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Contamination of Rice Grains with Mycotoxins (Review)

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Abstract:

Cereal grains hold significant importance globally due to their essential role in food security. They are a primary source of calories and protein for the humanity (Molina, 2011). Among these grains, rice stands out as a staple food for half of the world's population, ranking second after wheat in terms of yield and cultivated area (FAO, 2022). Notably, 90% of rice production and consumption occurs in Asia (Agro & Economic, 2007). Consequently, any biological or chemical contamination of these grains poses a hunge risk of people lives. Mycotoxins are the most concerning contaminants. According to a survey study, 25% of the world's crops, including nuts, grains, and rice, are contaminated with fungi (Pandya & Arade, 2016).

Keywords: Rice, Mycotoxins, Contamination, Fungi, Aflatoxins, Ochratoxin .

تلوث حبوب الارز بالسموم الفطرية (مراجعة)

سلام نصيف جاسم ، سمية نعيمة حوار
جامعة بغداد / كلية التربية للعلوم الصرفة / ابن الهيثم ، قسم علوم الحياة.

مستخلص

تحظى الحبوب الغذائية بأهمية بالغة في العالم وذلك لارتباطها بالأمن الغذائي للشعوب ؛ اذ توفر هذه الحبوب ومنتجاتها السعرات الحرارية للجنس البشري و امداده بالبروتينات (Molina, 2011). ومن اهم تلك الحبوب هو الرز، اذ يعتبر غذاء اساسي لنصف سكان العالم ، فهو يحتل المرتبة الثانية بعد القمح من حيث الانتاج والمساحة المزروعة في العالم (FAO,2022)، حيث ان ٪90 من انتاج واستهلاك الرز في العالم يحدث في اسيا (Agro and Econamic,2007). وبالتالي فان اي تلوث بايلوجي أو كيمائي لهذه الحبوب يشكل خطر كبير على حياة ملايين من البشر، ومن اكثر هذه الملوثات هاجس هي السموم الفطرية، فوفقاً لدراسة استقصائية، فإن ٪25 من محاصيل العالم، بما فيها المكسرات والحبوب والأرز، هي ملوثة بالفطريات (Pandya and Arade, 2016).

الكلمات المفتاحية: الرز ، السموم الفطرية ، تلوث ، الفطريات ، الافلاتوكسين ، الاوكراتوكسين .

Rice (Oryza sativa L.)

Rice (Oryza et al.) is one of the most important cereal crops worldwide. It serves as the primary food source for half of the global population, particularly for the Far East peoples (Ghazi, 1974). Ranking third after wheat and barley, rice is cultivated in Asia, the Americas, Australia, Africa, and Europe (Motlagh, 2011). It is believed that rice originated from Southeast Asia (India, Vietnam, Burma), with its cultivation prevalent in India and China for over 5,000 years. Historical documents suggest that rice cultivation was known in Babylon as early as 400 years BC (Younis, 1993), and it is likely that its cultivation in Iraq dates back at least 2,000 years, as the word "rice" appears in manuscripts from the Seleucid period around 300 years BC (Ghazi, 1974). Production was not strong enough for the local markets, which led the government to work on an encouraging policy by supporting rice prices due to the population increase and the stability of the local domestic product and to meet the local need for rice (Al-Wasiti and Fatima,2023).

International and local rice varieties

There are thousands of varieties of rice around the world. All cultivated rice varieties belong two species: *Oryza sativa* and *Oryza glaberima*. *O.sativa* has most varietiesin the world and divided into two main groups: India Group and Japonica Group.

India Group is grown in Pakistan, Ceylon, Thailand, Iran, and the United States of America. Japonica Group is grown in Spain, Egypt, Italy, China, Australia, and Iraq. These two groups are differ clearly in morphological and agronomic traits, in physiological and biochemical characteristics ,in their genomic structure and proteins (Yang *et al*., 2014). The common varieties in the central and southern regions in Iraq include: Al-Amber Al-Khadrawi, Al-Naima, Al-Mawlani, Al-Ahmar, and Al-Hawaizawi. While, Al-Nakaza is one of the most prominent varieties in the northern regions is of Iraq, belonging to the type O. glaberrima (Al-Ansari, 1980). The production of one dunum ranges between 400-600 kg and one ton according to the sowing method and seedlings, respectively (Al-Ansari, 1980).

