REVIEW

# Ochratoxin A in hazelnuts

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**Summary**

Hazelnut represents a significant agricultural plant cultivated in numerous countries worldwide. Hazelnuts are quite rich in macro- and micro-components. They are highly susceptible to growth of fungi with development of mycotoxins. Among the mycotoxins, ochratoxin A (OTA) is one of the most prevalent contaminants found in a variety of food products. OTA is produced by various fungi including those from genera *Aspergillus* and *Penicillium*. Awareness is created regarding hazelnuts and OTA through a comprehensive analysis of the existing literature obtained from the Web of Science (Clarivate, Philadelphia, Pennsylvania, USA). This review provides a comprehensive summary of the chemical structure of OTA, its effects on health, applied detoxification methods and analytical methods. While the current research advances our understanding of hazelnuts and OTA, the feasibility of appropriate analysis methods underscores the need for further research and OTA studies in hazelnuts to confirm findings as well as to establish safe and effective practices.

**Keywords**

food; hazelnut; mycotoxin; ochratoxin A

The hazelnut (*Corylus avellana* L.), a member of the Betulaceae family, is one of the most widely produced nuts in the world. Among the most significant producers of hazelnuts are Turkey, Italy, USA, Azerbaijan and Spain. The hazelnut is a perennial climax plant, grows in humid and temperate climatic conditions. The plant exhibits optimal growth in regions where the average annual total precipitation is 755 mm and the average temperature is 13–16 °C. Its fruits, hazelnuts and products produced from them are consumed on a global scale due to their nutritional value, which provides amino acids, fatty acids, vitamins and minerals necessary for human health. The distinctive attributes of hazelnuts include colour, taste, aroma and texture, influence consumer preference [1–5]. Hazelnut kernels are utilised as a raw material in the production of a multitude of food products. Nevertheless, the majority of hazelnut kernels are utilised in the chocolate industry [2].

A comparison of the changes in hazelnut production and consumption over time reveals a clear correlation between the growing demand from consumers for health-promoting foods and the increasing interest in hazelnuts. According to data from the Food and Agriculture Organization (FAO, Rome, Italy), hazelnuts are currently cultivated in 30 countries worldwide. With the ongoing expansion of interest within the hazelnut cultivation sector, the quantity of production continues to increase [6–8].

Hazelnuts are also a rich source of biologically active compounds. They are reported to contain significant levels of protein, fatty acids (in particular oleic acid and linoleic acid), minerals, vitamins and antioxidant compounds, depending on differences in growing areas [1, 9, 10]. Conversely, due to their composition, hazelnuts are highly susceptible to the growth of fungi and development of mycotoxins, which have been demonstrated to have mutagenic and carcinogenic effects on humans and animals [11, 12].

The principal objective of this review was to present a synopsis of the current knowledge on hazelnuts, with a particular focus on ochratoxin A (OTA). Furthermore, this review aimed to contribute to the existing body of literature on OTA, a mycotoxin of significant concern in hazelnuts. It also seeked to provide insights into the legal regulations pertaining to OTA, its effects on human health. the latest development in analytical methods and devices employed in the detoxification process.

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#### A field distribution analysis

A review of the subject areas covered in the selected documents in the Web of Science (Clarivate, Philadelphia, Pennsylvania, USA) database revealed that the research focus was predominantly on food science and technology, applied chemistry, plant sciences, environmental sciences and nutrition dietetics. Furthermore, the countries where most of the research on hazelnuts was conducted were Turkey, Italy, USA, China and Spain. It is noteworthy that the aforementioned countries are among the leading producers of hazelnuts.

#### Mycotoxins and ochratoxin A

Mycotoxins are defined as secondary metabolites produced by various fungi. To date, more than 400 mycotoxins have been identified. In humans and animals, various toxic effects were observed upon consumption of these toxins. Indeed, the formation of these toxins is common in a multitude of food products [13, 14]. While mycotoxins are known to cause a quality loss in foods, they can also have a number of undesirable socio-economic and health consequences for humans and animals [15, 16]. In particular, these compounds are stated to exhibit a range of adverse effects, including cytotoxicity, nephrotoxicity, neurotoxicity, carcinogenicity, mutagenicity, immunosuppression and estrogenicity [17]. The most prevalent and frequently encountered mycotoxins in food products are aflatoxins, ochratoxins, trichothecenes, zearalenone and fumonisins [18].

Another significant group of mycotoxins produced by fungi, including *Aspergillus* and *Penicillium* species, are ochratoxins. It is stated that there are more than 20 subtypes of ochratoxins. Of the various subtypes, OTA is the most prevalent and toxic ochratoxin [19–21]. This mycotoxin was first identified in 1965 as a metabolite of *Aspergillus ochraceus*, and it is identified now as a potent nephrotoxin [18, 22]. Upon examination of its chemical structure, OTA is defined as a mycotoxin consisting of phenylalanine and dihydroisocoumaric acid connected by an amide bond [23]. OTA is a white, odorless, heat-resistant, crystalline solid with poor water solubility [24]. The chemical structure of OTA is given in Fig. 1.

