

# EFFECTS OF INTERACTION BETWEEN ABIOTIC STRESS AND PATHOGENS IN CEREALS IN THE CONTEXT OF CLIMATE CHANGE: AN OVERVIEW

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## ABSTRACT

*The scenario that climate change will lead to higher incidence of crop diseases, following geographical distribution of the host and cropping technology, suggests that can be positive, negative or neutral depending of multiple interactions between host, pathogens and abiotic stress factors. Both plants and pathogens are constantly threatened by abiotic stress factors such as high temperature, moisture, drought, salinity, soil pH, greenhouse gases, Ultraviolet-B (UVB) radiation and air pollutants. Currently the research focused on this topic is inconsistent therefore these interactions are poorly understood. In the process of adaptation to these adverse conditions, it is expected that abiotic stress factors impact pathogens into a wide range of responses such as changes in life cycles (pathogen reproduction – shorter incubation -, dispersal, survival and activity), increased incidence, modified pathogenicity, genetically recombination and aggressiveness traits. The present review is focused particularly on the impact of abiotic stress factors on cereals pathogens and all changes in their life cycles and host-pathogen interaction associated with under climate change conditions. However, our study suggest that a better understanding of interaction between pathogens and abiotic stress factors can be an important mechanism to estimate disease risk on a large scale and to introduce new understandings in developing management strategies.*

## INTRODUCTION

During the last decades many changes in agricultural system have contributed worldwide to significant progress in food, fiber, fuel production as a consequence of the interaction among multiple factors: world population increase, urbanization, technical progress, income growth, genetically progress, improved cropping technologies, globalization on food production, machinery revolution, markets, consumption, faster access to the information (ALEXANDRATOS and BRUINSMA, 2012; BONCIU, ELENA, 2012, 2016, 2017; DRAGOMIR, C.L. and Elena PARTAL, 2016; MATEI, GH et al.,

2008, 2009, 2010; Elena PARTAL et al., 2013, 2014; POPP et al., 2013; REILLY, J. and SCHIMMELPFENNING, D., 2000). The question is if this progress is able to fix the issues of global food production and food security and for how long? Additional factors, as climate variability and climate changes come to threaten both of them when most climate projections using GCMs show warming for all continental interiors, leading to variable responses to the level of each ecosystem (Pan et al, 2004; PARRY et al., 2004).

However, the current awareness of climate change in the agriculture land

use (e.g. land sparing – save some natural ecosystems from conversion into cropland), crop production and future food security appears to be high, especially due to high uncertainties about future food production (DÖÖS and SHAW, 1999) and estimations about population increase to 10 billion in 2050.

The possible increases in extreme weather events might cause higher yield variability, lower harvestable yields, reductions/extensions in land use in some areas, introduction of new crop species, changes in soil organic matter levels, in nitrate leaching risk, in soil erosion and salinization, in new crop protection challenges (BONEA DORINA, 2016; BONEA, D. and URECHEAN, V, 2017; LEIRLÓS et al., 1999, REILLY, 1994, 1999; YEO, 1999; REILLY and SCHIMMELPFENNING, 1999; OLSEN and BINDI, 2002; HEYDER et al. 2011; PERKINS et al., 2011; SIN GH. and PARTAL ELENA, 2010) and also changes in crop host and pathogens and pests interaction, which will drive emergence of infectious diseases in both agricultural and non-managed ecosystems through multiple pathways (COTUNA et al., 2013 a, b; ENGLER et al., 2011; HEYDER et al., 2011; SCHERM, H., 2004; TEIXEIRA et al., 2012). Also, the effects of climate change and climate variability will impact differently food security being location-specific and societally-specific especially in the countries with low income and limited adaptive capacity facing significant threats to food security (von Brown, 2007).