Rice Planting Timing

Within the context of the environmental conditions suitable for rice cultivation, it is established that rice is a crop for warm countries, requiring hot and humid weather (Ghazi, 1974). The timing for planting rice depends on climatic conditions, planting methods, and regional variances. In Iraq's central and southern regions, the Amber variety is typically planted at the beginning of June, while the Naima kind is planted towards the end of April. Conversely, in the northern region of Iraq, the Bazian kind is sown in the latter half of April. It is worth noting that the kinds planted in the central and southern areas (primarily Najaf, Qadisiyah, Maysan, and Dhi Qar) and the northern areas (Sulaymaniyah, Nineveh, Dohuk) of Iraq include Indian types such as Amber and Naima, as well as Japanese types like. Nikaza and Bazian, respectively (Younis, 1993). MohammadAli et al (2024) stated that harvest date has a significant impact on crop productivity.

The Global and Local Production of Rice

The global production of rice is predominantly concentrated in the Far East, especially within the humid tropical regions of Asia, where it is estimated that Asia's rice production accounts for approximately 90% of the global output. Rice is also cultivated in other parts of the world, including the United States of America, Australia, Greece, Egypt, Italy, and Spain (Younis, 1993). The annual global production of rice is estimated to be around 700 million tons (FAO, 2018), ranking it second only to wheat in terms of cultivated areas worldwide (Ansari, 1980). Thailand is recognized as one of the world's largest rice-exporting countries, with an export ratio of 70% (Agro and Economic, 2007). In Iraq, the provinces of Najaf, Qadisiyah, Maysan, and Dhi Qar lead in terms of cultivated area and production (Younis, 1993). China and India are the largest rice-producing countries, with productions of 148.5 and 116.4 million tons, respectively, in the 2018/2019 period (Shahbandeh, 2020). In Iraq, the consumed rice is either imported or locally produced, with the two main local varieties being Anber and Yassamine, cultivated in the provinces of Najaf, Diwaniyah, and Babylon. The local rice production quantities in 2015, 2016, and 2017 were 200,000, 43,000, and 100,000 tons, respectively (Alhendi *et al.*, 2019).

The Economic Significance of Rice

Rice serves as a staple food for 50% of the world's population, especially among the people of tropical and subtropical countries. The rice seeds contain 9-12% protein and 65-70% starch, along with 4-6% oil, making it a significant source of nutrition and an essential commodity with various industrial applications. Beyond its dietary importance, rice has utilitarian roles in medicine, the production of cosmetics, textile industries, and even in manufacturing specific types of cigarette paper, cardboard, hats, threads, and baskets. Furthermore, it is used to produce soap, candles, and synthetic organic fertilizers. The straw and broken grains of rice are also employed as animal feed. Rice flour is used in manufacturing baby foods and biscuits, highlighting its versatile role in the food industry and beyond (Younis *et al*., 1987).

Nutritional Value of Rice

Milled rice grains contain 9.8% protein and 88.95% soluble carbohydrates, with 90-94% being starch. They also have a minimal crude fiber content of 0.3% and mineral matter of 0.6%. Vitamins A, C, and D are present in very small quantities. Certain rice varieties may also contain distinctive flavors, as found in the Iraqi Anber variety (Younis *et al*., 1987).

