Review paper
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TRITICALE CROP AND CONTAMINATION WITH MYCOTOXINS UNDER THE INFLUENCE OF CLIMATE CHANGE - GLOBAL STUDY

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Abstract

Triticale is a cereal obtained by crossing wheat and rye to improve production and biochemical composition from parental organisms and to cultivate the regions with unfavourable agro-climatic conditions (arid and semiarid areas, wetlands, acid soils). The article reviews global triticale crop and trend of mycotoxin contamination based on an integrated analysis of mycotoxins occurrence by: geographical coordinates of regions, climate types, climatic risk index, annual averages of temperature and rainfall, in context of global climate change.

The top 10 producers of triticale are in Europe (Poland, Germany, France, Belarus, Hungary, Sweden and Lithuania), Asia (Russian Federation and China) and Australia. Although triticale is grown in areas with different climate and soil types, the most favourable conditions are in northern Europe, with an oceanic mild temperate climate and minimum to medium global climate risk index. The global climate changes will increase the risk of lowering the productivity, physico-chemical and rheological properties of crops, as well as increasing the risk of mycotoxin contamination on the agri-food and feed chains. The Intergovernmental Panel on Climate Change has shown that there will be „hot spots" where the temperature will rise by 2...4n ^{0}C and rainfall will decrease, which will lead to desertification and damage to crops. In hot areas, it is estimated an increase of cereals contamination with mycotoxins produced by *Aspergillus* sp. and *Penicillium* sp. (aflatoxin, ochratoxin A), while in temperate areas it is estimated an increase of mycotoxins produced by *Fusarium* sp. (deoxynivalenol, zearalenone). Triticale research has approached the germplasm analysis for production, amelioration, regional acclimatisation and hybridization.

To date, no study has been conducted on triticale contamination with deoxynivalenol under the influence of agro-climatic conditions. In 2018, Romania

will evaluate the triticale crop for contamination with deoxynivalenol by geographical position and pedoclimatic factors of the country, in the context of climate change for Southeast Europe.

***Key words**: Triticale, Deoxynivalenol, Productivity, Climate change, Geographic position, Pedoclimatic conditions, Romania.*

1. Introduction

Triticale (x*Triticosecale* Wittmack) is a cereal obtained by crossing rye (male) and wheat (female) to improve production and biochemical composition from parental organisms, and to cultivate the regions with unfavourable agro-climatic conditions (arid and semiarid areas, wetlands, acid soils) [1, 2]. Compared to parental cereals, triticale has improved productivity, physicochemical properties and chemical composition, being used in feed, food and biofuel production [2]. Under unsuitable pedoclimatic conditions, triticale crops are attacked by toxigenic fungi, which produces declines in crop's yield and quality.

Mycotoxins are produced by fungi in the field or during storage of cereals [3] under the influence of climate conditions [4, 5]. Mainly, mycotoxins contaminate cereals [6], causing gastrointestinal and haematological disorders in most animal species [7, 8], headaches and fever [3]. However, the correlation of mycotoxins with human disease was ignored [9].

The review aims to raise awareness of the adverse effects of present climate conditions and future climate change on triticale crops (on physical, chemical and biological characteristics) to be used by researchers, farmers and agro-food industry and to develop preventive and control measures by the competent authorities.

The present study is based on processing of the official data and research articles: Global triticale crops: areas and productivity (Food and Agriculture Organisation) [10], Global climate change (Intergovernmental Panel on Climate Change [11, 12], World Bank [13]), Global prevalence of mycotoxins [14], and contamination with mycotoxins in the context of climate change [15].

The topic is correlated with other author's research on mycotoxins (deoxynivalenol, total aflatoxins), productivity and physicochemical quality of grain crops under the influence of the geographical position and pedoclimatic conditions of Romania between 2012 and 2016, in the context of climate change for Southeast Europe (Gagiu *et al.*, unpublished).

2. Triticale crop and contamination with mycotoxins under the influence of climate change

2.1 Triticale production

2.1.1 Global production

Based on data reported by the Food and Agricultural Organisation [10], the global evolution of harvested areas and production/yield of triticale (Figure 1), global classification of triticale cultivation by year, region and country between 1975 - 2016 (Figures 2, 3 and 4) were determined.

2.1.1.1 The global evolution of harvested areas and production/yield of triticale

Reported to the period 1975 - 1983 when cultivated areas and productions were approximately constant, and triticale was cultivated predominantly in Australia, China and Spain, in the period 1984 - 2000 there was an increase by 1.5x of cultivated area and 1.95x of production and triticale was cultivated predominantly in Australia and China, with expansion in Europe and Canada. In the period 2001 - 2016, there was an increase by 34.8x of cultivated area and 79x of production (Figure 1), and triticale was cultivated predominantly in Australia, China, Europe and Canada, with expansion in Russian Federation, Brasil and Chile [10].

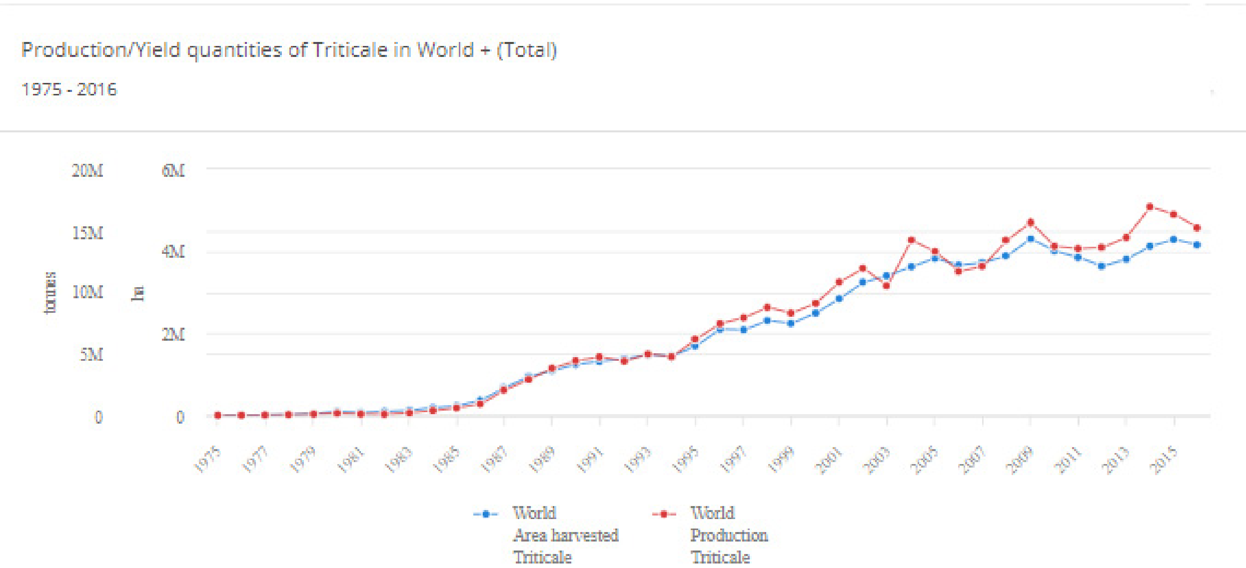

Figure 1. Evolution of global triticale production by year, average 1975 - 2016 [10]

2.1.1.2 Production share of triticale by global region

The highest production shares of triticale were recorded in Oceania (70.9%) and Asia (23.4%) in period 1975 - 1983, after which the production share increased in Europe to 89.5% in period 1984 - 2000 and 90.4% in period 2001 - 2016 (Figure 2). Between 1975 - 2016, triticale cultivation regions were classified as: Europe (89.7%), Oceania (4.9%), Asia (3.8%), Americas (1.4%) and Africa (0.2%) [10].

