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Review

Challenges and issues concerning mycotoxins contamination in oil seeds and their edible oils: Updates from last decade

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ABSTRACT

Safety concerns pertaining towards fungal occurrence and mycotoxins contamination in agri-food commodities has been an issue of high apprehension. With the increase in evidence based research knowledge on health effects posed by ingestion of mycotoxins-contaminated food and feed by humans and livestock, concerns have been raised towards providing more insights on screening of agri-food commodities to benefit consumers. Available reports indicate majority of edible oil-yielding seeds to be contaminated by various fungi, capable of producing mycotoxins. These mycotoxins can enter human food chain via use of edible oils or via animals fed with contaminated oil cake residues. In this review, we have decisively evaluated available data (from the past decade) pertaining towards fungal occurrence and level of mycotoxins in various oil seeds and their edible oils. This review can be of practical use to justify the prevailing gaps, especially relevant to the research on presence of mycotoxins in edible plant based oils.

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1. Introduction

Contamination of agri-food commodities by mycotoxins-producing fungi (molds) and their mycotoxins is a recurring food safety problems world over. In recent years, serious concerns are being raised by consumers as well as by health professionals for the presence of various toxigenic fungi or their secondary metabolites (as mycotoxins) in food and feed. This concern is mainly due to increased evidence based research knowledge, and the available monographs related to the health effects caused by ingestion of food or feed contaminated by toxigenic fungi in humans and livestock.

Majority of the mycotoxins reported till date are potentially carcinogenic, teratogenic, tremorogenic, nephrotoxic, immunotoxic or hemorrhagic. In addition, most of the mycotoxins are capable of causing dermatitis in both humans and livestock. Some of the common mycotoxins identified in human food and animal feeds include aflatoxins, ochratoxins, trichothecenes (deoxynivalenol, nivalenol), zearalenone, fumonisins, patulin, citrinin, cyclopiazonic acid, sporidesmins, slaframine, stachybotryotoxin, and phomopsin (Bhat, Rai, & Karim, 2010). Contamination of human food and livestock feed by fungi and their respective toxins presents a serious food safety issue globally, leading to incredible yield and economic losses. As per the International Agency for Research on Cancer (IARC), aflatoxins are considered group 1, and ochratoxin A (OTA) and fumonisins (B1 and B2) as group 2B possible human carcinogens, while zearalenone is a group 3 carcinogen. Zinedine and Mañes (2009) have opined that mycotoxins, being heat-stable, represent an impending risk for human and animal health. In majority of the cases, mycotoxin-producing fungi is reported to belong to genera of *Aspergillus*, *Fusarium*, and *Penicillium* (Bhat et al., 2010; Kumar, Basu, & Rajendran, 2008).

Today, with widely available reports and updated database on fungal occurrence and mycotoxins contamination in marketed commodities, health protection bodies have imposed stringent regulations, especially for imported commodities (Bhat et al., 2010). Fungal contamination in a seed generally occurs either during pre-harvest or during postharvest conditions. In majority of the instances, fungi might be present as an endophyte and invisible to the naked eye. Improper storage conditions and other eco-physiological factors, especially prevailing in the tropics and sub-tropics (wherein high temperature and humidity prevail) contribute immensely for the rapid growth of molds. These fungi can thrive even at low moisture and water activity levels and produce mycotoxins.

In recent years, edible oils (fat) extracted from plant seeds have gained immense popularity over animal-based fats, mainly due to their potential therapeutic/health-promoting potential. Several reports are available on fungal contamination of various oil-yielding seeds, as well as on the presence of mycotoxins in the extracted oil. Contamination of oil seeds by toxigenic molds is a menace, as the seeds and the oil extracted from the infected seeds tend to become unfit for consumption. Accordingly, some of the world's health-governing bodies [such as the Food and Agriculture Organization (FAO), Codex Alimentarius Commission (CODEX), EU Commission and the World Health Organization (WHO)] have put forth stringent laws/regulations for the maximum tolerable levels (limits) of mycotoxins contamination in oilseeds, some of which are depicted in Table 1.

To our knowledge, no review is available wherein various data and reports are compiled to provide comprehensive information on the presence of toxigenic fungi or the mycotoxin level in oil yielding seeds and their edible oil. In this review, we have attempted to disseminate details on the presence of various

Table 1
Global regulation of mycotoxins contamination in oilseeds.

Country	Mycotoxins	Seeds/tolerable levels (μg/kg)						
		Groundnut (peanuts)	Maize (corn)	Oats	Mustard	Rape seed	Soy bean	Sun flower
Australia	Total AF	15	–	–	–	–	–	–
Brazil	Total AF	30	30	50 (f)	–	–	50 (f)	50 (f)
Bulgaria	Total AF	15	4	–	–	–	–	–
Canada	Total AF	15	–	–	–	–	20 (f)	20 (f)
China	AFB1	20	20	–	–	–	5	–
Egypt	Total AF	10	10	–	–	–	20 (f)	20 (f)
France	FB1	–	1000	–	–	–	–	–
	ZEA	–	50					
Hungary	Total AF/OTA	15	4	–	–	–	–	–
			5					
India	Total AF	30	30	–	–	–	–	–
Iran	Total AF	15	30	–	–	–	20 (f)	20 (f)
	OTA	–	50	–	–	–	–	–
	DON	–	1000	–	–	–	–	–
	ZEN	–	200	–	–	–	–	–
	Fumonisins	–	1000	–	–	–	–	–
Israel	Total AF/OTA	15	–	–	–	–	–	–
		–	50	–	–	–	–	–
Japan	AFB1	10	10	10	10	10	10	10
Kenya	Total AF	20	–	–	–	–	–	–
Korea	AFB1	10	10	–	–	–	10	–
Malaysia	Total AF	35	35	35	–	35	35	35
Mexico	Total AF	–	20	–	–	–	–	–
Morocco	AFB1	1	–	–	–	–	–	–
Nigeria	AFB1	20	20	–	–	–	–	–
Russia	AFB1	5	5	5	5	5	5	5
Taiwan	Total AF	15	15	–	–	–	–	–
Turkey	AFB1	5	2	–	–	–	–	–
USA	Total AF	20	20	–	–	–	–	–

AF: Aflatoxins; FB1: Fumonisin B1; ZEA: Zearalenone; OTA: Ochratoxin A; DON: Deoxynivalenol; f: Feed; (Compiled from: Bhat et al., 2010; FAO, 2004; van Egmond, Schothorst, & Jonker, 2007; Reddy et al., 2010).

