PLANTS AND FUNGAL PATHOGENS UNDER CLIMATE CHANGE, A REVIEW

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Abstract

Climate change has become one of a major problem in the recent world in the past few decades. Pollution caused by human activity affects environment factors universally. The global increase of atmospheric carbon dioxide (CO_2) level, temperature and unpredictable extreme weather caused by greenhouse effect influence the environment. It is observed that climate change factors affect various ecosystems. Nowadays, global food safety is an issue for increasing human population. The decrease of areas suitable for agriculture, deforestation, increased pathogen activity contributes to threats to global food safety. Changes in the environment also affect flora and fauna, causing unpredictable behaviour. Rapid changes in the environment cause abiotic stress to plants and decrease the possibility to survive. The number of studies reveals that adaptation, migration, changes of chemical compounds, the mutation is the key to survival for plants. Scientists agree that climate change has a significant impact on agriculture and horticulture, affecting not only plants but also microorganisms which cause plant diseases. One of the most important threats to global food safety comes from fungal pathogens, which cause numerous loss in agriculture and horticulture annually. The scientific publications reveal that increases in CO_2, temperature and unpredictable precipitation patterns have an influence not only on plants but also their fungal pathogens. These pathogens develop mechanisms which help to adapt to environmental changes and become more resistant to current fungicides. Host shifts, migration, new genetic strains, disease outbreaks also occur more often under changing environment. Understanding how climate change factors can affect plant host and fungal pathogens interactions will make a considerable influence on pest and disease management in future. Widely used fungicides are well known for their harmfulness and limited effect to pathogens. New alternative biocontrol methods are under investigation in the presence of climate change when fungal pathogens become more resistant to chemical control.

Key words: adaptation, fungi, pathogens, CO_2 level, temperature.

Introduction

Climate change has become as one of the most important problems in the recent century. Temperature, rainfall, humidity are the properties that have been changing in the past decades are related to human activity (Lake et al., 2012). Rising of atmospheric temperature occurs due to increased CO_2 level in the whole world, and this phenomenon causes global warming (Santini, Ghelardini, 2015; Nazir et al., 2018). As a result, ecosystems in the whole world faces with extreme temperature changes, unpredictable extreme and intense weather conditions and rainfalls, ocean warming and acidification (Tirado et al., 2010). These consequences of climate change are related to global food security: changes in the environment affect the survival and pathways of many plant species. Besides, it affects bacteria, viruses and fungal pathogens (Tirado et al., 2010;

Wheeler, Braun, 2013). The management of global food security risk caused by climate change is one of the major priorities in the present century. Crop, livestock and fisheries production, the prevalence of crop pests will be influenced by climate change (Ziervogel, Ericksen, 2010; Lake et al., 2012). In the last decades, pest and plant disease control has played an essential role in increasing production. However, the global yield is still 10-16 % reduced by pests and diseases annually (Campbell et al., 2016; Fisher et al., 2012). Environmental and climate change, pests, diseases of plants and animals increase risk of production loss in forestry, crops, fisheries, horticulture and agriculture (Sundstrom et al., 2014). Increased virulence and resistance of plant fungal pathogens, migration, plant host changes and disease outbreaks threaten food security by reducing global harvest (Chades et al., 2011), Most diseases on agricultural, horticultural and ornamental plants are caused by fungal pathogens, due to development of specific mechanisms for a broad attack of plants (Shuping, Eloff, 2017). Primary fungal pathogens in horticulture, infecting a wide range of crops, vegetables, fruits and berries are *Botrytis* spp., *Fusarium* spp., *Alternaria* spp., *Colletotrichum* spp., *Puccinia* spp. etc. (Dean et al., 2012). It is essential to understand how climate change factors affect these pathogens in order to maintain effective pests and fungal diseases control and management in the future. Therefore, this paper aimed to do a scientific literature review of publications about climate change factors and their effect on plants, fungal pathogens and food safety, emphasizing the horticultural crops and production.

Methodology

Scientific literature review of climate change factors and their effect on plant fungal pathogens and food safety was performed in this paper. Publications from databases were explored using keywords: climate change, plant, fungal, pathogens, agriculture, horticulture, food safety. Keywords were used in separate, or in combinations. Publications used for the literature review was published from 2010. Observed data is presented below in the text, figure and table.