Between 1975 - 2016, the largest triticale cultivating countries were: Poland, Germany, France, Belarus, Russian Federation (> 370,370.51 t), China, Australia, Sweden, Hungary, Austria, Lithuania (<= 370,370.51 t); Brazil, Chile, Spain, England, Turkey, Romania, Serbia (<= 123.308,75 t), Canada (<= 50.680,22 t), and Algeria, Tunisia (<= 17.283,0 t) (Figure 3).

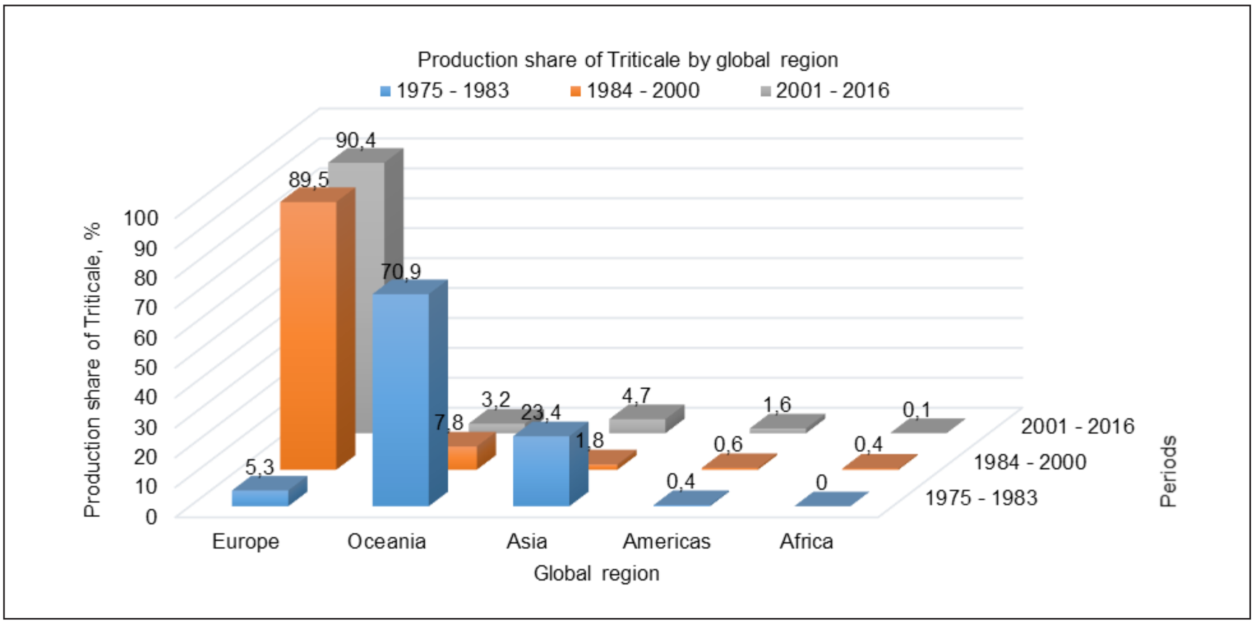

Figure 2. Global triticale production by region, average 1975 - 2016 (processing according to [10])

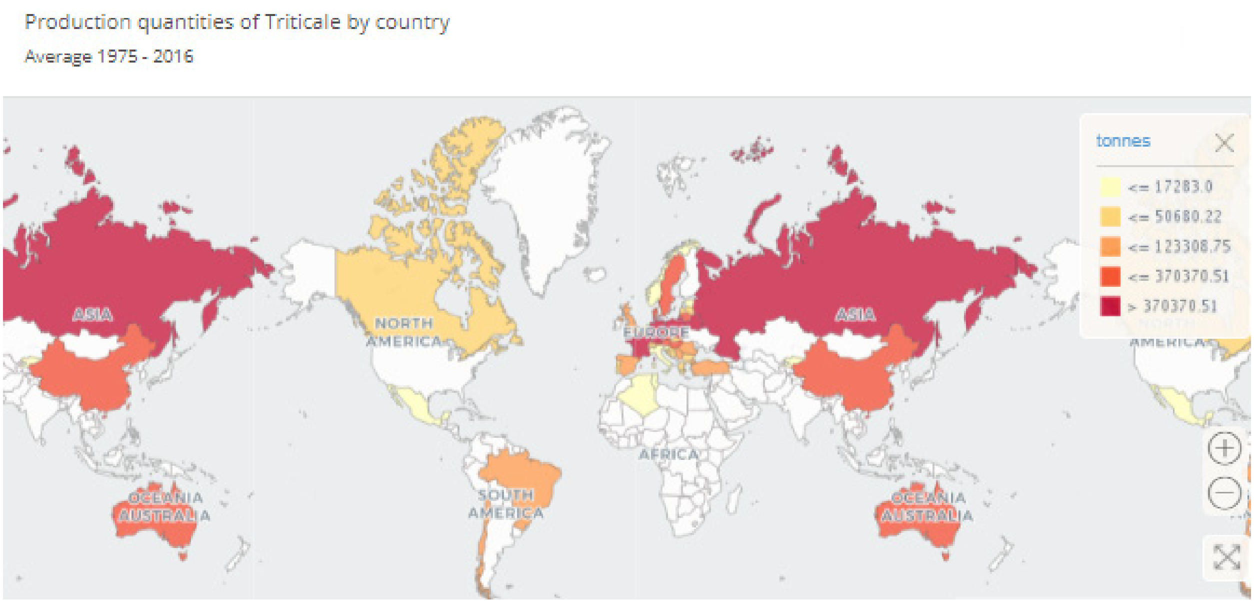

Figure 3. Global triticale production by country, average 1975 - 2016 [10]