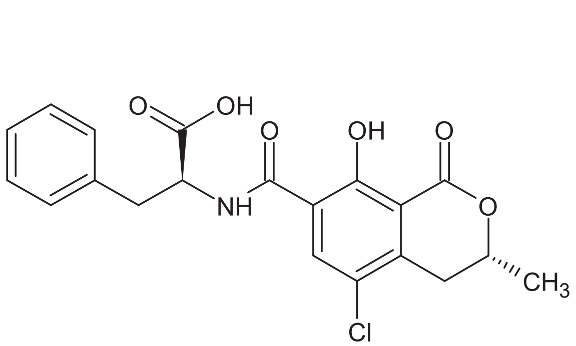

**Fig. 1.** Ochratoxin A chemical structure.

Humans and animals may be exposed to OTA through a number of routes, including dermal contact, inhalation and ingestion [21]. A number of factors, including temperature, humidity, storage conditions and suboptimal agricultural practices, is accepted as important pathways or factors in the formation of OTA [25, 26]. The intake of OTA can occur through the consumption of a variety of foods and beverages, including grains and grain products, cocoa and cocoa products, foods prepared with coffee, beer and wine, rice, biscuits, flour, palm oil, olive oil, spices and meat products [23, 27]. Indeed, a number of studies identified varying levels of OTA in human urine and blood samples [23, 28–32]. A review of studies on animals stated that OTA, in addition to being toxic and carcinogenic, has a number of adverse effects, including immunotoxicity, inhibition of macromolecular synthesis, increased lipid peroxidation and inhibition of mitochondrial respiration. Based on animal experiments, the International Agency for Research on Cancer (IARC, Lyon, France) classified OTA as a Group 2B carcinogen, which is a probable human carcinogen [23, 25, 26]. European Food Safety Authority (EFSA, Parma, Italy) established the tolerable weekly intake for OTA at 120 ng per kilogram of body weight [33, 34].

#### Effects of ochratoxin A on health

While the consumption of foods can prevent the onset of numerous diseases, it is also possible for these foods to cause disease. World Health Organization (WHO, Geneva, Switzerland) highlighted the significance of instilling healthy nutrition practices at an early age stating that this can significantly reduce the occurrence of numerous diseases [35, 36]. As a matter of fact, individuals may be exposed to chemical pollutants and microbial-derived toxins in a number of ways. It has been stated that mycotoxins, which are particularly the secondary metabolites of filamentous fungi, can be introduced to humans through contact, ingestion or inhalation [14, 37–39]. Humans and animals may be exposed to mycotoxins by ingesting contaminated food. Foodstuffs contain macro- and micro-components that support the growth of microorganisms and production of toxins by them. Previous studies demonstrated the presence of mycotoxins in human urine and blood samples. Therefore, diseases may result from these toxins [14, 39]. Aflatoxin B1, fumonisin B1 and OTA are the most toxic mycotoxins for mammals, with

**Tab. 1.** The conditions under which ochratoxin A is produced by various fungi [46].

| | *Penicillium verrucosum* | *Aspergillus ochraceus* | *Aspergillus carbonarius* | *Aspergillus niger* |
|---|---|---|---|---|
| Minimum temperature [°C] | 4–10 | 5–10 | 5–15 | 10–15 |
| Maximum temperature [°C] | 21–31 | 30–40 | 30–45 | 35–41 |
| Optimum temperature [°C] | 24–25 | 20–35 | 15–30 | 15–35 |
| Minimum water activity | 0.80–0.83 | 0.87–0.90 | 0.85–0.94 | 0.90–0.95 |
| Optimum water activity | 0.95–0.99 | 0.95–0.99 | 0.95–0.99 | 0.95–0.99 |
| Minimum time [d] | 7 | 3 | 2–5 | 3–7 |
| Optimum time [d] | >14 | 9–21 | 10–15 | 5–30 |

various toxic effects including hepatotoxicity, teratogenicity and mutagenicity. Furthermore, these mycotoxins may cause a number of further diseases, including hepatitis, bleeding, oedema, immunosuppression, hepatic carcinoma, equine leukoencephalomalacia, oesophageal cancer and renal failure [14].

A significant group among mycotoxins is that of ochratoxins. In particular, OTA has been classified by the IARC as a Group 2B carcinogen, which may potentially affect humans. In studies, it was demonstrated that ochratoxin A is present in human urine and blood samples, and that it tends to accumulate in organs. This phenomenon can be attributed to the high affinity of OTA to proteins [38, 40]. OTA is structurally analogous to the amino acid phenylalanine and thus exerts an inhibitory effect on enzymes that utilise phenylalanine as a substrate. Additionally, OTA was reported to exert effects that enhance mitochondrial damage, oxidative stress, lipid peroxidation, oxidative phosphorylation and also apoptosis in a range of cell types [41]. Moreover, it was stated that OTA is associated with various diseases (chronic interstitial nephropathy, testicular cancer and kidney tumors) in men [14, 38, 42].

**Formation of ochratoxin**

Mycotoxins are secondary metabolite toxins that can develop in a variety of food products. It is evident that a multitude of factors influence the formation of mycotoxins. These factors are typically classified as physical (humidity, temperature, mechanical damage, time), chemical ($CO_2$, $O_2$, chemical structure of the substrate) and biological (inoculum density, plant tolerance, interactions of microorganisms) [43].

The presence of ochratoxins in a multitude of food products of plant and animal origin represents a general toxic risk to humans [44]. *Aspergillus* and *Penicillium* genera of fungi are the primary sources of OTA. The formation of ochratoxins is influenced by a multitude of factors [45]. Amezqueta et al. [46] presented a table (Tab. 1) that indicates temperature, water activity and time parameters at which OTA is produced by various species of *Aspergillus* and *Penicillium* genera.

