Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) in relation to the effects of climate change on the presence of mycotoxins in food

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Working group

Sonia Marín Sillué (Coordinator), Álvaro Daschner, Francisco José Morales Navas, Carmen Rubio Armendáriz, María José Ruiz Leal and Pedro Burdaspal Pérez (AESAN)

Abstract

Mycotoxins are toxic metabolites produced by multiple species of molds that can develop in crops and food under certain conditions of humidity and temperature. Therefore, it is believed that the appearance of mycotoxins will be greatly affected by future climate scenarios. Mycotoxin contamination is a problem, therefore, in foods of plant origin, mainly in cereals and nuts, but also in foods of animal origin, when the animal has been fed with contaminated feed. The review of the existing scientific evidence in relation to climate change points to a geographical redistribution of the incidence of the different mycotoxins, which at a global level may not necessarily represent an increase, since the possible reduction in cultivable areas as a consequence of extreme weather conditions must be taken into account. However, even locally, and focusing on Southern Europe, a clear increase in the incidence of aflatoxins in corn, traditionally linked to tropical climates, and also a worsening of the already existing problem of fumonisins in this same cereal, can be expected.

There are various mitigation strategies for the growing mycotoxin problem, including preventive

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agricultural practices in the field, during the harvest and storage of cereals, physical, chemical and biological decontamination processes, and self-monitoring based on sampling and analysis in the different steps of the food chain.

For all the above, it is necessary to insist on the convenience of joining efforts not only against climate change as a global phenomenon, but also in the promotion and adoption of specific projects and programs aimed at preventing and mitigating the incidence of the presence of mycotoxins in feed and food products, with the participation of the public and private sectors, naturally including the scientific community, those responsible for risk management, producers and even consumers through the appropriate communication strategies.

Key words

Climate change, mycotoxins, *Aspergillus, Fusarium*, aflatoxins, trichothecenes, fumonisins.

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1. Introduction

Mycotoxins are toxic metabolites produced by multiple species of mould that may develop in crops and foods under certain conditions of humidity and temperature.

There are a large number of mycotoxins and within the most frequent ones, the ones that pose a greater risk to human and animal health are aflatoxins (AF), ochratoxin A (OTA), patulin (PAT), fumonisins (FBs), zearalenone (ZEN) and deoxynivalenol (DON). Some of these toxins are among the most powerful natural carcinogenic agents known to science (Ostry et al., 2017). Additionally, their adverse effects on health may include digestive problems, renal toxicity, immunosuppression, and oestrogenic effects.

Once mycotoxins are present in raw materials, they become highly stable and resistant to processes of drying, milling and processing. Additionally, due to their thermal stability, they are not significantly affected by heat treatments. According to a recently updated report by the World Bank (Kos et al., 2019) (Eskola et al., 2020), 25 % of crops worldwide may be contaminated with mycotoxins at levels exceeding the legally established maximum limits. This value may ascend to 80 % if we consider the mere detectable presence of mycotoxins. This high rate is possibly due to a combination of the improved sensitivity of testing methods and the impact of climate change. It is extremely important that detectable levels are not ignored, as human beings are exposed to a blend of mycotoxins through their diet, which may lead to combined adverse effects on health (Eskola et al., 2020).

In its 2019 annual report, the Rapid Alert System for Food and Feed (RASFF) concluded that, as has been the case since this system was implemented, problems related to mycotoxins and pathogenic microorganisms are the primary problems in third-country products, mycotoxins being the most reported type of hazard. AFs are the most frequently reported mycotoxins, especially in nuts. OTA is found primarily in fruits and vegetables, especially in raisins, followed by dried figs.

Climate change has been identified as an emerging global problem. Climate change entails increased levels of CO_2 and other greenhouse gases in the atmosphere, leading not only to increased temperatures, but also to greater variability in weather conditions, including changes in rainfall patterns, droughts and storms. The effects of climate change may in turn lead to changes in Nature and the appearance of hazards to food safety. Generally, it has been accepted that the influence of climate change on agricultural systems has a considerable impact on food safety (Camardo Leggieri et al., 2019).

Consequently, it is estimated that the appearance of mycotoxins shall be greatly affected by future climate scenarios (Cotty and Jaime-García, 2007). Increased temperatures and CO_2, variation in the intensity and distribution of rainfall, as well as extreme weather events, have an effect on the species of moulds that are predominant in different forms, based on their ecological needs (Camardo Leggieri et al., 2019). Environmental changes are modifying the relationship between plant growth, associated fungal diseases, and pest populations, owing to an imbalance in the relationship between the pathogen/pest, plant and the environment (Grulke, 2011). New combinations of mycotoxins/host plants/geographical areas are drawing the attention of the scientific community, as they require new tools for detection and identification, and a deeper knowledge of the biology and genetics of toxigenic fungi (Moretti et al., 2019). Climate change may also alter other factors such as the effectiveness of the pre-harvest application of pesticides, changes in geographical distribution, or the life cycles of insects that promote fungal infections in crops.

For all of these reasons, and faced with the foreseeable increase of mycotoxins in foods, the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) has been asked to review the currently available scientific literature on the effects of climate change in the production and presence of mycotoxins in foods, and to highlight possible measures for mitigation that may be applied.

2. Mycotoxins

The biological effects of mycotoxins, molecules that usually have a low molecular weight, may have various functions: antibiotic, insecticide, plant killer, enzymatic and pigmentation functions, etc. They are called mycotoxins when they lead to diseases in vertebrate animals or humans, owing to their toxic effects. Ever since man invented agriculture, there have been diseases and outbreaks from the consumption of contaminated foods or feeds. Plant domestication is linked to the loss of genetic variability and with it, to the risk of losing the capacity for defence against fungi. Fungi may alter foods at different stages of the food chain, from their cultivation to their final consumption by human beings (Pleadin et al., 2019). Thus, unfavourable conditions during plant growth, harvesting, storage, shipping and processing may carry the risk of mycotoxin contamination. Chemical stability, like thermal stability of mycotoxins, is an added problem as processing (including high temperatures) does not destroy and eliminate them.

Given that mycotoxins are one of the risks associated with regularly consumed foods, special attention is paid to them by food safety agencies. The foods most prone to mycotoxin accumulation are cereals (including maize), nuts and their by-products, and dried fruits. When mycotoxins make their way to the end consumer in this manner, leading to food poisoning, it is deemed primary mycotoxicosis, while secondary mycotoxicosis is that which is produced by exposure to mycotoxins upon ingesting food products of animal origin (dairy or meat products) after biotransformation processes, when the animals have been fed with contaminated feed.

The first identified mycotoxin was aflatoxin (AF) in 1961. Since then, some 400 mycotoxins have been identified. *Aspergillus*, *Fusarium* and *Penicillium* species are considered the most important producers of mycotoxins. The most important mycotoxins today are AFs, DON, T-2 and HT-2 toxins, ZEN, FBs, OTA, ergot alkaloids, PAT and citrinin (Eskola et al., 2020).

Acute or chronic exposure to mycotoxins through diet can lead to a series of toxic effects on human and animal health. These include neurotoxicity, hepatotoxicity, pulmonary toxicity, renal toxicity, haematological toxicity, damage to the immune system, the digestive tract, or endocrine glands (Edite Bezerra da Rocha et al., 2014).

Apart from the dosage of the mycotoxin in question, the biological effects produced depend on other factors such as individual sensitivity (derived from genetic variability and genetic differences of which those related to the cytochrome p450 (CYP 450) are noteworthy), age, nutritional and basal health status, and normal intestinal function. The last is of especial interest, given that mycotoxins that may contaminate foods first enter into contact with the gastrointestinal tract. There is some evidence that intestinal flora may be able to degrade certain mycotoxins, especially trichothecenes and OTA, if the host has a balanced flora (Liew and Mohd-Redzwan, 2018).

Another aspect to be considered is the difficulty of assessing the possible toxic effects when different mycotoxins are simultaneously present in foods, or in synergy with other toxic agents such as endocrine disruptors.

Owing to their importance, seriousness and frequency, this report focuses on AFs and *Fusarium* toxins.

2.1 Aflatoxins

AFs produced by *Aspergilus flavus* and *Aspergillus parasiticus* are the most common and relevant mycotoxins. More than 14 AFs have been identified. Aflatoxin B1 (AFB1) is the most potent and active aflatoxin. The most common dietary sources of exposure are cereals and nuts, although other foods such as coffee, oilseeds (soy, sunflower), spices or milk (prone to containing the aflatoxin M1 (AFM1), a product of AFB1 metabolism) may be equally contaminated owing to defects in production and storage, or due to animal exposure (WHO, 2018). AFs are among the most mutagenic and carcinogenic substances known and they are placed in group 1 (substance deemed carcinogenic to humans) of the classification of the International Agency for Research of Cancer (IARC). AFs are genotoxic and AFB1 may cause hepatocellular carcinomas in human beings (EFSA, 2020). Chronic exposure induces hepatocellular cancer. There is sufficient experimental and epidemiological evidence that chronic exposure induces hepatocellular cancer and therefore a No Observed Adverse Effect Level (NOAEL) is lacking, and its exposure must be reduced as much as possible (Fromme et al., 2016).

The CONTAM Panel of the European Food Safety Authority (EFSA) selected a Benchmark Dose Level (BMDL) for a benchmark response of 10 % of 0.4 µg/kg b.w./day for the incidence of hepatocellular cancer in male rats following AFB1 exposure to be used in a Margin of Exposure (MOE) approach. In Europe, MOE values range between 5000 and 29 for exposure to AFB1 and between 100 000 and 508 for exposure to AFM1. The calculated MOEs are below 10 000 for AFB1 and also for AFM1 where some surveys, particularly for younger age groups, have an MOE below 10 000 (EFSA, 2020). According to the EFSA, this poses a health hazard. The estimated risks of cancer in human beings from exposure to AFB1 and AFM1 are in line with the conclusions obtained from the MOEs. The conclusions are also applicable to the combined exposure to the five AFS (AFB1, AFB2, AFG1, AFG2 and AFM1) (EFSA, 2020).