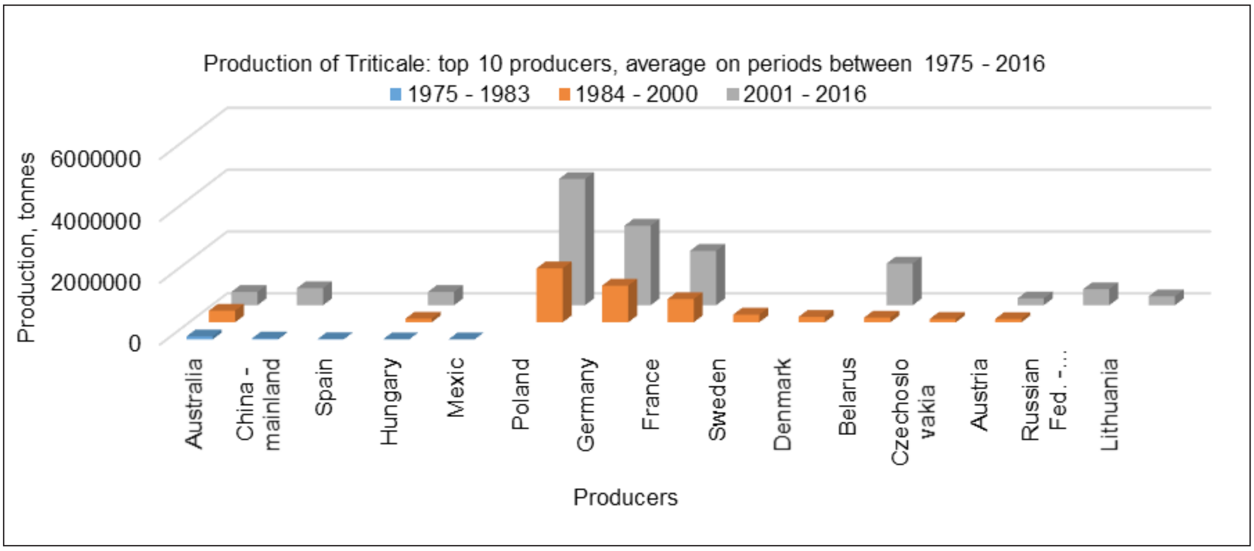

Figure 4. Triticale production: top 10 producers on periods, average 1975 - 2016 [10]

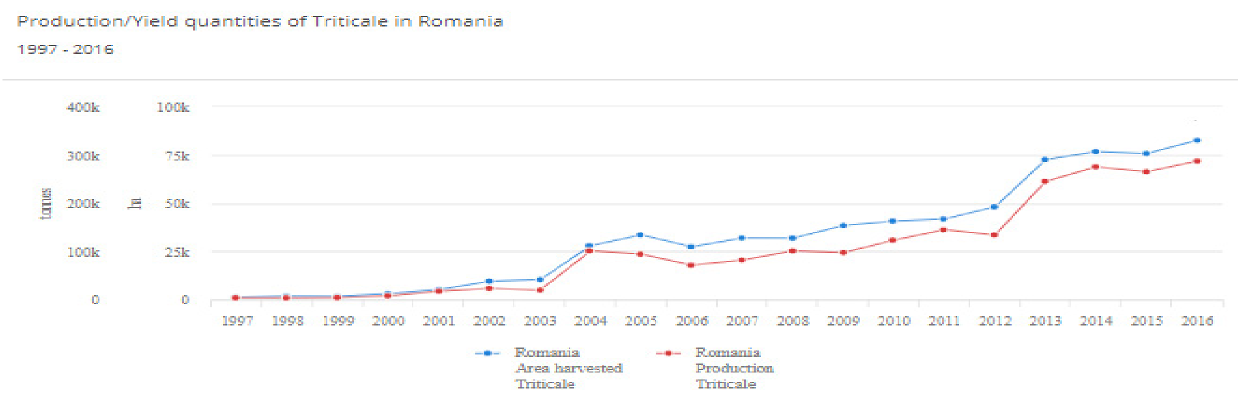

Figure 5. Triticale production in Romania, average 1975 - 2016 [10]

The top 10 producers of triticale are: Poland (2.914.567,44 t), Germany (1.879.323,94 t), France (1.240.742,18 to), Belarus (918.100,12 t), Russian Federation 520,431.75 t), Australia 370,370.51 t), China (252,020.98 t), Hungary (223,565.23 t), Sweden (220,008,33 t) and Lithuania (219,127,38 t) (Figure 4).

Romania is located at latitude 43 - 48^{0}N and longitude 20 - 29^{0}E, having a temperate continental climate. Figure 5 shows an increased triticale growing area and annual production over the period 1997 - 2016, according to the FAOSTAT data [10].

2.2 Climatic areas for triticale growing

2.2.1 Global climatic areas

Globally, triticale is grown in areas with different climate types (Figure 6):

- Mediterranean climate (Spain, Turkey, Algeria, Tunisia).
- Oceanic mild temperate climate (Poland, Germany, France, Belgium, Denmark, Luxemburg, The Netherlands, Switzerland).
- Temperate climate with four seasons (Romania, Hungary, Czechoslovakia, Belarus).

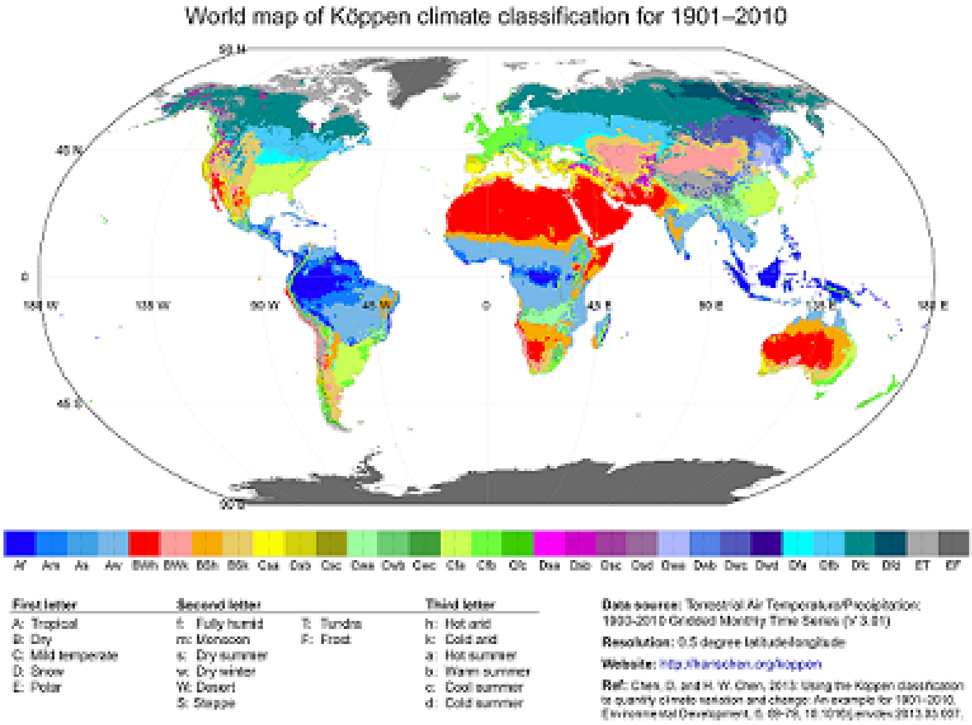

Figure 6. The main characteristic of the Köppen climate major groups and sub-types for 1901 - 2010 [16]

- More climate types, including intracontinental arid climate (Russian Federation, China).
- cold temperate climate (Canada, North Europe, North Asia).
- Tropical and sub-tropical climate (Brazil, Chile, Mexico).
- Semi-arid climate (Australia), and
- Equatorial climate (Brazil) (Figure 6) [16, 17, and 18].

According to these climatic areas and the classification of countries on triticale production (Figures 3 and 4), triticale crops prove to be favoured by the oceanic mild temperate climate from Europe (Poland, Germany, France, Denmark, Belgium - Luxemburg, The Netherlands), countries that have plains with chernozem soils.