Results

The influence of climate change on plants. A. C. Newton et al. (2011) reported that unpredictable changes in weather affect all kind of ecosystems, and plants are not an exception. Winters have become more wet and warmer in some regions. Meanwhile, summers in other region have become drier, have elevated temperature, and for some crops, this leads to a longer growing season. Authors state, that this results in a lack of chill and can affect the development of some plants. M. Pautasso et al., (2012) stated that plant health depends on abiotic stress, which can be enhanced by accelerated pathogen evolution, shorter incubation periods, mismatches between ecosystems and climate, and more frequent extreme weather events. A. H. Chappelka and N. E. Grulke (2016) modified the classic disease triangle where plant host and pathogens interactions depend on the environment and include changes in physical and chemical environment components (temperature, atmosphere chemistry, precipitation patterns, underground processes) (Fig.). M. Pautasso et al., (2012) also highlight that plant health is an important factor, and it is predicted to be negatively affected by these climate change conditions. M. A. Altieri et al., (2015) report that evolution is a key to survive under changing climate conditions, therefore, adaptation to changes is considered to become one of the main solutions to maintain global food productivity. Another key to survival is noticed to be migration causing the increased appearance of invasive species. Warm and dry environments increase demand of new species adapted to these conditions and transportation performed by humans plays a significant role to plant invasion (Van der

Veken et al., 2008; Bradley et al., 2012; Bebber et al., 2013). I. G. Alsos et al., (2012) investigated how increases in temperature and absence of humidity will affect northern plants. They concluded that the main threat to these plants comes from the loss of genetic diversity and invasive plant species. According to this data, it is predictable that adaptation and migration will become vital for the survival of plant species.

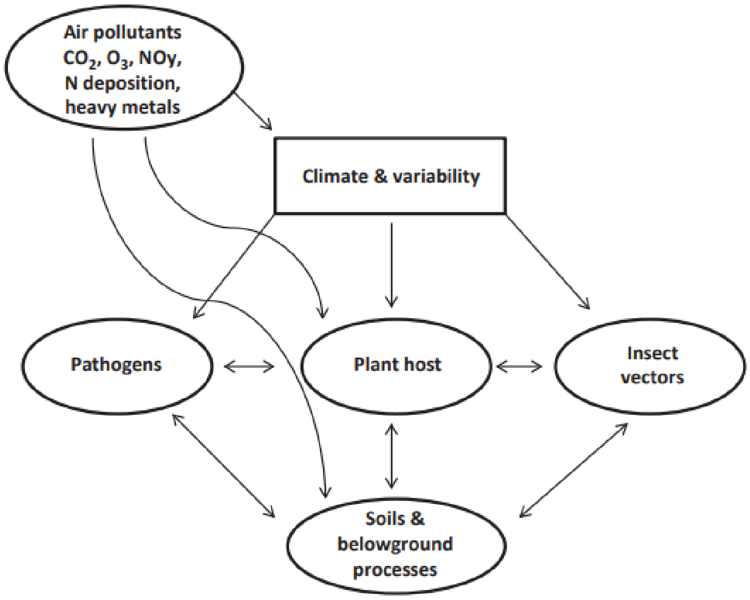

Fig. Modified classic disease triangle (Chappelka, Grulke, 2016)

***Fungal pathogens under climate change conditions*.** Elevated temperature and atmospheric CO_2 level cause changes in ecosystems where pathogens are an inseparable part of living organisms. The growth, development and virulence of fungal pathogens and their interactions with plant hosts are fully dependent from environmental conditions. Climate change affects environment conditions and accelerates the evolution of fungal pathogens and geographic distribution where new races evolve more rapid and their fertility are more significant (Chakraborty et al., 2013). To understand the specific climate change factor influence on specific fungal pathogens, several studies were carried out during recent years (Table). G. B. Brosi et al., (2010) research about *Lolium arundinaceum–Neotyphodium coenophialum* symbioses showed that elevated CO_2 level has more effect than changes in temperature or precipitation. Authors pointed out that increased CO_2 level can promote grass – fungal symbiosis, where endophyte infection frequency (EIF) was elevated. Plant biomass can be increased under elevated CO_2 level, and this can affect some fungal pathogens. P. Melloy et al., (2010) investigated *Fusarium pseodograminearum*, which cause crown rot disease, and the study was carried out to verify if this wheat disease can become more severe under elevated CO_2 level. In this study, authors used the inoculum production of *Fusarium* to investigate this pathogen development under ambient and elevated CO_2, and the results showed that fungal biomass increased under a higher level of CO_2 consequently to the increase of plant biomass. Maize also becomes more susceptible to *Fusarium verticillioides* (Vaughan et al., 2014). Elevated CO_2 can also influence *Magnaporthe oryzae*, the fungal pathogen causing rice blast disease. M. M. Goria, R. Ghini and W. Bettiol (2013) studied the CO_2 influence on three rice cultivars and noticed that rice blast disease was more severe under higher CO_2 concentration. Study about wheat fungal diseases shoved the importance of breeding for resistant wheat varieties in future (Bencze et al. 2013).

