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The Risk of *Fusarium* and Their Mycotoxins in the Food Chain

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Abstract

Fusarium sp. and mycotoxins of these species pose a major risk to consumer health, agriculture and the food industry. This paper is a worldwide bibliographic study on impact of *Fusarium* and mycotoxins on the food chain. The factors influencing the development of fungi *Fusarium sp.*, the formation of mycotoxins and their microbiological risk on the food chain must be considered as a whole. For cereals and oilseeds before and after harvest, fungal infections and mycotoxin contamination present serious problems worldwide. This paper is an overview of the factors that include the microbiological risk and impact of *Fusarium* in the food chain mentioned in national and international studies. The methods and results obtained in this direction internationally are mentioned, such as: infrared spectroscopy, Raman spectrometry and hyperspectral imaging. Also, in review are presented solutions to reduce this impact on the food chain.

Keywords

Fusarium sp., Mycotoxins, Food Chain, Management Systems in Agriculture and Food Industry, Food Safety

1. Introduction

Mycotoxins are produced by fungi under certain conditions of temperature and humidity and pose a risk to the health of consumers [1]. World Health Organization (WHO) in collaboration with Food and Agriculture Organization of the United Nations (FAO), is monitoring this major issue globally [2] [3]. Mycotoxins are secondary metabolites of *Aspergillus*, *Fusarium* and *Penicillium*, fungi present in the soil, that grow and multiply rapidly on various agricultural raw materials showing a risk to both animals and humans [1] [4] [5] [6]. Fungi and their metabolites, including *Fusarium sp.*, have been a stringent problem for decades [7] [8] [9] [10]. Fungi can pose a risk to agricultural products cereals, nuts, fruits, and products derived from these raw materials [11]-[16].

Temperature and humidity favor the rapid growth of fungi. As an example, *Fusarium oxysporum* is often reported in works related to plant pathology [17] [18] [19] [20] [21]. *Fusarium* species have been isolated from food: *Fusarium oxysporum* (beans, beverages, chocolate, cereals, fruit, nuts, seeds, and vegetables) [22]; *Fusarium verticillioides* (maize/corn, rice, and wheat) and other *Fusarium sp.* (beans, barley, millet etc.) [19] [22] [23] [24] [25]. For example, the study [26] states that *Fusarium* Head Blight and *Gibberella* Ear Rot decrease the yield of the corn crop and may present a risk of contamination with type B toxins. Studying the risk of mycotoxin contamination of raw materials helps to make the most relevant decisions when it comes to storing cereals, fruits, animal feed and food manufacturing [27]. This study has been undertaken to evaluate the factors that promote the risk caused by *Fusarium* in the food chain and how the occurrence of mycotoxins in food can be controlled. Food safety is ensured not in the manufacture of food, but throughout the food chain.

2. The Fungi in the Food Chain

There are currently many studies [28] [29] [30] where the production of special secondary metabolites and mycotoxins specific to significant models of fungal pathogens-host plants has been analyzed. Serios problems created by *Fusarium sp.* and their mycotoxins can be found in the works [31] [32] [33]. The authors of the studies [22] [27] [34] note the conditions that influence the development of fungi in *Fusarium sp.* are pH, temperature, moisture content and nitrogen source. Many authors note that spores and hyphae of the fungi *Fusarium sp.* in different climatic conditions produce toxins including trichothechenes such as deoxynivalenol (DON) [35] [36] [37] [38], nivalenol (NIV) and T-2 and HT-2 Toxins, as well as zearalenone (ZEN) [39] [40] [41] [42] and fumonisins (FUM): maize [11] [42] [43] [44] [45]; corn [46] [47], nuts [48]; grape-wine chain [49], wine [50] [51], and asparagus [44]. The microbiological and chemical risk posed by fungi and their metabolites is a cumulative process throughout the food chain [52]. **Figure 1** shows the factors that favor the risk caused by fungi.

Biological factors

Fungi from different species of *Aspergillus*, *Fusarium*, *Penicillium* and *Alternaria* produce secondary metabolites presenting a major risk, have been isolated from: cereals [35] [36] [37] [38], corn [60], peas [63], seeds oilseeds [64], fruits (nuts [42] [48], grapes [49]), and wine [50] [51]. **Table 1** presents reported results on the influence of biological factors on the growth of fungal biomass and mycotoxin production.

Environmental factors

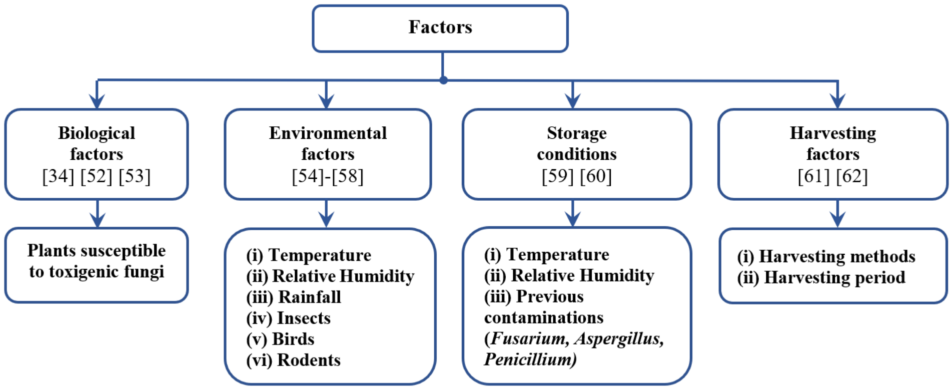

Figure 1. Factors that favor the risk caused by fungi.

Table 1. The reported results about the influence of biological factors on the growth of fungal biomass and the production of mycotoxins.