2.2.2 Global climate risk index (CRI) for 1997 - 2016

The high and very high climate risk indices (51 - ≥100) are for equatorial and tropical countries (Africa: Maroc, Algeria, Libia, Egipt, Mauritania, Niger, Sudan, Ethiopia, South Africa, Namibia; Middle East: Arabian Peninsula, Turkey, Iran; South America: Brazil, Argentina, Peru). The low and minimum climate risk indices (1 - 20) are in Asia (Russian Federation, China, Afganistan), Oceania (Australia) and the United State of America. Northern countries have medium climate risk index (51 - 100), of which two top producers with low and very low climate risk index (France 11 - 20; Germany 21 - 50) (Figure 7) [19].

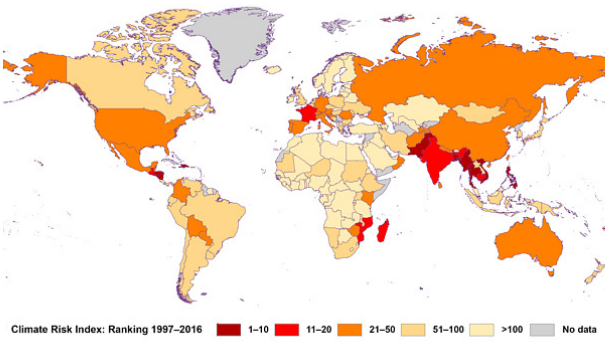

Figure 7. Global Climate Risk Index, Ranking 1997 - 2016: 1 - 10: Minimum risk, 11 - 20: Low risk, 21 - 50: Medium risk; 51 - 100: High risk, >*100*: Very high risk) [19]

Romania has a temperate climate with four seasons and medium climate risk index (21 - 50) [16, 19]. The highest triticale productions are obtained in the submontane regions and depressions in Transylvania, north-west of the country and north of Moldavia. Triticale is cultivated as a fodder plant in the plains of Romanian Plain, Dobrogea, Banat Plain and Transylvania Plain [20].

2.3 Climate change

2.3.1 Global climate changes

Climate change will increase the frequency and intensity of extreme weather events (temperatures, abundant precipitations, tropical cyclones, drought and floods), followed by changes in the distribution of affected areas and increased the vulnerability of particular social groups and economic sectors [11, 12]. The most affected region will be Sub-Saharan Africa where 75 - 250 million people will suffer from water scarcity by 2020, and 2 - 7 million people will be affected by flooding by 2080 [21, 22]. In different regions of the world, temperature raising by +2...4 ^{0}C will result in the appearance of "hot spots", rainfall patterns and drought events will increase, resulting in desertification and significant impact on the production of crops [23] (Figure 8).

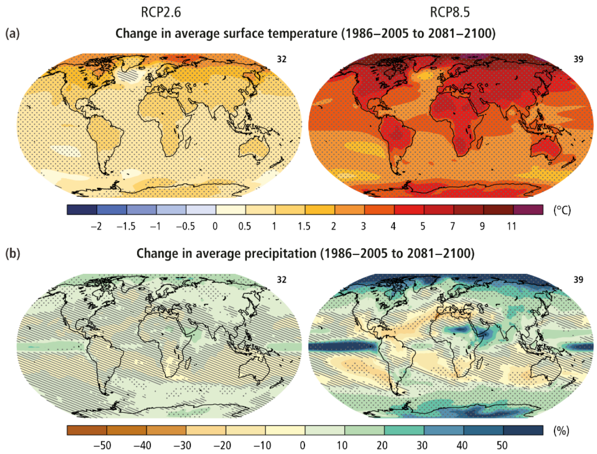

Figure 8. Changes in average surface temperature and precipitation based on multi-model average projections for 2081 - 2100, compared to 1986 - 2005, in RCP2.6 and RCP8.5 scenarios [15]

In Europe, an increase in regional differences in natural resources is foreseen [11, 12]. High temperature and drought will reduce water availability and crop productivity in the southern part. In South-East Europe, a temperature increase of 4...5 ^{0}C is predicted, and the availability of water will be reduced, especially during the summer. These conditions will lead to: a decrease of agricultural production (by 10…30%), drought, temperature shocks, soil and ecosystem degradation, desertification. Increasing the frequency of violent rains will increase erosion and loss of organic matter in the soil. In Central Europe, the temperature rise of 3...4 ^{0}C is predicted, and precipitation may increase in the winter and decrease in summer, with an increased risk of flooding. Agriculture is expected to be affected by soil erosion, organic soil loss, pest and disease migration, high temperature and drought [24].

The predicted climate changes for Romania were a 4…5 ^{0}C increase in temperature and water scarcity in the summer (South-East of Romania) and a 3…4 ^{0}C increase in temperature and a fall in rainfall during the summer (North Romania) [11, 25, and 26].

2.4 Research on triticale crop

2.4.1 Global research on triticale crop

In the case of the global research, the scientific articles have mainly reported on:

- Nutritional composition and food use [2].
- Effects of fertilisation on productivity and quality of triticale winter crops [27].
- Prediction of triticale resistance to fusariosis disease [28, 29].
- The effects of interaction between genotype and environmental factors on the triticale resistance to fusariosis disease and the production of deoxynivalenol mycotoxin [30].
- Proteomic alteration of triticale varieties after infection with *Fusarium culmorum* [31].
- Triticale contamination with deoxynivalenol [30].

2.4.2 Romanian research on triticale crop

In the case of Romanian research, the scientific articles have mainly reported on:

- Analysis of triticale germplasm for the regional production, amelioration, acclimatization and hybridization potential from Transylvania in the Braila Plain [32].
- Triticale allelic potential in the Southern Plain [33].
- Production under different pedoclimatic conditions in different areas in the centre of Moldavia [34], Southern Hilly Area [35, 36], Southern Plain [37, 38, and 39] and southern Oltenia [40, 41].
- Physical-chemical quality indicators (hectolitres mass, humidity, falling index, protein content, wet gluten, broken grains, grains attacked by *Fusarium* sp., grains attacked by insects, toxic seeds) in Transylvania and Moldavia [42, 43].
- Rheological properties [44], the influence of fertilisation and herbicide on the physicochemical properties (moisture, protein and gluten content, Zeleny index) of triticale crops in the Western Plain [45, 46].
- Milling, functional and thermo-mechanical properties of the triticale grown in southeast Moldavia [47].
- Effects of climatic conditions on the variability of certain productivity characters of the winter triticale crop in Transylvania [48] and Moldavia [49].
- Triticale improvement programs for resistance to *Fusarium* sp. and production of deoxynivalenol [50, 51, 52, and 53].

Scientific data have shown that triticale has improved genetic potential, productivity, rheological and technological properties compared to wheat and rye, especially in unfavourable conditions from the dry areas.

2.5 Mycotoxins occurrence

2.5.1 European occurrence of deoxynivalenol in triticale

The grain's contamination with *Fusarium* sp. and deoxynivalenol mycotoxin is influenced by the agroclimatic factors [54, 55, and 56], especially during the flowering period [57].

In Europe, more trials on the triticale's amelioration for the attack by *Fusarium* sp. and production of deoxynivalenol were carried out, but very few publications have been found on incidence and level of deoxynivalenol in a relatively small number of cereals and food samples.

In Hungary, deoxynivalenol was reported between 50 - 870 μg/kg in maize, triticale and rye, while grains were contaminated between 70 - 1,560 μg/kg in period 1991 - 1998 [58].