Epidemiological studies reported since 2006 have added to the weight of the evidence that AF exposure is associated with a risk of developing hepatocellular cancer, and people infected with the hepatitis B (HBV) or hepatitis C virus (HCV) are at greater risk. The data suggests that HBV infection of the liver alters the expression of the gene coding for the enzymes, which metabolise/detoxify AFs, such as an induction of CYP 450 or decrease in glutathione-Stransferase (GST) activity. This may provide one mechanistic basis for the higher risk of liver cancer among HBV-infected individuals exposed to AFs (EFSA, 2020).

To set the maximum permitted limits of AFs, the "ALARA" (As Low As Reasonably Achievable) principle has been followed, that is to say, values with acceptable level of risk without provoking a food shortage or ruining production sectors.

The hepatotoxicity of AFB1 depends on the variations in the gene coding for CYP 450, as the isoenzymes of CYP 450 metabolise AFB1 in the liver to exo-epoxides that are highly reactive to DNA, RNA and proteins, that subsequently react with the gene suppressor p53, facilitating mutations and thus malignant transformation (carcinogenic capacity), especially in the simultaneous presence of hepatitis B infection. It is estimated that up to 155 000 deaths occur annually due to hepatocarcinoma caused by chronic exposure to AFs all over the world, especially in Africa and Asia (Liu and Wu, 2010).

Acute exposure to high doses may lead to acute hepatitis and death due to the above-mentioned biotransformation into aflatoxin-8,9-epoxide. Clinical symptoms include vomiting, abdominal cramps, pulmonary oedema (Kensler et al., 2011). Since the 1960s, outbreaks of acute hepatic insufficiency have been observed among human populations (jaundice, lethargy, nausea, death) identified as aflatoxicosis (WHO, 2018).

AFs exposure has also been linked to other types of renal or colon cancer, as well as congenital deformities in children. Other effects of chronic exposure to AFB1 are susceptibility to infections due to immunosuppressant effects and delayed growth in human beings (Liew and Mohd-Redzwan, 2018).

The effects on the intestinal tract lead to alterations in the intestinal wall and the effects of apoptosis have been observed in the jejunum in animals, leukocyte and lymphocyte infiltration, and degeneration of the intestinal microvilli. These toxic effects are comparable to those of other mycotoxins (Liew and Mohd-Redzwan, 2018).

Consequently, Regulation (EC) No. 1881/2006 has set maximum permitted limits for cereals, nuts, oilseeds, dried fruits and spices between 4 and 15 µg/kg for total AFs, and between 2 and 12 µg/kg for AFB1, in addition to 0.05 µg/kg of AFM1 for raw milk, heat-treated milk, and milk for the manufacture of milk-based products (EU, 2006).

2.2 Trichothecenes

Trichothecenes are a group of mycotoxins produced by the *Fusarium* genus. There are approximately 170 identified trichothecenes (Marin et al., 2013) which have been divided into four types (A-D) based on variations in the functional hydroxyl and lateral acetyl groups. DON and its acetyl derivatives, 3-acetyl-deoxynivalenol (3-ADON) and 15-acetyl-deoxynivalenol (15-ADON) belong to Group B.

DON, also called vomitoxin, is highly stable in storage, milling and processing, and does not degrade at high temperatures (Minervini et al., 2005) (EFSA, 2011). It is produced by fungi from the *Fusarium* genus and it is mainly found in cereal grains such as wheat, maize, oats, barley, rye and rice (Sahu et al., 2010). The main producers of DON are *Fusarium graminearum* in temperate and humid areas (North America, South America and China) and *Fusarium culmorum* in areas with cold environmental conditions (Finland, France, Poland and the Netherlands). These fungi are present in the soil and constitute important plant pathogens that grow in crops (Marin et al., 2013). It is considered one of the most important and most widespread trichothecenes in cereals and feeds, responsible for significant financial losses in the animal industry (Cetin and Bullerman, 2005). DON is not homogenously distributed in grain, it is more concentrated in the outer layers and therefore foods with bran constitute a greater risk (Soriano del Castillo, 2007).

DON is considered to be one of the most important mycotoxins in this family in terms of toxicity to human and animal health. It targets the gastrointestinal system, generally entering the organism orally, and the intestinal epithelium is the first tissue targeted by food poisoning. As a result, it may cause anorexia, weight loss, and malnutrition (Lori and Rizzo, 2007). The main toxic effects of DON include gastrointestinal disorders, blood disorders and modifications of biochemical parameters in blood, inhibiting macromolecule synthesis (RNA, DNA and proteins), disorders of the immune system, endocrine dysfunction, hepatotoxicity, etc. (Ndossi et al., 2012) (Savard et al., 2014) (Yang et al., 2014).

In high doses, it may cause acute toxicity leading to skin irritation and abdominal symptoms (vomiting and diarrhoea). Studies on animals have revealed necrotic lesions in the gastrointestinal tract with increased intestinal permeability, which affects the function of intestinal absorption and immune function (Liew and Mohd-Redzwan, 2018). DON is also able to cross the blood-brain barrier leading to dizziness and headaches (Maresca, 2013). Outbreaks have been reported above all in India, China and the United States (Rotter et al., 1996).

Chronic effects are not as clear in human beings, but weight loss and anorexia have been observed in animals. Direct damage to intestinal flora has been observed in pigs (Maresca, 2013).

Chronic intoxication is indicated by signs such as necrosis, skin problems, leukopenia, gastrointestinal inflammation, weight loss and haemorrhages (Cetin y Bullerman, 2005). With regard to immune response, there is data that reveals an inhibition of the proliferation of human lymphocytes by DON (Zain, 2011).

Chronic exposure to DON may be a causal factor of IgA nephropathy in humans and it is also involved in the etiology of oesophageal cancer in men (Juan-García et al., 2015).

There are studies on the presence of DON in contaminated foods, compiled in the national monitoring programmes of Finland, Sweden, Norway and the Netherlands over a period of 20 years, which reveal that DON has an incidence higher than 46 % in the products tested (Van Der Fels-Klerx et al., 2012). Additionally, DON has been found in different types of foods from different countries of the European Union (EU) including Spain (Rodríguez-Carrasco et al., 2015). Therefore, given the toxicity of DON and its presence in foods, a Provisional Maximum Tolerable Daily Intake (PMTDI) of 1 μg/kg b.w./day (SCF, 2002) has been established. The maximum DON levels have been set by Regulation (EC) No. 1881/2006 and Regulation (EC) No. 1126/2007, which vary between 200 μg/kg for cereal-based processed baby foods and 750 μg/kg in cereals for direct human consumption; and up to 1750 μg/kg for unprocessed durum wheat, oats and maize (EU, 2007).

3. Factors that influence mycotoxin production in fields

The ability of fungi to grow, survive and interact with crops and produce mycotoxins is largely dependent on a series of environmental factors, mainly temperature, relative humidity, and the presence of insects. These factors are directly related to climate change and variations in temperature and rainfall.

Climate change from global warming can alter the stages and rates of development of toxigenic fungi and modify host resistance and host-pathogen interactions, also greatly influencing the conditions for mycotoxin production that vary for each individual pathogen (Moretti et al., 2019). Therefore, the effects of climate change on toxigenic fungi and mycotoxin contamination are currently drawing the attention of scientists, especially from a risk analysis perspective (Uhlig et al., 2013) (García-Cela et al., 2015) (Battilani et al., 2016) (Assunção et al., 2018) (Milićević et al., 2019).

In vitro studies reveal that the expected rise in temperature promotes the proliferation of toxigenic moulds, especially those belonging to the *Aspergillus* genus. Toxigenic species such as *A. flavus* are predominant in tropical and sub-tropical zones, where they proliferate in the soil, in crop residue, and in the crops themselves. The progressive rise in temperatures in temperate regions entails a corresponding increase in the risk of *A. flavus* contamination, when approaching its optimal temperature range of 30-33 ºC (Jaime-García and Cotty, 2010) (Paterson and Lima, 2010). However, extreme heatwaves with temperatures higher than 37 ºC may reduce the presence of AFs by inhibiting biosynthesis (O'Brian et al., 2007). *Fusarium* related infections are more common in temperate climates, especially in cereal-growing zones characterised by high average and maximum temperatures during anthesis. Additionally, *Fusarium* spp. appears to be negatively affected by an increased number of days with temperatures below 0 ºC, probably due to an adverse effect of low temperatures on the inoculum of *Fusarium* spp. in the field in winter. Additionally, high average and maximum temperatures in summer may have a negative effect on the incidence of *Fusarium* spp. (Pereyra et al., 2004).

Periods of drought are also associated with the growth of toxigenic moulds, as they promote their sporulation and consequently, their dispersion. Their development is also stimulated by stress in colonised plants and the lowering of the plants' natural immunity to pathogens. Drought conditions also contribute, for example, to cracks in the shells of pistachios and peanuts, thus leading to a greater incidence of *A. flavus* and consequent AF contamination (Cotty and Jaime-García, 2007). On the other hand, torrential rains that occur during the flowering of cereals may unleash the development of *Fusarium* in crops.

Studies on the concentration of atmospheric CO_2 throw up varied results. Toxigenic moulds are able to grow in CO_2 conditions that are much higher than those predicted in different climate change scenarios. For example, elevated levels of atmospheric CO_2 increase the susceptibility of maize to *Fusarium verticillioides*, but this is due to the attenuated induction of maize defences at elevated CO_2 levels. Nevertheless, it leads to a reduction in the amount of FB produced per unit of *F. verticillioides* biomass, such that FB concentration does not suffer significant variation (Vaughan et al., 2014).