The responses depend on the particularities of the agricultural systems and on the changes in the crop management. There are scenarios that climatic change will lead to a higher incidence of crop diseases (especially plant host and susceptibility, pathogen reproduction – shorter incubation - dispersal, survival and activity, host-pathogen relationship) and to a potentially larger use of pesticides (NEWTON et al., 2011; SUTHERST et al., 2011). Thus,

new pathogens may occur in certain regions, while other pathogens may decrease to be economically important, following geographical distribution of the host and cropping technology (COAKLEY et al., 1999; GHINI et al., 2008; GHINI and HAMADA, 2008;). General tendency is that pathogens are likely to remain limited to their host distribution and not become disconnected from them. There is serious concern that climate zones will move faster than it is possible for plant populations to track them, which is expected to determine disproportionate extinction of local endemic species (LOARIE et al., 2009). However, many cereals pathogens exhibit considerable capacity for generating, recombining, and selecting fit combinations of variants in key pathogenicity, fitness, and aggressiveness traits that there is little doubt that any new opportunities resulting from climate change will be exploited by them.

This review aims to discuss mainly the impact of climate change on wheat pathogens and host-pathogen relationship which is very important to demonstrate that wheat pathogens can adapt to new environment, despite the fact that currently we are not able to predict accurately the trajectory of each pathosystem under climate change. However, in the last decade the evidence for the measured climate change on cereal crops and their associated pathogens is starting to be documented.

### **CLIMATE CHANGE AND INTERACTION BETWEEN CEREALS HOST AND PATHOGENS**

There are reports of climatic factors affecting the interaction between cereals and pathogens changing host-pathogen relationship. Thus, extreme temperatures (warmer than long-term means, or including lack of, or occurrence of, unseasonal frosts), precipitation (including snow, hail or extreme intensity), wind, light (lack of intensity due to cloud or dust), humidity, CO<sub>2</sub> and other greenhouse gasses have been

associated with changes in pathogens life cycles, increased incidence, pathogenicity, genetically recombination and aggressiveness traits, which involves the urge to rethink the integrated management strategies. These become more difficult when rapid changes in the climate caused by extreme events are likely to lead to disease epidemics because control measures are difficult to apply quickly enough or on a sufficiently large scale to contain the problem. However, there is evidence that, stress conditions stimulate the activity of retrotransposons enhancing the generation of variability in pathogens, enhancing mutation rate and new traits aggressiveness (ANAYA N and RONCERO MIG, 1996; NEWTON A.C., 1988; Halterman D.A. et al., 2003). Clearly these and other post-translational regulatory mechanisms may contribute to adaptive response to climate of pathogens.

There are other examples where the distribution ranges of pathogens have been shown to change in response to climatic variables such as, for example, *Puccinia striiformis* f.sp. *tritici* in response to rainfall patterns in South Africa (BOSHOF et al., 2002). Changes in crop rotations in response to climate change may also influence the future importance of specific pathogens. For example, if warming of northern latitudes enables forage maize to be grown in the rotation then this will leave residues in which pathogens such as Fusarium Head Blight (FHB) could build up high levels of inoculum for subsequent wheat and barley crops (MAIORANO et al., 2008).

However, enhancing crop resilience to the effects of climatic stress, and stresses in general, might be the solution to improve crop performance in the relationship with pathogens (NEWTON et al., 2009).

#### **CO<sub>2</sub>, other greenhouse gasses and UV-B radiation effects**

Carbon dioxide (CO<sub>2</sub>), ozone (O<sub>3</sub>) and other greenhouse gasses along

UV\_B radiation are individual climate change factors that have direct effects on plants and biotic agents (GUDERIAN et al., 1985; DOWING, 1988; KRUPA and MANNING, 1988; MANNING and KEANE, 1988; BAZZAZ, 1990; ASHMORE and BELL, 1991; COLLS and UNSWORTH, 1992; BAKER and ALLEN, 1994; ROGERS et al., 1994, RONECKLES and KRUPA, 1994;)

The changes in the chemical composition of atmosphere such as increases of carbon dioxide (CO<sub>2</sub>), chlorofluorocarbons (CFCs), methane (CH<sub>4</sub>) and ozone (O<sub>3</sub>) concentrations, along with increased solar UV-B radiation have been widely reported (BISHOF et al., 1985; KRUPA and KICKERT, 1989; CRUTZEN, 1992; SECKMEYER and MCKENZIE, 1992; KERR and MCELROY, 1993). There is estimated that tropospheric CO<sub>2</sub> concentration are projected to increase from 355 ppm to 710 ppm, by the year 2050.

