Problems Associated with Moulds in Foodstuffs

Subjects: Others

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Keywords: foodborne moulds ; food safety ; food quality ; antifungal agents

1. Introduction

Moulds are a key microbial group in the food industry, since they are capable of growing in a wide range of environmental conditions. Firstly, the application of moulds and derived products to produce and preserve food and food ingredients is very broad [1]. Mould enzymes are ubiquitous, used in starch processing, in the bakery, and brewery industries, and to produce beverages, including wines and in food fermentation [1]. Apart from producing beneficial effects, moulds are the most commonly found spoilage microorganisms at every stage of the food chain and could be the primary causes of significant financial losses in some foodstuffs [2]. Additionally, this microbial group poses issues to human health because of their potential production of undesirable compounds, especially mycotoxins. Both harmful activities linked to mould development are a concern in the food industry since they can seriously damage the brand image [3].

During the period 2018-2022 more than 100 notifications related to mould contamination of different animal and vegetal food products and food supplements were accepted in the European Union [4]. The highest occurrence of moulds was declared in cereals and bakery products. Regarding mycotoxin notifications during this period, more than 1000 have been stated, with aflatoxins being the most frequently found, followed by ochratoxin A [4]. Most of the notifications concerned the categories “nuts, nut products and seeds”, “cereals and bakery products”, “herbs and spices”, and “fruits and vegetables”.

To guarantee the quality and safety of foodstuffs in relation to undesirable moulds, different approaches for their detection and control have been reported.

2. Problems Associated with Moulds in Foodstuffs

As stated before, two downsides associated with the mould contamination of food are of interest: spoilage and mycotoxin production provoking food quality and food safety concerns, respectively.

Regarding alteration, filamentous fungi are considered a severe pathogen of food due to their ability to penetrate and break down food components using extracellular enzymes [5]. They thus cause different types of spoilage, including unwanted visible mycelium on the product surface and undesirable sensory characteristics, such as flavour, colour, odour, and texture [6], with the consequent consumers’ rejection. *Penicillium*, *Aspergillus*, *Rhizopus*, *Mucor*, *Geotrichum*, *Fusarium*, *Alternaria*, *Cladosporium*, *Eurotium*, *Botrytis*, and *Byssochlamys* genera are involved in the spoilage of different foodstuffs [6][7]. Most of the problems related to mould spoilage have been described in fruits, vegetables, and grains and cereal products. For instance, bread and bakery products can rapidly spoil, mainly due to the growth of *Aspergillus*, *Penicillium*, *Rhizopus*, and *Mucor* species [8][9][10]. *Botrytis cinerea* is the main biological cause of pre- and post-harvest damage since it is responsible for grey mould formation in many plant species [7][11], including tomatoes [12] and table grapes [13]. Indeed, this undesirable mould is ranked second in the “world top 10 fungal pathogens in molecular plant pathology” in terms of economic and scientific relevance, preceded only by *Magnaporthe oryzae* [14]. Blue mould produced predominantly by *Penicillium expansum* and to a lesser extent other *Penicillium* spp. provokes the most detrimental infection of stored apples [15]. The white mould disease, caused by *Sclerotinia sclerotiorum*, is a major problem in rapeseed oil production [7]. Concerning food products of animal origin, black spot spoilage by moulds belonging to the *Cladosporium* genus (*Cladosporium oxysporum*, *C. cladosporioides*, and *C. herbarum*) has been reported in dry-cured ham and dry-cured fermented sausages [16][17]. *C. cladosporioides*, *C. herbarum*, *Penicillium hirsutum*, and *Aureobasidium pullulans* were isolated from chilled meat spoiled by black spot [18].

Considering the food safety issue associated with moulds, mycotoxins are a group of secondary metabolites with low molecular weight produced before and after the harvest of foodstuffs from vegetal origin and during ripening and the following processing of those from animal origin. In the latter, mycotoxin contamination could also be due to their presence in the animal feed [19][20]. These metabolites can provoke harmful effects, such as carcinogenic, immunosuppressive, teratogenic, and mutagenic ones [20] (**Table 1**). Hundreds of mycotoxins have been identified, but toxicity, frequency of outbreaks, and target organs differ among them [19]. Mycotoxin contamination is a great challenge to food safety since many of them cannot be eliminated using heat, physical, and chemical treatments [20][21].

Table 1. Some important foodborne mycotoxins, commodity of origin, main producing moulds, and toxic effects on human health [19][20][22][23][24][25][26].

Mycotoxins	Major Foods	Mould Sources	Toxic Effects
Aflatoxins: B_1, B_2, G_1, G_2,	**Cereals, nuts, spices**	***Aspergillus* section Flavi**	**Hepatotoxic, immunosuppressive, carcinogenic, teratogenic, genotoxic**
Ochratoxin A	**Cacao, dried fruits, wine, cereals, spices, dry-cured meats**	***Aspergillus* section *Circumdati* *Aspergillus* section *Nigri* *Penicillium verrucosum*, *P. viridicatum*, *P. nordicum***	**Carcinogenic, teratogenic, genotoxic, immunotoxic**
Fumonisins: B_1, B_2	**Maize**	***Fusarium* section Liseola**	**Carcinogenic, pulmonary oedema, neurotoxic, cardiovascular toxicity**
Patulin	**Apple**	***P. expansum*, *Aspergillus clavatus*, *Bysochlamis nivea***	**Acute toxicity, neurotoxic, genotoxic, carcinogenic, teratogenic, immunotoxic**
Trichothecenes: T-2, DON, DAS, HT-2, NIV, etc. [a]	**Cereals**	***Fusarium acuminatum, F. poae, F. sporotrichioides, F. graminearum, F. colmorum, F. cerealis***	**Vomiting, diarrhoea, leukopenia, necrotic lesions, haemorrhage, kidney problems, immunosuppressive**
Zearalenone	**Cereals**	***F. graminearum, F. culmorum, F. equiseti, F. cerealis, F. verticillioides, F. incarnatum***	**Oestrogenic effects, reproductive toxicity**
***Alternaria* mycotoxins: AOH, AME, ALT, TeA, etc. [b]**	**Tomato, sunflower seed, cereals**	***Alternaria* sp.**	**Acute toxicity, cytotoxic, fetotoxic, teratogenic, haematological disorders, oesophageal cancer**