Climate change also affects predominant pests, therefore the incidence of *Fusarium*, linked to the role of insects as vectors in crops such as maize, may largely depend on the survival, increase or disappearance of these insects (Vaughan et al., 2014).

Insects and other arthropods that feed on nuts, pods and spikes usually facilitate the establishment of toxigenic fungi (Dowd et al., 2003). There are insects such as beetles (*Carpophilus lugubris*) that feed on fungus-infested maize and later act as vectors of *Fusarium* species to contaminate the ears of corn, as these beetles feed on the pollen and flowers of corn. These insects, such as the

European corn borer, *Ostrinia nubilalis*, or the corn earworm *Helicoverpa zea*, damage corn ear tissue and facilitate the establishment of fungi. Rates of *Fusarium* spp. contamination of ears of corn as high as 90 % have been reported.

Given that insects are ectothermic, increased environmental temperature has a direct influence on their metabolic and developmental rates and activity patterns (Altermatt, 2010). All of these factors may lead to increased insect populations, increased damage to crops, greater incidence of fungal contamination, and by extension, greater levels of mycotoxins.

In temperate regions, insects must synchronise their development and reproduction with favourable warm periods and their diapause with adverse periods of cold (Roff, 1983). It is probable that warmer winter temperatures shall lead to greater survival of insects during their hibernation period (Porter et al., 1991); and higher summer temperatures of prolonged duration shall influence population growth and number of generations per year (Van Dyck and Wiklund, 2002).

Voltinism in the European corn borer varies from one generation per year in the Northern Corn Belt to two or more per year in the Southern Corn Belt in the United States (Showers, 1993). Since the mid-19th century, studies have indicated that voltinism has increased, leading to an important rise in the proportion of moths and butterflies in Central Europe (Altermatt, 2010). This study showed that voltinism had increased in 44 out of 263 evaluated species since 1980. These results are linked to rising temperatures in Central Europe, especially in the last 30 years (Altermatt, 2010). In Iowa (United States) two generations of *O. nubialis* are produced each year, but in summers with elevated temperatures, there may occasionally be a third generation.

A study that researches the impact of climate change on *O. nubilalis* in Europe estimated that a change of 1-3 ºC in temperature would result in the dispersal of this maize pest up to 1220 km to the North, with an increase of one generation in almost all regions where it currently reproduces (Porter et al., 1991). The predictions made by Bebber et al. (2013) suggest that crop pests and diseases are migrating towards the poles at the rate of 3-5 km/year, and the diversity of the populations is undergoing significant change (Crespo-Pérez et al., 2015).

Recently, there has been a change in the species of insects that feed on maize kernels in the United States. Other types of insects are important in the process of *F. Verticillioides* infection in dry and warm climates. The feeding of thrips (*Frankliniella* spp.) is the key factor influencing FB levels in maize cultivated in California (Parsons and Munkvold, 2010). Although thrips are currently not a maize pest in the United States Corn Belt, this may change as a result of climate change. Climate-led changes to the feeding patterns of insects may affect mycotoxin contamination.

4. Variation in the geographic distribution of toxigenic fungal species as a result of climate change

As mentioned in the earlier section, toxigenic fungi have temperature and humidity requirements for crop infestation, the survival and production of mycotoxins, which is reflected in their geographic distribution and determines a gradient of mycotoxin contamination for the whole world. The current distribution of toxigenic moulds all over the planet depends on the climate conditions of each zone. Some species may change their geographic distribution in response to global warming, which would lead to changes in the pattern of appearance of mycotoxins.

There are two major difficulties in interpreting prospective data on toxins and toxigenic species. Firstly, climate and weather effects are confused with the effects of agricultural practices, as farm, soil and cultivated crop types are grouped together on a geographical basis. Secondly, only large-scale climate differences in the area of study determine the possibility of detecting climate-based effects.

The first and most relevant evidence emerged from a large-scale survey undertaken by the EFSA in 2007, which established the increasing problem of possible AF contamination in maize, almonds and pistachios cultivated in Southern Europe, owing to the sub-tropical climate of previous years (EFSA, 2007). In this regard, and with reference to AFs, Mediterranean zones may be affected during periods of high heat and drought, which may stress host plants, especially maize, and therefore, enable *A. flavus* infection. Over the last 15-20 years, this effect has been observed in several European countries, including Italy, Romania, Hungary, Serbia, Croatia and Spain (Paterson and Lima, 2017). The effect was mainly observed in Italy during 2003 and 2004, and subsequently in 2012, concluding that new weather conditions had led to the substitution of *F. verticillioides* and FB contamination by *A. flavus* and AF contamination. This event has resulted in incidents of AFM1 contamination in milk (Battilani et al., 2016).

On the other hand, numerous studies warn of a possible increase in the incidence of *Fusarium* in cereals from different parts of the world. Traditionally, *F. graminearum* is the main producer of DON in Central and Southern Europe; and *F. culmorum* is the predominant DON producer in Nordic areas (Logrieco et al., 2008) along with *Fusarium avenaceum*, *F. graminearum* and *Fusarium poae*. Nevertheless, in the last two decades, there has been a decrease in the presence of *F. culmorum* (adapted to cold and humidity) and an increase in the presence of *F. graminearum* (adapted to warm and humid conditions) in some areas in Central and Northern Europe (Nielsen et al., 2011). In the cooler maritime climate of the United Kingdom and the Netherlands, as well as in Germany where the most common species involved in the *Fusarium* head blight of cereals was *F. culmorum* in the early 2000s, *F. graminearum* became the most widespread species of *Fusarium* in wheat (Logrieco et al., 2008) (Miedaner et al., 2008) (Edwards, 2009). There has also been a significant increase in the frequency of *F. graminearum* in all regions of Poland over the last decades, including the northern areas (Stępień et al., 2010). Additionally, species that infect under relatively dry conditions, such as *Fusarium langsethiae* (producer of T-2 and HT-2 toxins) and *F. poae* (producer of mostly Type A trichothecenes) have expanded their presence (Parikka et al., 2012). Contamination by T-2 and HT-2 toxins are becoming more frequent in oats and barley in the United Kingdom, France, Slovakia and the Czech Republic (Edwards, 2009) (Hudec et al., 2009) (Malachova et al., 2010) and in wheat in Poland (Lukanowski et al., 2008) which has been linked to the detection of *F. langsethiae* in the grain. To conclude, although climate changes in Northern Europe may lead to better growing conditions for many crops, the warmer and more humid conditions expected are also favourable for *Fusarium* infestations in cereals.

In general, the incidence of *Fusarium* head blight is low or nil in regions of Southern Italy and Spain; however, *F. graminearum* is often found in ripe cereals in regions more to the north of Italy, Spain and Portugal, the south of France and the entire Balkan peninsula (Logrieco et al., 2008). On the other hand, studies conducted during the last decade in Italy in order to identify the *Fusarium* spp. responsible for *Fusarium* head blight in wheat, revealed that when climate conditions were not suitable for the main agents that cause *Fusarium* head blight, such as *F. graminearum*, other secondary species such as *F. avenaceum* and *F. poae*, increased their presence (Covarelli et al., 2015). However, studies conducted on barley in the same zone revealed the presence of *F. graminearum,* but it was never the main cause of *Fusarium* head blight; *F. poae* and *F. avenaceum* were the main agents responsible. *F. avenaceum* is a species endemic to cold and wet zones, and in the aforementioned studies, it was aided by a combination of low temperatures and high levels of humidity during anthesis. Nevertheless, the presence of *F. avenaceum* in Europe has increased over the years, having been isolated in a wide range of climate zones (Uhlig et al., 2007) and it cannot be ignored that it may have adapted to an even wider range of climate conditions (Beccari et al., 2017).

In general, studies point to increased mycotoxins in maize, one of the reasons being that there are many different pathogens with partially different environmental requirements that are able to colonise maize. Therefore, one species may simply be replaced by another that is better suited to the modified environment. Without there being a noticeable change in the general symptoms of rot in corn ears, this may lead to dramatic effects in human and animal health upon shifting to the prevalence of more damaging toxigenic species. Thus, in the event of elevated temperatures, drought and insect damage in tropical and subtropical regions, there may be an increase in *A. flavus* (producer of AFs) and *F. verticillioides* (producer of FB) to the detriment of *F. graminearum* (producer of DON and ZEN) (Juroszek and Tiedemann, 2013).

Evidently, climate change will have a significant effect on crop feasibility, in many areas of the planet. Certain crops may not be able to adapt to the new conditions, while they may be feasible in new geographical zones. A healthy crop will always be less susceptible to diseases than one that is stressed due to climate change.

Finally, it makes no sense to study toxigenic mould contamination at high temperatures if the host crop is unable to survive at these temperatures. In a similar vein, a scenario that has not been sufficiently explored is whether stress from global warming may also bring about the disappearance of toxigenic fungi. The presence of aflatoxigenic fungi may be reduced by climate change in warm countries due to the faster propagation of thermotolerant and non-toxigenic thermophilic fungi (Russell et al., 2010). In this same line of thought, Paterson and Lima (2010) suggest that *A. flavus* and *A. parasitpicus* may become extinct in certain regions of the planet, such as India and Pakistan, which already experience periods of temperatures higher than 41 ºC.

5. Changes in the incidence of aflatoxins

Changes in the presence/prevalence of AFs in milk and cereals as a result of climate change, and the consequences to the dietary exposure of consumers, constitute a topic of growing concern. The mycotoxins AFB1, AFB2, AFG1 and AFG2 are produced by toxigenic strains of *A. flavus* and *A. parasiticus* fungi. AFM1 is the result of AFB1 hydroxylation in the digestive process in cattle, and consequently appears in milk and dairy products obtained from cattle fed with contaminated feed.