As demonstrated in Tab. 1, temperature, water activity and time exert a significant influence on OTA formation. It is evident that environmental factors play a pivotal role in this process. In addition to temperature and water activity, various other factors, including the composition of the medium, concentration of micronutrients, pH and the presence of competitive substances also have a direct influence on the formation of OTA [43, 46, 47]. Indeed, it is believed that the formation of OTA, which was identified in numerous food products, can be significantly reduced by taking these parameters into account.

**Detoxification of ochratoxin A**

Mycotoxins can cause significant economic and nutritional losses. FAO reported that 25 % of the world‘s agricultural products are contaminated with mycotoxins [48, 49]. Consequently, a number of techniques were developed to reduce the levels of mycotoxins in food and various products [49]. Physical, chemical and biological detoxification methods are employed to reduce the ochratoxin A levels. Physical methods generally consist of sorting, separation, peeling and cleaning processes [21]. As further physical methods, heating, extrusion, adsorption, ultraviolet or gamma irradiation and treatment with cold plasma are used [45]. Data on physical detoxification of various foods were published in several studies [50–52]. In a study published in 2014, Mustapha et al. [53] reported that the OTA contents of Tunisian millet samples subjected to gamma radiation at various dosages (1 kGy, 3 kGy, 10 kGy) decreased by 13 %, 44 % and 74 %, respectively. In a further study, Abbasi Pirouz et al. [54] synthesized a new adsorbent, magnetic graphene oxide adsorbent, modified with chitosan to beused to reduce mycotoxins. Furthermore, the authors indicated that at 50 °C and pH 5, a new magnetic graphene oxide modified with chitosan could reduce aflatoxin B1, OTA and zearalenone. In a study published in 2019, CASAS-JUNCO et al. [55] subjected roasted coffee samples to cold plasma treatment. The cold plasma treatment was conducted at an input power of 30 W and an output voltage of 850 V, with helium flowing at a rate of 1.5 l·min$^{-1}$. The results indicated that the OTA content decreased by 50 % after 30 min of treatment. In a separate study [56], it was demonstrated that various heat treatment processes (roasting and microwave heating) had a reducing effect on aflatoxins and OTA in pistachios.

Chemical detoxification methods are based on the use of chemical compounds to bind or destroy OTA [21]. The chemical methods including alkalization, oxidation and the use of certain chemicals are commonly employed [45]. Several published studies demonstrated the efficacy of chemical methods in reducing the levels of OTA in food products [57, 58]. ÖZCAN and GÖKMEN [59] demonstrated that the OTA contents of raisin samples decreased by up to 50 % following alkali application. In a study on various nuts using citric, lactic and propionic acids, JUBEEN et al. [60] demonstrated that the decontamination of aflatoxin B1 and total aflatoxins in contaminated hazelnuts was significantly improved with increasing acid concentration.

Another detoxification process, the biological method, has many advantages such as being easy to access, low cost, causes less nutritional losses and is environmentally friendly [21]. As biological methods, inhibition of OTA biosynthesis, microbial bioadsorption and enzymatic degradation of OTA are utilised [45]. The method in question employs microorganisms and/or their metabolites that are capable of transforming, adsorbing or degrading OTA [21]. The fundamental mechanism of OTA degradation is hydrolysis of the amide bond between the isocoumarin residue and phenylalanine by carboxypeptidase. The major degradation products are the amino acid L-β-phenylalanine and OTα. It is stated that the toxicity of L-β-phenylalanine and OTα is lower [45]. VARGA et al. [61] reported that an atoxigenic *Aspergillus niger* strain was capable of degrading OTA in both liquid and solid media. Additionally, the kinetics of detoxification were studied using thin layer chromatography, high performance liquid chromatography and an immunochemical technique. The method was also reported to effectively remove OTA from both liquid and solid media as well as to degrade its breakdown product, OTα. PETCHKONGKAEW et al. [62] isolated *Bacillus licheniformis* from soybeans and demonstrated that the strain was capable of removing 92.5 % of OTA after 48 h at 37 °C. RODRÍGUEZ et al. [63] reported that *Brevibacterium* spp. were capable of completely degrading OTA even at a concentration as high as 40 mg·l$^{-1}$. In their study, WEI et al. [64] reported that *Cryptococcus podzolicus* Y3 eliminated 100 % of OTA (1 μg·ml$^{-1}$) in a culture medium within 5 days and by intracellular substances in the grape juice medium within 3 days.

A number of studies demonstrated that physical, chemical and biological detoxification processes can have a significant effect on OTA in a variety of food products. However, the application of the detoxification processes resulted in the retention of levels of OTA as well as in the loss of certain essential nutrients in food products. One significant drawback of certain detoxification techniques is their high cost of implementation. Consequently, it is postulated that the detoxification process applied to foods should be conducted in a manner that preserves the existing food composition and does not result in the formation of any chemical residue. In the time of preparing this review, no studies on detoxification of hazelnuts and products containing them for OTA were available. This could be an inspiration for future research, with studies to be carried out in this context.

### Analytical methods, limitations and detection amounts

The growing concern about food safety in recent years has prompted the development of various methodologies for the detection of mycotoxins. As it is not feasible to eradicate these naturally occurring mycotoxins entirely, internationally agreed maximum acceptable levels have been established for the most prevalent and toxic members of this group. For OTA, European Union, Egypt, China, Gulf Cooperation Council, Kenya, Nigeria, Russia, India, Brazil and Uruguay values between 2 μg·kg$^{-1}$ and 50 μg·kg$^{-1}$ in cereals, dried fruits, coffee, cocoa, wine, beer, grape juice, spices, licorice and blood products are applied [65]. While there are limits for OTA in various foods, there is no limit for hazelnuts alone. However, China has set legal limits of 5 μg·kg$^{-1}$ for nuts and seeds, while Turkey has set legal limits of 3 μg·kg$^{-1}$ for "other products" containing oilseeds, nuts and/or dried fruits [21, 66].