Rice Milling Processes

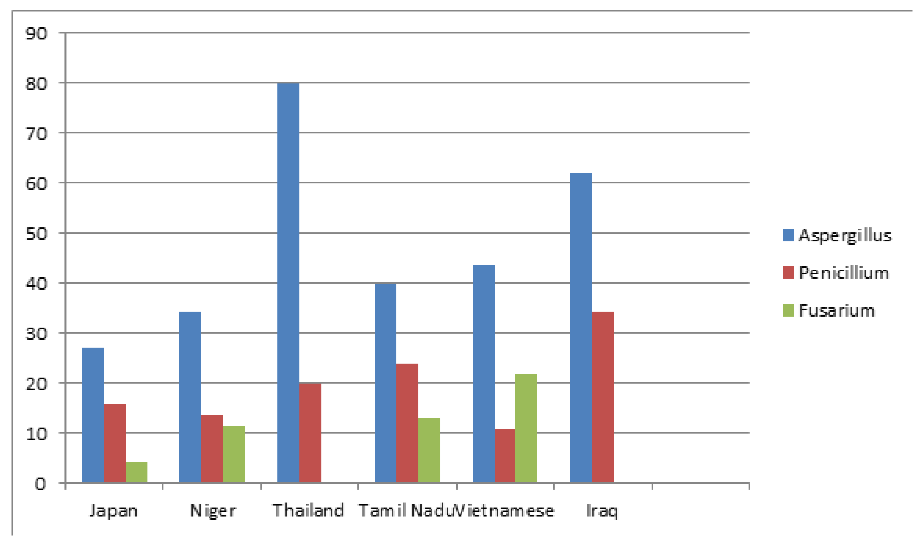
The rice grain is enveloped in an outer husk that protects the seed and its germ from external factors. Following the husk is the pericarp, commonly known as the bran, which consists of two layers rich in oils, proteins, minerals, and vitamins. Subsequently, there is a lighter-colored layer called the polish. These coverings are removed because they are hard and indigestible by humans. The preparation of raw rice (paddy) for human consumption involves the following processes: cleaning, hulling, whitening, polishing, and grading, collectively known as rice milling processes (Younis *et al*., 1987).

Rice Storage

The optimal method for storing rice is in safe plastic containers and Mylar bags (Connor, 2008), along with the use of food-safe oxygen absorbers (Bjs; Briefing, 2008) to maintain the quality of the rice and protect it from fungal and insect infestations. The preferred temperature for storing rice is 40 degrees Fahrenheit or lower. Well-polished white rice can be stored for 25 to 30 years; however, once opened, it should be used within one to two years (Kansas, 2008).

Rice Contamination by Fungi

Rice grains, due to their high moisture content, are susceptible to fungal invasion in the field and storage, leading to the production of mycotoxins (Reddy *et al*., 2008). The harmful effects of fungal invasion on rice grains include discoloration, loss of vitality and quality, and contamination with toxins. Most of the fungi that produce mycotoxins and are capable of infecting rice belong to the genera Aspergillus, Penicillium, Fusarium (Lee & Ryu, 2015), and Alternaria (Pitt *et al*., 1994), which are commonly found in rice. Reddy (2008) found that 1200 rice samples (675 paddies and 525 milled) collected from 43 locations across 20 states in India were all contaminated with *Aspergillus* sp. The prevalence of the *Aspergillus* genus in rice samples from countries in East Asia, South America, and South Africa is attributed to high temperatures and dry conditions (Lee & Magan, 2000), as well as the high moisture content of rice grains during harvesting and storage (Reddy *et al*., 2008). The presence of rice weevil (Choudhury *et al*., 1999), insects, and rodents in rice storage areas also contributes to the problem. *Curvularia tuberculata* growth was recorded in July and November on rice (Jaaz & Al-Shibli ,2017). Al-Hindi et al,(2023) evaluated the microbial quality of paddy fields in Iraq, revealing elevated microbial levels in both irrigation water and paddy samples. Additionally, rice samples surpassed established limits, indicating irrigation water as a primary source of contamination and emphasizing the necessity for implementing control measures.



Percentages of contamination of rice grains with the three genera in some countries

KOBAYASHI, 2019, Makun *et al*., 2007, Lautetal. 2023, Sundaram *et al*., 1988, Trung and colleagues, 2001, and Al-Himyari, 2020).

The moisture content, level of infestation by storage pests, and storage conditions, particularly in developing countries, contribute to the increase in contamination levels by toxic fungi and their mycotoxins. This, in turn, severely affects the final quality of rice and its products, impacting food safety (Reddy *et al*., 2007).