The contamination of agricultural products by AFs is deemed inevitable, although in the best-case scenario, certain practices may be established to minimise human and animal exposure (Russell et al., 2010). Nevertheless, and in spite of the geographic pervasiveness of AFs, their prevalence in foods for human beings and animals is greater in certain regions than in others, depending on climate conditions, agricultural practices, crop development, pest damage and post-harvest processing (Sanders et al., 1984) (Russell et al., 2010) (Benkerroum, 2020).

On general lines, AFs are common in tropical and sub-tropical climates, similar to desert climates with irrigation systems, as humidity and heat are the two main parameters that define the probability that a food will be invaded by toxigenic fungi. In this regard, the effects of climate change may have a significant effect on the geographical distribution of AFs (Medina et al., 2017). Cases of AF contamination predominate in periods of high temperatures and drought that provoke plant stress, favouring *A. flavus* infection (Marasas et al., 2008).

In a climate scenario with an increase of + 2 ºC with regard to current climate, there is a clear increase in the risk of the presence of AFs in Europe, mainly in Central and Southern Spain, Southern Italy, Greece, South-East Portugal, Bulgaria, Albania and Cyprus, as well as the European zone of Turkey (Moretti et al., 2019). AFs may be present in oilseeds, nuts with shells, dried fruits, cacao, unprocessed vegetal oils, spices and cereals, nevertheless most of the studies conducted on the impact of climate change focus on cereals and dried fruits (including peanuts).

5.1 Aflatoxins in cereals

It is worth recalling the aflatoxicosis outbreak of April 2004 in a rural area of Kenya with 317 cases and 125 deaths derived from the entry of AF contaminated homegrown maize into the distribution system, which resulted in a generalised AF contamination of marketed maize. The maize was harvested in February of that year during unseasonable, early rains, and was stored wet under conditions conducive to the growth of mycotoxin-producing mould. 55 % of food products thereof had AF levels higher than the Kenyan regulatory limit of 20 μg/kg, 35 % had levels >100 μg/kg, and 7 % had levels >1000 μg/kg (Lewis et al., 2005).

High concentrations of AF in maize are the result of high temperatures and drought-related stress. Additionally, stress due to temperature and humidity leads to genetic changes in *A. flavus* populations and this genetic recombination may affect the capacity for AF management (Miller, 2016).

In the United States, it is expected that climate change will lead to increased AF contamination in maize which would largely affect the economy of the Mid-West with the highest losses in the warmest years. Mitchell et al. (2016) estimated that AF contamination in the United States could cause losses ranging between 52.1 million and 1.68 billion dollars per year if climate change causes AF contamination on a regular basis in the Corn Belt, as was the case in 2012 (Mitchell et al., 2016).

In order to improve productivity and to avoid possible outbreaks, predictive models have been developed that seek to correlate a number of environmental and agricultural factors with the potential for *A. flavus* growth in maize, wheat and rice and consequently, in AF production (Battilani and Leggieri, 2015) (Battilani et al., 2016). But the main factor limiting the precision of the model is the large variety of influencing factors, other than environmental ones, as well as the need for precise and detailed information on each variable in the model. To predict AF contamination in maize and wheat cultivation during the next 100 years with a climate change scenario of +2 °C and +5 °C by applying a modelling approach, was precisely the goal of Battilani et al. (2016). These authors predict that AFB1 will become a food safety problem to maize in Europe, especially within the scenario of +2 °C, the most probable climate change scenario (Battilani et al., 2016). Thus the plains of Baragan have been highlighted as the area in Romania that is most sensitive to the climate change predicted for South-Eastern Europe, which exposes it to increased AF and OTA contamination of cereals (Gagiu et al., 2018). The simulation proposed by Medina et al. (2017) is relevant for change in *Aspergillus* and AF growth in a temperature increase scenario of 3 °C and different situations of water stress. With an increase of 3 °C in temperature and a_w (water activity) conditions of 0.95, it is expected that the growth factor of *A. flavus* will increase by 5.6 times. Consequently, these authors predict an increased AFB1 between 102 and 138 times of the initial values of the mycotoxin for the same climate conditions. This situation was confirmed in Hungary in 2012 where drought and high temperatures resulted in 69 % of all maize crops being contaminated (Kos et al., 2013).

In the Philippines, however, a study on the risk of AF and FB contamination of maize under current conditions of climate change, and projected by means of a predictive methodology based on the published range of temperature and rain conditions that favour mycotoxin development, showed that the projected climate change would reduce the risk of AF contamination due to increased rainfall (Salvacion et al., 2015).

The possible influence of climate change on the health risks associated with dietary exposure to AFs for the Portuguese population has been studied by Assunção et al. (2018). The burden of disease associated with current AF exposure for the Portuguese population in terms of Disability Adjusted Life Years (DALY) estimated that in the future the number of DALYs and the associated cases of hepatocellular cancer due to AF exposure would increase due to climate change (Assunção et al., 2018).

In order to provide a precise, statistically relevant estimate, a large amount of high-quality data is needed. This requires extensive surveys on the presence of mycotoxin contamination in food crops all over the world, with common sampling strategies and analytical performance criteria, such as those distributed by the *Codex Alimentarius* Commission, for various crop seasons (Eskola et al., 2020). Recently, the EFSA (2000) confirmed the need to continue to monitor the appearance of aflatoxins in light of possible increases due to climate change using highly sensitive methods for detection.

Finally, it must not be forgotten that harvesting grains with the lowest possible humidity and their storage in conditions of homogenous humidity and close to or lower than 14 % are necessary to reduce the post-harvest risks of increased AFs, along with the control of the mechanical damage of grain, grain cleaning practices and storage temperatures (Prandini et al., 2009).

5.2 Aflatoxins in milk

AFM1 is the hydroxylated metabolite of AFB1 and it is found in milk and dairy products obtained from livestock that have ingested contaminated feed, and also in human milk (EFSA, 2020).

While the EU has established the maximum permitted level of AFM1 at 0.05 µg/kg, the United States and Brazil have set the limit at 0.50 µg/kg (Codex Alimentarius, 2001) (FAO, 2004) (EU, 2006), (Brazil, 2011). Nevertheless, the AFM1 levels detected in milk samples from some locations have been identified as a serious public health risk that is as yet unregulated (Ghazani, 2009) (Ruangwises and Ruangwises, 2009, 2010) (Fallah et al., 2011) (Iqbal et al., 2013). In Iran, AFM1 was detected in 100 % of the milk samples (62 % of them above the EU maximum limit) (Ghazani, 2009). In Pakistan, Iqbal et al. (2013) analysed milk and dairy products and detected AFM1 in 71 % of the milk samples (58 % of them exceeding the permitted EU limit).

All the authors appear to agree that the AFM1 contamination of milk and dairy products varies according to geography, environmental and climate conditions, and the level of development of the country (Ghazani, 2009) (Prandini et al., 2009) (Rahimi et al., 2010) (Asi et al., 2012) (Almeida Picinin et al., 2013). For this reason, numerous studies have analysed the levels of AFM1 in milk and milk products factoring in their place of production and consumption (Cano-Sancho et al., 2010) (Assem et al., 2011) (Siddappa et al., 2012) (Almeida Picinin et al., 2013) (Duarte et al., 2013) (Xiong et al., 2013) (Bilandžić et al., 2014) (Akbar et al., 2019).

Although Almeida Picinin et al. (2013) confirmed that AFM1 contamination of milk is significantly affected by climate conditions, numerous studies had previously linked high concentrations of AFM1 in milk to dry seasons, compared to conditions of rainfall (Kamkar, 2005) (Hussain and Anwar, 2008) (Prandini et al., 2009) (Ruangwises and Ruangwises, 2009, 2010) (Nemati et al., 2010) (Fallah et al., 2011) (Akbar et al., 2019).

In Thailand, the average AFM1 concentration in milk samples collected in winter was significantly higher than the average concentrations found in samples collected in the monsoons and summer (Ruangwises and Ruangwises, 2009). Thus AFM1 was detected in unpasteurised milk from 80 milk farms, with an average concentration of AFM1 in milk samples collected in winter (0.089 ± 0.034 μg/l) that was significantly higher than those collected in rainy season (0.071 ± 0.028 μg/l) and summer (0.050 ± 0.021 μg/l) (Ruangwises and Ruangwises, 2010).

The seasonal variation in the incidence of AFM1 contamination in unpasteurised milk samples from Punjab (Pakistan) revealed that the highest average contamination was detected in winter (0.875 μg/l), followed by autumn (0.751 μg/l), spring (0.654 μg/l) and summer (0.455 μg/l) (Akbar et al., 2019).

The seasonal variation in the concentration of AFM1 in milk, apart from being linked to the temperature and rainfall, has also been linked to variations in herding practices between summers and winters (Iqbal et al., 2013). According to Fallah et al. (2011), seasonal variations influence AFM1 concentrations in most dairy products tested in Iran and the highest levels of AFM1 contamination were detected in cold seasons, possibly due to the fact that in cold periods, lactating animals are fed greater amounts of compound feed which are possibly contaminated with higher levels of AFB1.

In Morocco, AFM1 contamination in unpasteurised milk sourced directly from traditional dairies had a higher incidence in samples collected in autumn in comparison to those collected in other seasons, which suggests a link between feeding practices, such as the use of silage, and AFM1 contamination (El Marnissi et al., 2012).