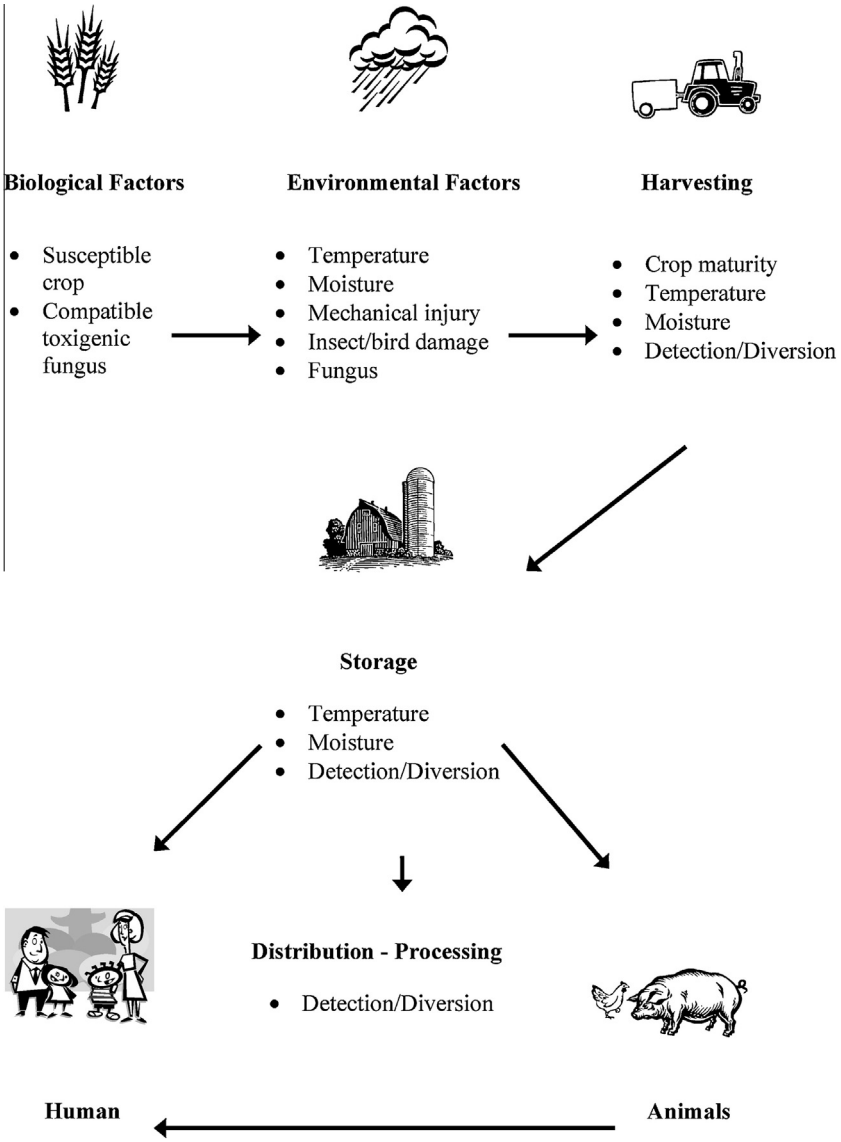

Fig. 1. Factors affecting mycotoxin occurrence in the human food and animal feed chains. *Source:* Bryden (2012). Licence number: 3901680915087; License dated: July 03, 2016; Publication Journal: Animal Feed Science and Technology; Elsevier Publishers originally adapted by the authors from Pestka and Casale (1990).

toxigenic fungi (molds) colonizing some of the common and popular edible oil yielding seeds and report on the levels of mycotoxins present in their oils. In addition, we have aimed to provide sufficient baseline informations, which are envisaged to be useful for both health-conscious consumers as well as for all public health agencies.

2. Fungal contamination and mycotoxins level

Fungal contamination and levels of mycotoxins present in an oil yielding seed and their oil can differ from region to region. Generally, high humidity and warm temperature favours the growth of toxigenic molds, which holds true for both the tropical and subtropical regions. Presence of toxigenic molds is also well known in cold and temperate regions, but is based on a particular commodity. Some of the vital factors influencing the occurrence of mycotoxins in food and feed are depicted in Fig. 1 (Bryden, 2012). In Fig. 2, interactions occurring among different intrinsic and extrinsic factors along the food chain that can influence the spoilage and mycotoxin production in stored food commodities are provided (Magan & Aldred, 2007). In the following text, a few of the popular and commonly used oil seeds for extraction of edible oils are discussed.

2.1. Groundnuts (peanuts)

Peanuts (*Arachis hypogea* L.) have been widely cultivated for extraction of edible oil. Both the seed and oil are rich in protein, vitamins, and essential minerals and in certain instances are also being used as a replacement for almonds. Seeds are also used for preparing nourishing peanut milk and peanut butter. The extracted oil from peanuts has been extensively used for cooking purposes in most of the growing regions of the world. Peanut oil possesses a mild flavour (aroma) and is believed to be stable at high cooking temperatures and can provide resistance to rancidity.

Peanuts are probably the most extensively studied oil seeds for the presence of contaminating fungi and their mycotoxins, especially those of aflatoxins. Peanuts based feed contaminated by *Aspergillus flavus* is historically known for the outbreak of

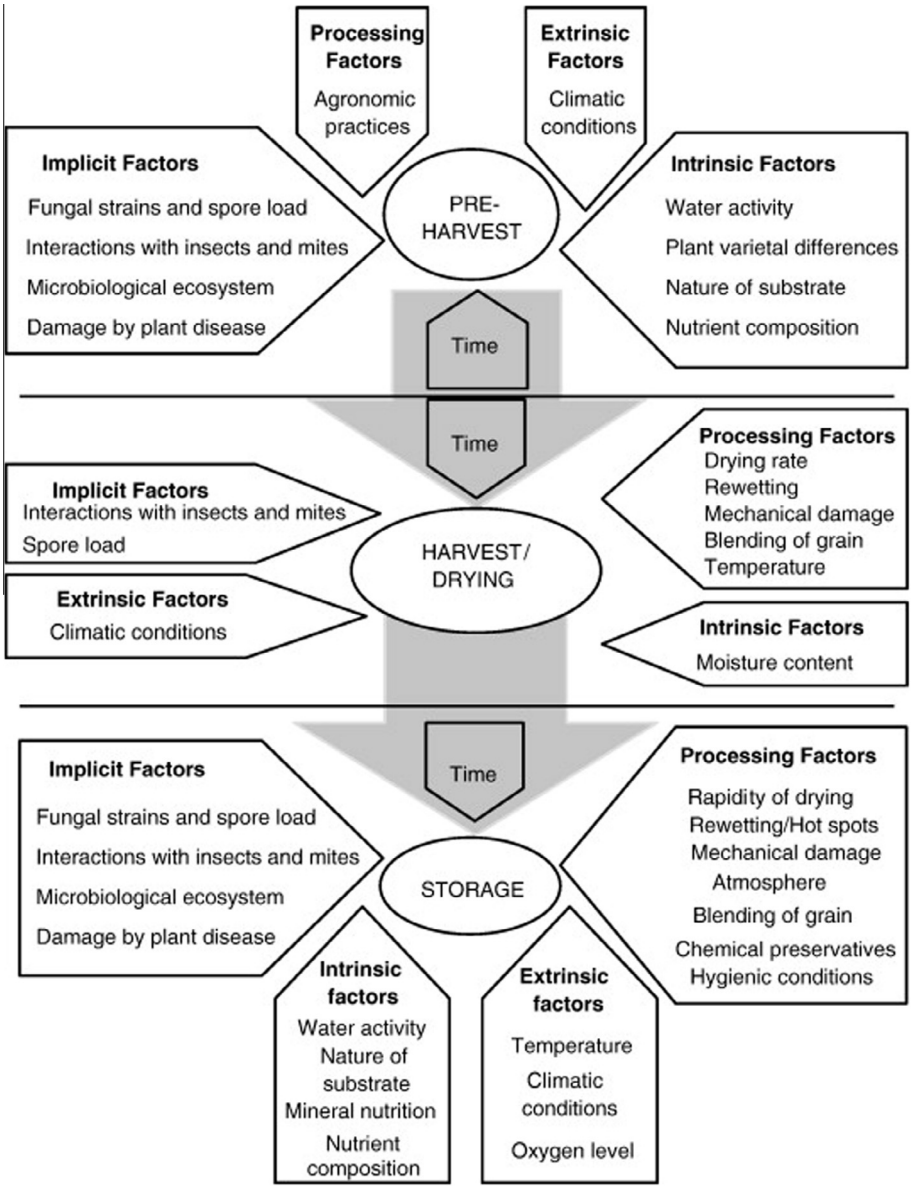

Fig. 2. The interaction between intrinsic and extrinsic factors in the food chain which influences mold spoilage and mycotoxin production in stored commodities. *Source:* Magan and Aldred (2007); Licence number: 3902840670167; License dated: July 05, 2016; Publication Journal: International Journal of Food Microbiology; Elsevier Publishers (originally authors had adopted this figure from Magan, Sanchis, and Aldred, 2004).

turkey-X disease in the UK during 1960's, which had lead to the death of nearly 1 lakh turkey birds, as well as other farm animals (Bhat et al., 2010). Apart from aflatoxins, peanut and their derived products such as like oil, sauce, butter and the pressed oil cake is also been reported to contain high amounts of fumonisins, ochratoxin, zearalenone, and cyclopiazonic acid (see Table 2). In peanuts, mycotoxin contamination can occur both at the 'on farm level' by invading soil fungi or during post-harvest storage. However, pre-harvest contamination can be of much higher threat than post-harvest contamination. Some of the major contaminating fungi includes: *Aspergillus flavus*, *A. niger*, *A. parasiticus*, and *A. nominus* (Li, Li, Wang, & Luo, 2009). Recently (Ezekiel, Sulyok, Warth, Odebode, & Krska, 2012) seven fungal metabolites were reported for the first time in contaminated peanut grain, nut and oil seeds and their products from Nigeria (toxic metabolites produced mainly by *Aspergillus* sp.; concentration up to 7400 μg/kg in case of kojic acid). Besides, Wu et al. (2016) working on peanut samples (total of 2494) from 4 different peanut producing areas in China found close relationship to occur between climatic conditions (weather conditions prior to harvest) and aflatoxin contamination levels.