Changes in CO<sub>2</sub> concentration increase plant photosynthesis, transpiration rate per unit leaf area and resources use efficiency for water and nitrogen, enhancing wheat canopy, which impact both yield (increases in crop yield are 10-20% for C3 crops and 0-10% for C4 crops according with AINSWORTH and LONG (2005) and wheat-pathogen relationship (THOMSON et al., 1993; THOMPSON and DRAKE, 1994; COAKLEY et al. 1999; PRITCHARD et al., 1999; DOWNING et al., 2000, JONES and CURTIS, 2000; LOLADZE, 2002; LI et al. 2003; PANGGA et al., 2013). Thus, some types of resistance can be more affected in some diseases in wheat (e.g. reduced expression of induced resistance (PLESSL et al., 2005), due to changes in host physiology and in pathogen cycles (e.g. higher spore production) leading to epidemics (CHAKRABORTY et al., 2003; GHINI et al., 2008). Analyzing the effects of the increased CO<sub>2</sub> concentration on wheat pathogens, MANNING and TIEDEMANN (1995) emphasized that wheat rusts, powdery mildew, leaf spots and blights incidence increase due to the

effect of carbohydrate contents which stimulates sugar-dependent pathogens. Also, the amount of primary inoculum due to greater overwintering crop debris would be also increased. An early study on the effects of CO<sub>2</sub> effects on cereals rusts showed that optimal concentration of carbon dioxide for growth of stem rust and stripe rust on wheat were higher (0,3-0,75%) than for crown rust on oats, leaf rust on rye and wheat (0,15-0,5%) (GASSNER and STRAIB,1930).

Ozone is likely to have adverse effects on plant growth and diseases incidence (MANNING et al., 1969; DOHMEN, 1988; MANNING and KEANE, 1988; TIEDEMANN, 1922). Thus, TIEDEMANN and FIRSCHING (2000) analyzed the combined effect of increased CO<sub>2</sub> and O<sub>3</sub> in wheat leaf rust (*Puccinia recondita* f.sp. *tritici*) and observed that wheat leaf rust was strongly inhibited by O<sub>3</sub>, but unaffected by high CO<sub>2</sub> concentration. Barley powdery mildew was found to be relatively ozone tolerant and only inhibited by elevated ozone doses acting during germ-tube growth (HEAGLE and STRICKLAND, 1972). Rusts on cereals have been found to be insensitive to elevated doses of ozone. (HEAGLE, 1970; HEAGLE and KEY, 1973).

High level of SO<sub>2</sub> emissions seems to be correlated with incidence of *Phaeosphaeria nodorum* and *Mycosphaerella graminicola* in wheat (BEARCHELL et al., 2005; FITT et al., 2011). SHOW et al. (2008) reported that fluctuations in amounts of *P. nodorum* in grain were related to changes in spring rainfall, summer temperature and national SO<sub>2</sub> emission. Also, in leaves, annual variation in spring rainfall affected both pathogens similarly, but SO<sub>2</sub> had opposite effects. Higher canopy growth will promote higher residue amount which favors necrotrophic pathogens development, while increased roots biomass will favor soil-born diseases occurrence. However, there is less knowledge about potential impact of climate change on soil-borne pathogens