In China, the concentration of AFM1 in unpasteurised milk was significantly higher in winter (123 ng/l) than in other seasons, and there were no significant differences between spring (29.1 ng/l), summer (31.9 ng/l) and autumn (31.6 ng/l), which indicates that unpasteurised milk collected in winter has a high risk of containing AFM1 (Xiong et al., 2013). Seasonal variability in AFM1 contamination of unpasteurised milk may be due to seasonal variation in the type and quality of feed given to dairy cows. The scarcity of fresh green feed in winter leads to the use of preserved or stored feed, such as maize, cotton seeds and silage, which may be easily contaminated by AFs in unsuitable storage conditions (Xiong et al., 2013).

In Brazil, high AFM1 values were detected in milk during the dry period therefore, according to these authors, the compulsory monitoring for AFM1 in milk in tropical countries, especially during dry periods, must be accompanied by the implementation of good agricultural practices, especially during the dry period in order to prevent and minimise AFM1 contamination in feeds given to animals (Almeida Picinin et al., 2013).

In Croatia, a significant difference was found in average AFM1 concentrations in cow's milk from the east and other regions, possibly due to the use of contaminated supplementary feed in some farms during the period of study (Bilandžić et al., 2014).

In order to investigate the impact of climate change on AFB1 production in maize and its consequences for the AFM1 contamination of cow's milk and to develop a predictive methodology, Van der Fels-Klerx et al. (2019) have used the Monte Carlo simulation to connect datasets of AFB1 in maize cultivated in Eastern Europe and imported into the Netherlands to feed dairy cows, and AFM1 in the dairy production chain. The results of all combinations of climate models suggest a similar or slight (up to 0.6 %) increase in the possibility of detecting AFM1 in milk, beyond the European Union's limit of 0.05 μg/kg for 2030 (Van der Fels-Klerx et al., 2019).

In Europe, the highest average concentrations of AFM1 were reported in "milk and dairy products" and dairy foods belonging to the category of "foods for infants and young children" (EFSA, 2020). Therefore, according to the EFSA (2020), liquid milk and fermented dairy products were the main contributors to mean AFM1 exposure in Europe.

According to Coffey et al. (2009), the evidence suggests that it is possible that mycotoxins may never be fully eliminated from the food chain, but it is probable that the current exposure levels derived from the consumption of cow's milk will be very low and well under EU directives. From a risk-based perspective, the presence of mycotoxins in bovine milk presents minimal risk for human beings.

In the case of Spain, Cano-Sancho et al. (2010) estimated that the consumption of dairy products did not entail a significant risk of AFM1 contamination for the Catalan population, including mean and high consumers (Cano-Sancho et al., 2010).

In Europe, the recent risk characterisation performed by the EFSA (2020) for AFM1 highlighted that the calculated Margins of Exposure (MOE) are less than 10 000 for some surveys, especially for the youngest groups, which poses a health problem. Nevertheless, according to the EFSA, high exposure to AFM1 through milk and dairy products may be limited to a short period of life.

5.3 Aflatoxins in nuts (including peanuts)

AFs may be found in nuts as the result of *A. flavus* or *A. parasiticus* contamination before and after harvesting, with a prevalence and degree of contamination that depends on the temperature, humidity, soil conditions and storage (EFSA, 2009). On the other hand, AF levels in nuts may be reduced in roasting, in proportion to the duration of the processing, but it depends on the initial concentration (Martins et al., 2017) (EFSA, 2020).

Aspergillus species rarely flourish below 10 ºC and the majority are known to grow in temperatures of 37 ºC or higher. Under climate conditions of 22-29 ºC, and average annual rainfall higher than 700 mm, aflatoxigenic fungi begin to develop and generate significant levels of AFs, especially when the a_w is between 0.9 and 0.99 (Sanchis and Magan, 2004) (Benkerroum, 2020) and 350 ppm CO_2 (Medina et al., 2017). The climate may also affect host susceptibility as in conditions of heat and drought, plants produce fewer antimicrobial compounds such as phytoalexins, and consequently, their susceptibility is increased, for example, that of peanuts to infection (Wotton and Strange, 1987) or cracks in pistachio shells (Hadavi, 2005) (Cotty and Jaime-García, 2007). Drought also leads to the decrease of protective compounds in plants such as phenols, favouring the expansion of the aflatoxigenic fungus (Kambiranda et al., 2011).

The EFSA identified AF contamination as an emerging risk in the cultivation of almonds, hazelnuts and pistachios in Southern Europe owing to a sub-tropical climatological profile (EFSA, 2007). The study compiled more than 40 000 test results from the EU and Turkey, collected between 2000 and 2006. AFs were not detected in 75 % of the samples. AFB1 was the most frequently detected AF in the samples, it was also the main contributor to the total AF content. Additionally, the presence of AFB2, AFG1 and AFG2 was, in most cases, related to the presence of AFB1. With regard to the nuts analysed (almonds, cashews, hazelnuts, peanuts and pistachios), the relation between the presence of AFB1 and AFB2, AFG1 and AFG2 was between 83 % (hazelnuts) and 99 % (almonds and cashews). Nevertheless, the presence of AFs in quantities higher than the Limit of Detection (LOD) in analysis for almonds, cashews, hazelnuts, peanuts and pistachios was 27 %, 10 %, 30 %, 20 % and 44 %, respectively. In these cases, the lower limit of the average content of total AFs was 19.2 µg/kg (pistachios), 1.61 µg/kg (almonds), 1.50 µg/kg (hazelnuts), 2.44 µg/kg (peanuts) and 0.35 µg/kg (cashews). When we consider the samples with levels between the LOD and a total AF content of 4 µg/kg, the prevalence in almonds, cashews, hazelnuts, peanuts and pistachios was 22.9 %, 8.3 %, 22.9 %, 15.7 % and 24.3 %, respectively. Nevertheless, the report pointed out that in samples containing over 200 µg/kg, some were of pistachios (n= 110), peanuts (n= 23) and almonds (n= 2), and the highest content was found in pistachios. Later, the EFSA report also detected higher concentrations in the average AF values in pistachios and peanuts.

Both EFSA studies (2007 and 2020) make no reference to the possible effects of climate change as neither climate conditions nor soil conditions, agricultural practices or storage conditions are described during the sampling years. Nevertheless, the reports conclude that the possible AF contamination of foods cultivated in the EU must be continually reviewed, especially in light of possible climate changes (EFSA, 2007, 2020).

6. Changes in the incidence of *Fusarium* toxins in cereals

As mentioned, *Fusarium* species that may infect crops have different optimal environmental conditions related to temperature, rain, and relative humidity, in order to infect crops, to colonise them, to produce mycotoxins, and for their own survival. Besides, other factors such as agricultural practices or insect-related damage (Wu et al., 2011) (Parikka et al., 2012) (Marroquín-Cardona et al., 2014) also exert an influence.

Mycotoxin production is modulated by the environmental surroundings of the fungus, carbon and nitrogen supply, pH and pathway-specific activators (Woloshuk and Shim, 2013), as well as other factors such as the environmental increase of CO_2 which modifies plant nutrients infested by fungi (Trail et al., 2003).

6.1 Trichothecenes

There are various ongoing studies researching the effects of factors linked to climate, crops and pathogens in DON accumulation in wheat grains, and empirical and mechanistic models to predict the relationship between Fusarium head blight in cereals and their DON content in the grain (Wu et al., 2011). DON production depends largely on climate conditions (humidity, temperature, rain), the plant's status, resistance to infection, cultivation systems, agricultural practices and post-harvest handling of cereals (Reyneri, 2006) (Marroquín-Cardona et al. 2014).

According to Miller (2008), the optimal conditions for DON production in maize by *F. culmorum* and *F. graminearum* are an $a_w \geq$ 0.98-0.998 and an optimal temperature between 20-25 ºC (minimum 5 ºC and maximum 35 ºC). With $a_w \geq$ 0.99, *F. graminearum* grows at an optimal temperature of 29-30 ºC and *F. culmorum* at optimal temperatures between 25-26 ºC. Additionally, heavy rainfall may promote the formation of DON.

The Italian summer of 2014 was mild and rainy, with reports of a significant DON contamination in Northern Italy, in comparison to the data for the period 2009-2011, when AFs were detected (Camardo Leggieri et al., 2015).

DON is a trichothecene associated with cereals and the most prevalent in Europe (Paterson and Lima, 2010), where warm summer temperatures have led to the replacement of species such as *F. culmorum* with more pathogenic and virulent species such as *F. graminearum.* The isolated trichothecenes of *F. graminearum* are mainly three, 15-ADON, 3-ADON, and nivalenol (NIV). 15-ADON is predominant in North America and 3-ADON in South America and Europe (Ward et al., 2002) (Gale et al., 2007). Nevertheless, recent studies have shown that the frequency of 3-ADON is rapidly increasing in North America, replacing 15-ADON (Gale et al., 2007) (Ward et al., 2008) (Puri and Zhong, 2010). For example, in North Dakota (United States), 3 % of *F. graminearum* strains produced 3-ADON prior to 2002, whereas this percentage increased to 44 % in 2008 (Puri and Zhong, 2010). In parallel, Ward et al. (2008) observed that the frequency of 3-ADON increased substantially (14 times) in Western Canada between 1998 and 2004. This increased frequency may be partially due to the pathogenic superiority of 3-ADON in wheat over 15-ADON, as the strains that produce 3-ADON have been shown to be more aggressive, to produce more DON spores, and have a more rapid growth rate (Ward et al., 2008) (Ali et al., 2009) (Gale et al., 2009) (Puri and Zhong, 2010). Studies conducted in greenhouses in North Dakota where different varieties of maize that are resistant or susceptible to Fusarium head blight were inoculated with different species of *F. graminearum* which preferably produce 3-ADON or 15-ADON, displayed greater DON production in grains susceptible to *Fusarium* head blight than those inoculated with species producing 15-ADON. Nevertheless, this difference was not observed in grains that were moderately resistant to *Fusarium* head blight (Puri and Zhong, 2010). Other authors made similar observations in field studies conducted in North Dakota and Minnesota (Ward et al., 2008) (Ali et al., 2009) (Gale et al., 2009). In Minnesota, a new species of *Fusarium* called "Northland" was observed which did not produce DON or NIV trichothecenes, which confirms that climate change may decrease mycotoxin production (Paterson and Lima, 2017).