Isolated fungi	Reported results	Reference
Fusarium proliferatum	FUM 1 gene expression being affected by asparagus extract, encodes the polyketide synthase.	[44]
Fusarium proliferatum	An important role in regulating fumonisin biosynthesis is played by carbon sources. Sucrose further added to the culture medium significantly reduced fumonisin production, but its absence led to increased fumonisin production.	[10]
Fusarium avenaceum	Hydroxycinnamic acids are effective in inhibiting fungal growth and Enniatins (ENNs).	[65]
Fusarium sp.	Ferulic acid is active in significantly suppressing genes expression for the biosynthesis of ENN.	[66]

Temperature and high relative humidity favor the development of fungi, respectively the production of mycotoxins [57] [67]. Fusarium toxins, usually found in the soil, is caused by relative humidity, temperature for storage and diverse handling that can contaminate different types of cereals, crops, which cand lead to major economic losses [57]. Most fungal species have an optimal growth temperature of 25˚C - 30˚C but can also grow in a range of 5˚C - 30˚C [34] [68]. Optimal temperature for mycotoxin production is 24˚C - 26˚C. The influence of temperature on the growth of fungi, including the FUM1 gene has been studied in fungi *Fusarium verticillioides* and *Fusarium proliferatum* isolated from corn [56]. Fumonisins are mainly produced by *Fusarium verticillioides* [69] [70]. In the study conducted by Sandra N. Jimenez-Garcia *et al.* [57] the authors mentioned that the drought caused a major contamination of maize with *Fusarium verticillioides*.

Storage conditions

The accumulation of *Fusarium* toxins depends on the composition of the substrate (the presence of simple sugars), pH and temperature [53] [71]. The authors of the studies [52] [54] reported data attesting that pH influences the metabolic processes of plants, the risk of fungal development and the interaction between water activity (a_w) and temperature are the major factors on which the accumulation of mycotoxins depends.

Harvesting factors

Harvesting period, harvesting and storage methods have a significant correlation with fungal plant infestation and the amount of mycotoxins produced. There are studies that have investigated this addiction: the influence of wheat variety and different harvest periods [62], late crop harvesting [53], storage conditions [53], stress sores [57] [61].

In other studies by Liu *et al.* [72] and Uppala *et al.* [73] it is reported that the production of mycotoxins depends on the sugar content of the substrate. The authors argue this interdependence. The accumulation of *Fusarium* toxins depends on the composition of the substrate (the presence of simple sugars), pH and temperature [53] [71].

3. Methods for the Quantification of Mycotoxins and Mycotoxigenic Fungi

It is necessary to detect fungi and their metabolites in the initial stage of development [74]. For this purpose, various classical and advanced methods have been developed and tested. Mycological methods involve common culturing techniques performed through multiple steps including culture, isolation, and identification [34].

From the advanced methods we can mention utilizing infrared spectroscopy, Raman spectroscopy, capillary electrophoresis, multispectral imaging system, chromatographic technique, radioimmunoassay and enzyme-linked immunosorbent and others found in the work of many world-class researchers [74] [75] [76] [77] [78]. Currently, the Fourier-transform infrared spectroscopy methods (FTIR) [79] [80] [81] [82], near-infrared analysis (NIR) [83] [84] [85], the electronic nose [86] [87] are increasingly used to detect mycotoxins in food, FTIR–photoacoustic spectroscopy (FTIR PAS) [88], color imaging [89] [90], neutron tomography [87] and others, which give exact results even in the presence of very low doses. At the current stage, the study of the problem of fungi and mycotoxins is quite advanced and is done at the level of chromosomes [91] [92]. Adriaan Vanheule *et al.* [92] have shown that the different biology of the fungal cell, rather than its origin, is responsible for the properties of genomes. The authors of the study [61] López-Errasquín E. *et al.* reported a positive correlation between FUM1 and the amount of fumonisins biosynthesized by *Fusarium* fungi (*Fusarium verticillioides* and *Fusarium proliferatum*).

4. Management and Control

To control the risk of fungi and their mycotoxins it is necessary to take certain measures, which is studied and implemented internationally. These approaches include: appropriate planting method [93] [94]; post-planting land and crop management (proper use of fertilizers, irrigation methods, phytosanitary control, etc.) [95] [96]; use of various techniques to reduce contamination of plants and food [97] [98]; implementation of management systems in agriculture and food industry hazard analysis and critical control points (HACCP), good agricultural practice (GAP), good manufacturing practices (GMP), threat assessment critical control points (TACCP), and vulnerability critical control points (VACCP) [99] [100].

Information on the toxicology of purified fumonisins from the FB series can be found in papers published in different years, e.g.: Nelson, P. E. *et al.* (1993) [101], Gary Munkvold (2017) [102], Claudia Salazar-González *et al.* (2020) [103]. Other toxic fumonisin analogues are being investigated. Research is being carried out on maize [67] because these grains may show major sources of contamination with FB1, FB2, and FB3.

Current management strategies to reduce the risk of *Fusarium sp*. and its metabolites consist in crop rotations [104]; fumigation [97] [105]; fungicide treatments [46] [96]; avoiding plant stress [104]; selection of varieties resistant to *Fusarium* infestation [106]; sanitation [104].

Fusarium poses a major risk to the food chain. Only by having certain knowledge in this field, this risk can be kept under control. In this context, at the Technical University of Moldova, research is being done to detect by rapid methods the outbreak of the formation of the risk produced by fungi and to take prompt measures to prevent its spread. Research is carried out at the genome level of the fungal cell.

Ensuring food safety can only be guaranteed when monitoring the collection of raw materials, transport, processing, storage, manufacture of food and its transportation to consumers [107].