Table(1) of fungi contaminating rice

	type of rice	Country	Reference
Alternaria alternata ,Arthrium spp , Aspergillius clavatus , A. flavus , A. fumigatus , A. glaucus ,A. niger ,A. ochraceus , A. parasiticus , A. terreus , A. versicolor , Bipolaris spp , Cladosporium spp , Cladosporium werneckil , Cryptococcus neoforman , Curvularia lunata , Fusarium spp , F. oxysporium , F. semitectum ,F. solani , F. verticillioides , Geotrichum candidum ,Grilocladium spp , Helminthosporium spp , Mucor spp , Nocardia brasiliensis , Penicillium spp , P. citrium , P. cyclopium , P.exapnsium , P. viridicatum , Rhizopus spp , Rhodotorula rubra , Syncephalastrum spp and Trichoderma spp.	rice collected from fields, markets, and store	Niger State	Makun et al., 2007
Aspergillus spp, Aspergillus flavus, A. niger, A. ochraceus, A.candidus, Fusarium spp., Penicillium spp. and Curvularia spp.	Local and imported rice	Iraq	Al-Hemyari,2020
Fusarium, Alternaria, Penicillium, Rhizopus, and Aspergillus	Rice	South Korea	Ok et al., 2014
F. proliferatum, A. flavus, Fusarium spp., Penicillium spp., F. oxysporum, F. equiseti, F. culmorum, F. solani, F. graminearum, A. carbonarius, A. oryzae, and A. niger. F. proliferatum	Vietnamese rice chain	Mekong Delta, Vietnam.	Phan et al.,2021

	type of rice	Country	Reference
A. flavus, A. fumigatus, A. sydowii, A. terreus, A. ochraceus, Alternaria tenuis, F. oxysporum, P. chrysogenum	Paddy	Egypt	Hafez et al. (2004).
A. flavus	Polished	China	Jayaraman and Kalyanasundaram (1990)
A. flavus, A. fumigatus, A. nidulans, A. niger, F. oxysporum, P. citrinum	Milled	India	Chary and Reddy (1987). Reddy et al. (2009)
P. islandicum	Stored	Japan	Sakai et al. (2005)
A. candidus, P. citrinum, F. proliferatum	Polished	Korea	Park et al. (2005)
A. candidus, A. flavus, A. fumigatus, A. niger, A. versicolor, P. citrinum	Milled	Malaysia	Kumar et al. (2008), Salleh and Farhana (2009),
F. fujikuroi, F. graminearum, F. semitectum, F. oxysporum	--------------------------	Nepal	Desjardins et al. (2000)
Alternaria, Aspergillus, Curvularia, Fusarium, Penicillium	-----------------------	Nigeria	Makun et al. (2007)
A. flavus, A. niger, F. semitectum	Harvested	Northern Argentina and southern Paraguay	Tonon et al. (1997).
Aspergillus spp., Penicillium spp.	Parboiled	Sri Lanka	Bandara et al. (1991)
A. candidus, A. flavus, A. niger, E. rubrum, P. citrinum, Talaromyces spp.	Milled	Uganda	Taligoola et al. (2004)
A. flavus, A. fumigatus, A. oryzae, A. candidus, A. niger, A. glaucus, Fusarium spp., P. citrinum, P. islandicum	--------------------	Vietnam	Trung et al. (2001)

	type of rice	Country	Reference
Absidia spp. , Alternaria spp., A. aureolatus , A. candidus , A. clavatus , A. fumigatus , A. chevalieri (Eurotium chevalieri) , A. glaucus (Eurotium herbariorum) , A. montevidensis (Eurotium amstelodami) , A. nidulans (Emericella nidulans) , A. penicillioides , A. pseudoglaucus (Eurotium repens) , A. restrictus , A. ruber (Eurotium rubrum) , A. section Flavi , A. terreus , A. wentii , Aspergillus spp. , Bipolaris spp. , Chaetonium spp. , Chrysonilia crassa , Cladosporium spp. , Colletrotrichum spp. , Curvularia spp. , Fusarium spp. , Mucor spp. , Nigrospora oryzae, Penicillium aethiopicum, P. chrysogenum , P. charlesii, P. cinnamopurpureum, P. citrinum, P. expansum, P. hispanicum, P. islandicum, P. paxilli, P. vancouverense, Penicillium spp. , Pestalotiopsis spp. , Phoma spp. , Rhizopus spp. , Syncephalastrum racemosum, Trichoderma spp. , Dematiaceous fungi, Yeasts, and Filamentous yeast	dryland rice paddy rice,) husked rice, broken rice, brown, polished, parboiled and red (rice	Brazil	Katsurayama et al., 2020
Alternaria spp, candidus , A. clavatus , A. chevalieri (Eurotium chevalieri) , A. glaucus (Eurotium herbariorum) , A. montevidense (Eurotium amstelodami) , A. penicillioides , A. pseudoglaucus (Eurotium repens) , A. restrictus , A. ruber (Eurotium rubrum) , A. sydowii , A. terreus , A. ustus , A. versicolor , A. westerdijkiae , A. section Nigri , Aspergillus spp. , Bipolaris spp. , Curvularia spp. , Fusarium spp. , Monascus ruber , Nigrospora oryzae , Penicillium citrinum , P. paxilii , Penicillium spp. , Phoma spp. , Syncephalastrum racemosum , Dematiaceous fungi and Hyphomycetes	rice samples from São Paulo (SP) markets. (paddy rice, husked rice, broken rice, brown, polished, parboiled and red rice)	Brazil	Katsurayama et al., 2020