The role of climate change in the displacement of the *F. graminearum* population in the Unites States is unknown, although it is evident that changes in climate conditions lead to changes in the fungus and in mycotoxin production.

In the Chinese region of Jiangsu, Dong et al. (2016) conducted a study between 2013 and 2015 to determine the predominant type of *Fusarium* and trichothecene production based on annual rainfall. It was observed that, depending on precipitation, the type of *Fusarium* and trichothecenes produced were different. Thus in 2013, the central region was humid (47.4 ± 12.5 mm), the southern region had greater rainfall (78.7 ± 24.0 mm) and it increased from north to south, and in 2015, the southern region received less rainfall and it increased from south to north (56.4 ± 21.2 mm). Every year, *Fusarium asiaticum* (linked to the production of 3-ADON and NIV and warm zones) was the most frequently detected species, followed by *F. graminearum* (linked to the production of 15-ADON and cooler zones) and the order of trichothecene concentration was DON (max. 18 709.4 µg/kg in 2015) > 3-ADON (max. 730.2 µg/kg in 2015) > 15-ADON (max. 259.9 µg/kg in 2013) > NIV (max. 204.1 µg/kg in 2015). In the province of Jiangsu, the average concentration of DON and NIV in wheat was positively correlated with levels of rainfall, but not 3-ADON levels, which were negatively correlated with the amount of rainfall. No relationship between trichothecene production and temperature was demonstrated.

Zhao et al. (2018) observed that Fusarium head blight and trichothecene production is boosted in anthesis in warm and humid climates with relative humidity >75 %. A similar association between humidity and DON production in wheat was obtained in studies conducted in Serbia (Jajić et al., 2008) (Stanković et al., 2012), Uruguay (Pan et al., 2009), West Romania, Bulgaria and Brazil (Vrabcheva et al., 1996) (Curtui et al., 1998) (Calori-Domingues et al., 2016). Madgwick et al. (2011) studied the impact of climate change on the anthesis dates of wheat and concluded that *Fusarium* epidemics would be more serious, especially in the south of England, due to increased *F. graminearum* and associated DON.

The association between the environmental concentration of CO_2 and DON concentration has also been studied. In accordance with Vaughan et al. (2014) and Váry et al. (2015), maize and wheat are more susceptible to diseases when CO_2 concentrations increase. Váry et al. (2015) indicate that acidification produced by elevated CO_2 levels will increase trichothecene production by *F. graminearum*. Similarly, Trail et al. (2003) indicate that elevated concentrations of CO_2 have an effect on *F. graminearum* growth and mycotoxin production, as the concentration of nitrogen in the fungus decreases as CO_2 concentration increases, and nitrogen limitation induces the biosynthesis of trichothenes. Similarly, Cuperlovic-Culf et al. (2019) associate DON production with reduced nitrogen content in the fungus due to increased CO_2.

6.2 Other *Fusarium* mycotoxins

There are also many studies that draw a connection between climate conditions and FB production in maize, although no studies have been found that include series of annual data that would allow us to detect trends due to the effect of climate change, nor models whose calculations demonstrate it. The largest concentrations of FB appear in maize and to a lesser degree, in wheat or barley, as the main species that produce this mycotoxin (*Fusarium* section *Liseola* which includes *F. proliferatum, F, subglutinans, F. verticilloides,* among others) most frequently contaminate maize. The difference in the nutritional composition of different cereals affects FB biosynthesis by the contaminating fungi (Stanković et al., 2011).

The factors that have the greatest influence on the risk of *Fusarium* infection and FB production are temperature, insect damage to grain, drought stress, and a_w (Warfield and Gilchrist, 1999) (Miller, 2001) (Munkvold, 2003a) (Bush et al., 2004).

Temperatures in most maize producing areas are within the range suitable for the growth of *F. verticillioides* and FB production, but the risk increases in warmer temperate or sub-tropical zones or in the warmest seasons in temperate zones (Miller, 2001) (De la Campa et al., 2005). According to Sanchis and Magan (2004) and Adhikari et al. (2020), the optimal conditions for FB production in maize by *F. verticillioides* and *F. proliferatum* are: $a_w \geq 0.9$ and an optimal temperature of 30 °C (minimum 4 °C and maximum 37 °C), and an $a_w \geq 0.93$ and optimal temperature of 15-30 °C (minimum 10 °C and maximum 37 °C), respectively. They also mention that extreme drought may favour FB formation. Therefore, increased temperatures brought about by climate change may lead to a greater production of these mycotoxins (Marin et al., 1999) (Battilani et al., 2003, 2011) (Adhikari et al., 2020). Stanković et al. (2011) studied the presence of FB1 in maize, wheat and barley from 2007 to 2009 in Serbia. The greatest incidence of FB1 was obtained during the months of July-August in 2007, as these were the months with the highest average environmental temperature of the entire period of study and without rainfall.

Based on field studies, De la Campa et al. (2005) described the complex seasonal effects of temperature on FB accumulation. At the moment of initiation of female flowering, temperatures between 15 and 34 °C were the most favourable, but during the peak period of flowering, when the maximum daily temperature exceeded 34 °C, it led to the final highest FB concentration (De la Campa et al., 2005). Additionally, it was observed that episodes of rainfall > 2 mm at the start of female flowering increased FB concentrations, but were linked to lower FB concentrations if rains fell after the period of maximum flowering. This trend coincides with that highlighted by Battilani et al. (2008) who found a negative correlation between FBs and mid-season rainfall, which reinforces the association between drought stress and FB production. In the same line Krnjaja et al. (2016) observed that in July 2013, in certain areas in Serbia, the average daily temperature (21.9 to 22.8 °C), relatively low rainfall (23.2 to 50.6 mm) and relative humidity (60 to 62 %) favoured the intensive development of the *F. verticilloides* toxigenic fungus and FB production. On the contrary, Pleadin et al. (2012) observed that during the pre-harvest period for maize (from August to October 2010) in Croatia, the months were warm and with extremely high levels of rainfall, and that FB concentration was higher than in previous years when the maize growing period was less warm and humid.

De la Campa (2005) identified insect damage as one of the primary factors for predicting FB production, along with high temperatures and low levels of rainfall during a period of 2 to 8 days after female flowering.

Another parameter related to climate change that was recently studied is increased environmental concentration of CO_2. Nevertheless, the expected increase in CO_2 levels does not appear to have a significant effect on FB production (Vaughan et al., 2014) (Váry et al., 2015) (Cuperlovic-Culf et al., 2019) (Mshelia et al., 2020).

In maize cultivation areas, the risk of FB tends to be higher in the lowest latitudes and altitudes, where conditions are relatively warmer than in high latitudes or altitude zones for maize cultivation. Thus, for example, in North America, the risk of FB is higher in Texas and the south-western states, compared to the central area of the United States (Shelby et al., 1994). A similar pattern may be detected in Asia north of the Tropic of Cancer. In most of Central and South America and South-East Asia, FBs constitute a significant risk in low-altitude zones for maize cultivation. In Europe, the risk of FBs is higher in Italy, Spain and the south of France. In Africa, all maize producing areas are susceptible to the risk of producing FBs, according to the altitude (Wu et al., 2011).

More frequent climate extremes may lead to alterations in the composition of *Fusarium* species that infect maize kernels, which in turn may alter the composition of mycotoxins that contaminate the infected kernels. In Iowa, *F. verticillioides* infects maize predominantly in the south and the centre of the state, and *F. subglutinans* in northern Iowa where it is colder (Munkvold, 2003b). However, *F. subglutinans* does not produce FBs, it produces other mycotoxins, of less concern to human health, which include fusaproliferin, beauvericin and moniliformin. What is unknown is how climate change may lead to alterations in *Fusarium* species and consequently, to variations in the potential for mycotoxin contamination.

Moreover, Pleadin et al. (2012) observed that during the pre-harvest period for maize (from August to October 2010 in Croatia), the months were warm and with extremely high rainfall, and the concentration of the T-2 toxin was higher than in previous years when the growing period of maize was less warm and humid. Arroyo-Manzanares et al. (2019) additionally insisted that to ensure the absence of mycotoxins, emerging mycotoxins must always be considered in all monitoring activities.

6.3 Predictive models for the incidence of *Fusarium* mycotoxins

Predictive models may be mechanistic or empirical. Normally they are based on weather patterns (temperature, precipitation and relative humidity). Van der Fels-Klerx et al. (2012) additionally include patterns of agricultural practice, date of flowering, duration of period between flowering and complete ripening, date of harvesting, variety of wheat/cereal, use of fungicides against *Fusarium* spp. and DON levels in the harvested wheat. The results of this predictive model indicate that DON concentration rises in contaminated wheat in spring compared to winter in North-Eastern Europe and it is expected to increase in the next three decades.

There are few predictive models for maize compared to wheat, as the flowering period is more variable, there are more maize hybrids than wheat hybrids, and there is a relationship between the damage caused by insects to maize and the production of mycotoxins, that does not exist in wheat

(Van Asselt et al., 2012).