5. Conclusion

Fusarium sp. poses a risk to plants and food when there are favorable conditions for the development of these fungi and the production of toxins. The use of proper management can control this risk. The negative impact of *Fusarium sp*. and mycotoxins in the food chain must be monitored simultaneously in two directions: protecting plants by various methods and reducing the risk of infestation by creating the right conditions. The implementation of proper methods from the beginning of the food chain until the end including all stages of production like planting, harvest, drying, storage, processing, packaging, transport helps to decrease the level of contamination and maintain it below the tolerable levels assigned by different countries. In order to ensure food safety, fast and reliable methods of analyzing contamination with fungi and mycotoxins must be implemented.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Bilal, M., Zou, X., Arslan, M., Tahir, H.E., Usman, M., Li, Z. and Shi, J. (2020) Nondestructive Spectroscopic Techniques for Detection of Fungal and Mycotoxin Infections in Food Products: A Review. *Spectroscopy*, **35**, 28-36.

[2] WHO (World Health Organization) (2018) Mycotoxins. https://www.who.int/news-room/fact-sheets/detail/mycotoxins

[3] European Commission (2007) Commission Regulation (EC) No. 1126/2007 of 28 September 2007 Amending Regulation (EC) No. 1881/2006: Setting Maximum Levels for Certain Contaminants in Foodstuffs as Regards Fusarium Toxins in Maize and Maize Products. European Union, Brussels.

[4] Hadi, M. and Kashefi, B. (2012) Importance of Mycotoxins and Rapid Detection of Contamination in Hazelnuts. *Acta Horticulturae*, **963**, 47-50. https://doi.org/10.17660/ActaHortic.2012.963.6

[5] Hyunjung, M. and Byoung-Kwan, C. (2015) Spectroscopic Techniques for Nondestructive Detection of Fungi and Mycotoxins in Agricultural Materials. *Journal of Biosystems Engineering*, **40**, 67-77. https://doi.org/10.5307/JBE.2015.40.1.067

[6] Sturza, R. and Lazacovici, O. (2017) Quantification of Ochratoxin A in Moldavian Wines. *Scientific Study & Research Chemistry & Chemical Engineering, Biotechnology, Food Industry*, **18**, 339-334.

[7] Kos, G., Lohninger, H. and Krska, R. (2003) Development of a Method for the Determination of Fusarium Fungi on Corn Using Mid-Infrared Spectroscopy with Attenuated Total Reflection and Chemometrics. *Analytical Chemistry*, **75**, 1211-1217. https://doi.org/10.1021/ac0260903

[8] Perincherry, L., Lalak-Kańczugowska, J. and Stępień, Ł. (2019) Fusarium-Produced Mycotoxins in Plant-Pathogen Interactions. *Toxins*, **11**, 664. https://doi.org/10.3390/toxins11110664

[9] Manikandan, P., Galgóczy, L., Selvam, K.P., Shobana, C.S., Kocsubé, S., Vágvölgyi, C. and Narendran, V. (2011) Fusarium. In: Liu, D., Ed., *Molecular Detection of Human Fungal Pathogens*, CRC Press, Boca Raton, FL, 417-433. https://doi.org/10.1201/b11375-55

[10] Wu, Y., Li, T., Gong, L., Wang, Y. and Jiang, Y. (2019) Effects of Different Carbon Sources on Fumonisin Production and FUM Gene Expression by *Fusarium proliferatum*. *Toxins*, **11**, 289. https://doi.org/10.3390/toxins11050289

[11] Bhat, R. (2013) Potential Use of Fourier Transform Infrared Spectroscopy for Identification of Molds Capable of Producing Mycotoxins. *International Journal of Food Properties*, **16**, 1819-1829. https://doi.org/10.1080/10942912.2011.609629

[12] Tolosa, J., Font, G., Manes, J. and Ferrer, E. (2013) Nuts and Dried Fruits: Natural Occurrence of Emerging *Fusarium* Mycotoxins. *Food Control*, **33**, 215-220. https://doi.org/10.1016/j.foodcont.2013.02.023

[13] Alsuhaibani, A.M.A. (2018) Effects of Storage Periods and Temperature on Mold Prevalence and Aflatoxin Contamination in Nuts. *Pakistan Journal of Nutrition*, **17**, 219-227. https://doi.org/10.3923/pjn.2018.219.227

[14] Sandulachi, E., Rubţov, S. and Costiş, V. (2015) Microbiological Contamination of

Nuts. *International Scientific Practical Conference*, Azerbaijan State Agrarian University, Ganja, Azerbaijan, 139-141. (In Russian)

[15] Magan, N. and Lacey, J. (1984) Effect of Water Activity, Temperature and Substrate on Interactions between Field and Storage Fungi. *Transactions of the British Mycological Society*, **82**, 83-93. https://doi.org/10.1016/S0007-1536(84)80214-4

[16] Gurjui, A., Sandulachi, E. and Silivestru, E. (2013) Microbiological Risk Estimation at Walnuts Long Term Storage. *Journal of Food and Packaging Science*, *Technique and Technologies*, No. 2, 93-95.

[17] Peltonen, K., Jestoi, M. and Eriksen, G. (2010) Health Effects of Moniliformin: A Poorly Understood Fusarium Mycotoxin. *World Mycotoxin Journal*, **3**, 403-414. https://doi.org/10.3920/WMJ2010.1232

[18] Jestoi, M., Kokkonen, M. and Uhlig, S. (2009) What about the "Other" Fusarium Mycotoxins? *World Mycotoxin Journal*, **2**, 181-192. https://doi.org/10.3920/WMJ2008.1124

[19] von Bargen, K.W., Lohrey, L., Cramer, B. and Humpf, H.-U. (2012) Analysis of the Fusarium Mycotoxin Moniliformin in Cereal Samples Using $^{13}C_2$-Moniliformin and High-Resolution Mass Spectrometry. *Journal of Agricultural and Food Chemistry*, **60**, 3586-3591. https://doi.org/10.1021/jf300323d

[20] Ma, N., Abdul Haseeb, H., Xing, F., Su, Z., Shan, L. and Guo, W. (2019) *Fusarium avenaceum*: A Toxigenic Pathogen Causing Ear Rot on Maize in Yunnan Province, China. *Plant Disease*, **103**, 1424. https://doi.org/10.1094/PDIS-11-18-2034-PDN