In the literature, there are many studies using different devices and methods to determine mycotoxin contents in various hazelnut products and foods [11, 34, 67–70]. It is seen that OTA is detected in many food products and various methods are used to determine it [34, 70–73]. However, it was shown in studies that high performance liquid chromatography (HPLC) is generally used to determine OTA levels in hazelnut samples. Additionally, there are very few studies in the literature that determine the OTA content of hazelnuts. OTA contents determined in the studies are summarized below.

In his study on the presence of aflatoxins and OTA in chocolate products consumed in Turkey, Kabak [71] determined the OTA contents of samples containing hazelnuts and various nuts to be between 0.18 $\mu g \cdot kg^{-1}$ and 0.75 $\mu g \cdot kg^{-1}$. Analysis of mycotoxins was carried out using HPLC with fluorescence detection (FLD).

Using liquid chromatography mass spectrometry (LC-MS/MS), Er Demirhan and Demirhan [39] reported that the OTA contents of hazelnut paste samples ranged between 0.01 $\mu g \cdot kg^{-1}$ and 0.94 $\mu g \cdot kg^{-1}$. In a study published in 2023, Calderón et al. [74] reported that OTA was not detected in hazelnut samples analysed over years. The analysis was conducted using HPLC-FLD. Ugur et al. [73] reported that the OTA contents of shelled, raw and roasted hazelnut samples ranged between 0 $\mu g \cdot kg^{-1}$ and 0.1111 $\mu g \cdot kg^{-1}$. The study used dried fruits and nuts as materials. The determination of OTA content was conducted using HPLC. Kulahi and Kabak [75] reported in their study using HPLC on various food materials that the OTA contents of hazelnut samples ranged between 0.167 $\mu g \cdot kg^{-1}$ and 0.636 $\mu g \cdot kg^{-1}$.

## CONCLUSION

From the past to the present, hazelnuts have been the subject of interest due to their nutrional profile and to the presence of various biologically active ingredients, including lipids and fatty acids, proteins, polyphenols, flavonoids and various bioactive compounds. Hazelnuts have a significant potential to improve human health and combat various diseases, including cardiovascular disease, diabetes and cancer. Nevertheless, hazelnuts, which are widely produced and consumed, are also susceptible to the formation of mycotoxins. Mycotoxins are fungal toxins that present a significant risk to human and animal health. The existence and prevalence of hundreds of mycotoxins have attracted the attention of numerous researchers. In the classifications made by numerous researchers, OTA has been identified as one of the most toxic mycotoxins. The number of studies on OTA is considerable, given that it is present in numerous food and feed products, has a wide range of toxic effects and is linked to numerous diseases. It appears that the number of studies investigating the OTA content in hazelnuts and their derivatives is relatively limited. Furthermore, it has been established that additional studies are required to investigate detoxification of hazelnuts and their products cultivated in numerous countries worldwide.

## REFERENCES


1. Alasalvar, C. – Shahidi, F. – Liyanapathirana, C. M. – Ohshima, T.: Turkish tombul hazelnut (*Corylus avellana* L.). 1. Compositional characteristics. Journal of Agricultural and Food Chemistry, *51*, 2003, pp. 3790–3796. DOI: 10.1021/jf0212385.
2. Köksal, A. İ. – Artik, N. – Şimşek, A. – Güneş, N.: Nutrient composition of hazelnut (*Corylus avellana* L.) varieties cultivated in Turkey. Food Chemistry, *99*, 2006, pp. 509–515. DOI: 10.1016/j.foodchem.2005.08.013.
3. An, N. – Turp, M. T. – Türkeş, M. – Kurnaz, M. L.: Mid-term impact of climate change on hazelnut yield. Agriculture, *10*, 2020, article 159. DOI: 10.3390/agriculture10050159.
4. Allegrini, A. – Salvaneschi, P. – Schirone, B. – Cianfaglione, K. – Di Michele, A.: Multipurpose plant species and circular economy: *Corylus avellana* L. as a study case. Frontiers in Bioscience-Landmark, *27*, 2022, article 11. DOI: 10.31083/j.fbl2701011.
5. Zhao, J. – Wang, X. – Lin, H. – Lin, Z.: Hazelnut and its by-products: A comprehensive review of nutrition, phytochemical profile, extraction, bioactivities and applications. Food Chemistry, *413*, 2023, article 135576. DOI: 10.1016/j.foodchem.2023.135576.
6. Fideghelli, C. – De Salvador, F. R.: World hazelnut situation and perspectives. In: Varvaro, L. – Franco, S. (Eds.): VII International Congress on Hazelnut, ISHS Acta Horticulturae 845. Leuven : International Society for Horticultural Science, 2009, pp. 39–52. ISBN: 978-90-66057-12-8. DOI: 10.17660/ActaHortic.2009.845.2.
7. Aktaş, A. R. – Öztürk, E. – Hatırlı, S. A.: Dünya findik pi̇yasasinda Türki̇ye’ni̇n rolü. (Importance of Turkey in the world hazelnut market.) Süleyman Demirel Üniversitesi Vizyoner Dergisi, *1*, 2016, pp. 36–54. ISSN: 1308-9552. <https://dergipark.org.tr/en/download/article-file/214027> In Turkish.
8. 2020 Yili findik sektör raporu. (2020 Hazelnut sector. Report.) Ankara : Toprak Mahsullerġ Ofġsġ Genel Müdürlüğü, 2021. <https://www.tmo.gov.tr/Upload/Document/sektorraporlari/findik2020.pdf> In Turkish.
9. Oz, E. – Ekiz, E. – Savaş, A. – Aoudeh, E. – El-Aty, A. A. – Oz, F.: Impact of roasting level on fatty acid composition, oil and polycyclic aro-