Van Asselt et al. (2012) applied models adapted from *F. verticillioides* in Italy to *F. graminearum* in the Netherlands between 2002 and 2007, to estimate levels of DON and ZEN production. ZEN is mainly produced by *F. graminearum* and *F. culmorum* in cereals, therefore its presence is generally related to the production of DON (Paterson and Lima, 2010). The lowest levels of DON and ZEN were obtained in 2003 when there was no rain during the maize flowering period. The years with the highest DON concentrations (2002, 2006 and 2007) were years when the average rainfall was 0.1 mm/hour during the flowering period. 2005 was also humid during the flowering period (average rainfall of 0.28 mm/hour) but temperatures were low, therefore there was a lower concentration of mycotoxins. In 2007, the wind and rain were above average, resulting in high levels of infection during flowering. These authors concluded that: a) during flowering, the rain and windspeed determined fungal infection, b) the temperature and relative humidity determined the subsequent germination of the spores, and c) the temperature in later stages of growth determined the growth of the fungus and the formation of mycotoxins.

According to West et al. (2012) the pre-harvest rain may significantly increase DON production. Nevertheless, in real conditions, periods of rainfall at this stage vary from one year to another. In their "DONcast"·model, Paterson and Lima (2010) demonstrate that during the ripening of grain, a rainfall of 5 mm/day leads to a potential increase of DON production, whereas a temperature lower than 10 ºC limits DON production.

7. Possible measures for mitigation that may be applied

In order to tackle the possible rise in the incidence of mycotoxins in foods as a result of climate change, it is worth developing a two-pronged strategy based on the adoption of a series of specific measures that seek to mitigate this incidence; and in parallel, attempt to naturally boost all actions meant to slow down, halt, and when applicable, revert the global changes to the environmental conditions that mark the current climate situation.

7.1 Measures directly related to mycotoxins

With regard to measures directly related to mycotoxins, we shall first distinguish their preventive measures. Undoubtedly, these actions meant to prevent or minimise the fungal infection of agricultural products at the sowing, harvesting, transportation and storage stages, constitute the first line of defence and the most effective tool to combat the presence of mycotoxins; followed by good manufacturing practices in the preparation and distribution of foods and feeds. Several authors have conducted an in-depth review of this question, such as: (Aldred and Magan, 2004) (Kabak et al., 2006) (Jouany, 2007) (Magan and Aldred, 2007) (Amezcueta et al., 2009) (Awad et al., 2010) (Chulze, 2010) (Jard et al., 2011) (Kolosova and Stroka, 2011) (Karlovsky et al., 2016). Likewise, the *Codex Alimentarius* has so far developed ten codes of practice for the prevention and reduction of the presence of different mycotoxins in different agricultural substrates, dealing specifically with AF contamination in peanuts (Codex Alimentarius, 2004), nuts (Codex Alimentarius, 2005) and dried figs (Codex Alimentarius, 2008), also specifically on AFB1 in raw materials and supplementary feeds for milk-producing animals, as a preventive measure against the appearance of AFM1 in milk and dairy products (Codex Alimentarius, 1997), on OTA in wine (Codex Alimentarius, 2007), coffee (Codex Alimentarius, 2009) and cocoa (Codex Alimentarius, 2013), on PAT in apple juice and other drinks (Codex Alimentarius, 2003), and finally on mycotoxins in general, in spices (Codex Alimentarius, 2017a) and in cereals (Codex Alimentarius, 2017b). These codes of practice seek to promote feasible and realistic measures, although as textually mentioned in the last document, "the complete prevention of dissemination by pre-harvest and post-harvest toxigenic fungal species is not practically achievable, even when good agricultural practices and good manufacturing practices are followed". Therefore, a more or less sporadic and inevitable presence of certain mycotoxins in agricultural products intended for food and feed use is to be expected.

Although these measures depend on each crop and specific product, as well as the toxin referred to in each case, generally and whenever applicable, it includes aspects such as the use of especially resistant varieties as well as seeds with quality certification, maintaining the appropriate distance between plants, crop rotation, appropriate irrigation and use of fertilisers, use of authorised pesticides, measures to prevent bird and rodent attacks, eliminating the remains of previous crops -although this must be performed with a certain degree of consideration since it may lead to an excessive erosion of the fertile soil and the loss of the soil's water retention capacity-, choosing the correct date for harvesting, and using the correct equipment and ideal procedures to cause as little damage as possible to the plants or fruits, as well as attempting to minimise the contact of the fruits and grains with the soil. After harvesting, one of the critical factors on which there is unanimous consent is the adoption of suitable measures to obtain and maintain a correct moisture level, generally, an a_w value lower than 0.7 is accepted as the safe level to prevent fungal growth, which is equivalent to a moisture content of 15 % in general (Kolosova and Stroka, 2011). Additionally, it is always recommended that crops be quickly transported to the storage areas which must be clean and properly ventilated, and fumigated with pesticides, etc. Certainly, these measures require a level of training and support to be given to farmers which unfortunately is not always made available to them, given the different socio-economic conditions of the country or geographic location in question. In a recent study conducted in Malawi, it was confirmed that some training programmes for farmers had low results precisely because of a lack of sufficient incentives for their implementation and the need to prioritise solving other, more immediate problems that exist in many cases (Anitha et al., 2019).

It is also worth highlighting the proposals that advocate using different natural and synthetic agents with the capacity to inhibit toxigenic fungal growth and mycotoxin production, such as certain antioxidants, essential oils (Xiang et al., 2020), etc. Proposals have even included the use of enemy bacteria, fungi and yeasts as a possible alternative to pesticides, with special attention to non-aflatoxigenic strains of *A. flavus* as a means to prevent maize contamination. Their mechanism of action is based on what is called "competitive exclusion" of natural aflatoxigenic natural strains (Cotty and Bayman, 1993). In this regard, a certain number of strains have been patented or are in the process of development; as for example, the International Institute of Tropical Agriculture in collaboration with the Department of Agriculture of the United States has registered and marketed a series of non-aflatoxigenic strains (www.aflasafe.com) for use in maize and peanut crops, already available in a large number of African countries: Nigeria (2014), Kenya (2015), Senegal and Gambia (2016), Burkina Faso (2017), Zambia (2018), Tanzania (2018), and Mozambique (2019) (Sarrocco et al., 2019).

With regard to decontamination and detoxification measures, numerous techniques and procedures have been studied with the goal of fully or partially decontaminating raw materials, feeds and even foods prepared from products with pre-existing mycotoxin contamination, as well as inhibiting or cancelling their toxic actions. A large proportion of these works have focused on AFs although not exclusively, there are also studies on trichothecenes and especially on DON, PAT, FB and OTA. It is not the purpose of this report to provide a detailed description, which would necessarily have to be quite extensive, on this topic, rather we shall attempt to make a general and realistic overview of the measures applicable today and those that are worth focusing our efforts on in the near future. These measures may be classified according to whether the method involved is based on physical principles or on chemical or biological treatments.

With regard to the physical methods studied, these include, among others, the manual or electronic sorting and separation of infested or deteriorated grains or fruits, washing, separation by floating, extraction by means of solvents, thermal inactivation, autoclaving, extrusion, irradiation, etc. In this regard, the European Commission accepts as physical treatment for reducing contamination, any procedure that does not involve the use of chemical products (EU, 2010) and presents, as an example, scalding combined with the sorting of damaged units or the procedure that is already well-known and implemented for AFs in the dried figs industry in some countries (EU, 2013), based on the separation of those units whose surfaces display a bright greenish-yellow fluorescence under long-wavelength ultraviolet light (366 nm), a procedure that is cost-effective and may be efficiently applied to maize kernels (Shotwell and Hesseltine, 1981). The European Commission also points out that roasting is not a procedure admitted in this category due to the thermal stability of AFs, except when applied to pistachios in certain conditions. Likewise, in this category, the EU allows the use of active carbon by the edible oils industry in the purification stage. Active carbon appears to be the most effective absorbent to eliminate different mycotoxins in liquid foods such as wine, beer or milk, although it is true that standardised conditions have still not been established for their effective use without negative side-effects (Kolosova and Stroka, 2011). These materials, also called chelating agents by some authors, have been the focus of several studies over the years. As a matter of fact, EU legislation has included a new functional group among technological additives for feeds which includes substances to reduce mycotoxin contamination, those that are able to prevent or reduce their absorption, favour their excretion or modify their behaviour (EU, 2009). Among all of these substances, it is worth highlighting a type of clay known as montmorillonite, chemically, hydrated sodium calcium aluminosilicate. This substance has displayed very good results when it comes to protecting numerous animal species, especially against AFs (Phillips et al., 2008). It may be worth mentioning that this is until now, the only proven procedure with promising results in clinicals trials conducted in Ghana with people exposed to high doses of AFs (Afriyie-Gyawu et al., 2008) (Wang et al., 2008), and its use has been proposed as a new, cost-effective and harmless procedure (Phillips et al., 2019). It must also be highlighted that one drawback common to this type of clay or chelating agent is its capacity to absorb minerals such as copper, zinc, iron and manganese, which must be considered prior to its routine application. Another alternative that is used for the absorbent capacity of its cell walls, is yeast (Luo et al., 2020).

Another physical technique that has already been successfully implemented in some maize and peanut processing industries is based on detecting grains or units with colour changes, by means of optical sensors, followed by their extraction from the main cascade by using ultra-thin blasts of compressed air (Fraenkel, 1962). With regard to the other afore-mentioned techniques that have exhibited initially promising results for different mycotoxins and highly varied agricultural soil types, we shall only point out that much progress must still be made before they may be routinely used on a real-life scale in a cost-effective and efficient manner (Karlovsky et al., 2016).