[21] Sandulachi, E. (2018) Redox Properties of Strawberries and Raspberries. Lambert, Academic Publishing, SIA Omni Scriptum Publishing, Latvia, 109 p. (In Russian)

[22] Paterson, R.R.M. and Nelson, L. (2017) Filamentous Fungal Human Pathogens from Food Emphasising *Aspergillus*, *Fusarium* and *Mucor*. *Microorganisms*, **5**, 44. https://doi.org/10.3390/microorganisms5030044

[23] Siripatrawan, U. and Makino, Y. (2015) Monitoring Fungal Growth on Brown Rice Grains Using Rapid and Non-Destructive Hyperspectral Imaging. *International Journal of Food Microbiology*, **199**, 93-100. https://doi.org/10.1016/j.ijfoodmicro.2015.01.001

[24] De Girolamo, A., Cervellieri, S., Visconti, A. and Pascale, M. (2014) Rapid Analysis of Deoxynivalenol in Durum Wheat by FT-NIR Spectroscopy. *Toxins*, **6**, 3129-3143. https://doi.org/10.3390/toxins6113129

[25] Zhao, T., Chen, M., Jiang, X., Shen, F., He, X., Fang, Y., Liu, Q. and Hu, Q. (2020) Integration of Spectra and Image Features of Vis/NIR Hyperspectral Imaging for Prediction of Deoxynivalenol Contamination in Whole Wheat Flour. *Infrared Physics & Technology*, **109**, Article ID: 103426. https://doi.org/10.1016/j.infrared.2020.103426

[26] Gauthier, L., Bonnin-Verdal, M.N., Marchegay, G., Pinson-Gadais, L. Ducos, C., Richard-Forget, F. and Atanasova-Penichon, V. (2016) Fungal Biotransformation of Chlorogenic and Caffeic Acids by *Fusarium graminearum*: New Insights in the Contribution of Phenolic Acids to Resistance to Deoxynivalenol Accumulation in cereals. *International Journal of Food Microbiology*, **221**, 61-68. https://doi.org/10.1016/j.ijfoodmicro.2016.01.005

[27] Borutova, R. (2020) Alltech European Summer Harvest Survey Shows Variability in Mycotoxin Risk. News & Analysis on the Global Animal Feed Industry. https://www.feednavigator.com/News/Promotional-Features/Alltech-European-Summer-Harvest-Survey-shows-variability-in-mycotoxin-risk

[28] Wenneker, M., Pham, K.T.K., Lemmers, M.E.C., de Boer, F.A., van der Lans, A.M.,

van Leeuwen, P.J., Hollinger, T.C. and Thomma, B.P.H.J. (2016) First Report of *Fusarium avenaceum* Causing Postharvest Decay on "Conference" Pears in the Netherlands. *Plant Disease*, **100**, 1950. https://doi.org/10.1094/PDIS-01-16-0029-PDN

[29] Ploetz, R.C. (2015) Fusarium Wilt of Banana. *Phytopathology*, **105**, 1512-1521. https://doi.org/10.1094/PHYTO-04-15-0101-RVW

[30] Nganje, W.E., Bangsund, D.A., Leistritz, F.L., Wilson, W.W. and Tiapo, N.M. (2004) Regional Economic Impacts of *Fusarium* Head Blight in Wheat and Barley. *Applied Economic Perspectives and Policy*, **26**, 332-347. https://doi.org/10.1111/j.1467-9353.2004.00183.x

[31] Chittem, K., Mathew, F.M., Gregoire, M., Lamppa, R.S., Chang, Y.W., Markell, S.G., Bradley, C., Barasubiye, T. and Goswami, R.S. (2015) Identification and Characterization of *Fusarium* spp. Associated with Root Rots of Field Pea in North Dakota. *European Journal of Plant Pathology*, **143**, 641-649. https://doi.org/10.1007/s10658-015-0714-8

[32] Tiwari, N., Ahmed, S., Kumar, S. and Sarker, A. (2018) Fusarium Wilt: A Killer Disease of Lentil. In: Asku, T., Ed., *Fusarium-Plant Diseases*, *Pathogen Diversity*, *Genetic Diversity*, *Resistance and Molecular Markers*, IntechOpen, Rijeka. https://doi.org/10.5772/intechopen.72508

[33] Del Fiore, A., Reverberi, M., Ricelli, A., Pinzari, F., Serranti, S., Fabbri, A.A., Bonifazi, G. and Fanelli, C. (2010) Early Detection of Toxigenic Fungi on Maize by Hyperspectral Imaging Analysis. *International Journal of Food Microbiology*, **144**, 64-71. https://doi.org/10.1016/j.ijfoodmicro.2010.08.001

[34] Daou, R., Joubrane, K., Maroun, R.G., Rabbaa Khabbaz, L., Ismail, A. and El Khoury, A. (2021) Mycotoxins: Factors Influencing Production and Control Strategies. *AIMS Agriculture and Food*, **6**, 416-447. https://doi.org/10.3934/agrfood.2021025

[35] Perincherry, L., Ajmi, C., Oueslati, S., Waśkiewicz, A. and Stępień, Ł. (2020) Induction of *Fusarium* Lytic Enzymes by Extracts from Resistant and Susceptible Cultivars of Pea (*Pisum sativum* L.). *Pathogens*, **9**, 976. https://doi.org/10.3390/pathogens9110976

[36] Hope, R., Aldred, D. and Magan, N. (2005) Comparison of Environmental Profiles for Growth and Deoxynivalenol Production by *Fusarium culmorum* and *F. graminearum* on Wheat Grain. *Letters in Applied Microbiology*, **40**, 295-300. https://doi.org/10.1111/j.1472-765X.2005.01674.x