Authors used *Puccinia triticina, Puccinia graminis, Fusarium culmorum* which causes leaf rust, stem rust and Fusarium head blight diseases and they became more severe under elevates CO_2 level in susceptible varieties. Authors also noticed that spontaneously appeared powdery mildew also had a significantly higher level of infection in susceptible varieties.

Table. Specific fungal pathogens affected by climate change factors

Climate change factor	Fungal pathogen	Effect	References
Elevated CO_2 level	*Neotyphodium coenophialum*	Promoted symbiosis *Lolium arundinaceum–Neotyphodium coenophialum*	Brosi et al. 2010
	Fusarium pseodograminearum	Elevated crown rot biomass on wheat	Melloy et al. 2010
	Alternaria alternata	Increased spore production	Wolf et al. 2010
	Magnaporthe oryzae	Increased rice blast severity	Goria et al. 2013
	Fusarium verticillioides	Increased maize susceptibility to pathogen	Vaughan et al. 2014
	Puccinia triticina, Puccinia graminis, Fusarium culmorum	Higher disease severity	Bencze et al. 2013 Vary et al. 2015
	Podosphaera xanthii	Increased severity of powdery mildew	Bencze et al. 2013 Itagaki et al. 2015
	Botrytis cinerea	Inhibited postharvest grey mold	Tshwenyane et al. 2012 Gatto et al. 2013 Palou et al. 2016
Elevated temperature and/or humidity	*Alternaria mali*	Apple disease outbreaks	Bhat et al. 2015
	Alternaria alternata	Sporulation may decrease	Damialis, Mohammad 2014
	Alternaria arborescens	Increased growth under 14,2 – 28,4 ºC	Van de Perre et al. 2015
	Botrytis gladiolorum	Increased growth at 20±1 ºC and leaf wetness	Sehajpal, Singh 2014
	Botrytis fabae	Increased growth and sporulation at 22 ºC	Terefe et al. 2015
Elevated CO_2 level and temperature	*Podosphaera xanthii*	No effect on grapevines powdery mildew	Pugliese et al. 2010
	Fusarium oxysporum f.sp. conglutinans	Elevated disease index on rocket plants	Chitarra et al. 2015
	Alternaria alternata	Increased disease index and mycotoxin production	Siciliano et al. 2016

Powdery mildew disease can be caused by *Podosphaera xanthii* and it can infect many plant species. K. Itagaki et al., (2015) studied powdery mildew intensity on cucumber leaves under the wide range of CO_2 were it was lower, ambient and evaluated to examine plant host-pathogen interactions. Acclimatization was correlated with leaf mass per area, dry matter, carbon and nitrogen content. Authors revealed that acclimatization of powdery mildew is affected more under lower and higher than ambient CO_2 levels. Otherwise, another study of powdery mildew, caused by *Erysiphe necatrix*, showed that disease severity on grapevines was not increased under higher CO_2 level and temperature because of increased photosynthetic activity of tested plants (Pugliese et al. 2010). *Alternaria* spp. a genus of fungi is one of the major plant pathogens, causing at least 20 % of spoilage in agriculture (Nowicki et al., 2012). J. Wolf et al., (2010) report that spore production of *Alternaria alternata* can increase under elevated CO_2 level, however, other study shows that it can also decrease under high temperature (Damialis, Mohammad, 2014). K. A. Bhat et al., (2015) reported that humidity, caused by consistent rainfall and higher temperature, created a most favourable environment for *Alternaria mali* fungal apple pathogen which caused the widespread epidemic and as a result, The Valley of Kashmir in India known for apple produce faced *Alternaria* disease outbreak in 2013. Increased temperature in Central and Northern areas, for example, Poland, can become more suitable for *Alternaria arborescens* and can cause pathogen migration (Van de Perre et al., 2015). I. Siciliano et al., (2016) noted that *Alternaria* spp. pathogens can produce mycotoxins, and it is observed, that disease index and mycotoxin production can be elevated on rocket and cabbage plants under higher CO_2 and temperature level.

