2008)

The effect of 18 different chemicals, which included acidic compounds (sulfuric acid, chloridric acid, phosphoric acid, benzoic acid, citric acid, and acetic acid), alkaline compounds (ammonia, sodium bicarbonate, sodium hydroxide, potassium hydroxide, and calcium hydroxide), salts (acetate ammonium, sodium bisulfite, sodium hydrosulfite, sodium chloride, and sodium sulfate), and oxidizing agents (hydrogen peroxide and sodium hypochlorite), on the reduction of AFs B(1), B(2), G(1), and G(2) and OTA was investigated in black and white pepper. Almost all of the applied chemicals showed a significant degree of reduction on mycotoxins. The lowest and highest reduction of AF B(1), which is the most dangerous AF, was 20.5% using benzoic acid and 54.5% using sodium hydroxide. There was no significant difference between black and white peppers (Jalili et al., 2011).

CONCLUSION

Mycotoxins are secondary fungal metabolites that contaminate agricultural commodities and can cause sickness or death in humans and animals. Food processing has an impact on mycotoxins. In cleaning, substantial reduction of mycotoxins is achieved by removal of infected kernels. Milling can also result in their substantial reduction if bran and shorts (outer skin of kernels; which contains higher amount of DON) are discarded. High temperature processes cause varying degrees of reduction of mycotoxin concentrations, but most mycotoxins are moderately stable in most food-processing systems. Aqueous cooking and steeping reduces mycotoxin concentrations. Reduction of fungal toxins is dependent on cooking time, temperature, pH, recipe, food additives, and other factors. Roasting and extrusion cooking at high temperatures (above 150°C) appear to reduce mycotoxin concentrations. In summary, the available data clearly show that mycotoxins are reduced step by step during processing, but not completely removed from final products. However, it is important to look into possible long-term drawbacks of these processing techniques, associated impact on nutritional parameters of food grains and their economical and technical feasibility for mycotoxin reduction.

FUTURE SCOPE

In addition to reduction of mycotoxins by processing it is important to focus attention on various dietary strategies to contain the toxic effects of mycotoxins using antioxidant compounds (selenium, vitamins, and provitamins), food components (phenolic compounds, coumarin, chlorophyll and its derivatives, fructose, and aspartame), medicinal herbs and plant extracts, and mineral and biological binding agents (hydrated sodium calcium aluminosilicate, bentonites, zeolites, activated carbons, bacteria, and yeast). Interesting results have been obtained by studies on food components contained in coffee, strawberries, tea, pepper, grapes, turmeric, *Fava tonka*, garlic, cabbage, and onions. Additionally, some medicinal herbs and plant extracts could potentially provide protection against AF B_1 and fumonisin B_1. Activated carbons, hydrated sodium calcium aluminosilicate, and bacteria seem to effectively act as binders. Hence, dietary strategies seem to be the most promising approach to the problem, considering their limited or nil interference in the food production process. Nevertheless, a great research effort is necessary to verify the in vivo detoxification ability of the purposed agents, their mode of action, possible long-term drawbacks of these detoxification-decontamination procedures, and their economical and technical feasibility.

Though cooking processes generate new compounds that are structurally different from parent compounds but their toxicity is not known and the common analytical methods cannot determine their concentrations so it is necessary to estimate their toxicological effects.

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