Rice Contamination by Mycotoxins

Rice grains can become contaminated with mycotoxins, which include aflatoxins, ochratoxins, fumonisins, zearalenone, trichothecenes, and deoxynivalenol. Aflatoxin B1 and ochratoxin A are the most common mycotoxins in rice extracted from these grains (Reddy *et al*., 2007). The most toxic mycotoxins to mammals are AFB1, OTA, and FB1, as they cause liver toxicity, kidney toxicity, teratogenic effects in fetuses, mutagenic activity, and liver and kidney cancer (Altuntas *et al*., 2003). The levels of mycotoxin contamination in rice grains vary from country to country, place to place, or even from one rice type to another due to differences in determining factors such as temperature, relative humidity, grain moisture content, agricultural practices, and the availability of suitable conditions for harvesting, transportation, storage, and marketing. Therefore, nations and concerned institutions strive to establish programs and regulations to minimize exposure to these toxins. Aflatoxin contamination of fish feed (Saad & Falah, 2020), foods, grains, and crops.

Aflatoxins (AF): Aflatoxins are a group of secondary metabolic byproducts that are primarily secreted by Aspergillus flavus and Aspergillus parasiticus (Oznurlu et al., 2012). They encompass four main types: B1, B2, G1, and G2 (Sargeant et al., 1961). These compounds have been classified within Group 1 of human carcinogens (IARC, 2012). the detection of aflatoxin B1 in 71 of the samples minced meat, basterma, liver and muscles were contaminated with aflatoxin ranging from 42-467 ppb, 25-442 ppb, 44-492 ppb and 242-459 ppb for respectively (Jaloud and Hassan,2018). The ozone gas was more effective in aflatoxin B1 reduction when compared with microwave (Hassan et al.,2022). In a study by Habib & Al-Obaidy, (2004) to investigate the presence of aflatoxins B1 and B2 in rice and paddy rice stored for six months, the study showed the presence of B1 at the beginning of storage in paddy rice samples and it amounted to 0.3 parts per million, and its absence in rice samples. As for aflatoxin B2 It did not appear in both samples. After six months of storage, the concentration of aflatoxin B1 (3 ppm) for unpeeled rice and 0.9 ppm in paddy, while the concentrations of aflatoxin B2 reached 0.9 ppm and 0.14 ppm in paddy and rice, respectively. The concentration of aflatoxin in rice was higher than in polished rice due to processing, which reduces the toxin (Habib and Al-Obaidy,2004). AFB1 concentrations of 10.08, 5.95, 4.27, and 7.10 ppb for buffaloes, cows, sheep, and goats, respectively(Al-Rubaye et al.,2023).