compared to foliar pathogens (EASTBURN et al., 2011). Previous studies emphasized that the exposure to high CO<sub>2</sub> concentration affects the defensive response in plants against pathogens (BRAGA et al., 2006), altering cultivar resistance. Wheat pathogens and wheat-pathogen relationship are affected by CO<sub>2</sub> changes, which also interfere with uptake of systemic fungicides, with both positive and negative effects on efficacy (COAKLEY et al., 1999; GHINI et al., 2008). Studying the impact of increased atmospheric CO<sub>2</sub> concentration plant viruses, MALMSTRÖM and FIELD (1997) observed that CO<sub>2</sub> enrichment may increase the size of plants affected by barley yellow dwarf virus (BYDV) attenuating the dwarfing symptom due to the increase in root biomass and to the water-use efficiency by diseased plants, positively impacting the disease severity. Also, changes in plant growth and physiology resulting from higher atmospheric CO<sub>2</sub> concentration associated with changes in temperature and precipitation conditions, can affect the efficacy of systemic fungicides altering their penetration, translocation and mode of action into the plants. Changes in cultivars susceptibility can determine a new fungicide application calendar (CHAKRABORTY and PANGGA, 2004; PRITCHARD and AMTHOR, 2005). MADGWICK et al. (2010) predicted that by the 2050s the risk of FHB epidemics and the number of crops where mycotoxin levels would exceed the limit set by the EU will increase across the whole of the UK. VÁRY et al. (2015) investigated the effects of elevated CO<sub>2</sub> on Septoria tritici blotch (STB), which infects leaves and Fusarium head blight (FHB), which infects flowers. The results showed that elevated CO<sub>2</sub> increased the severity of both diseases and the acclimation of the pathogens and the plant worsened disease development. Thus, for FHB, the highest disease levels were found for plants that had been acclimated under elevated CO<sub>2</sub> infected by pathogens that had also been

acclimated at elevated levels affecting yield and reducing the number of grains by 76% and the weight of grain by 59%. In case of a resistant wheat variety it was observed that elevated CO<sub>2</sub> lead to 27% lower number of grains produced was also and 20% lower weight of grain due to FHB. Also, increasing crop biomass by an average 17% by elevated CO<sub>2</sub> (AINSWORTH and LONG, 2005) will further increase the amount of pathogen inoculum in stubble and crop residues. However, further new studies are needed to be done about the effect of CO<sub>2</sub> and other green gases concentrations on plant diseases in both controlled and field trials under cumulated action of other abiotic constrainers.

Relatively little work has been done on the effects of increased UV-B on the occurrence and severity of cereal diseases, and contradictory results showed that UV-B lead to increased (BIGGS et al., 1984), decreased infection (ORTH et al., 1990) or have no effect.

### **Temperature effects**

Higher temperatures are expected to occur in northern areas which will expand the cropping area for cereals by 2050; further more increased diseases severity and Area Under the Diseased Curve are expected too (GHINI et al., 2008). HARVELL et al (2002) argue three hypotheses how pathogens will be influenced by climate change. He suggested that that rising temperatures will (i) increase pathogen development transmission, and generation number; (ii) increase overwinter survival and reduce growth restrictions during this period and (iii) alter host susceptibility. Warmer climates are more favorable for virus-vectors proliferation, because they can complete a greater number of reproductive cycles and additional insect generations which suggests higher incidence of virus diseases in wheat (CAMMEL AND KNIGHT, 1992; NEILSON AND BOAG, 1996; HARRINGTON, 2002; NEWMAN, 2004; HARRINGTON ET AL., 2007; DOBSON,