In Poland, triticale was less contaminated with deoxynivalenol than durum wheat and more contaminated than barley [59], but the most contaminated cereal [60].

In Lithuania, contamination with deoxynivalenol was 125 - 164 μg/kg in triticale from the period 2006 - 2007 [61], traces - 370 μg/kg in rye, triticale and winter wheat and 1,121 μg/kg in wheat from the years 2004 and 2005 [62]. Low contamination is because climatic conditions are not favourable for cereals' attack by *Fusarium* sp. and deoxynivalenol production.

The climatic changes for Romania will increase the risk of lowering the productivity and physicochemical, rheological and technological properties of triticale crops, increasing the risk contamination with mycotoxins in the agro-food chain. Romanian scientific publications have shown that certain areas in the Western Plain, Transylvania and the Southern Hilly Area have experienced a higher incidence and level of *Fusarium* sp. and deoxynivalenol [63, 64, 65, 66, 67, and 68]. In southeast Romania, deoxynivalenol was between 0 - 2248.2 μg/kg in samples of corn, wheat, barley, oats, soybean, rye and triticale from the period 2008 - 2010 [69].

Annual grains crops (common wheat, durum wheat, triticale, rye) were analysed for contamination with deoxynivalenol and association with meteorological factors (precipitation and temperature) between 2012 and 2014. Triticale's contamination with deoxynivalenol ranged between <18.5 - 3378.4 μg/kg in the year 2012, between <18.5 - 3106.4 μg/kg in the year 2013 [63] and between <18.5 - 3.592.7 μg/kg in the year 2014 [55]. The scientific results for triticale's contamination with deoxynivalenol have not been statistically analysed in the context of geographical, pedoclimatic and soil types of agricultural areas of Romania.

2.5.2 Global occurrence of mycotoxins in the food and feed chain by geographic coordinates and climate type

Analyses are based on processing the data published by Schatzmayr and Streit [14], who conducted a global survey programme to assess mycotoxin contamination in feed and feed raw materials, in period 2005 - 2015: 19,757 [finished feed, maize, wheat and wheat bran, barley, silage, soybean meal, distillers dried grain with solubles, corn gluten meal, rice and rice bran, straw, and other feed ingredients (e.g. cotton seed, sorghum, cassava, peanut, copra, etc.)], 64,166,566 individual analyses of aflatoxins (AF), zearalenone (ZEN), deoxynivalenol (DON), fumonisin B (FB) and ochratoxin A (OTA) (Table 1, Figure 9).

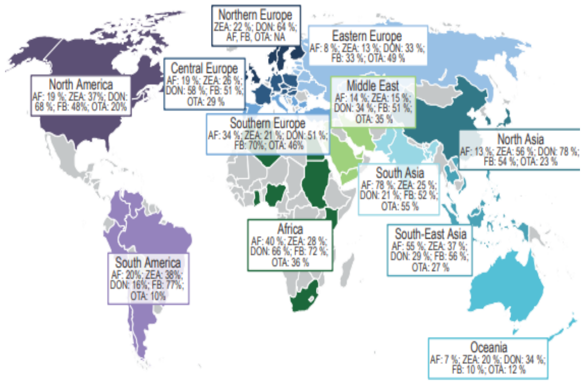

Figure 9. Global occurrence of mycotoxins in the food and feed chain, 2005 - 2012 [14]

Table 1. Summary of the global survey results [14]

Parameters	Aflatoxin[2]	Zearalenone	Deoxynivalenol	Fumonisin[2]	Ochratoxin A
Tested samples	11,967	15,533	17,732	11,139	7,195
Positive samples	3,142	5.797	9,960	6,204	1.902
Percentage of positives	26%	37%	56%	54%	25%
Average positives (μg/kg)	57	286	1,009	1,647	14
Median positives (μg/kg)	11	85	453	750	2.6
1st quartile positives (μg/kg)	3	43	234	332	11
3rd quartile positives (μg/kg)	40	225	972	1.780	6.2
Maximium (μg/kg)	6,323	26,728	50,289	77,502	1,589
Sample orifin	Myanmar	Australia	Central Europe	China	China
Sample types (analysis year)	other feed (2012)	silage (2007)	wheat (2007)	finished feed (2011)	finished feed (2011)

[1]Results of the analysis of 19,757 samoles of feed and feed raw materials sourced globally, specified the number of samples analysed for each of the mycotoxins/micotoxin groups, the number and percentage of samples testing positive (LODs specified in Streit *et al.*, 2013) for the respective mycotoxin as well as the average, median, first quartile and third quarile of the concentrations detected in positive samples (μg/kg), regarding maximum values, the type and origin of the sample and the year of analysis is given.

[2]Aflatoxin: sum of aflatoxin B_1, aflatoxin B_2, aflatoxin G_1, aflatoxin G_2, Fumonisin: sum of fumonisin B_1, fumonisin B_2 and fumonisin B_3.

Highest levels of mycotoxins were detected and reported as: AF of 6,323 μg/kg in feed from Myanmar, 2012; ZEA of 26,728 μg/kg in silage from Australia, 2007; DON of 50,289 μg/kg in wheat from Central Europe, 2007; FB of 77,502 μg/kg in finished feed from China, 2011; OTA of 1,589 μg/kg in finished feed from China, 2011 (Table 1) [14]. According to Sandu [70], the years 2007, 2011 and 2012 are part of 10 years series of global warming.

Prevalence of mycotoxins was dependent on regional climatic conditions (AF 78% in South Asia; ZEA 56% in North Asia; DON 78% in North Asia, FB 77% in South America; OTA 55% in South Asia) but no trend was reported (Figure 9) [14].

The current study evaluated the global trend of mycotoxin contamination based on an integrated analysis of global mycotoxin occurrence from 2005 - 2012 [14], geographical coordinates of global regions (northern and southern latitude, eastern and western longitude) [71], global climate types [16, 17], global climatic risk index from 1997 - 2016 [19], global map of annual averages of temperature and rainfall from 1901 - 2015 [72], in context of global climate change scenarios by 2010 [73] (Tables 2 and 3; Figures 10 - 12).

The highest prevalences of AF and OTA were detected in areas with equatorial and tropical climate [52°N; 38 - 76°E: South and South-East Asia, (North) Africa, Middle East, South-East Europe], the Northern Hemisphere was more contaminated (Table 2, Figures 10 and 12). The optimum climatic conditions for AF and OTA were established for warm and arid or very humid areas (average annual temperature 20.5 - 30 °C, total annual rainfall 475 - 2476 mm) (Table 2). Amra *et al.*, [74] and Paterson and Lima [75], reported optimum conditions for AF and OTA, produced by *Aspergillus* sp., in the warm areas. OTA produced by *Penicillium verrucosum* was reported in cool temperate regions from Canada, east and north-west Europe and parts of South America at a temperature < 30 °C and a_w 7 [76, 77]. Battilani *et al.*, [16], estimated an increase of AF contamination in wheat and maize from Europe in the climatic scenarios of temperature increase +2...+5 °C.