Ochratoxins are a group of toxic metabolic products produced by molds, specifically Aspergillus ochraceus and Penicillium verrucosum, and they include three types: OTA, OTB, and OTC. Ochratoxin A (OTA) is the most dangerous and significant, contaminating food and feed. It has been classified within Group 2B by the International Agency for Research on Cancer (IARC, 1993), indicating it is possibly carcinogenic to humans. The fungi producing ochratoxins include the genera Aspergillus and Penicillium (IARC,1993). In cold countries, OTA is produced by strains of Penicillium, whereas in tropical and subtropical regions, it is produced by Aspergillus (Merck, 1989). Thus, in countries with hot and dry climates, such as those in South America, South Asia, and Africa, Aspergillus species are the primary producers of OTA (Lee & Magan, 2000), while in colder regions like the United States, Canada, and Europe, Penicillium species are responsible for its production (Kuruc *et al*., 2015). These toxins target the kidneys in living organisms (Ismail, 2014) and are found in grain crops, coffee, dried fruits, and fruit juices.

Ochratoxin A (OTA) is produced by several fungi, especially Aspergillus ochraceus, Aspergillus carbonarius, Aspergillus niger, and Penicillium verrucosum (Atumo, 2020). Al-Baldawi *et al*,(2009) reported that all *A. ochraceus* isolates were producers of ochratoxin. OTA production by A. carbonarius and A. ochraceus occurs in tropical and warm countries, while in temperate regions, it is produced by P. verrucosum (Iqpal *et al*., 2013). The International Agency for Research on Cancer (IARC) has classified OTA as a possible carcinogen (Group 2B), indicating its potential to cause cancer (IARC, 2002; IARC, 1993). OTA accumulates and induces toxicity primarily in the liver, with the kidney being the primary target organ (Qi *et al*., 2015). High moisture content in products significantly increases the risk of OTA contamination. Furthermore, various environmental conditions play a crucial role in forming OTA in different foodstuffs

(Atumo, 2020). Ochratoxin A possesses genotoxic, teratogenic, hepatotoxic, immunotoxic, and carcinogenic properties in several animals, leading to liver and kidney tumors in mice and rats (Berger et al., 2003), as well as nephrotoxicity (Bansal et al., 2011). It is the primary causative agent of Balkan Endemic Nephropathy (BEN) and associated urinary tract tumors. OTA is detectable in human blood due to its long half-life (approximately 35 days in serum), resulting from its binding to plasma proteins, enterohepatic recirculation, and reabsorption from urine. This makes OTA one of human blood's most frequently detected mycotoxins worldwide (PFOHL-LESZKOWICZ and MANDERVILLE, 2007). Histopathological study showed various pathological effects of rabbit's kidneys and Nephrotoxicity treated with 0.5 mg/kg with OTA (Hassan *et al*.,2023). Histopathological changes were noticed in liver, kidney and spleen of all treated groups including: necrosis, congestion, and infiltration of inflammatory cells and vacuolation of cytoplasm (Abbas,2012).

Fumonisins

They were discovered to contaminate both brown (unhulled) and polished rice in Korea (Chung & Kim, 1995; Kim et al., 1998), as well as rice in China (Trucksess, 2000). Fumonisins cause leukoencephalomalacia (LEM) in horses, pulmonary edema in pigs, neural tube defects in laboratory animals and humans, and are associated with esophageal cancer in humans (Desjardins, 2006).

Table(2) of Mycotoxins contaminating rice

Type of Toxin	Concentration range (µg/kg)	Analysis method	Type of rice sample	Country	References
Aflatoxin B1	5–50		Polished rice	China	Zhen-zhen (1989)
	0.5-3.5		Milled rice	India	Reddy et al. (2009)
	28–960		Rice bran	India	Jayaraman and Kalyanasundaram (2009)
	0.5 - 38.5	ELISA	rice grains	India	Reddy (2008)
	Mean 1.89			Iran	Mazaheri (2009)
	20–1640			Nigeria	Makun et al. (2007)
	Mean 3.3			Vietnam	Nguyen et al. (2007)
Total aflatoxins	0.45–11.4		Long grain rice	Austria	Reiter et al. (2010).
	0.99–3.9		Dehusked, brown	China	Liu et al. (2006)
	4.4–35		Bran	Iran	Zaboli et al. (2010)
	1.4 to 10.2 µg/kg		Paddy	Iraq	Alhendi,2020
	1.1 to 8.8 µg/kg		Rice	Iraq	
	1–21		Bran	UK	Scudamore et al. (1999)
	n.d. to 2.7		Polished	Philippines	Sales and Yoshizawa (2005)
	0.14–0.24		Basmati	Qatar	Abdulkadar et al. (2004)