2009). NEWMAN (2004) pointed out the simultaneous effect of higher temperatures and elevated CO<sub>2</sub> concentration lead to 10% earlier timing of cereal aphids peaks (as much as a month earlier) and to 10% increase in winged forms, which results in greater spread and incidence of *Barley yellow dwarf virus* for which the aphid is the vector. Warmer winter temperatures may also allow wheat pathogens to overwinter in areas where they are limited now by cold, increasing the primary inoculum amount and causing greater and earlier infections during the following crop season. Also, warmer temperatures associated with cropping practices appear to have been associated with shifts in plant hosts for some pathogens, particularly when talking on long-term view (MADGWICK et al., 2011; WEST et al., 2012). Thus, Fusarium Head Blight (FHB) is expected to enhance higher levels of inoculum for subsequent wheat and barley crops in warmer northern latitudes due to introduction of forage maize in crop rotation (MAIORANO et al., 2008). For example, disease incidence of Fusarium head blight in the United Kingdom and Germany might increase middle of this century, whereas disease severity of *Septoria tritici blotch* might decrease in France end of this century (JUROSZEK and VON TIEDEMANN, 2013). Also, it is expected that wheat flowering will be around 2 weeks earlier by the 2050s (4 weeks earlier if we switch to using „Mediterranean-type” cultivars) and harvest will be 3 weeks earlier (or 5 weeks). Consideration of these altered growth stages is important because without it we would conclude that the incidence of fusarium ear blight will reduce substantially due to a decrease in occurrence of suitable wet conditions for infection occurring in early flowering stage (date) (JUROSZEK. P., VON TIEDEMANN, A., 2013). In the case of *F. graminearum*, warmer spring weather will increase spore production and additional spore release from maize debris is likely to lead to an overall increase in fusarium

ear blight on wheat. This is an example of an indirect effect of climate change on a crop disease. Climate change also has an impact on food safety, particularly on the incidence and prevalence of mycotoxins. The main consequence of FHB is that trichothecene mycotoxins, such as deoxynivalenol (DON), accumulate in the grain, presenting a food safety risk and health hazard to humans and animals (GOSWAMI and KISTLER, 2004).

Temperature can also affect disease resistance in plants, thus affecting the incidence and severity of the diseases. Ambient temperature perception in plants is well recognized and plants have been shown to be able to detect temperature changes as little as 1°C (ARGYRIS et al., 2005). The efficacy of current resistance genes may be compromised under more extreme and variable climatic conditions. Thus, previous findings emphasized that under drought stress, resistance expression can be reduced or lost temporary, as well as reduced disease symptoms (BITA and GERATS, 2013). Also, some organisms enhance their ability to generate variants as an adaptive response to climate change (because pathogens exert very intensive selection over few generations), changes which can later become fixed through conventional mutation and recombination (HOVMØLLER et al., 2016). For example, there is an increased range of stem rust a possible explanation is that enhanced levels of free radicals were found under drought stressed conditions.

The same breakdown problem occurred in response to cold stress, rainfall stress, but not salt stress (STEWART, 2002).

## CONCLUSIONS

Anthropogenic activities on the environment have intensified in the last century resulting in a devastating increase in greenhouse gases and triggering global climate oscillation. In the coming years, there could be more changes in the biosecurity of food crops

due to escalating global climate change. Along with climate impact a range of regional and global political and economic factors intensify food insecurity and long term vulnerability in certain regions.

The impact of climate change also need to be considered along with other factors that affect crop yields, such as specific biotic constrainers (pathogens) and its impact on the host-pathogen relationship.

Moreover extreme temperatures and precipitation have been associated with changes in pathogens life cycles, increased incidence, pathogenicity, genetically recombination and aggressiveness traits. Co2 concentrations will continue to increase and we need to know more about elevated CO<sub>2</sub> effects on disease incidence and severity. The climate change may affect not only the optimal conditions for infection but also host specificity and mechanisms of plant infection. Changes in the abiotic conditions are known to affect the microclimate surrounding plants and the susceptibility of plants to disease.

Although, many previous studies have emphasized the sensitivity of plants to various biotic constrainers, the host-pathogen interactions are poorly understood in the context of climatic change. Therefore, the response of pathosystems to climate change is of high interest currently in order to estimate disease risk on a large scale and to introduce new understandings in developing management strategies in this new reality.

On this terms new models of crop and pest and pathogens interactions linked with more performant climate forecasting monitoring systems, breeding for durable resistance in wheat and improving modelling of the many interacting processes, would be an essential investment for future food security.

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