The best recommended procedure for minimizing toxin formation in peanuts is correlated to the cleaning of farmers stock (harvested and during storage) to an acceptable standard before marketing and amending harvest timing (Dorner, 2008). So also, peanuts, co-inoculated with *A. niger* and *Trichoderma viride* (pre-contaminated with *A. flavus*) has been reported to substantially reduce production of aflatoxins (Bhat et al., 2010). Further, post-harvest reduction in aflatoxins (AFB1) concentration is reported on application of ionizing radiation (1 Mrad of gamma rays) as well as roasting (of the peanut meal) in a microwave oven (Bhat et al., 2010). However, contradictorily, dry-roasted groundnuts are also known to contain significant levels of aflatoxins.

The major ecological factor contributing to mold (fungal) growth and accumulation of aflatoxins in peanuts can be attributed to extremely high temperature variations as well as harvesting

Table 2
Selected reports on contamination by mycotoxins in peanuts since last decade.

Country	Mycotoxin	Type of product	Concentration range (μg/kg)	References
Argentina	Ochratoxin-A	Peanuts	5.6–130	Magnoli et al. (2007)
Australia	Aflatoxins	Peanuts	0–1600	Chauhan et al. (2010)
Brazil	Aflatoxins	Peanuts	4.2–198.8	Nakai et al. (2008)
	Cyclopiazonic acid		260–600	Oliveira, Gonçalves, Rosim, and Fernandes (2009)
	Fumonisins		0.0	
	Aflatoxins		3.3–116	
China	Aflatoxins	Peanut butter	0–68.51	Li et al. (2009)
France	Aflatoxins	Peanuts	1.5–10	Tigori et al. (2006)
	Fumonisins		<0.03–0.06	
	Ochratoxins		0.0.64	
	Zearalenone		50–200	
Indonesia	Aflatoxins	Peanuts	37–107	Rahmianna, Taufiq, and Yusnawan (2007)
Japan	Aflatoxins	Peanut butter	2.59	Kumagai et al. (2008)
Kenya	Aflatoxins	Peanuts	0–7525	Mutegi, Ngugi, Hendriks, and Jones (2009)
Korea	Aflatoxins	Peanut butter	1.30–6.44	Chun et al. (2006)
Malaysia	Aflatoxins	Peanuts	0.85–762.05	Sulaiman, Yee, Hamid, and Yatim (2007)
Nigeria	Aflatoxins	Peanuts	7.2–10.7	Odoemelam and Osu (2009)
			74.03–82.1	
			23.2–42.2	
Nepal	Aflatoxins	Peanuts	>30	Koirala, Kumar, Yadav, and Premarajan (2005)
Sri Lanka	Aflatoxins	Peanuts	0–12.5	Dissanayake and Manage (2009)

season. The maximum growth of *A. flavus* and aflatoxin production in peanuts can occur between 27 and 30 °C.

In the European Union context, aflatoxin B1 and total aflatoxins level in peanut products have been controlled with maximal residue levels not to exceed 2 and 4 ng/g, respectively (EC, 2001). However, recent amendments of commission regulation (EC-No. 1881/2006, No. 165/2010 of 26 February 2010) in peanuts and other oilseed or their processed products (intended for human consumption or as an added ingredient in foodstuffs), the maximal levels set for aflatoxin B1 was 2 μg/kg, while for the total of B1, B2, G1 and G2, the maximal limit was set at 4.0 μg/kg (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2006R1881:20100701:EN:PDF; assess date 30th June 2016).

From the available information, it is clear that peanuts harbour potential toxigenic fungi capable of producing high amounts of mycotoxins. However, a much anticipated wider gap still persists towards identifying the contamination rate of peanuts by ochratoxins and fumonisins, including their management in oil and other peanut-based products. Additionally, research studies are warranted to evaluate the status of mycotoxins present in peanut oil and in animal feeds during extended storage. Evaluating the status of mycotoxins during cooking (heating) process also demands further investigations.

2.2. Soybeans

Soybeans (*Glycine max* L.) and their products (sauce, oil, flour, tofu, and more) are immensely popular as a major source of protein for both human and animal consumption. Soybeans are reported to be contaminated by various toxigenic molds with several interesting reports being available. According to Nesheim and Wood (1995), soybeans are capable of supporting the growth of molds that can produce mycotoxins like aflatoxins, trichothecene (e.g. T-2), and cytochalasins. However, these authors have opined that presence of these toxins may not to be a major problem in soybeans, as their results was based on inadequate survey pursued on soybeans or soy-based infant formulas. Further, soy meal analysed for the presence of 16 *Fusarium* toxins showed eight samples to be positive with varying levels of up to 240 μg/kg (Schollenberger et al., 2006). Measurable levels of aflatoxins were detected in soybean and their products (Chun, Ok, Kim, Hwang, & Chung, 2006). Results revealed, among the various samples analysed, soy sauce and soybean paste to be positive for aflatoxins (range between 0.11 and 1.81 μg/kg). However, no aflatoxins were detected in soybean, soybean oil, and in hot soy paste.

Nearly 45 soy-based food products (whole beans, roasted soy nuts, flour, flakes, textured soy protein, tofu, protein isolate, infant formula, and soy sauce) were evaluated for *Fusarium* toxins, which were randomly collected from markets in Germany (Schollenberger et al., 2007). Fusarial toxins like scirpentriol (SCIRP), 15-monoacetoxyscirpenol, 4,15-diacetoxyscirpenol, T-2 tetraol, HT-2 toxin, deoxynivalenol (DON), 15- and 3-acetyl deoxynivalenol, ZEA, and α- and β-ZOL were noticed in at least one of the soy products. From their results, SCIRP, DON, and ZEA were present at varying concentration levels of 108, 260, and 214 μg/kg, respectively, while other toxins under the study did not exceed the level of 61 μg/kg. From this study, authors were able to demonstrate the possibilities of co-occurrence of different mycotoxins in soy food, with up to seven toxins being present in the same sample.

Future studies are warranted to identify the degradation kinetics of these mycotoxins in soybeans or their products and also put-up an appropriate management strategy.

2.3. Sunflower

Sunflower seeds (*Helianthus annuus* L.) are cultivated extensively for oil production. The seeds are reported to be rich in polyunsaturated fatty acids (65% linoleic acid) with low levels of saturated fats. Sunflower seeds are also a good source of dietary fiber, minerals, and vitamin E. Reports are available that indicate sunflower seeds to exhibit good antimicrobial and antioxidant properties (Giada, 2008; Mendoza, Manna, Crespi, Crowe, & Cavestany, 2008). The oil extracted from the seeds is considered healthy and can minimize the risk of cardiovascular disease.

Sunflower seeds is reported to harbour molds such as *Fusarium verticillioides*, *Penicillium chrysogenum*, *Alternaria alternata*, *Aspergillus* spp., *Cladosporium* spp., *Drechslera* spp. and *Curvularia* spp., which are all able to produce mycotoxins like that of citrinin, aflatoxins, alternariol, alternariol monomethyl ether, and tenuazonic acid (Pozzi et al., 2005). Contamination by *Rhizopus* species is also well established leading to the production of low-quality sunflower seeds, with discoloured as well as reduced oil contents.