matic hydrocarbon contents of various dried nuts. Turkish Journal of Agriculture and Forestry, *45*, 2021, pp. 213–221. DOI: 10.3906/tar-2006-43.
10. Brown, R. – Ware, L. – Tey, S. L.: Effects of hazelnut consumption on cardiometabolic risk factors and acceptance: A systematic review. International Journal of Environmental Research and Public Health, *19*, 2022, article 2880. DOI: 10.3390/ijerph19052880.
11. Salvatore, M. M. – Andolfi, A. – Nicoletti, R.: Mycotoxin contamination in hazelnut: current status, analytical strategies, and future prospects. Toxins, *15*, 2023, article 99. DOI: 10.3390/toxins15020099.
12. Savaş, A.: Fındık meyvesinin besinsel içeriği üzerine kısa bir perspektif. (A brief perspective on the nutritional content of hazelnut fruit.) Food Science and Engineering Research, *3*, 2024, pp. 100–103. ISSN: 2980-1451. <https://dergipark.org.tr/tr/download/article-file/3851371> In Turkish.
13. Gürses, M.: Mycoflora and aflatoxin content of hazelnuts, walnuts, peanuts, almonds and roasted chickpeas (LEBLEBI) sold in Turkey. International Journal of Food Properties, *9*, 2006, pp. 395–399. DOI: 10.1080/10942910600596597.
14. Reddy, K. R. N. – Salleh, B. – Saad, B. – Abbas, H. K. – Abel, C. A. –Shier, W. T.: An overview of mycotoxin contamination in foods and its implications for human health. Toxin Reviews, *29*, 2010, pp. 3–26. DOI: 10.3109/15569541003598553.
15. Wang, Y. – Nie, J. – Yan, Z. – Li, Z. – Cheng, Y. – Chang, W.: Occurrence and co-occurrence of mycotoxins in nuts and dried fruits from China. Food control, *88*, 2018, pp. 181–189. DOI: 10.1016/j.foodcont.2018.01.013.
16. Khan, R. – Anwar, F. –Ghazali, F. M.: A comprehensive review of mycotoxins: Toxicology, detection, and effective mitigation approaches. Heliyon, *10*, 2024, article e28361. DOI: 10.1016/j.heliyon.2024.e28361.
17. Krska, R. – Schubert-Ullrich, P. – Molinelli, A. – Sulyok, M. – MacDonald, S. – Crews, C.: Mycotoxin analysis: An update. Food Additives and Contaminants: Part A, *25*, 2008, pp. 152–163. DOI: 10.1080/02652030701765723.
18. Kumar, V. – Basu, M. S. – Rajendran, T. P.: Mycotoxin research and mycoflora in some commercially important agricultural commodities. Crop Protection, *27*, 2008, pp. 891–905. DOI: 10.1016/j.cropro.2007.12.011.
19. Ma, L. – Qiu, X. – Li, Y. – Tang, S. – Shen, W. – Xing, C. – Kong, D. – Sheng, J.: Carboxypeptidase A immobilization with zeolitic imidazolate framework for enhancement of ochratoxin A degradation ability. Food and Agricultural Immunology, *31*, 2020, pp. 587–599. DOI: 10.1080/09540105.2020.1749570.
20. EFSA Panel on Contaminants in the Food Chain (CONTAM) – Schrenk, D. – Bodin, L. – Chipman, J. K. – del Mazo, J. – Grasl-Kraupp, B. – Hogstrand, C. – Hoogenboom, L. – Leblanc, J.-C. – Nebbia, C. S. – Nielsen, E. – Ntzani, E. – Petersen, A. – Sand, S. – Schwerdtle, T. – Vleminckx, C. – Wallace, H. – Alexander, J. – Dall'Asta, C. – Mally, A, – Metzler, M. – Binaglia, M. – Horváth, Z. – Steinkellner, H. – Bignami, M.: Risk assessment of ochratoxin A in food. EFSA Journal, *18*, 2020, article e06113. DOI: 10.2903/j.efsa.2020.6113.
21. Mwabulili, F. – Xie, Y. – Li, Q. – Sun, S. – Yang, Y. – Ma, W.: Research progress of ochratoxin a biodetoxification. Toxicon, *222*, 2023, article 107005. DOI: 10.1016/j.toxicon.2022.107005.
22. Grollman, A. P. – Jelaković, B.: Role of environmental toxins in endemic (Balkan) nephropathy. Journal of the American Society of Nephrology, *18*, 2007, pp. 2817–2823. DOI: 10.1681/ASN.2007050537.
23. Erdal, İ. – Yalçın, S. S.: The relationship between ochratoxin A and blood pressure in adolescents. Environmental Toxicology and Pharmacology, *95*, 2022, article 103959. DOI: 10.1016/j.etap.2022.103959.
24. Kőszegi, T. – Poór, M.: Ochratoxin A: molecular interactions, mechanisms of toxicity and prevention at the molecular level. Toxins, *8*, 2016, article 111. DOI: 10.3390/toxins8040111.
25. Bui-Klimke, T. R. – Wu, F.: Ochratoxin A and human health risk: A review of the evidence. Critical reviews in Food Science and Nutrition, *55*, 2015, pp. 1860–1869. DOI: 10.1080/10408398.2012.724480.
26. Hajok, I. – Kowalska, A. – Piekut, A. – Ćwieląg-Drabek, M.: A risk assessment of dietary exposure to ochratoxin A for the Polish population. Food Chemistry, *284*, 2019, pp. 264–269. DOI: 10.1016/j.foodchem.2019.01.101.
27. Meerpoel, C. – Vidal, A. – Andjelkovic, M. – De Boevre, M. – Tangni, E. K. – Huybrechts, B. – De Saeger, S.: Dietary exposure assessment and risk characterization of citrinin and ochratoxin A in Belgium. Food and Chemical Toxicology, *147*, 2021, article 111914. DOI: 10.1016/j.fct.2020.111914.
28. Scott, P. M.: Biomarkers of human exposure to ochratoxin A. Food Additives and Contaminants, *22*, 2005, Supplement 1, pp. 99–107. DOI: 10.1080/02652030500410315.
29. Muñoz, K. – Vega, M. – Rios, G. – Muñoz, S. – Madariaga, R.: Preliminary study of ochratoxin A in human plasma in agricultural zones of Chile and its relation to food consumption. Food and Chemical Toxicology, *44*, 2006, pp. 1884–1889. DOI: 10.1016/j.fct.2006.06.008.
30. Akdemir, C. – Ulker, O. C. – Basaran, A. – Ozkaya, S. – Karakaya, A.: Estimation of ochratoxin A in some Turkish populations: an analysis in urine as a simple, sensitive and reliable biomarker. Food and Chemical Toxicology, *48*, 2010, pp. 877–882. DOI: 10.1016/j.fct.2009.12.026.
31. Ates, I. – Ulker, O. C. – Akdemir, C. – Karakaya, A.: Correlation of ochratoxin A exposure to urinary levels of 8-hydroxydeoxyguanosine and malondialdehyde in a Turkish population. Bulletin of Environmental Contamination and Toxicology, *86*, 2011, pp. 258–262. DOI: 10.1007/s00128-011-0225-z.
32. Heyndrickx, E. – Sioen, I. – Huybrechts, B. – Callebaut, A. – De Henauw, S. – De Saeger, S.: Human biomonitoring of multiple mycotoxins in the Belgian population: Results of the BIOMYCO study.