[37] Górna, K., Pawłowicz, I., Waśkiewicz, A. and Stępień, Ł. (2016) *Fusarium proliferatum* Strains Change Fumonisin Biosynthesis and Accumulation When Exposed to Host Plant Extracts. *Fungal Biology*, **120**, 884-893. https://doi.org/10.1016/j.funbio.2016.04.004

[38] Atanasova-Penichon, V., Pons, S., Pinson-Gadais, L., Picot, A., Gisèle Marchegay, G., Bonnin-Verdal, M.N., Ducos, C., Barreau, C., Roucolle, J., Sehabiague, P., Carolo, P. and Richard-Forget, F. (2012) Chlorogenic Acid and Maize Ear Rot Resistance: A Dynamic Study Investigating *Fusarium graminearum* Development, Deoxynivalenol Production, and Phenolic Acid Accumulation. *Molecular Plant-Microbe Interactions*, **25**, 1605-1616. https://doi.org/10.1094/MPMI-06-12-0153-R

[39] De Oliveira, T.R., de Souza Jaccoud-Filho, D., Henneberg, L., Michel, M.D., Demiate, I.M., Pinto, A.T.B., Machinski Jr., M. and Barana, A.C. (2009) Maize (*Zea Mays* L) Landraces from the Southern Region of Brazil: Contamination by *Fusarium sp*, Zearalenone, Physical and Mechanical Characteristics of the Kernels. *Brazilian Archives of Biology and Technology*, **52**, 11-16.

https://doi.org/10.1590/S1516-89132009000700002

[40] Cerveró, M.C., Castillo, M.A., Montes, R. and Hernández, E. (2007) Determination of Trichothecenes, Zearalenone and Zearalenols in Commercially Available Corn-Based Foods in Spain. *Revista Iberoamericana de Micología*, **24**, 52-55. https://doi.org/10.1016/S1130-1406(07)70013-X

[41] Alshannaq, A. and Yu, J.-H. (2017) Occurrence, Toxicity, and Analysis of Major Mycotoxins in Food. *International Journal of Environmental Research and Public Health*, **14**, 632. https://doi.org/10.3390/ijerph14060632

[42] Schollenberger, M., Müller, H.-M., Rüfle, M., Suchy, S., Planck, S. and Drochner, W. (2005) Survey of *Fusarium* Toxins in Foodstuffs of Plant Origin Marketed in Germany. *International Journal of Food Microbiology*, **97**, 317-326. https://doi.org/10.1016/j.ijfoodmicro.2004.05.001

[43] Alemu, T., Birhanu, G., Azerefgne, F. and Skinnes, H. (2008) Evidence for Mycotoxin Contamination of Maize in Southern Ethiopia: The Need for Further Multidisciplinary Research. *Cereal Research Communications*, **36**, 337-338.

[44] Witaszak, N., Lalak-Kańczugowska, J., Waśkiewicz, A. and Stępień, L. (2020) The Impacts of Asparagus Extract Fractions on Growth and Fumonisins Biosynthesis in *Fusarium proliferatum*. *Toxins*, **12**, 95. https://doi.org/10.3390/toxins12020095

[45] Bankole, S.A. (1994) Changes in Moisture Content, Fungal Infection and Kernel Germ Inability of Maize in Storage. *International Journal of Tropical Plant Diseases*, **12**, 213-218.

[46] Brown, D., Butchko, R., Busman, M. and Proctor, R. (2007) The *Fusarium verticillioides* FUM Gene Cluster Encodes a Zn(II)2Cys6 Protein That Affects FUM Gene Expression and Fumonisin Production. *Eukaryotic Cell*, **6**, 1210-1218. https://doi.org/10.1128/EC.00400-06

[47] Sun, L., Wang, S., Zhang, W., Chi, F., Hao, X., Bian, J. and Li, Y. (2020) First Report of Sheath Rot of Corn Caused by *Fusarium verticillioides* in Northeast China. *Journal of Plant Pathology*, **102**, 1301-1302. https://doi.org/10.1007/s42161-020-00582-7

[48] Baquião, A.C., Zorzete, P., Reis, T.A., Assunção, E., Vergueiro, S. and Correa, B. (2012) Mycoflora and Mycotoxins in Field Samples of Brazil Nuts. *Food Control*, **28**, 224-229. https://doi.org/10.1016/j.foodcont.2012.05.004

[49] Logrieco, A.F., Ferracane, R., Cozzi, G., Haidukowsky, M., Susca, A., Mulè, G. and Ritieni, A. (2011) Fumonisin B_2 by *Aspergillus niger* in the Grape-Wine Chain: An Additional Potential Mycotoxicological Risk. *Annals of Microbiology*, **61**, 1-3. https://doi.org/10.1007/s13213-010-0133-1

[50] Covert, S.F. (1998) Supernumerary Chromosomes in Filamentous Fungi. *Current Genetics*, **33**, 311-319. https://doi.org/10.1007/s002940050342

[51] Bolton, S.L., Brannen, P.M. and Glenn, A.E. (2016) A Novel Population of *Fusarium fujikuroi* Isolated from Southeastern U.S. Winegrapes Reveals the Need to Re-Evaluate the Species' Fumonisin Production. *Toxins*, **8**, 254. https://doi.org/10.3390/toxins8090254

[52] Richard, J.L., Payne, G.A., Desjardins, A.E., Maragos, C., Norred III, W.P., Pestka, J.J., Phillips, T.D., van Egmond, H.P., Vardon, P.J., Whitaker, T.B. and Wood, G. (2003) Mycotoxins: Risks in Plant, Animal and Human Systems. Council for Agricultural Science and Technology, Ames, IA.