[a] T-2: toxin T2; DON: deoxynivalenol; DAS: diacetoxyscirpenol; HT2: toxin HT2; NIV: nivalenol. [b]; AOH: alternariol; AME: alternariol monomethyl ether; ALT: altenuene; TeA: tenuazonic acid.

The main mycotoxin-producing moulds belong to the genera *Fusarium*, *Aspergillus*, and *Penicillium*, which include several species producing toxins of the greatest concern worldwide, such as aflatoxins, ochratoxins, and fumonisins (**Table 1**). Other genera, such as *Claviceps*, *Alternaria*, etc., can also be involved [19] (**Table 1**). Other ones, such as *Fusarium* beauvericin, enniatins, and moniliformin, are so-called emerging mycotoxins and their serious risk on human and animal health have been stated despite the fact that a proper risk assessment has not been performed [20][27]. On the other hand, not every strain belonging to a mould species produce mycotoxins, and those that do usually produce them only in particular conditions [19].

Risks associated with mycotoxins depend on both hazard and exposure [28]. The hazard of mycotoxins to human beings is probably universal (while other factors are, occasionally, also important, for instance hepatitis B virus infection in relation to the hazard of aflatoxins). Exposure to mycotoxins is present worldwide; although, there are geographic and climatic differences in their production and occurrence as well as different dietary habits in various parts of the world [23][28]. However, the implication of global climate change in the toxigenic mould ecology and their pattern of mycotoxin production has been stated. As a result, the number of crops damaged by insects will increased because of global warming, and, therefore, render them more susceptible to mould infection [29], but it could also modify the diversity of diseases invading crops, certain mould might disappear from an environment and appear in new regions previously considered safe, along with the consequent economic and social implications [29]. Global warming will make crop growth impossible in some areas and, where growing crops will be possible, plants will be subjected to suboptimal climatic conditions, resulting in increased susceptibility to mould contamination [29]. Furthermore, warmer climates will favour thermotolerant species, leading to the prevalence of *Aspergillus* over *Penicillium* species [29]. Thus, climate change remains the primary factor for high levels of mycotoxins in African foods [30].

Many countries have regulated maximum limits and guidelines for relevant mycotoxins, such as aflatoxins, ochratoxin A, deoxynivalenol, zearalenone, fumonisins, T-2 toxin, HT-2 toxin, citrinin, Ergot sclerotia, ergot alkaloids, and patulin [23][31][32]. Current regulations are based on scientific opinions of authoritative bodies, such as the FAO/WHO Joint Expert Committee on Food Additives of the United Nations (JECFA) and the European Food Safety Authority (EFSA), which work with the known toxic effects [28].

Control of mould contamination is a major concern for the food industry and scientists that are looking for efficient solutions to prevent and/or limit not only their growth, but also their mycotoxin production. Chemical fungicides and good hygiene practices are the primary strategy for the treatment of undesirable foodborne moulds. Nonetheless, there is a growing demand from consumers for food free of synthetic fungicides and with a minor impact on the environment. Among the problems described for such products are the development of resistance to fungicides and the presence of residues in food, apart from causing allergies or side effects in some consumers [2][33]. As a result, major progress is being made in finding more sustainable and safer alternatives to such preservatives, including biopreservation, using microorganisms as well as legally permitted ingredients, and physical treatments. These alternatives generally do not have as wide a spectrum of activity as the synthetic fungicides [15] and, consequently, their combined application has been suggested [34][35][36].

Biological control using microorganisms have been reported for different food products. For instance, *Candida intermedia* provoked a significant reduction of ochratoxin A production when applied against *Aspergillus carbonarius* [37]. Both yeasts and bacteria have been investigated as biocontrol agents against grey mould decay in table grapes [13]. Biopreservation by lactic acid bacteria is considered the most promising alternative candidates to chemical fungicides in the dairy industry due to their Generally Regarded as Safe (GRAS) and Qualified Presumption of Safety (QPS) statuses in the United States and European Union, respectively [3][38]. To prevent OTA contamination in dry-cured meat products, different microorganisms isolated from them have been studied as potential protective cultures [39][40][41]. Antimicrobial compounds of biological origin have also been investigated against undesirable foodborne moulds. Natural antimicrobials, including plant extracts, edible coating, and putrescine, amongst others, have been investigated against grey mould decay in table grapes [42]. Within plant extracts, essential oils from many plants have shown remarkable potential as biocontrol agents. Thus, numerous essential oils have been examined as antifungal agents for enhancing the shelf life of bread showing different degrees of impact; although the consumer does not always appreciate the flavour and aroma they provide [43]. For instance, tea tree oil inhibited the spore germination and mycelial growth of *B. cinerea* [44]. Against such undesirable mould, the inhibitory biological effects of wuyiencin produced by *Streptomyces albulus* var. *wuyiensis* has also been reported [45]. In addition, some plant derivatives, such as oregano, rosemary or thyme, are proven to be effective in reducing OTA production by *Penicillium nordicum* and *Aspergillus westerdijkiae* in meat substrates [46][47].

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