With regard to chemical procedures, it must once again be pointed out that there are a large number of studies and alternatives that have been tested over the years and where it is necessary to check not only their intrinsic complexity but also their effectiveness, and among other factors, their safety and that of their by-products or processed products with regard to the mycotoxin in question. It must also be checked that there are no side-effects to the nutritional and organoleptic characteristics of the feeds or foods that may make them unacceptable for consumption, and all of it executed naturally, in a cost-effective manner so they may be of practical use. The EU has published a series of highly strict criteria to be followed prior to authorising this type of treatment to be applied to feeds (EU, 2015) without there currently being nothing similar that may be applied to the human diet. It must be pointed out that for now, only treatment with ammonia under highly specific conditions of pressure, temperature, etc. is currently authorised, and specifically for AF detoxification in peanut cake. This procedure has already been applied in the United States, Senegal, Mexico and France, its use extending in some cases to maize and cotton and always within the scope of animal feeds. Apart from certain acids and bases, other chemical agents researched that have shown promising results are for example, ozone treatment, hydrogen peroxide or sodium bisulphate, and not only against AFs but also against other mycotoxins, especially DON (Kolosova and Stroka, 2011) (Karlovsky et al., 2016).

When we refer to the methods that we may classify as biological methods and which may be used by the food industry, it may include several fermenting processes that have demonstrated an appreciable capacity to reduce the toxic effect of mycotoxins (Karlovsky, 2014). In spite of the lack of specific enzymes that may be industrially produced and possess the capacity to irreversibly deactivate the different mycotoxins, perhaps with the exception of PAT where it seems more feasible although further development is still required (Zhu et al., 2015), the potential of enzymes as a technology compatible with the normal processing of foods, able to act efficiently without producing toxic or undesirable residues, must be mentioned (Karlovsky et al., 2016) (Vanhoutte et al., 2016). A similar statement may be made regarding the use of bacterial culture and yeasts and this in spite of the fact that there is a long list of microorganisms where detoxifying activity has been identified for mycotoxins in the laboratory. One of the most recent examples may be the detoxifying activity of *Rhizopus oryzae* and *Trichoderma reesei* against AFs (Hackbart et al., 2014), without knowledge on the final conclusions regarding its practical use. As such, the perspective on the generalised use of enzymes or microorganisms as detoxifying agents of food products contaminated with mycotoxins is currently limited to a promising and highly desirable prospect, owing to its undoubted advantages over chemical methods which are much more aggressive. In the case of feeds, EU legislation has included two fumonisin sterases produced by *Komagataella phaffii* (EU, 2018) and *Komagataella pastoris* (EU, 2017a) and a strain of the *Coriobacteriaceae* family for trichothecene degradation (EU, 2017b) in the functional group of substances for reducing mycotoxin contamination, among technological additives for feeds.

In addition to specific decontamination techniques, the in-house control of different food industries is based on mycotoxin analysis in raw materials with a certain frequency, and this limits mycotoxin access to the food chain. In this regard, apart from instrumental techniques that permit greater sensitivity and precision, it is worth highlighting the importance of immunological techniques for sampling and rejection of contaminated batches. Likewise, there is a growing interest in the application of photons in the selection of samples and contaminated batches (Tao et al., 2018).

In conclusion, and as a reflection of the interest in this question within our country, it is worth mentioning the presence of the so-called National Network on Mycotoxins and Toxigenic Fungi and their Decontamination Processes (MICOFOOD, https://micofood.es) which includes 11 primarily academic research groups that expressly refer to one of their main activities as "assessing the effect of thermal treatments on mycotoxin stability and content during food production, processing and storage". In this regard, the MICOTOX Network Conference celebrated in 2019 dedicated a session to the topic of "Reduction and Prevention Strategies" in a wider sense and not just limited to heat treatments (González-Peñas et al., 2019).

7.2 Measures against climate change

With regard to general measures against climate change and insofar as anthropogenic attitudes may contribute to enabling them, it seems evident that there are opportunities to combat it. The year 2019 has been the second warmest year of all time, marking the end of the hottest decade (2010-2019) on record, when CO_2 and other greenhouse gases reached record levels of concentration. This news may serve to justify the need to urgently adopt the measures put forward by several international agencies on this subject. At the Paris Agreement in December 2015, the United Nations Member States specifically approved and included Climate Action as one of the goals of the Agenda 2030 for sustainable development, advocating for the implementation of a series of favourable measures for the climate and thus constituting the first universal and legally binding agreement on climate change. This set of measures was recently re-stated by the UN Secretary General in response to the situation unleashed by Covid-19, so Governments might adopt them once the process of economic and social reconstruction resulting from the current pandemic is underway: 1) Green transition: investments must speed up the decarbonisation of all aspects of our economy; 2) Green employment and sustainable and inclusive development; 3) Green economy: make societies and people more resilient by means of a fair transition for all and not leave anyone behind; 4) Invest in sustainable solutions: fossil fuel subsidies must be eliminated and polluting companies must pay for their pollution; 5) Face climate risks; 6) Cooperation: no country can succeed by itself (UN, 2015).

Based on the European Council Decision to back the goal of climate neutrality for 2050, in March 2020, the European Commission proposed the European Climate Law, which seeks to convert the climate neutrality of emissions into a legal requirement (EU, 2020). Previously in November 2019, the European Parliament declared a climate emergency, urging the Commission to guarantee that all of its proposals took into account the goal of limiting global warming to 1.5 ºC, reducing greenhouse gas emissions by 55 % in 2030 with regard to 1990 emissions, in order to attain neutrality in 2050, likewise promoting decreased emissions in sea and air traffic (EU, 2019). This European Climate Law is yet to be enacted, some Member States having expressed certain objections to it.

As mentioned in the Press Release of the Ministry for Ecological Transition and the Demographic Challenge of 23 October 2020, Spain would be highly in favour of the implementation of this Law, therefore, the National Integrated Energy and Climate Plan (PNIEC) which establishes the roadmap for the next decade, goes beyond the objectives laid out by the EU for Spain, with the target to reduce greenhouse gas emissions in 2030 by 23 % with regard to 1990 levels, 42 % renewable energy share of the total energy used, a 39.5 % improvement in energy efficiency, and 74 % of renewable energy in electricity generation (MTE, 2020). This set of good resolutions requires firm social support and it is here that citizens must play their role, after a period of raising awareness that appears to be making its mark.

To complete this overview of a global problem, we may revisit some of the data provided by the Food and Agriculture Organisation (FAO) of the United Nations in its Strategy on Climate Change, which proposes investing in and supporting the development of projects and programmes for small-scale producers in rural areas, to adopt preventive measures instead of the more or less hasty implementation of solutions to sudden situations of ecological crisis or disaster. The FAO reminds us that one-third of the proposed feasible solutions to achieve the proposed objectives with regard to climate change, are from the agricultural sector, such as the rehabilitation and harnessing of damaged soils to prevent the emission of up to 51 gigatonnes (10^9 t) of CO_2 into the atmosphere in a year, and an additional 5 % with the implementation of repopulation and reforestation activities, simultaneously with an agricultural production of 17.6 million tonnes. Decreased livestock production could prevent 30 % of methane emissions. Climate change promotes the appearance and distribution of pests and plant diseases with an estimated cost of two hundred twenty thousand million dollars per year. Finally, it is estimated that agricultural activities consume 70 % of available fresh water therefore, the adoption of more efficient irrigation systems would increase the availability of this vital element and improve production levels (FAO, 2019).

Conclusions of the Scientific Committee

In the last two decades, there has been a growing trend in the prevalence of mycotoxins in foods, a trend that may be attributed, among others, to climate change, without forgetting that the generalisation of monitoring systems and the advent of advanced analysis techniques have also contributed to this trend.

The production of different mycotoxins depends essentially on the eco-physiology of the moulds that produce them in each case, with the ecosystem and especially the humidity and environmental temperature, rainfall and the presence of insects being determining factors of invasion by toxigenic moulds and the accumulation of mycotoxins in crops. Consequently, the current distribution of toxigenic moulds all over the planet depend on the climate conditions in each zone.

There is evidence that aflatoxigenic moulds native to tropical and subtropical zones are increasingly present in cereals cultivated in temperate climates that have transformed into warmer climates over the last years, with the consequent problem of aflatoxin contamination. This trend appears to be indirectly responsible for increasing episodes of aflatoxin M1 contamination in milk.

The case of *Fusarium* toxins is more complex, but there appears to be a geographical redistribution of different species of *Fusarium*, with a growing incidence of *F. graminearum* (producer of Zearalenone and Deoxynivalenol), *F. poae* and *F. langsethiae* (producers of T2 and HT2 toxins, among others), and *F. avenaceum* (producer of mycotoxins with lower toxicological relevance) in various geographical zones. Additionally, there may be greater risk of Fumonisins in maize producing areas, linked to episodes of drought, while the species that produce Fumonisins may also move to higher latitudes. All of this does not necessarily imply that there shall be a significant global variation in the incidence of these mycotoxins as a result of climate change, although there might be variations at the local level.

There are various strategies to mitigate this growing problem of the presence of mycotoxins:

- Preventive agricultural practices in the field, including the development of mycotoxin-resistant varieties.
- Good harvesting and storage practices of cereals, including moisture control and the use of fungistatic products, that prevent the additional production of mycotoxins, beyond those already accumulated in the field.
- Physical, chemical and biological processes of decontamination; physical methods including processes of cereal cleaning and sorting, whereas biological methods, more recently developed, enable the use of microorganisms or enzymes for the degradation of mycotoxins.
- Sampling, analysis and discarding of cereal batches contaminated with mycotoxins.

Climate change may lead to the disappearance of some crops in certain areas, eliminating the fungi that colonise them or extreme climate conditions may simply prevent the survival of toxigenic moulds but maintain the continuity of the crops.

For all of the above reasons, we must emphasise the need to unite efforts not only against climate change as a global phenomenon, but also to promote and adopt specific projects and programmes aimed at preventing and mitigating the incidence of mycotoxins in feeds and food products, in collaboration with the public and private sector, which naturally includes the scientific community, those in charge of risk management, the producers, and even consumers, by means of suitable communication strategies.

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