Type of Toxin	Concentration range (µg/kg)	Analysis method	Type of rice sample	Country	References
Ochratoxin A (OTA)	2.4 – 4 mg/Kg	Thin layer chromatography			(Pittet and Royer, 2002)
	5 µg/kg		paddy	Iraq	Alhendi,2020
	3 µg/kg		rice	Iraq	Alhendi,2020
	0.1–5.3			Iran	Azizi and Azarmi (2009)
	n.d. to 12.5			Chile	Vega et al. (2009)
	n.d. to 6.0		Polished	Korea	Park et al. (2005).
	0.02–32			Morocco	Zinedine et al. (2006)
	0.08–47			Portugal	Juan et al. (2008)
	0.01–2.2		Parboiled	Nigeria	Williams et al. (2008).
	24–1160			Nigeria	Makun et al. (2007)
	0.09 –3.5			Portugal	Pena et al. (2005)
	n.d. to 27		Nonorganic	Spain	Gonzalez et al. (2006)
	n.d.		Brown	Taiwan	Lin et al. (2005)
	.n.d		Cooked		Lin et al. (2005)
	1.65–1.95		Basmati	Qatar	Abdulkadar et al. (2004)
	n.d. to 2.3			Tunisia	Ghali et al. (2008)
	n.d. to 150			Tunisia	Zaied et al. (2009)
	1.0–19			UK	Miraglia and Brera (2000)
	21.3–26.5			Vietnam	Trung et al. (2001)
	n.d. to 2.78			Vietnam	Nguyen et al. (2007)
	1.0–27.3 µg/Kg				Gonzalez et al.,2006
	9-92 µg/kg for rice collected from markets in Abidjan, Côte d'Ivoire of 1998-2002	HPLC			Sangare-Tigori et al.,2006

Type of Toxin	Concentration range (µg/kg)	Analysis method	Type of rice sample	Country	References
OTA	180 µg/kg in rice collected from India in 1994				Usha,1994
	8.5µg/kg		Rice		Iqbal et al. (2016)
	Maximum (µg/kg) 4.98 Average (µg/kg) 1.29		rice	Lebanon	Hassan et al.,2022
	Maximum (µg/kg) 9.58 Average (µg/kg) 2.76		rice	UAE	Hassan et al.,2022
			Rice	Portugal, Spain, Turkey, Egypt, Nigeria, Cote d'Ivoire, Morocco, Tunisia, Jordan, Chile, Vietnam, Japan, Korea, Italy, the United States, Iran, Bulgaria, the United Kingdom, and the Philippines	Bansal et al., 2011) Bui-Klimke and) (Wu,2015

Type of Toxin	Concentration range (µg/kg)	Analysis method	Type of rice sample	Country	References
Fumonisins	Canada 0 - 10 ng/g India 0.01 - 65 mg/kg				
	Korea 48.2 - 66.6 ng/g US 2.2 - 5.2 mg/kg				
	0.028		Basmati	UK	Patel et al. (1996)
Fumonisin B1	0.8–0.9		-------	Argentina	Lerda et al. (2005)
	4.4–7.1		Polished	Korea	Park et al. (2005).
Nivalenol	0.2–2.2			Japan	Tanaka et al. (2007)
Deoxynivlenol	Germany 0 - 0.058 mg/kg				
	0.12–2.9		-----------	Japan	Tanaka et al. (2007)
	140		Basmati	Qatar	Abdulkadar et al. (2004)
Zearalenone	n.d. to 106				
	24–1170				
	49–92		Basmati	Qatar	Abdulkadar et al. (2004)
	700–1130		--------	Taiwan	Liao et al. (2009)
	Mean 0.38			Iran	Azizi and Azarmi (2009)
				Nigeria	Makun et al. (2007)

Contamination of Rice Grains with OTA

Mazaheri (2023) reported that 4.43% (19 out of 449) rice samples and 34% (18 out of 58) rice flour samples were contaminated with Ochratoxin A (OTA) for the years 2020, 2021, and 2022 in Iran. In a similar study, 98 rice samples from six different cities in Canada for the years 2018 and 2019 were collected to test for OTA contamination, where the contamination rate was found to be 13.2% (13 out of 98) with an average level of 1.1 PPb, reaching a maximum of 11 PPb and a minimum of 0.049 PPb.