Sharfun-Nahar Mushtaq and Hashmi (2005) screened 35 samples of sunflower for seed-borne mycoflora and accordingly reported the presence of *Acremonium fusidioides*, *Arthrobotrys oligospora*, *Aspergillus ochraceus*, *Bipolaris bisepta*, *Cephaliophora tropica*, *Chaetomium spinosum*, *Cladobotryum varium*, *Cladosporium cladosporioides*, *Emericella nidulans*, *Gonatobotrys simplex*, *Humicola grisea*, *Memnoniella echinata*, *Mucor mucedo*, *Myrothecium verrucaria*, *Phialophora verrucosa* and *Syncephalastrum racemosum*. Additionally, *Absidia corymbifera*, *Alternaria alternata*, *Aspergillus flavus*, *A. niger*, *A. terreus*, *Chaetomium bostrychodes*, *C. globosum*, *Emericella nidulans*, *Fusarium pallidoroseum*, *F. solani*, *Macrophomina phaseolina*, *Penicillium* spp., *Rhizoctonia solani*, and *Rhizopus stolonifer* were also isolated from the sunflower seeds. Further, by adopting seed plating technique, fungi such as *Aspergillus awamori*, *A. ustus*, and *Exerohilum halodes* were also detected in sunflower seeds, which were all grouped as the newly reported species.

Pozzi et al. (2005) in one of their studies (in Brazil) analysed the mycoflora of sunflower seeds during different stages of plant development. Their results revealed the presence of *Fusarium verticillioides*, *Penicillium* spp. and *Alternaria alternata*, along with the presence of mycotoxins like alternariol and alternariol monomethyl ether. Occurrence of mycotoxicosis in poultry birds owed to the presence of aflatoxin B1 (16 ppb) and ochratoxin A (800 ppb) contamination in sunflower seed based feed, is being documented in the database during 1990s.

Banu and Muthumary (2005) undertook a detailed study on the fungal occurrence in sunflower seed, which included various junctures like seed stage to kernel, oiled cake (OC) and de-oiled cake (DOC), solvent-extracted oil (SEO), expeller oil (EO) and refined oil (RO). In their study, 24 nonxerophilic fungal species belonging to 12 genera were identified. *A. flavus* was the pre-dominant fungus to be present in the seeds (22.3%), *Mucor racemosus* was dominant in kernels (31.6%), while in OC and DOC, *Rhizopus stolonifer* was dominant (31.1% and 45.9%, respectively). In the EO and SEO, *A. flavus* and *A. japonicus* were the dominant fungi with their presence being 21% and 32.4%, respectively. However, refined oil was found to be devoid of any fungal contamination. The reason behind this was attributed to the fact that refining processes undertaken at high temperature (of 240 °C for 6 h.) could have possibly destroyed the fungal spores in the raw oil obtained from the seed.

As sunflower seed oil are one of the most extensively marketed and consumed oil for edible/cooking purposes, the status of mycotoxins during processing, storage and cooking process merits further examination.

2.4. Safflower

Safflower seed (*Carthamus tinctorius* L.) oil are odourless, rich in polyunsaturated fatty acids (PUFAs), with the overall qualities believed to be comparable to those of sunflower oil. Safflower oil contains derivatives of serotonin, which is reported to exhibit excellent *in vitro* anti-oxidative activity, thus exerting several biological effects on plasma and liver lipids (Cohn, Wat, Kamili, & Tandy, 2008).

Safflower seeds are reported to harbour various toxigenic molds, which include: *Alternaria carthami*, *Fusarium* spp., *A. flavus*, and *Penicillium* spp. Several fusarial toxins (DON, vomitoxin; T-2 toxin, and trichothecenes) are often isolated from the seeds (Miller, Simon, Blackwell, Greenhalgh, & Taylor, 2001). As early as during 1970's *Fusarium oxysporum* f. sp. *carthami* was isolated from the seeds of safflower (Ghosal, Chakrabarti, & Basu Chaudhary, 1977). These researchers detected three toxic compounds that were adequate to lead to mycotoxicosis following prolonged ingestion. Two of the compounds identified were ascertained as diacetoxyscirpenol and T-2 toxin, while the third compound was partially characterized to be 12,13-epoxytrichothecene. Quality deterioration in oil owing to the presence of storage fungi such as *Curvularia pellescens*, *Penicillium chrysogenum and Fusarium equiseti*, *Curvularia lunata* is reported in safflower (Kakde & Chavan, 2012). However, not much detailed reports are available on the status of these contaminating fungi or their mycotoxins in oil or in oil cake, a gap that needs to be filled.

2.5. Linseed

Linseed (flaxseed, *Linum usitatissimum* L.) oil extracted from the dried ripened seed contains high amounts of omega-3-fatty acids, with the seed oil being proved beneficial for overcoming cardiovascular related problems, heart diseases and arrhythmia. Besides the seed oil is believed to possess anti-cancer and anti-inflammatory properties.

Some of the fungal species harbouring flax seeds belong to genera of *Colletotrichum*, *Fusarium*, *Rhizoctonia*, *Alternaria*, *Aspergillus*, *Penicillium* (Kumud, Jitendra, & Yadav, 1997). Fungal contamination of flax seed generally occurs during the ripening of capsules, and is presumed to be dependent on weather conditions, especially divergent air temperature, relative humidity and moisture. Fungal and mycotoxin contamination of oil flax seed in 6 cultivars differing in length of growing season was analysed by Gruzdevienė, Mankevičienė, Lugauskas, and Repečkienė (2006). Results of this study revealed internal seed fungal infection (at harvesting and during storage) to have occurred with the presence of fungal genera belonging to *Alternaria* (*A. alternata*, *A. linicola*, *A. dianthi* and *A. pluriseptata*), *Fusarium* spp. and *Penicillium* spp. The researchers also reported flax seed samples to be positive for DON contamination (except for cv. 'Blue Chip'), and after eight months of storage, the levels of aflatoxins (2.5 μg/kg) and ochratoxin A (1.2 μg/kg) were enhanced.

Working on linseeds, Sahay, Prasad, and Sinha (2006) isolated 18 fungal species with *Aspergillus flavus* being dominant. In this study, out of 105 samples analysed, 46 showed positive results for aflatoxin contamination, with concentration of aflatoxin B_1 in contaminated samples ranging from 120 to 810 μg/kg. Additionally, Králová et al. (2006) detected *Alternaria* toxins in linseed samples with relatively high levels of alternariol (AOH, 104 μg/kg), alternariol monomethyl ether (AME, 30 μg/kg), and altenuene.

From these reports, it is clear that linseeds harbour a wide range of molds capable of producing mycotoxins. However, no reports are available on the possible presence of these toxins in the extracted oil or in the oil cake (supposed to be utilized as livestock feed). In addition, a wide gap persists with regard to the management of these fungal contaminants and their contributing factors in linseed.

2.6. Maize (Corn)

Maize (*Zea mays* L.) is one of the most important cereal crop frequently being used as a basic raw material to prepare popular food products such as the flour, grits, breakfast cereals, baby food or germ oil (Schollenberger, Müller, Rüfle, Suchy, & Drochner, 2008).

Maize/corn is an extensively studied food crop for the presence of toxigenic fungi and mycotoxins. Table 3 provides the information on the worldwide contamination of corn/maize by various mycotoxins. Pathogenic fungi belonging to *Fusarium* species is reported to commonly infest maize plants. Further, it is suspected that the inoculum or fusarial toxins produced can be carried over to maize grains or their products (Schollenberger et al., 2005, 2006). Infection of corn kernels by toxigenic fungi like *Aspergillus flavus*, *A. parasitcus*, *Fusarium verticillioides* (syn. *F. moniliforme*), and *F. proliferatum* is well established. Contamination by fumonisins in stored maize is also well documented in the databases. Screening of 180 maize samples intended for human consumption

Table 3
Selected reports on contamination by mycotoxins in corn/maize in the last decade.