[53] Reverberi, M., Ricelli, A., Zjalic, S., Fabbri, A.A. and Fanelli, C. (2010) Natural Functions of Mycotoxins and Control of Their Biosynthesis in Fungi. *Applied Microbiology and Biotechnology*, **87**, 899-911.

https://doi.org/10.1007/s00253-010-2657-5

[54] Hope, R. and Magan, N. (2003) Two Dimensional Environmental Profiles of Growth, Deoxynivalenol and Nivalenol Production by *Fusarium culmorum* on a Wheat-Based Substrate. *Letters in Applied Microbiology*, **37**, 70-74. https://doi.org/10.1046/j.1472-765X.2003.01358.x

[55] Sturza, R., Găină, B., Ionete, E.R. and Costinel, D. (2017) Autenticitatea și inofensivitatea produselor uvologice. MS Logo, Chişinău, 47-90.

[56] Marín, P., Magan, N., Vázquez, C. and González-Jaén, M.T. (2010) Differential Effect of Environmental Conditions on the Growth and Regulation of the Fumonisin Biosynthetic Gene FUM1 in the Maize Pathogens and Fumonisin Producers *Fusarium verticillioides* and *Fusarium proliferatum*. *FEMS Microbiology Ecology*, **73**, 303-311. https://doi.org/10.1111/j.1574-6941.2010.00894.x

[57] Jimenez-Garcia, S.N., Garcia-Mier, L., Garcia-Trejo, J.F., Ramirez-Gomez, X.S., Ramon, G., Guevara-Gonzalez, R.G. and Feregrino-Perez, A.A. (2018) *Fusarium* Mycotoxins and Metabolites That Modulate Their Production. In: Ascun, T., Ed., *Fusarium—Plant Diseases*, *Pathogen Diversity*, *Genetic Diversity*, *Resistance and Molecular Markers*, IntechOpen, Rijeka. https://doi.org/10.5772/intechopen.72874

[58] Vylkova, S. (2017) Environmental pH Modulation by Pathogenic Fungi as a Strategy to Conquer the Host. *PLoS Pathogens*, **13**, e1006149. https://doi.org/10.1371/journal.ppat.1006149

[59] Sandulachi, E. (2020) Water Activity in Food Products. Monograph, Tehnica-UTM, Chisinau. (In Romanian)

[60] Miller, J.D. (2001) Factors That Affect the Occurrence of Fumonisin. *Environmental Health Perspectives*, **109**, 321-324. https://doi.org/10.1289/ehp.01109s2321

[61] López-Errasquín, E., Vázquez, C., Jiménez, M. and González-Jaén, M.T. (2007) Real-Time RT-PCR Assay to Quantify the Expression of FUM1 and FUM19 Genes from the Fumonisin-Producing *Fusarium verticillioides*. *Journal of Microbiological Methods*, **68**, 312-317. https://doi.org/10.1016/j.mimet.2006.09.007

[62] Kochiieru, Y., Mankevi, A., Cesevi, J., Semaškienė, R., Ramanauskienė, J., Gorash, A., Janavičienė, S. and Venslovas, E. (2021) The Impact of Harvesting Time on *Fusarium* Mycotoxins in Spring Wheat Grain and Their Interaction with Grain Quality. *Agronomy*, **11**, 642. https://doi.org/10.3390/agronomy11040642

[63] Waśkiewicz, A., Stępień, L., Wilman, K. and Kachlicki, P. (2013) Diversity of Pea-Associated *F. proliferatum* and *F. verticillioides* Populations Revealed by FUM1 Sequence Analysis and Fumonisin Biosynthesis. *Toxins*, **5**, 488-503. https://doi.org/10.3390/toxins5030488

[64] Begum, F. and Samajpati, N. (2000) Mycotoxin Production on Rice, Pulses and Oilseeds. *Naturwissenschaften*, **87**, 275-277. https://doi.org/10.1007/s001140050720

[65] Bojja, R.S., Cerny, R.L., Proctor, R.H. and Du, L. (2004) Determining the Biosynthetic Sequence in the Early Steps of the Fumonisin Pathway by Use of Three Gene-Disruption Mutants of *Fusarium verticillioides*. *Journal of Agricultural and Food Chemistry*, **52**, 2855-2860. https://doi.org/10.1021/jf035429z

[66] Gautier, C., Pinson-Gadais, L., Verdal-Bonnin, M.-N., Ducos, C., Tremblay, J., Chéreau, S., Atanasova, V. and Richard-Forget, F. (2020) Investigating the Efficiency of Hydroxycinnamic Acids to Inhibit the Production of Enniatins by *Fusarium avenaceum* and Modulate the Expression of Enniatins Biosynthetic Genes. *Toxins*, **12**, 735. https://doi.org/10.3390/toxins12120735

[67] Wagacha, J. and Muthomi, J. (2008) Mycotoxin Problem in Africa: Current Status,

Implications to Food Safety and Possible Management Strategies. *International Journal of Food Microbiology*, **124**, 1-12. https://doi.org/10.1016/j.ijfoodmicro.2008.01.008

[68] Dix, N.J. and Webster, J. (1995) Fungi of Extreme Environments. In: *Fungal Ecology*, Springer, Dordrecht, 322-340. https://doi.org/10.1007/978-94-011-0693-1_12

[69] Rheeder, J.P., Marasas, W.F.O. and Vismer, H.F. (2002) Production of Fumonisin Analogs by *Fusarium* Species. *Applied and Environmental Microbiology*, **68**, 2101-2105. https://doi.org/10.1128/AEM.68.5.2101-2105.2002

[70] Greeff-Laubscher, M.R., Beukes, I., Marais, G.J. and Jacobs, K. (2020) Mycotoxin Production by Three Different Toxigenic Fungi Genera on Formulated Abalone Feed and the Effect of an Aquatic Environment on Fumonisins. *International Journal on Fungal Biology*, **11**, 105-117. https://doi.org/10.1080/21501203.2019.1604575

[71] Özcelik, S. and Özcelik, N. (2004) Interacting Effects of Time, Temperature, pH and Simple Sugars on Biomass and Toxic Metabolite Production by Three *Alternaria spp*. *Mycopathologia*, **109**, 171-175. https://doi.org/10.1007/BF00436806