Environment International, *84*, 2015, pp. 82–89. DOI: 10.1016/j.envint.2015.06.011.
33. Opinion of the scientific panel on contaminants in food chain on a request from the commission related to ochratoxin A (OTA) as undesirable substance in animal feed. EFSA Journal, *2*, 2004, pp. 1–36. DOI: 10.2903/j.efsa.2004.101.
34. Imperato, R. – Campone, L. – Piccinelli, A. L. – Veneziano, A. – Rastrelli, L.: Survey of aflatoxins and ochratoxin a contamination in food products imported in Italy. Food Control, *22*, 2011, pp. 1905–1910. DOI: 10.1016/j.foodcont.2011.05.002.
35. WHO-EM/NUT/282/E. Healthy diet. Geneva : World Health Organization, 2019. <https://iris.who.int/bitstream/handle/10665/325828/EMROPUB_2019_en_23536.pdf?sequence=1&isAllowed=y>
36. Gürbüz, M. – Korkmaz, B. İ. O.: The anti-campylobacter activity of eugenol and its potential for poultry meat safety: A review. Food Chemistry, *394*, 2022, article 133519. DOI: 10.1016/j.foodchem.2022.133519.
37. Bryden, W. L.: Mycotoxins in the food chain: human health implications. Asia Pacific Journal of Clinical Nutrition, *16*, 2007, Supplement, pp. 95–101. ISSN: 0964-7058. <https://apjcn.nhri.org.tw/server/apjcn/16/s1/95.pdf>
38. Thanushree, M. P. – Sailendri, D. – Yoha, K. S. – Moses, J. A. – Anandharamakrishnan, C.: Mycotoxin contamination in food: An exposition on spices. Trends in Food Science and Technology, *93*, 2019, pp. 69–80. DOI: 10.1016/j.tifs.2019.08.010.
39. Er Demirhan, B. – Demirhan, B.: Investigation of twelve significant mycotoxin contamination in nut-based products by the LC–MS/MS method. Metabolites, *12*, 2022, article 120. DOI: 10.3390/metabo12020120.
40. Heussner, A. H. – Bingle, L. E.: Comparative ochratoxin toxicity: A review of the available data. Toxins, *7*, 2015, pp. 4253–4282. DOI: 10.3390/toxins7104253.
41. Marin, S. – Ramos, A. J. – Cano-Sancho, G. – Sanchis, V.: Mycotoxins: Occurrence, toxicology, and exposure assessment. Food and Chemical Toxicology, *60*, 2013, pp. 218–237. DOI: 10.1016/j.fct.2013.07.047.
42. Bayman, P. – Baker, J. L.: Ochratoxins: a global perspective. Mycopathologia, *162*, 2006, pp. 215–223. DOI: 10.1007/s11046-006-0055-4.
43. Erzurum, K.: Gıdalarda mikotoksin oluşumunu etkileyen faktörler. (Factors affecting mycotoxin formation in foods.) Gıda, *26*, 2001, pp. 289–293. ISSN: 1300-3070. <https://dergipark.org.tr/tr/download/article-file/78841> In Turkish.
44. Petzinger, E. – Ziegler, K.: Ochratoxin A from a toxicological perspective. Journal of Veterinary Pharmacology and Therapeutics, *23*, 2000, pp. 91–98. DOI: 10.1046/j.1365-2885.2000.00244.x.
45. Wang, L. – Hua, X. – Shi, J. – Jing, N. – Ji, T. – Lv, B. – Lv, B. – Liu, L. – Chen, Y.: Ochratoxin A: Occurrence and recent advances in detoxification. Toxicon, *210*, 2022, pp. 11–18. DOI: 10.1016/j.toxicon.2022.02.010.