Contamination with FB was worldwide in areas with: equatorial, tropical, Mediterranean, oceanic temperate, cold temperate climates, with the highest prevalence in the Southern Hemisphere (South America, Africa) (Table 2, Figures 10 and 12). The optimum climatic condition for FB were established in warm and arid or very humid areas (average annual temperature 20.5 - 30 °C, total annual rainfall 475 - 2476 mm), and in oceanic climate zones (average annual temperature 5.5 - 10 °C, annual rainfall 475 - 724 mm) (Table 3). Mirete *et al.*, [78], reported the worldwide occurrence of FB produced by *Fusarium* sp. (*F. verticillioides*, *F. moniliforme* and *F. proliferatum*).

The highest prevalence of DON was in the Northern Hemisphere (54.53 - 61.01°N: North America, North Asia), but also in the Southern Hemisphere (possibly in southern part of Africa) (Table 2, Figures 10 and 12). The optimum climatic conditions for DON, produced by *Fusarium* sp. (mainly *F. culmorum*, *F. graminearum*), were in cold and dry temperate continental areas (average annual temperature 0.5 - 5 °C, total annual precipitation 225 - 374 mm), and b) in oceanic temperate areas (annual average temperature 5.5 - 10 °C, total annual rainfall 475 - 724 mm) (Table 3). Miller [79], and Snijder and Perkowski [80], reported growth of *Fusarium graminearum* in: North America, South China, East Europe, and *Fusarium culmorum* in colder areas from west Europe.

The highest prevalence of ZEA as in the Northern Hemisphere 61.01 - 62.28°N: North America, North Asia), but also in the Southern Hemisphere (possibly in southern part of Africa) (Table 2, Figures 10 and 12). The optimum climatic condition for ZEA were established in a) cold and humid climate areas (average annual temperatures 5.5 - 10 °C, total annual rainfall 475 - 724 mm) and b) hot and very humid climate (20.5 - 30 °C, 725 - 4974 mm) (Table 3). Miller [79] and Snijder and Perkowski [80] reported growth of *Fusarium culmorum* in colder areas of west Europe.

The climatic risk index is the highest in equatorial and tropical areas (CRI ≥ 100), with the highest prevalence of AF, OTA and FB. The triticale crop will be adversely affected in Turkey, Brazil and Algeria. In the northern areas with CRI ≤ 100 (62.28°N: North Europe), climate change will produce warming of the cold regions with a positive effect on crop vegetation but also changes in fungal and mycotoxin production (DON, ZEN, AF).

Among the main cultivating countries, Australia appears to have the lowest climate risk, to reduce triticale production and to increase mycotoxin contamination (Table 2, Figures 10 and 12).

In B2 scenario by 2050 and 2100 with climate sensitivity 5.5 °C, the most vulnerable to climate change were: sub-Saharan Africa, South Asia and South-East Europe, followed by South and Central America, and the southern part of North America [73]. By 2055, climate change will affect the production of the main cereal crops by 6 - 18% decrease in the equatorial areas (sub-Saharan Africa, Brazil, South Asia) and 1 - 7% increase in the northern areas (Canada, North Europe, North Asia) [13].

Table 2. Correlation between global regions, geographic coordinates, climate risk index, triticale productivity and mycotoxin prevalence (data processing [10, 14, 16, 17, 19, 71]).

HEMISPHERES	GLOBAL REGIONS	GEOGRAPHIC COORDINATES, degrees [71]		CLIMATE TYPE [16,17]	CLIMATIC RISK INDEX [19]	1975 – 2016, PRODUCTION OF TRITICALE BY COUNTRY, tonnes [10]	PREVALENCE OF MYCOTOXINS, % [14]					
		LATIT.	LONGIT.				AFLA	OTA	FB	DON	ZEA	
							7	10	10	16	13	Minim
							27	29	48	41	32	Average
							78	55	77	78	64	Maxim
NORTHERN HEMISPHERE	NORTH EUROPE	62.28	12.34	Arctic, Boreal, Oceanic	51 - 100 (Scandinavia)	<= 370,370.51 to	22	n.a.	n.a.	n.a.	64	
	NORTH ASIA	61.01	99.20	Arctic, Boreal, Oceanic, Temperate Continental, Sub-Tropical	21 - 50 (Russian Federation, China)	> 370,370.51 to	13	23	54	78	56	
	NORTH AMERICA	54.53	-105.26	Arctic, Boreal, Sub-Tropical, Tropical	51 - 100 (Canada) 21 - 50 (Alaska, USA, Mexic)	<= 50,680.22 to <= 17,283.0 to (Mexic)	19	20	48	68	37	
	EAST EUROPE	52.01	37.96	Temperat Continental	51 - 100 (Ukraine)	-	8	49	33	33	13	
	CENTRAL EUROPE	50.38	14.97	Oceanic mild Temperate	21 - 50 (Germany, Austria, Czech, Hungary) 51 - 100 (Poland)	> 370,370.51 to	19	29	51	58	26	
	SOUTH EUROPE	41.28	-1.21	Oceanic, Mediteranean, Sub-Tropical	11 - 20 (France) 51 - 100 (S. – E. Europe)	> 370,370.51 to <= 123,308.75 to (S. – E. Europe)	34	46	70	51	21	
	MIDDLE EAST	29.30	42.55	Mediteranean, Sub-Tropical, Tropical	>100 (Arabian Peninsula, Turkey) 51 - 100 (Iran)	<= 123,308.75 to (Turkey)	14	35	51	34	15	
	SOUTH ASIA	25.04	76.46	Tropical, Sub-Ecuatorial	1 - 10 (Pakistan, Mianmar, Thailand, Cambodgia), 11 - 20 (India)	-	78	55	52	21	25	
EQUATOR												
SOUTHERN HEMISPHERE	SOUTH - EAST ASIA	-2.22	115.66	Ecuatorial, Tropical	1 - 10 (Malaysia, Indonesia, Vietnam) 11 - 20 (Phillipines)	-	55	27	56	29	37	
	SOUTH AMERICA	-8.78	-55.49	Ecuatorial, Tropical, Sub-Tropical	21 - 50 (Columbia, Bolivia), 51 - 100 (Brazil, Argentina, Peru)	<= 123,308.75 to (Brasil, Chile)	20	10	77	16	38	
	AFRICA	-8.78	34.51	Tropical, Sub-Tropical, Sub-Ecuatorial Ecuatorial	>100 (Maroc, Algeria, Libia, Egipt) 51 - 100 (Mauritania, Niger, Sudan, Etiopia, Africa de Sud, Namibia), 21 - 50 (Kenya, Zimbabwe) 11 - 20 (Mozambique, Madagascar	<= 17,283.0 to (Algeria)	40	36	72	66	28	
	OCEANIA (Australia)	-22.74	140.02	Arid Temperat Continentala	21 - 50 (Australia)	<= 370,370.51 to	7	12	10	34	20	