[72] Liu, J., Sun, L.H., Zhang, N.Y., Guo, J., Li, C., Rajput, S.A. and Qi, D. (2016) Effects of Nutrients in Substrates of Different Grains on Aflatoxin B 1 Production by *Aspergillus flavus*. *BioMed Research International*, **2016**, Article ID: 7232858. https://doi.org/10.1155/2016/7232858

[73] Uppala, S.S., Bowen, K.L. and Woods, F.M. (2013) Pre-Harvest Aflatoxin Contamination and Soluble Sugars of Peanut. *Peanut Science*, **40**, 40-51. https://doi.org/10.3146/PS12-9.1

[74] Cheli, F., Campagnoli, A., Pinotii, L., Savoini, G. and Dell'orto, V. (2009) Electronic Nose for Determination of Aflatoxins in Maize. *Biotechnologie*, *Agronomie*, *Société et Environnement/Biotechnology*, *Agronomy*, *Society and Environment*, **13**, 39-43.

[75] Djeugap, J.F., Ghimire, S., Wanjuki, I., Muiruri, A. and Harvey, J. (2019) Mycotoxin Contamination of Edible Non-Timber Forest Products in Cameroon. *Toxins*, **11**, 430. https://doi.org/10.3390/toxins11070430

[76] Chen, P. and Sun, Z. (1991) A Review of Non-Destructive Methods for Quality Evaluation and Sorting of Agricultural Products. *Journal of Agricultural Engineering Research*, **49**, 85-98. https://doi.org/10.1016/0021-8634(91)80030-I

[77] Lee, K.M., Herrman, T.J., Bisrat, Y. and Murray, S.C. (2014) Feasibility of Surface-Enhanced Raman Spectroscopy for Rapid Detection of Aflatoxins in Maize. *Journal of Agricultural and Food Chemistry*, **62**, 4466-4474. https://doi.org/10.1021/jf500854u

[78] Kizis, D., Vichou, A.E. and Natskoulis, P.I. (2021) Recent Advances in Mycotoxin Analysis and Detection of Mycotoxigenic Fungi in Grapes and Derived Products. *Sustainability*, **13**, 2537. https://doi.org/10.3390/su13052537

[79] Balabin, R.M., Safieva, R.Z. and Lomakina, E.I. (2010) Gasoline Classification Using Near Infrared (NIR) Spectroscopy Data: Comparison of Multivariate Techniques. *Analytica Chimica Acta*, **67**, 27-35. https://doi.org/10.1016/j.aca.2010.05.013

[80] Levasseur-Garcia, C., Bailly, S., Kleiber, D. and Bailly, J.D. (2015) Assessing Risk of Fumonisin Contamination in Maize Using Near-Infrared Spectroscopy. *Journal of Chemistry*, **2015**, Article ID: 485864. https://doi.org/10.1155/2015/485864

[81] Lahlali, R., Kumar, S., Wang, L., Forseille, L., Sylvain, N., Korbas, M., Muir, D., Swerhone, G., Lawrence, J.R., Fobert, P.R., Peng, G. and Karunakaran, C. (2016) Cell Wall Biomolecular Composition Plays a Potential Role in the Host Type II Resistance to Fusarium Head Blight in Wheat. *Frontiers in Microbiology*, **7**, 910.

https://doi.org/10.3389/fmicb.2016.00910

[82] Orina, I., Manley, M. and Williams, P.J. (2017) Non-Destructive Techniques for the Detection of Fungal Infection in Cereal Grains. *Food Research International*, **100**, 74-86. https://doi.org/10.1016/j.foodres.2017.07.069

[83] Bauriegel, E., Giebel, A., Geyer, M., Schmidt, U. and Herppich, W.B. (2011) Early Detection of Fusarium Infection in Wheat Using Hyper-Spectral Imaging. *Computers and Electronics in Agriculture*, **75**, 304-312. https://doi.org/10.1016/j.compag.2010.12.006

[84] Kheiralipour, K., Ahmadi, H., Rajabipour, A., Rafiee, S., Javan-Nikkhah, M., Jayas, D.S. and Siliveru, K. (2016) Detection of Fungal Infection in Pistachio Kernel by Long-Wave Near-Infrared Hyperspectral Imaging Technique. *Quality Assurance and Safety of Crops & Foods*, **8**, 129-135. https://doi.org/10.3920/QAS2015.0606

[85] Williams, P.J., Geladi, P., Britz, T.J. and Manley, M. (2012) Near-Infrared (NIR) Hyperspectral Imaging and Multivariate Image Analysis to Study Growth Characteristics and Differences between Species and Strains of Members of the Genus Fusarium. *Analytical and Bioanalytical Chemistry*, **404**, 1759-1769. https://doi.org/10.1007/s00216-012-6313-z

[86] Paolesse, R., Nardis, S., Monti, D., Stefanelli, M. and Di Natale, C. (2017) Porphyrinoids for Chemical Sensor Applications. *Chemical Reviews*, **117**, 2517-2583. https://doi.org/10.1021/acs.chemrev.6b00361

[87] Jia, B., Wang, W., Ni, X.Z., Chu, X., Yoon, S.C. and Lawrence, K.C. (2020) Detection of Mycotoxins and Toxigenic Fungi in Cereal Grains Using Vibrational Spectroscopic Techniques: A Review. *World Mycotoxin Journal*, **13**, 163-178. https://doi.org/10.3920/WMJ2019.2510

[88] Narvankar, D.S., Singh, C.B., Jayas, D.S. and White, N.D.G. (2009) Assessment of Soft X-Ray Imaging for Detection of Fungal Infection in Wheat. *Biosystems Engineering*, **103**, 49-56. https://doi.org/10.1016/j.biosystemseng.2009.01.016

[89] Chelladurai, V., Jayas, D. and White, N. (2010) Thermal Imaging for Detecting Fungal Infection in Stored Wheat. *Journal of Stored Products Research*, **46**, 174-179. https://doi.org/10.1016/j.jspr.2010.04.002

[90] Chaitra, C. and Suresh, K.V. (2016) Identification and Evaluation of Technology for Detection of Aflatoxin Contaminated Peanut. *Communications on Applied Electronics* (*CAE*), **4**, 46-50.