Country	Mycotoxin	Concentration range (μg/kg)	References
Argentina	Aflatoxins	0–3.19	Broggi et al. (2007)
	Fumonisins	0.0–0.02	
	Deoxynivalenol	0–118.5	
	Zearalenone	0–230.8	
Bahrain	Zearalenone	3.1	Musaiger, Al-Jedah, and D'souza (2008)
Benin	Fumonisins	0.006–0.024	Fandohan et al. (2005)
Brazil	Fumonisins	0.046–0.71	Bittencourt, Oliveira, Dilkin, and Correâ (2005)
	Aflatoxins		
	Zearalenone		
China	Aflatoxins	0–0.99	Liu, Gao, and Yu (2006)
	Deoxynivalenol		
Egypt	Aflatoxins	2.7–7.5	Amra (2007)
	Ochratoxins	9.3–15	
	Zearalenone	5.7–9.4	
Iran	Fumonisins	71–10,674	Ghiasian et al. (2006)
Mexico	Zearalenone	3–83	Reyes, Martinez, and Rolón (2007)
Nigeria	Deoxynivalenol	9.6–745.1	Adejumo et al. (2007)
Portugal	Fumonisins	142–550	Lino, Silva, Pena, Fernández, and Mañes (2007)
Vietnam	Aflatoxins	0–126.5	Trung et al. (2008)
	Fumonisins	0.04–0.33	
USA	Fumonisins	26–774	Abbas et al. (2002)
	Moniliformin	21–699	
	Aflatoxins		

for *Fusarium* mycotoxins (like that of trichothecenes, collected from four South-Western Nigerian maize producing states) was performed by Adejumo, Hettwer, and Karlovsky (2007). Accordingly, the researchers were able to isolate *Fusarium verticillioides* (71%), *F. sporotrichioides* (64%), *F. graminearum* (32%), *F. pallidoroseum* (15%), *F. compactum* (12%), *F. equiseti* (9%), *F. acuminatum* (8%), *F. subglutinans* (4%) and *F. oxysporum* (1%). From this study, 66 samples were found to be contaminated with trichothecenes, DON, 3-AcDON, and DAS. However, all of the maize samples intended for direct human consumption was on par with the maximal permitted levels.

Mycotoxins production in corn can depend on several environmental related stress interacting factors such as low moisture levels, high day time temperatures with low temperature during night, high humidity, etc. Storage environment is also one of the main alleged factors that can enhance fungal contamination and mycotoxin production in maize. High levels of aflatoxins were detected in maize stored 'under' or on 'top of the roof' of farmers' house (Hell, Cardwell, Setamou, & Poehling, 2000). Additionally, high levels of *Fusarium* infection and fumonisin contamination in maize cobs stored in various storage systems has been reported in a country wide survey conducted in Benin (Fandohan, Gnonlonfin, Hell, Marasas, & Wingfield, 2005). Furthermore, insect infestation in stored maize has been correlated with aflatoxin production too (Hell, Cardwell, Setamou, & Schulthess, 2000). Further, there are reports identifying the presence of mycotoxins (e.g. ZEA and DON) during various stages of maize grain cultivation, harvest up to milling. The concentration levels of ZEA in endosperm-based fractions (like grits, meal, and flour) have been detected to be 50, 75, and 950 μg/kg when compared with original corn (1000 μg/kg). Brera et al. (2006) reported the concentration of ZEA in coarse and fine grit, and in the flour to be 15, 15, and 12%, respectively, and this was related to 100% for the maize grain, with 239 and 303% detected in the germ and bran. Further, Schollenberger, Müller, Rüfle, Suchy, et al. (2008) in one of their studies on seed germ oil detected the presence of 15-acetyldeoxynivalenol, HT-2 toxin, zearalenone, and T-2 toxin.

Ghiasian et al. (2006) screened a total of 52 corn samples collected from four major corn producing regions in Iran (Fars, Kermanshah, Khuzestan and Mazandaran province) and reported contamination by *Fusarium verticillioides* and fumonisins (FB1, FB2, FB3, and 3-*epi*-FB3). These researchers also reported that majority of the samples collected from Mazandaran province to be contaminated by fumonisins (mean level of 10,674 μg/kg). In contrast, fumonisin contamination level above 10 μg/kg was detected at the limit of 53% (8/15), 42% (5/12), and 57% (8/14) in samples collected from Fars, Kermanshah, and Khuzestan provinces, respectively, with the corresponding total fumonisin mean level being 215, 71, and 174 μg/kg, respectively.

Survey performed by Escobar et al. (2013) on 74 samples (12 wet milled maize germ, 12 dry milled maize germ, 25 refined corn oil, and 25 corn oil margarine), showed maize germ samples to be contaminated by FB1 and FB2, respectively (concentration of both toxins equivalent to 1302 in wet milled, 820 μg/kg in dry-milled maize germ samples, respectively). Further, these researchers correlated the low prevalence of FB1, FB2 and DON in edible oil and margarine (4–8%) to the industrial processes adopted. Additionally, 25% of maize germ samples showed positive for ZEA contamination with 32% being detected in corn oil and 24% in margarine. This was correlated to the lipophilic nature. The revisions of EC commission regulation (EC No. 1881/2006, No. 165/2010 of 26th February 2010), for refined maize oil, the maximal level set for zearalenone is set at 400 μg/kg (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2006R1881:20100701:EN:PDF; assess date: 30 June 2016).

2.7. Oats

Of late, oats (*Avena sativa* L.) and their products have become an integral part of human diet and are also been used as a nutritious feed material for raising the livestock. The oats oil obtained from the bran and germs (about 5.5% oil) are free of any *trans*-fatty acids. Besides, oats oil is abundant in phospholipids and glycolipids, and is considered as a healthy alternative to some of the routinely used cooking oils. Oats oil has high omega-6 and omega-9 fatty acids contents, but is low in omega-3 fatty acids.

Fungal contamination and mycotoxins presence (DON, T-2, ZEN and HT-2 toxins) are reported in oats from several regions world over (Krysińska-Traczyk, Perkowski, & Dutkiewicz, 2007; Sacchi et al., 2009; Schollenberger et al., 2006). In one of the mycological surveys (in an Argentinean province) pursued by Sacchi et al. (2009), oat samples showed the presence of aflatoxins, zearalenone, deoxynivalenol, and fumonisins. These researchers were able to isolate various toxigenic molds that included species of *Alternaria alternata*, *Aspergillus flavus*, and species of *Fusarium*, *Arthrinium*, *Acremonium*, and *Curvularia*. From this survey, only fumonisins B1 was detected in two samples (108.0 and 105.0 μg/kg). Other commonly encountered mycotoxins like aflatoxins, deoxynivalenol and zearalenone was not detected in any of the samples in this study. Contamination of Norwegian and Polish oats (0.035 and 0.037, respectively) by *Alternaria alternata* has also been reported (Krysińska-Traczyk et al., 2007).

Even though oat oil possesses multiple health benefits, it is commercially not available (rather oil is not popular). It is expected that oat oil can find high potential as a baking ingredient in the near future. Hence, additional research works needs to be pursued on the management of molds and mycotoxins in oats and oats products, including the oil.

2.8. Mustard

Mustard (*Brassica rapa*, *Brassica campestris*, *Brassica hirta*, or *Brassica nigra* L.) is extensively cultivated for extraction of the

'mustard essential oil', which is widely consumed in India and Bangladesh. Generally, the oil is extracted from the seeds of *Brassica nigra* (black mustard) or *Brassica hirta* (white mustard) species. Mustard oil posses rich health-promoting properties and is used in indigenous medicine systems to treat common cold, cough, headache, and chest congestion. Additionally, long-term use of the oil is believed to provide protection against cardiovascular diseases.

Mustard seeds are reported to be contaminated by various toxigenic fungi including *Aspergillus flavus*, *Fusarim* spp., *Penicillium* spp. Earlier, Tamoor, Khan, and Zahoor Ul Haq (2005) isolated seven seed borne storage fungi in 4 varieties of mustard seeds (B-raya, Y-raya, B-M-1, and S-9), which included *Aspergillus flavus*, *Alternaria brassicae*, *Helminthosporium brassicae*, *Penicillium* spp., *Pythium* spp., *Rhizoctonia solani*, and *Fusarium oxysporum*. These contaminant fungi was correlated to the decrease in weight and oil contents of seeds in all the 4 varieties during storage in comparison with the seeds that were stored in sterilized bottles.