46. Amezqueta, S. – Schorr-Galindo, S. – Murillo-Arbizu, M. – Gonzalez-Peńas, E. – De Cerain, A. L. – Guiraud, J. P.: OTA-producing fungi in foodstuffs: A review. Food Control, *26*, 2012, pp. 259–268. DOI: 10.1016/j.foodcont.2012.01.042.
47. Sert, S.: Mikotoksin üretimine tesir eden faktörler. (Factors affecting mycotoxin production.) Atatürk Üniversitesi Ziraat Fakültesi dergisi A, *16*, 1985, pp. 147–159. ISSN: 1300-9036. <https://dergipark.org.tr/tr/download/article-file/35132> In Turkish.
48. Wu, F.: Measuring the economic impacts of *Fusarium* toxins in animal feeds. Animal Feed Science and Technology, *137*, 2007, pp. 363–374. DOI: 10.1016/j.anifeedsci.2007.06.010.
49. Jard, G. – Liboz, T. – Mathieu, F. – Guyonvarc'h, A. – Lebrihi, A.: Review of mycotoxin reduction in food and feed: from prevention in the field to detoxification by adsorption or transformation. Food Additives and Contaminants: Part A, *28*, 2011, pp. 1590–1609. DOI: 10.1080/19440049.2011.595377.
50. Mine Kurtbay, H. – Bekçi, Z. – Merdivan, M. – Yurdakoç, K.: Reduction of ochratoxin A levels in red wine by bentonite, modified bentonites, and chitosan. Journal of Agricultural and Food Chemistry, *56*, 2008, pp. 2541–2545. DOI: 10.1021/jf073419i.
51. Olivares-Marín, M. – Del Prete, V. – Garcia-Moruno, E. – Fernández-González, C. – Macías-García, A. – Gómez-Serrano, V.: The development of an activated carbon from cherry stones and its use in the removal of ochratoxin A from red wine. Food Control, *20*, 2009, pp. 298–303. DOI: 10.1016/j.foodcont.2008.05.008.
52. Nones, J. – Nones, J. – Riella, H. G. – Kuhnen, N. C. – Trentin, A.: Bentonite protects neural crest stem cells from death caused by aflatoxin B1. Applied Clay Science, *104*, 2015, pp. 119–127. DOI: 10.1016/j.clay.2014.11.018.
53. Mustapha, M. B. – Bousselmi, M. – Jerbi, T. – Bettaďeb, N. B. – Fattouch, S.: Gamma radiation effects on microbiological, physico-chemical and antioxidant properties of Tunisian millet (*Pennisetum Glaucum* L.R.Br.). Food Chemistry, *154*, 2014, pp. 230–237. DOI: 10.1016/j.foodchem.2014.01.015.
54. Abbasi Pirouz, A. – Abedi Karjiban, R. – Abu Bakar, F. – Selamat, J.: A novel adsorbent magnetic graphene oxide modified with chitosan for the simultaneous reduction of mycotoxins. Toxins, *10*, 2018, article 361. DOI: 10.3390/toxins10090361.
55. Casas-Junco, P. P. – Solís-Pacheco, J. R. – Ragazzo-Sánchez, J. A. – Aguilar-Uscanga, B. R. – Bautista-Rosales, P. U. – Calderón-Santoyo, M.: Cold plasma treatment as an alternative for ochratoxin a detoxification and inhibition of mycotoxigenic fungi in roasted coffee. Toxins, *11*, 2019, article 337. DOI: 10.3390/toxins11060337.
56. Jalili, M. – Selamat, J. – Rashidi, L.: Effect of thermal processing and traditional flavouring mixture on mycotoxin reduction in pistachio. World Mycotoxin Journal, *13*, 2020, pp. 381–389. DOI: 10.3920/WMJ2019.2486.
57. Qi, L. – Li, Y. – Luo, X. – Wang, R. – Zheng, R. – Wang, L. – Li, Y. – Yang, D. – Fang, W. – Chen, Z.: Detoxification of zearalenone and ochratoxin A by