[91] Mehrabi, R., Gohari, A.M. and Kema, G.H.J. (2017) Karyotype Variability in Plant-Pathogenic Fungi. *Annual Review of Phytopathology*, **4**, 483-503. https://doi.org/10.1146/annurev-phyto-080615-095928

[92] Vanheule, A., Audenaert, K., Warris, S., van de Geest, H., Schijlen, E., Höfte, M., De Saeger, S., Haesaert, G., Waalwijk, C. and van der Lee, T. (2016) Living Apart Together: Crosstalk between the Core and Supernumerary Genomes in a Fungal Plant Pathogen. *BMC Genomics*, **17**, Article No. 670. https://doi.org/10.1186/s12864-016-2941-6

[93] Golob, P. (2007) On-Farm Mycotoxin Control in Food and Feed Grain. Food and Agriculture Organization of the United Nations, Rome.

[94] Rose, L.J., Okoth, S., Flett, B.C., van Rensburg, B.J. and Viljoen, A. (2019) Preharvest Management Strategies and Their Impact on Mycotoxigenic Fungi and Associated Mycotoxins. In: Njobeh, P.B. and Stepman, F., Eds., *Fungi and Mycotoxins*, IntechOpen, Rijeka.

[95] Mannaa, M. and Kim, K.D. (2017) Control Strategies for Deleterious Grain Fungi

and Mycotoxin Production from Preharvest to Postharvest Stages of Cereal Crops: A Review. *Life Science and Natural Resources Research*, **25**, 13-27.

[96] Mahuku, G., Nzioki, H.S., Mutegi, C., Kanampiu, F., Narrod, C. and Makumbi, D. (2019) Pre-Harvest Management Is a Critical Practice for Minimizing Aflatoxin Contamination of Maize. *Food Control*, **96**, 219-226. https://doi.org/10.1016/j.foodcont.2018.08.032

[97] Henry, P.M., Kirkpatrick, S.C., Islas, C.M., Pastrana, A.M., Yoshisato, J.A., Koike, S.T., Daugovish, O. and Gordon, T.R. (2017) The Population of *Fusarium oxysporum f. sp. fragariae*, Cause of *Fusarium* Wilt of Strawberry, in California. *Plant Disease*, **101**, 550-556. https://doi.org/10.1094/PDIS-07-16-1058-RE

[98] Haidukowski, M., Pascale, M., Perrone, G., Pancaldi, D., Campagna, C. and Visconti, A. (2005) Effect of Fungicides on the Development of Fusarium Head Blight, Yield and Deoxynivalenol Accumulation in Wheat Inoculated under Field Conditions with *Fusarium graminearum* and *Fusarium culmorum*. *Journal of the Science of Food and Agriculture*, **85**, 191-198. https://doi.org/10.1002/jsfa.1965

[99] Rychlik, M., Humpf, H.U., Marko, D., Dänicke, S., Mally, A., Berthiller, F., Klaffke, H. and Lorenz, N. (2014) Proposal of a Comprehensive Definition of Modified and Other Forms of Mycotoxins Including "Masked" Mycotoxins. *Mycotoxin Research*, **30**, 197-205. https://doi.org/10.1007/s12550-014-0203-5

[100] FAO/IAEA Training and Reference Center for Food and Pesticide Control (2001) Manual on the Application of the HACCP System in Mycotoxin Prevention and Control. Food and Agriculture Organization, Rome, 73.

[101] Nelson, P.E., Desjardins, A.E. and Plattner, R.D. (1993) Fumonisins, Mycotoxins Produced by Fusarium Species: Biology, Chemistry and Significance. *Annual Review of Phytopathology*, **31**, 233-252. https://doi.org/10.1146/annurev.py.31.090193.001313

[102] Munkvold, G. (2017) *Fusarium* Species and Their Associated Mycotoxins. In: Moretti, A. and Susca, A., Eds., *Mycotoxigenic Fungi. Methods in Molecular Biology*, Vol. 1542, Humana Press, New York, NY, 51-106. https://doi.org/10.1007/978-1-4939-6707-0_4

[103] Salazar-González, C., Velásquez-Ortiz, D. and Gómez-López, E. (2020) Detection of Mycotoxins Produced by *Fusarium* Species in Colombia. *Agronomía Colombiana*, **38**, 197-204. https://doi.org/10.15446/agron.colomb.v38n2.77176

[104] Koike, S.T. and Gordon, T.R. (2015) Management of *Fusarium* Wilt of Strawberry. *Crop Protection*, **73**, 67-72. https://doi.org/10.1016/j.cropro.2015.02.003

[105] Bankole, S.A. and Adebanjo, A. (2003) Mycotoxins in Food in West Africa: Current Situation and Possibilities of Controlling It. *African Journal of Biotechnology*, **2**, 254-263. https://doi.org/10.5897/AJB2003.000-1053

[106] Ferrigo, D., Raiola, A. and Causin, R. (2016) *Fusarium* Toxins in Cereals: Occurrence, Legislation, Factors Promoting the Appearance and Their Management. *Molecules*, **21**, 627. https://doi.org/10.3390/molecules21050627

[107] Anoman, A., Koffi, K., Aboua, K. and Koussemon, M. (2018) Determination of ETM, Histamine and Mycotoxins in Garba, a Traditional Ivoirian Meal. *American Journal of Analytical Chemistry*, **9**, 245-256. https://doi.org/10.4236/ajac.2018.94019