Makun et al. (2007) indicated that the levels of Ochratoxin A (OTA) contamination in rice grains in the field, markets, and stores were: (0-624 µg/kg), (0-1164 µg/kg), and (0-1164 µg/kg) respectively. Moreover, during the Dry Harmattan and scorching dry seasons, the pollution levels were recorded at 0 1164 µg/kg. 0 1139, µg/kg respectively. In research conducted by Iqbal and colleagues in 2016, it was revealed that 19% of the rice samples analyzed contained OTA contamination, with 14% of these samples surpassing the limits set by the European Union. the inhibition of mycelia growth of the fungus by Trigonella foenum وTrigonella Voinum and is observed as a zone of in hibition near the wells (Al-Shuwaikh et al., 2019).

In their research, Ryu and colleagues (2019) found that the levels of ochratoxin A (OTA) decreased by 43% in oats and 82% in rice when subjected to twin screw extrusion processing. The reduction rates saw improvements of 65% and 80% after adding baking soda. OTA production rises in conditions, with water activity and temperatures for fungal growth, especially in the A. Carbonarius fungus produces the toxin between 8 and 40°C (Lappa et al., 2017; Mannaa & Kim, 2017). The antibacterial activity shows MgONPs at 100, 200 and 400µg/ml were active against gram negative and gram positive (Al-Salhie and Al-Kalifawi). A study conducted by Toman et al. (2015) found a contamination rate of 100% for OTA in both boiled and white rice samples (30 samples each). The reduction rates showed 65% and 80% enhancements upon adding baking soda. The production of OTA increases under conditions involving water activity and temperatures to fungal growth, particularly by the A. Carbonarius fungus produces the toxin within the temperature range of 8 to 40°C (Lappa et al., 2017; Mannaa & Kim, 2017). A research study by Toman et al. (2015) discovered a contamination rate of 100% for OTA in both boiled and white rice samples (30 samples each). Borage (Anchusa italica) and French jasmine powders were mixed separately at 5 % with a diet contaminated with 2 ppm Ochra A and 10 ppm DON, both Borage and French jasmine powders exhibited significant reduction in Ochra A concentrations (Hussein et al.,2014).

The amount of OTA contamination found in grains varied from 0.03 to 27.7 parts per million (ppm), as noted by Scott and colleagues in 1972. A study by Majeed and team 2013 mentioned that the OTA level in grains was recorded at 0.94 micrograms per kilogram (µg/kg) accounting for an intake of 57.8%—additionally, the oral lethal dose 50 (LD50). The dosage is anticipated to cause fatality in half of the population. Ranges from 1 mg/kg to 46 58 mg/kg for pigs and mice, respectively. When compared the cytotoxic effect of Aflatoxin B1 with zearalenone on Aflatoxin B1 with zearalenone L20 B cell line. No concentrations of Aflatoxin B1 showed a significant reduction of the cellular viability (Ragad et al.,2013).

Extent of exposure to OTA toxin in micrograms per kilogram of body weight per day

نوع السم	Concentration range (µg/kg)	Type of rice sample	Country	**source**
OTA	Maximum (µg/kg) 4.98 Average (µg/kg) 1.29		rice collected from Lebanon	Hassan et al.,2022
	Maximum (µg/kg) 9.58 Average (µg/kg) 2.76		rice collected from UAE	Hassan et al.,2022
	0.17 ng/kg b.w./day)		OTA exposure from rice in Spain	González et al., 2006
	(1.27 ng/kg b.w./day		OTA exposure from the rice in Lebanon	Hassan et al.,2022
	(1.42 ng/kg b.w./day		OTA exposure from the rice in UAE	González et al., 2006
	4.2 ng/kg body weight/day		OTA exposure from rice in Pakistan	Iqbal et al.,2016
	0.62 ng/kg body weight/day		OTA exposure from rice in Iran	Rahimi,2014

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