ozone and quality evaluation of ozonised corn. Food Additives and Contaminants: Part A, *33*, 2016, pp. 1700–1710. DOI: 10.1080/19440049.2016.1232863.
58. Torlak, E.: Use of gaseous ozone for reduction of ochratoxin A and fungal populations on sultanas. Australian Journal of Grape and Wine Research, *25*, 2019, pp. 25–29. DOI: 10.1111/ajgw.12362.
59. Özcan, S. – Gökmen, V.: Alkali-based pre-treatment may prevent ochratoxin A in grapes. World Mycotoxin Journal, *9*, 2016, pp. 517–523. DOI: 10.3920/WMJ2015.2017.
60. Jubeen, F. – Sher, F. – Hazafa, A. – Zafar, F. – Ameen, M. –Rasheed, T.: Evaluation and detoxification of aflatoxins in ground and tree nuts using food grade organic acids. Biocatalysis and Agricultural Biotechnology, *29*, 2020, article 101749. DOI: 10.1016/j.bcab.2020.101749.
61. Varga, J. – Rigó, K. – Téren, J.: Degradation of ochratoxin A by *Aspergillus* species. International Journal of Food Microbiology, *59*, 2000, pp. 1–7. DOI: 10.1016/S0168-1605(00)00230-0.
62. Petchkongkaew, A. – Taillandier, P. – Gasaluck, P. – Lebrihi, A.: Isolation of *Bacillus* spp. from Thai fermented soybean (Thua-nao): screening for aflatoxin B1 and ochratoxin A detoxification. Journal of Applied Microbiology, *104*, 2008, pp. 1495–1502. DOI: 10.1111/j.1365-2672.2007.03700.x.
63. Rodriguez, H. – Reveron, I. – Doria, F. – Costantini, A. – De Las, R.B. – Muňoz, R. – Garcia-Moruno, E.: Degradation of Ochratoxin A by Brevibacterium Species. Degradation of ochratoxin A by *Brevibacterium* species. Journal of Agricultural and Food Chemistry, *59*, pp. 10755–10760. DOI: 10.1021/jf203061p.
64. Wei, M. – Dhanasekaran, S. – Ngea, G. L. N. – Godana, E. A. – Zhang, X. – Yang, Q. – Zheng, X. – Zhang, H.: *Cryptococcus podzolicus* Y3 degrades ochratoxin A by intracellular enzymes and simultaneously eliminates citrinin. Biological Control, *168*, 2022, article 104857. DOI: 10.1016/j.biocontrol.2022.104857.
65. Anfossi, L. – Giovannoli, C. – Baggiani, C.: Mycotoxin detection. Current Opinion in Biotechnology, *37*, 2016, pp. 120–126. DOI: 10.1016/j.copbio.2015.11.005.
66. Türk Gıda Kodeksi Bulaşanlar Yönetmeliği. (Turkish Food Codex Contaminants Regulation.) T. C. Resmî Gazete, 5 November 2023, No. 32360, pp. 1–50. <https://www.resmigazete.gov.tr/eskiler/2023/11/20231105.pdf> In Turkish.
67. Bacaloni, A. – Cavaliere, C. – Cucci, F. – Foglia, P. – Samperi, R. – Laganà, A.: Determination of aflatoxins in hazelnuts by various sample preparation methods and liquid chromatography–tandem mass spectrometry. Journal of Chromatography A, *1179*, 2008, pp. 182–189. DOI: 10.1016/j.chroma.2007.11.081.
68. Ekinci, R. – Otağ, M. – Kadakal, Ç.: Patulin & ergosterol: New quality parameters together with aflatoxins in hazelnuts. Food Chemistry, *150*, 2014, pp. 17–21. DOI: 10.1016/j.foodchem.2013.10.120.
69. Varga, E. – Glauner, T. – Berthiller, F. – Krska, R. – Schuhmacher, R. – Sulyok, M.: Development and validation of a (semi-)quantitative UHPLC-MS/MS method for the determination of 191 mycotoxins and other fungal metabolites in almonds, hazelnuts, peanuts and pistachios. Analytical and Bioanalytical Chemistry, *405*, 2013, pp. 5087–5104. DOI: 10.1007/s00216-013-6831-3.
70. Hegedüs, Z. – Gömöri, C. – Varga, M. – Vágvölgyi, C. – Szekeres, A.: Separation of ochratoxins by centrifugal partition chromatography. Journal of Chromatography A, *1724*, 2024, article 464898. DOI: 10.1016/j.chroma.2024.464898.
71. Kabak, B.: Aflatoxins and ochratoxin A in chocolate products in Turkey. Food Additives and Contaminants: Part B, *12*, 2019, pp. 225–230. DOI: 10.1080/19393210.2019.1601641.
72. Cüce, M.: Incidence of aflatoxins, ochratoxin A, zearalenone, and deoxynivalenol in food commodities from Turkey. Journal of Food Safety, *40*, 2020, article e12849. DOI: 10.1111/jfs.12849.
73. Uğur, H. – Omurtag, G. Z. – Omurtag-Korkmaz, B. İ. – Yaman, M.: Determination of aflatoxins and ochratoxin A levels in nuts and dried fruits in Turkey with evaluation of the estimated daily intake. Journal of Food and Nutrition Research, *62*, 2023, pp. 314–324. ISSN: 1336-8672 (print), 1338-4260 (online). <https://www.vup.sk/download.php?bulID=2210>
74. Calderón, R. – Palma, P. – Godoy, M. – Vidal, M. – Rivera, A.: Co-occurrence and estimation of the risk of total aflatoxins (B1, B2, G1, and G2) and ochratoxin A in agri-food products consumed in Chile. Food Control, *146*, 2023, article 109493. DOI: 10.1016/j.foodcont.2022.109493.
75. Kulahi, A. – Kabak, B.: A preliminary assessment of dietary exposure of ochratoxin A in Central Anatolia Region, Turkey. Mycotoxin Research, *36*, 2020, pp. 327–337. DOI: 10.1007/s12550-020-00397-6.

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