n.a. – non applicable

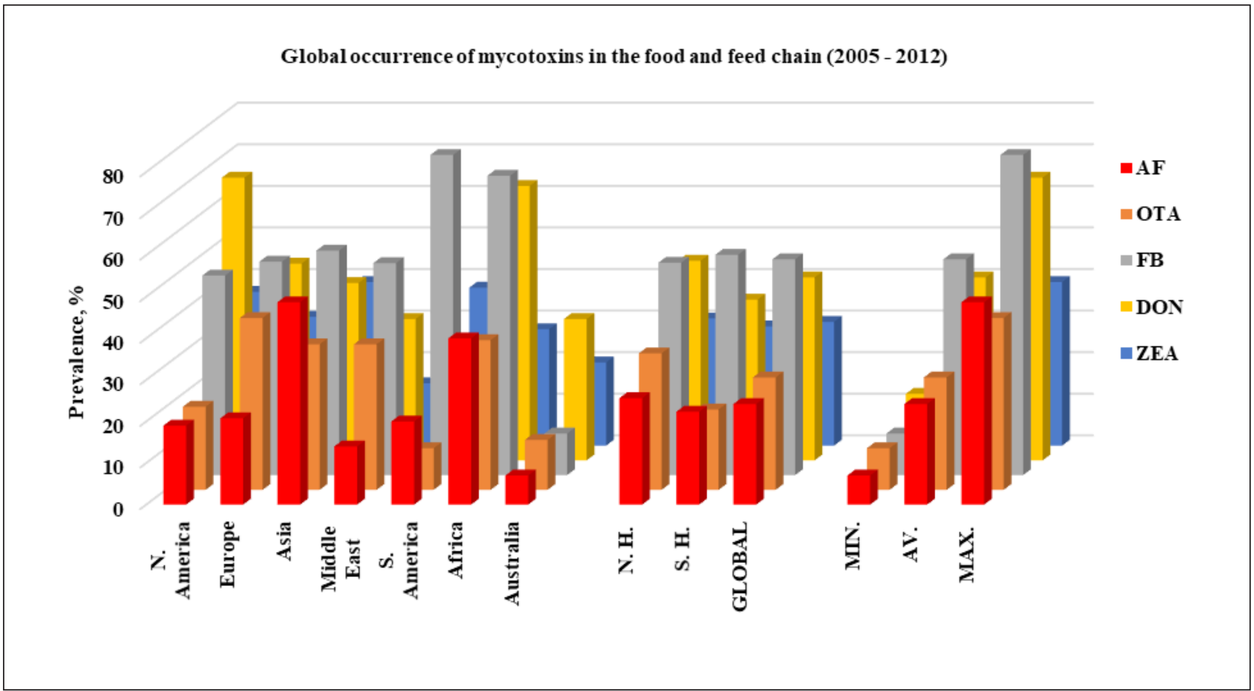

Figure 10. Global occurrence of mycotoxins in the food and feed chain (2005 - 2012) (data processing [14])

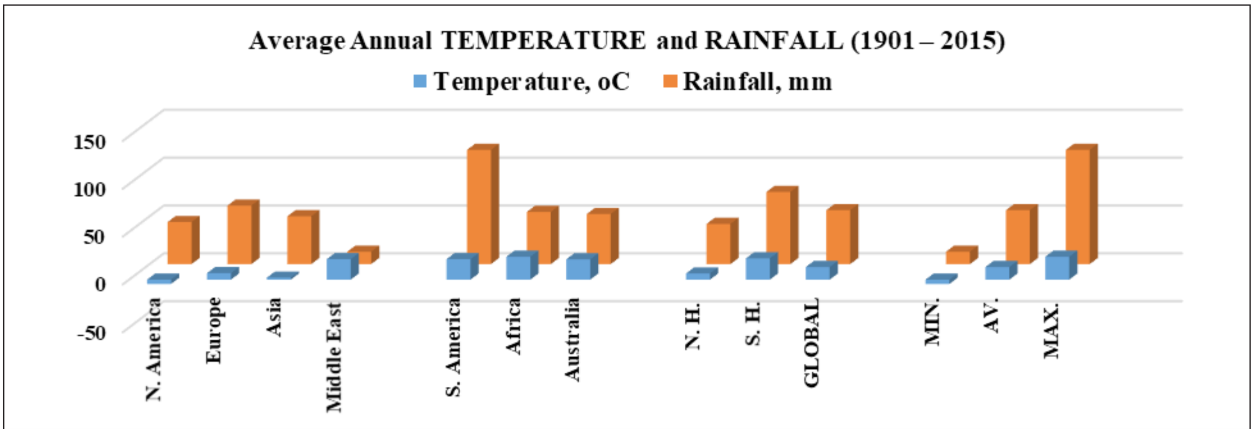

Figure 11. Global evolution of the annual average of temperature and rainfall from 1901 – 2015 (data processing [72])

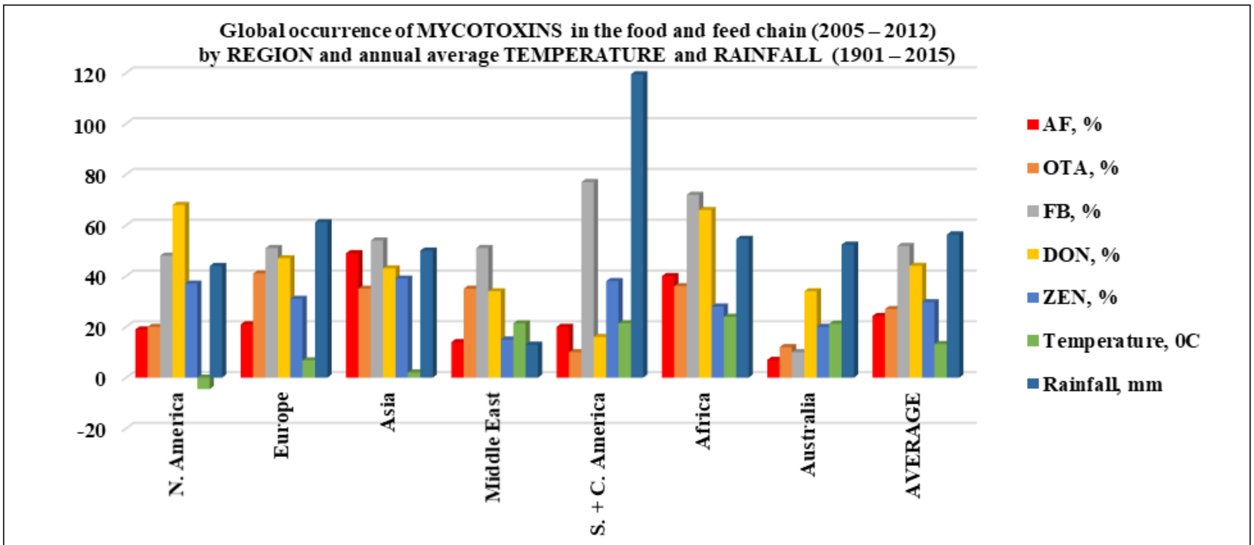

Fig. 12. Influence of the global regions and weather parameters on mycotoxins occurrence (data processing [14, 72])