2.9. Rapeseed

The rapeseed (*Brassica napus* L.) plant is exclusively grown for production of oil and the residue obtained after oil extraction process is assumed to be highly nutritious and are utilized as livestock feed in the growing regions. The rapeseed oil (or the rapa seed oil) encompasses high amount of omega-3 and omega-6 fatty acids. The oil is deemed to reduce cholesterol levels, lower serum triglyceride levels, and keep the blood platelets from sticking together. Additionally, glucosinolate compounds present in the oil are popularly believed to prevent cancer.

Various toxigenic fungi have been isolated from rapeseed world over. Seed samples analysed have shown occurrence of contaminant fungi such as *Alternaria brassicae* and *Alternaria brassisicola*. Previously, Kačergius et al. (2005) in one of their studies on rapeseed (from Lithuania) reported the occurrence of *Aspergillus niger*, *A clavatus*, *A. vesicolor*, *Fusarium oxysporum*, *F. avenaceum*, *Penicillium expansum*, *P. palitans*, *P. roquefortii*, *P. viridicatum*, *Alternaria alternata*, and *Rhizo-mucor pusillus*. Mycotoxins producing fungal species were identified to belong to *Alternaria brassicae*, *A. pluriseptata*, *Chrysosporium merdarium*, *Fusarium solani*, other *Fusarium* spp., and *Penicillium expansum*. Additionally, Brazauskienė, Petraitienė, and Mankevičienė (2006) studied the effects of environmental contusions on fungal contamination and mycotoxin production in rapeseed (from Lithuania). From their study, seed samples of all winter rape cultivars showed presence of *Cladosporium*, *Alternaria*, *Penicillium* and *Fusarium* as the dominant fungi. Furthermore, deoxynivalenol was detected in separate cultivars which ranged between 164 and 183 μg/kg seeds. Whereas, in the seed of cultivars 'Alaska' and 'Triangle', aflatoxins level ranged between 1.0 μg/kg and 3.1 μg/kg, respectively.

Apart from rapeseed oil, there is closely related canola seed oil. The canola seed edible oil has low levels of saturated fatty acids, including that of erucic acid (<2%, which is a mono-unsaturated omega-9 fatty acid). However, canola oil contains ample amount of omega-3 and omega-6 fatty acids. The canola plant was originally bred by researchers from Canada and is closely related to the original rapeseed plant, but is with a varietal difference. Of late, canola oil has gained popularity world over and is consistently being used as a cooking oil as well a source of biodiesel. Lin et al. (2013) have excellently reviewed various health benefits imparted by canola oil, based on the available scientific evidence. The authors have stated that canola seed oils consumption can lead to considerable decrease in the total blood cholesterol, enhance tocopherol levels and increase sensitivity towards insulin. However, scientific reports available on mycotoxins contamination directly in the canola crude or refined oils are scarce (though presence of *Alternaria* sp., *Peronospora parasitica* are known to inhabit the seeds during pre-harvest or on farm levels).

2.10. Sesame seed

Sesame (*Sesamum indicum* L.), an important oilseed is widely grown in Asia and African sub-continents. The oil is primarily used for cooking/culinary purposes. Moreover, sesame oil finds extensive use in salads and during manufacturing of margarine. The oil seed cake is considered as a nutritious feed for animals.

Various toxigenic fungi are reported to be associated with sesame seeds. Some of these include *Aspergillus niger*, *A. flavus*, *A. ochraceus*, *A. tamarii*, *Penicillium citrinum*, *Fusarium* spp. and *Alternaria* species. Li et al. (2009) detected Aflatoxin B1 to be present at levels of up to 20.45 μg/kg in 37 out of 100 in sesame paste samples. On artificial inoculation with *A. flavus* on 2 species of sesamum (*Sesamum indicum* Link, and *Sesamum radiatum* Schumach) (incubation period of 10 and 15 days) the samples were devoid of aflatoxins (Mbah & Akueshi, 2009). However, *S. indicum* inoculated samples with incubation period of 20 days showed presence of aflatoxin B1 (estimated to be 25 ppb). Further, seeds of *S. rediatum* inoculated with the same test fungus and incubation time were devoid of aflatoxins. These authors opined that seeds of sesame, which usually appear uninfected, might pose serious health risks on consumption, if contaminated.

2.11. Rice bran

The edible oil extracted from the inner husk and germ of rice (*Oryza sativa* L.) is referred to as 'rice bran oil.' This oil is widely popular in China, India, and Japan, and is believed to make food tastier and impart a unique flavour. The use of rice bran oil is recommended for deep-frying and stir-frying. Of late, rice bran oil is gaining popularity for its potential health benefits, as it encompasses ample amounts of oleic, linoleic and palmitic acids.

Reports are available wherein rice seeds are reported to be contaminated by toxigenic molds (Sempere Ferre, 2016). Rice bran obtained from raw rice and parboiled rice is reported to be contaminated by various toxigenic molds as well as by aflatoxins (Jayaraman & Kalyanasundaram, 2009). The residual bran obtained after oil extraction is regularly used as a cattle feed. However, this has been observed to contain substantial amounts of aflatoxin, thus raising serious safety concerns. Jayaraman and Kalyanasundaram (2009) investigated aflatoxins contamination in rice bran oil and de-oiled bran samples. In addition, mycoflora in crude and refined rice bran oil and de-oiled bran collected from mills and local market places in India were also investigated. Accordingly, presence of various types of toxin producing fungi in the rice bran oil and de-oiled bran samples were ascertained, which included *Aspergillus niger*, *A. flavus*, *A. candidus*, *A. glaucus*, *A. nidulans*, *A. fumigatus*, *Penicillium* spp. and *Gliocladium viride*. Additionally, 15 crude rice bran oil and 6 refined rice bran oil samples were found to be positive for aflatoxin B1, which was as higher as 956 ppb and averaged 618 ppb (sampling done out of 20 crude and refined rice bran oil samples). Furthermore, de-oiled bran (20 samples) was recorded for the presence of aflatoxins, level of which ranged between 7 and 144 ppb.

Of late, as rice bran oil is gaining high popularity owing to presence of health promoting bioactive compounds, it is recommended that future research works be initiated towards the management and minimizing the risks of fungal and mycotoxins contamination, for the benefit of consumers.

2.12. Olives

Olives (*Olea europaea* L.) are an important foreign exchequer in the growing regions of the world like California, Turkey, Spain,

Greece, Italy and Morocco (Zinedine & Mañes, 2009). After harvesting, olive fruits require proper processing (like fermentation) to reduce bitter taste (due to 'oleropein'). Processing renders them suitable for human consumption. Olives (both black and green) are considered to be an vital part in human diet and consumed along with bread, as an appetizer for dinner, or as an ingredient in salads and baked foods (Heperkan, 2013; Heperkan, Dazkır, Kansu, & Güler, 2009). Owing to rich nutritional and health promoting effects imparted in humans, today virgin olive oil has become the most preferred one. This oil obtained by the mechanical pressing of whole fruit, contains high amount of monounsaturated fatty acid, tocopherols, phytosterols, carotenoids, squalene, etc. Oil content in the seeds approximately varies between 2—and 4 g/100 g. Olive seed oil encompasses high amounts of campesterol, total 4-desmethylsterols, sitosterol, and others (Ghanbari, Anwar, Alkharfy, Gilani, & Saari, 2012).

Occurrence of microbial contamination during the post-harvest stages and prior to fermentation processes in olives is known. Reports available indicate olives to support the growth of molds and mycotoxins production (Roussos et al., 2006). Among the various types of molds, species of *Aspergillus* and *Penicillium* have been reported to contaminate olives at a higher rate and produce mycotoxins, especially throughout drying and storage periods (El Adlouni, Tozlovanu, Naman, Faid, & Pfohl-Leszkowicz, 2006). Moreover, natural occurrence of aflatoxin B1 and ochratoxin-A in Mediterranean virgin olive oil is also reported (Ferracane et al., 2007).