Table 3. Climatic conditions for fungal growth and mycotoxin production

MYCOTOXIN	REGIONS WITH HIGHEST PREVALENCE 2005 - 2012 [14]	CLIMATE TYPE [16, 17]	WEATHER PARAMETERS, 1901 - 2015 [72]	
			TEMP., °C Annual average	RAINFALL, mm Total annual
AFLATOXIN (AF)	S. Asia, S. - E. Asia, Africa, S. Europe	(sub) Equatorial, (sub) Tropical, Mediterranean	20.5 - 30	725 - 2476
OCHRATOXIN A (OTA)	S. Asia, E. and S. Europe, Africa, Middle East	(sub) Equatorial, (sub) Tropical, Mediterranean	20.5 - 30 20.5 - <30 (*P. verucossum*)	725 - 2476 475 - 724
FUMONISIN (FB)	S. America, Africa, S. Europe, S. and E. Asia	(sub) Equatorial, (sub) Tropical, Mediteranean	20.5 - 30	725 - 2476 475 - 724
	C. Europe	Oceanic Temperat Continental	5.5 - 10	475 - 724
DEOXINIVALENOL (DON)	N. Asia, N. America, (S.) Africa	Temperat Continental with Polar influences	0.5 - 5.0	225 - 274 275 - 374
	S. Europe, C. Europe	Mediterranean, Oceanic, Humid Temperat Continental	5.5 - 10	475 - 724
ZEARALENON (ZEA)	N. America, N. Asia	Temperat Continental with Polar influences	5.5 - 10	475 - 724
	S. America, S. - E. Asia	(sub) Equatorial, (sub) Tropical	20.5 - 30	2475 - 4974 725 - 2476

2.6 Influence of climate change on cereals' contamination with mycotoxins

Climate change will affect agriculture by altering harvest stability and increasing the risk of food and feed hazards [11, 12, 22, 81, 82, 83, 84, and 85].

Climate change will lead to modification in fungal flora and rate of mycotoxin production in cereals [86, 87, and 88]. Extreme weather events recorded in the recent years (drought in years 2012, 2013, 2015; heavy rain and floods in the year 2014) have caused a decrease in quantity and quality of grain crops, generating food safety and security issues. As a result of the price increase of raw materials, the pressure on agri-food chain across the world has increased [23, 24].

The risk assessment of cereals' contamination with mycotoxins should be conducted over a period of at least 10 to 30 years so that available data collection and their integration allow detection of contamination trends and the impact of climate change, the development and implementation of robust monitoring programs, harmonised at European level [81,82, and 88]. The very different agro-climatic conditions of the global regions cause different incidence and level of contamination with fungi and mycotoxins. Political and economic unions of member states have established rules for mycotoxin contamination of cereals, food and feed to protect human and animal health and to control trade. Worldwide mycotoxin regulations are in place in: European Union, United States, Brazil, Asia (Japan, China, Singapore, Indonesia, Malaysia, Korea) [89].

3. Conclusions

- Triticale was originally grown in arid and salty areas (Australia, China, Spain), then expanded to temperate wetlands (Europe, Canada), wet and hot lands (Brazil) and frost, cold or arid lands (Russian Federation). The top 10 producers of triticale are located in Europe (Poland, Germany, France, Belarus, Hungary, Sweden, Lithuania), Asia (Russian Federation, China) and Australia. Between 2001 and 2016, the most significant increases in triticale cultivated areas and production were reported, although this period was globally characterised as the warmest [90]. In Europe, favourable areas for triticale cultivation are the western, north-western and northern plains, with oceanic temperate climate.

- Sub-Saharan Africa will be most affected by climate change, water scarcity and floods in coastal areas will affect the population by 2080. Europe will record temperature increases of 3...5 ^{0}C and precipitation decreases, more obvious in the southern part compared to the central part. The climate changes predicted for Romania have the same trends as those of Europe, but Romania's vulnerability to climate change is average [19, 91]. Estimation of climate change and its effects depend on the simulation model used, but it is expected an increase of temperature +2...5 ^{0}C ("hot - spots"), a drop in rainfall in warm areas and a rise in cold areas, soil deterioration [92, 93] and changing pathogens populations. Climate change will modify growth conditions for cereals, fungal attack and mycotoxins' production [94, 95, 96, and 97] which will lead to a decrease of physical, chemical, nutritional and biological properties of cereal crops, including triticale.

- The results of the study show that triticale production appears to suffer insignificant changes in production under the influence of climate change in major cultivating countries from Europe (Poland, Germany, France) and Asia (Russian Federation, China). The production and quality of triticale crops may be affected by climate change (drought, extreme weather events etc.) predicted for southern and south-eastern Europe, South America and Africa countries with an increased climatic risk index (51 - 100).

- Changing global climate conditions will also affect the contamination pattern of triticale with fungi and mycotoxins. In the cold and humid areas of the northern regions that will heat up, the incidence and level of mycotoxins produced by *Fusarium* (DON, ZEN) will increase, while in southern areas with warm and dry climates or wetlands the incidence and level of contamination mycotoxins produced by *Aspergillus* and *Penicillium* (AF, OTA) will increase. Different agro-climatic conditions determine different production, physico-chemical and biological quality of agro-food products that require global regulations to ensure health protection and trade between continents.

- Advanced research to improve agricultural properties, nutrient quality and acclimatization of triticale crops, as well as to improve pathogen resistance, will enable triticale to be introduced into the agricultural crops of different countries with conditions less favorable to wheat.

- As a challenges can me mentioned following:

a). To date, no study has been conducted on triticale contamination with deoxynivalenol under the influence of geographic coordinates and pedoclimatic conditions.

b). In 2018, Romania will evaluate the triticale crop for contamination with deoxynivalenol by geographical position and pedoclimatic factors of country, in the context of climate change in Southeast Europe.

The main objectives of the ongoing project "Triticale's contamination with deoxynivalenol in the geographic and pedoclimatic context of Romania" (PN 18 02 01 03) are the following:

O1. Evaluation of the agricultural areas for grain growing in the context of geographic (coordinates, agricultural regions) and pedoclimatic (weather, aridity indices, types of soils) conditions of Romania.

O2. Evaluation of triticale crops' contamination with deoxynivalenol, in the geographic and pedoclimatic context (present and future) of Romania.

O3. Risk map for triticale crops' contamination with deoxynivalenol.

O4. Scientific transfer to the Ministry of Agriculture and Rural Development.

c). Countries should use all available data on mycotoxins and agro-climatic conditions and integrate them into the European and global knowledge. Contribution to innovation consists in the integrated research of triticale harvest quality over three consecutive years in the context of the geographic position, present pedoclimatic factors and predicted climate change for Romania. Through the activities that are foreseen, the project has a multidisciplinary character given by technical and scientific fields (food safety, contaminants, agriculture, meteorology and geography) and represents an added value for research, agri-food producers and traders, regulatory bodies in Romania and worldwide. Aware of the risk of cereals' contamination with DON under the influence of pedoclimatic factors in the context of climate change will lead to changes in cereals varieties, agro-technical practices, organisational chain (harvesting, sale/purchase, storage, primary processing of agricultural products), implementation of an official control system, especially in risk areas. The scientific results can be used by the Competent Authorities, producers, depositories and traders, processors and the Ministry of Public Finance. The scientific results will complete the primary agricultural chain within the official control system of mycotoxins and provide the national authorities with a clear situation of cereals' and food contamination. To prevent contaminated cereal batches from entering the processing chain, the Governments must provide subsidies for farmers affected by natural calamities (drought, abundant rainfall, floods) that cause cereal contamination with mycotoxins.

- The study demonstrates the need to know the unfavourable areas for wheat and favourable for triticale crops under the influence of current and future climatic conditions, so that agricultural measures and regulations are taken for agri-food safety and security.

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