Olive oil, a major product of pressed whole olive fruits are consumed in the crude form. Previously, during olive oil production campaigns in Morocco, strains of *A. flavus* and *A. niger* was isolated from the spoiled olives and olive cake (Roussos et al., 2006). The authors reported the existence of aflatoxin B1 and ochratoxin-A in the samples. Additionally, various mycotoxins such as aflatoxin B1, ochratoxin-A, citrinin, alternariol, alternariol methyl ether, altenuene, tenuazonic acid present at different concentration levels is reported in olive oil obtained from different regions.

From the available reports, it is evident that still a wide gap persists towards identifying the actual stage wherein olive fruit or their oil might get contaminated by toxigenic molds and their mycotoxin. Additional works relevant to management strategies is also necessity.

2.13. Tree nuts

Tree nuts like almond, cashew nut, chestnut, hazelnut, macadamia, pistachio, walnut and their products are eaten as a part of healthy snack food or are used as an ingredient of certain dishes in majority of the countries world over. Generally, fungal contamination of different kinds of tree nuts might occur during preharvest or during postharvest storage. During pre-harvest stages, when the nuts have ripened with opened hulls, they are often contaminated either by airborne or insect-borne (as vectors) spores of fungi. During post-harvest stages, the fungal contamination might occur after de-hulling, washing of nuts and also during sorted. Here, the water used can be a potential source of contamination, and if the nuts are allowed to remain wet, there are high possibilities of becoming susceptible to molds growth and mycotoxins contamination. Additionally, the storage conditions employed with adverse temperature and relative humidity fluctuation can result in mold growth.

Species of *Aspergillus*, *Penicillium* and *Fusarium* in kolanuts (used in pharmaceuticals and for flavoring soft drinks) used in the preparation of 'choca-cola' and wine from Nigeria is documented. Various fungal species has been reported (Lugauskas, Raudoniene, & Sevistyte, 2005) to inhabit tree nuts (cashew nuts, pistachios, almonds, hazel nuts, walnuts, almonds, and Brazil nuts). Presence of aflatoxins in pistachios (from Spain) is documented (Burdaspal, Legarda, & Iñigo, 2005). Some of the fungi isolated included the species of *Aspergillus*, *Penicillium*, *Rhizopus*, *Mucor*, *Mycelia sterilia* and *Geotrichum*. Occurrence of aflatoxins in pistachio nuts obtained from Isfahan province, Iran is reported (Pour, Rasti, Zhigamian, & Garmakhani, 2010). Further, presence of aflatoxin in nuts and commercial 'nutty products' from Malaysia and South Korea is also reported (Chun, Kim, Ok, Hwang, & Chung, 2007; Leong, Ismail, Latif, & Ahmad, 2010).

Investigations on the occurrence of 14 types of mycotoxins in 83 tiger-nut samples from various local markets from Spain (Valencia community) revealed the presence of aflatoxins, deoxynivalenol, ochratoxin-A and beauvericin in 26 samples (Rubert, Soler, & Mañes, 2012). Baquião et al. (2012) have reported contamination by various fungi and mycotoxins in nuts, shells and pods from Brazil nuts gathered during various time intervals in Brazil (Itacoatiara region). Their results showed the contaminant fungi to be dominated by *A. flavus* in fruit pods and nuts, and by *Fusarium* spp. in shells. Further, all the samples analysed were devoid of aflatoxins and cyclopiazonic acid. These researchers have opined contamination to occur prior to drying as well the soil condition to be major sources of fungal contamination in Brazil nuts. Ochratoxin-A contamination ranging from 1.87 to 890 ng/g in pistachio has been reported in market samples from United States (Palumbo, O'Keeffe, Ho, & Santillan, 2015). The contamination of nuts, shell, dried fruits and dates by toxins is reported to be 50, 80, 35.7 and 83.3%, respectively in samples collected from Valencia (Spain). Enniatin-A (ENA) in nuts was 45.2%, while Enniatin-B (ENB) in dates was 58.3% (Tolosa, Font, Mañes, & Ferrer, 2013). Presence of toxigenic molds such as *A. flavus* (74.4%), *A. nomius* (12.7%) in Brazil nuts is reported (Reis, Baquião, Atayde, Grabarz, & Corrêa, 2014). Results of this study also revealed 80% of the *A. flavus* to be mycotoxin producers with 14.3% producing aflatoxin-B, 22.85% producing cyclopiazonic acid (CPA), and 42.85% contributing to both of these toxins. The authors opined that the origin, processing methods adopted as well as the transport and storage conditions to significantly influence the occurrence of molds in the nuts. Recently, use of microwave dielectric heating as a mode of disinfestation process of contaminated Brazil nut seeds revealed that colonization in the internal part of the shell and on the kernel to be decreased by 61.67% and 81.75%, respectively without altering the organoleptic properties (da Silva et al., 2016). The European Food Safety authority (EFSA, 2009) has issued a notification highlighting increase in levels for total aflatoxins from 4 μg/kg to 10 μg/kg for tree nuts other than almond, hazelnuts and pistachios (http://ec.europa.eu/food/safety/chemical_safety/contaminants/catalogue/aflatoxins_en.htm; assessed on June 30, 2016). From the available reports, it is clear that various toxigenic fungi can contaminate tree nuts. However, reports on the studies relevant to their presence in oil and their management strategies recommended are scarce. Hence, this gap needs to be filled-in.

3. Oil seed cake and mycotoxins

Oilseed cake, which is the dense residue remaining post seed pressing and extraction of oil, is a valuable protein rich product used as a feed for livestock. Generally, these residues are fed to animals, either singly or in combination with the other oil cake obtained from others seeds (e.g. soybean mixed with sunflower or rapeseed or vice versa). This oilcake can get contaminated by various toxigenic fungi either during short- or long-term storage periods. Some of the pathogenic fungal strains reported belong to *Aspergillus*, *Fusarium*, *Monascus*, and *Penicillium*, which are all capable of producing mycotoxins (such as aflatoxin B1, alternariol,

fumonisin B1, ochratoxin A, T-toxin and zearalenone) (Garon et al., 2006). Lanier et al. (2009) conducted a survey to study the molds incidence and for the presence of mycotoxins (aflatoxin B1, alternariol, fumonisin B1, gliotoxin, ochratoxin A, T-2 toxin, and zearalenone) in oil seed cake stored for up to 5 months in farm. The sample material of oil seed cake consisted of pellets of an oleaginous mixture (70% rapeseeds, 15% soybeans, and 15% sunflower seeds). From their study, 34 fungal species could be isolated among which *A. fumigatus*, *A. repens*, *Alternaria* and *Cladosporium* spp. were the toxigenic fungi. Between the seven mycotoxins under evaluation, only gliotoxin was found at concentration levels varying between 5 and 45 μg/kg since the first month of monitoring. The presence of this toxin was attributed to contamination of oilseed cakes with *A. fumigatus*. From their results, it was concluded that the presence of toxigenic fungal isolates (of *A. fumigatus* and gliotoxin) in oilseed cakes should be monitored regularly during storage. Detailed investigations pertaining towards mycotoxins in oil seed cake used as livestock still remains scarce. Future research work needs to be initiated to explore the fungal contaminants in oil cake obtained from each of the individual plant seeds, plan their management strategies, and study various mechanisms involved under *in vivo* conditions along with evaluating possible health effects on entry into the human food chain. Additionally, it is more likely that during the oil extraction process, majority of mycotoxins in contaminated oil seeds might get partitioned into the seed cake rather than directly into the oil. However, very little information exists on these aspects and further detailed studies are warranted.

4. Fate of mycotoxins during oil extraction and refining

Several reports are available on the reduction of mycotoxins after employing conventional food processing techniques. The effect of thermal processing, extrusion cooking, milling, and brewing is shown to reduce the mycotoxins levels in various agricultural commodities (Bhat et al., 2010; Kabak, 2009; Park & Kim, 2006). However, very few reports are available on the fate of mycotoxins during oil extraction from seeds and its refining process. Hence, only a few of the reports are discussed in the preceding text.

In one of the studies by Kumar et al. (2008), the crude oil extracted from contaminated rice bran had considerable amount of aflatoxins, but on refining, the oil was free of toxin. In another study, Jayaraman and Kalyanasundaram (2009) tested aflatoxin levels in crude oil and refined oil collected from different markets in India. From their results, high aflatoxin levels were recorded in crude oil compared to refined oil which were either in trace or were not detectable.

Additionally, during 1990's reduction of aflatoxin levels during the oil refining process is documented in the available database in sesame, corn germ and olive oils, including those of good quality/highly ranked edible oils (up to 2000 ppb) (Isohata, Toyoda, & Saito, 1996). Contrastingly, Kamimura et al. (1986) in one of their studies, supplemented deoxynivalenol (DON), nivalenol (NIV) and zearalenone (ZEA) into crude corn germ oil and could not detect these mycotoxins after refinement process. Moreover, Schollenberger, Müller, Rüfle, and Drochner (2008) had analysed various fusarium mycotoxins in non-refined (61 no.) and refined (49 no.) oils including sunflower, soybean, corn germ, olive, rapeseed, safflower, peanut, walnut, sesame and linseed marketed in Germany. Based on the results, they reported 13 non-refined and 10 refined samples to be positive for at least one of the mycotoxins. The average mean and maximal level of six mycotoxins was recorded to be much higher in non-refined oils when matched with refined oil. In the non-refined corn germ oil, mean concentration of DAS, HT-2, T-2, DON, 15-ADON and ZEA was recorded to be 0, 4, 7, 48, 44, and 1375 μg/kg, respectively. Whereas in case of refined oil the corresponding level/values was recorded to be 12, 0, 5, 0, 3 and 70 μg/kg.

Generally, products of unrefined oil are devoid of application of heat during pressing process and are extracted mainly by mechanical process. This oil type is either washed, filtered or centrifuged without opting for any type of additional refining treatments (such as alkali refinement, bleaching and deodorization). The reduction of mycotoxins in refined oils can be attributed to various refinement processes employed. Through the refinement process of edible oil, the alkali refinement and deodorization processes are undertaken. In addition, in certain cases, bleaching or filtering processes are also accompanied. These processes are employed mainly for removal of impurities in the oils as well as to enhance the storage shelf life.

5. Conclusions

Based on the available reports, it is a well-established fact that commercial oil yielding seeds and their edible oils can get contaminated by various toxigenic fungi and mycotoxins, both during pre- and postharvest stages. Additionally, the by-product in the form of oil cake obtained after oil extraction (commonly used as an animal feed), can be contaminated by fungi and their toxins.

As of today, there are still major gaps that exist with regard to the various research aspects relevant to toxigenic molds and mycotoxins in oil seeds and in vegetable oil. In the majority of the cases, the available reports indicate the identification of fungi only up to the genus level. Hence, it is vital that the mycotoxins-producing species and the particular strain is authentically identified by adopting recently developed techniques (like PCR-based techniques, laser bio-speckle technique, apta-sensor, immune-sensors, enzymatic-sensors, and others), and by the development of new fungal selective agar media for the isolation of toxigenic fungal strains only. There are many other underutilized oils of seed origin (edible or non-edible) where research works initiated on mycotoxins are scare or remains unreported. Some of these include cashew nut oil, palm oil, macadamia oil, marula oil, pine nut oil, castor seed oil, grape seed oil, and others.

Adopting internationally recommended harvest procedures at farm levels by implementing hazard analysis and critical control point (HACCP) procedures as well as adopting good agriculture and good manufacturing practices (GAP and GMP) might significantly reduce the mycotoxins contamination in fresh produce. The 'European Guide to Good Hygiene Practices' provides more details on the handling procedures for oils (http://ec.europa.eu/food/safety/docs/animal-feed-guides-good-practice-gdbp_hygiene_en.pdf; asses date 30 June 2016). Some of the important criteria to be practiced at the farm level include: time of harvesting (early harvesting is recommended), handling of produce without injury, drying to acceptable moisture and water activity levels, proper transportation and premarketing storage to prevent damp storage abuse, and minimizing insect infestation. Practical implementation of these might significantly reduce fungal occurrence and mycotoxins contamination in oil seeds. Further research is warranted to explore the possibilities of inactivating toxigenic molds in oil seeds, their oils, and in oil cake in an environmental friendly way, by employing physical methods (like ultrasound, irradiation, pulse electric field), by using natural botanicals (herbs) or via microorganisms (yeasts like *Candida tropicalis*, *Torula sporadelbruckii*, *Zygosaccharomyces rouxi*, and *Saccharomyces* species that can degrade mycotoxins). These modes of treatment can help with minimal dependence on chemicals. Even though organic farming has been widely popularized as an alternative for chemicals (fungicides), its reports are obscure and, still, occurrence of

these toxigenic molds is seen and mycotoxins in oil seed have been identified. Development of rapid low-cost detection techniques for the presence of toxigenic fungi and mycotoxins in a commodity, especially at the market entry point, might further help to minimize the contamination and spread of fungal propagates.

Breeding disease-resistant oil seed plants can be an alternative for prevention of fungal contamination at the field/farm level. However, it needs to be considered over here that majority of the investigations undertaken are under *in vitro* conditions and, hence, future studies should be initiated by imitating or providing same environmental conditions as found at the farm level (e.g. varying temperature, humidity, etc), which can help to know the exact stage of mycotoxins production. Developing a suitable working model from this is expected to find a good practical applicability for minimizing fungal growth and mycotoxins in oil seeds and their oil. Recent reports have indicated 'Surface Active Maghemite Nanoparticles' to be a stable and a good magnetic nano-carrier for mycotoxins removal, the potential of which can be tapped by the food industries (Magro et al., 2016).

Livestock reared for meat can be potential carriers of mycotoxins into the human food chain, especially when they feed on oil cake residues contaminated with mycotoxins. To minimize this and the risk of mycotoxicosis in animals, suitable adsorbents (like alumino-silicates) could be mixed with the feed, which can bind to mycotoxins more competently inside the animals' gastro-intestinal tract. However, efficacy of mycotoxins binders might differ significantly and can depend on chemical configuration of the adsorbent as well as the toxin. Heating is opined to reduce fungal contaminants (or mycotoxins up to certain extent) in oils; however, consumers should note that prolonged heating might lead to the production of free radicals and other degradation compounds posing serious health risks.

There are several innovative methods being proposed for detection of various mycotoxins, which can be applicable for oil yielding seeds or their products [such as attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR), enzyme-linked immunosorbent assay (ELISA), liquid chromatography-tandem mass spectrometry (LC–MS/MS) via a multiple antibody immune-affinity column, suspension array technology, etc]. Use of these modern techniques can be of much help to identify the presence of mycotoxins in a commodity.

Educating consumers, training and creating public awareness relevant to the presence of toxigenic fungi and mycotoxins (in oil seeds and edible oil) and implementation of proposed plans (put forth by various governing bodies) at the farm level is a necessity especially in the tropical and subtropical regions. Those farmers who are indulged in mono-cropping system needs to be educated more on the occurrence of fungal contamination as well as mycotoxin contamination, and how they can affect the quality, safety and marketability of the produce. Impact of changing climatic conditions and other relevant sustainability issues needs to be addressed along the entire production and supply chain of both oil seeds and their extracted oil. Practicing of food safety ethics along the entire food production, management, supply and marketing chain needs to be accomplished by all of the personnel involved. Finally, apart from the popular and widely studied oil yielding seeds used for culinary purposes, there are several other underutilized seeds and their oil, which have been used traditionally for cooking purposes in selected regions of the world. This merits investigation in the near future.

Conflict of interest

The authors declare that 'NO Conflict of interest' exist in this review.

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