Additionally, higher temperature with elevated CO_2 affects *Fusarium oxysporum f.sp. conglutinans*. Study with this fungal pathogen and rocket plants revealed that CO_2 and temperature could affect the release of compounds from plant roots, and it can probably influence disease incidence (Chitarra et al., 2015). *Botrytis* spp. genus fungi are one of the significant plant pathogens in agriculture, causing heavy losses in horticulture and post-harvest (Rasiukevičiūtė et al. 2015; Dewey, Grant-Downton 2016). Various studies show that elevated temperature and/or humidity in some areas can increase *Botrytis gladiolorum* severity (Sehajpal, Singh 2014) and *Botrytis fabae* growth and sporulation (Terefe et al., 2015). Grey mold is one of major disease in horticulture, and some data showed that an elevated CO_2 level could control post-harvest grey mold. Studies with cut roses (Tshwenyane et al., 2012) table grapes (Gatto et al., 2013) and pomegranate fruit (Palou et al., 2016) revealed that atmosphere exposure with elevated CO_2 might inhibit post-harvest grey mold.

New species, new hosts, increased resistance and migration rates. As mentioned before, the increasing temperature in central and northern areas can be a reason for increased migration rates of plants and also fungal pathogens (Bebber et al., 2013). E. Van de Perre et al., (2015) shows that climate models and climate change scenarios are useful tools that help to predict future distributions of plants and pathogens. Authors predict that middle latitudes areas with increased temperature can become more attractive to *Alternaria* spp. and F. Shabani et al. (2014) also note that *Fusarium oxysporum f.sp.* might migrate to medium latitude areas in future. In 2010, a new species of *Botrytis* spp. (*Botrytis sinoallii*) was identified in China, as an agent causing leaf blight of green onion and garlic (Zhang et al., 2010). In 2013 *B. cinerea* was firstly reported as a cause of blossom blight of Japanese plums in Chile (Ferrada et al., 2015). Fungal pathogens can infect new plant species resulting in the expended host list. For example, it is reported about first in the world *B. cinerea* infection on mung bean in 2012 (Li et al., 2016).

Fungal pathogens have a feature to become resistant to fungicides. The rate of reported antifungal resistance is unprecedented in recent years (Fisher et al., 2018). It is observed that *A. alternata* possess new fungicide resistant strains that cause disease outbreak in peach orchards (Yang et al., 2015). M. Munoz et al., (2019) studied and revealed that *B. cinerea* isolates could be resistant to 4 – 5 chemical classes of fungicides.

Changes in plant protection. Resistance to fungicides causes many questions in global food security. Despite harmful composition, fungicides have another disadvantage – rapid erosion of activity against fungal strains, and it can become an issue for future fungicides (Hahn, 2014). Fungicide resistance complicates plant disease management; therefore, biocontrol of fungal pathogens became one of the solutions to control fungal diseases in the past decade (Rodriguez et al., 2014). Extensive usage of pesticides, including fungicides, also causes undesirable side effect in horticulture – the accumulation of active substances and side metabolites in its products (EFSA 2019). The results of the consumption of fungicides contribute to other human-influenced pollution and have a negative effect on the ecosystem. These are the reasons why alternative plant protection methods are under investigation. Alternative plant protection, including chemical substances from plants, animals and microorganisms, are applied increasingly in order to control the usage of fungicides (Shuping, Eloff, 2017). L. Šernaitė (2017) reviewed the application of plant extracts in plant protection and stated that plant extracts could be effective and valuable for plant protection and pest biocontrol. Under changing climate condition, it becomes increasingly important to investigate and apply more natural and safer plant biocontrol methods and sustainable agriculture.

Conclusions

Elevated CO_2 level, higher temperature, unpredictable rainfalls and drought are climate change factors have a significant effect on plants and their fungal pathogens. Rapid changes in the environment cause abiotic stress for plants, promote their migration and adaptation. Plant host and fungal pathogens interactions depend on environmental conditions; therefore, changes in temperature, CO_2 level and humidity can affect the growth, mutation, migration and resistance of fungal pathogens. Global food security faces with climate change and its consequences where fungal pathogens become more virulent and resistant to current chemical disease management. Sustainable agriculture with alternative plant security methods might become one of the major priorities in the future food industry.

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AUGALAI IR JŲ PATOGENAI KLIMATO KAITOS KONTEKSTE, APŽVALGA

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Santrauka

Klimato kaita tapo viena iš pagrindinių problemų pastaraisiais dešimtmečiais dėl žmogaus veiklos sukeltos taršos poveikio aplinkai visame pasaulyje. Atmosferoje didėjantis anglies dioksido (CO_2) kiekis, vidutinės temperatūros pokyčiai, nenuspėjamos ekstremalios oro sąlygos, atsiradusios dėl šiltnamio efekto, sukelia daug pokyčių aplinkoje. Pastebėta, kad klimato kaitos faktoriai veikia įvairias ekosistemas. Didėjant žmonių populiacijai pasaulyje, visuotinė maisto sauga išlieka svarbia problema. Žemdirbystei tinkamų žemės plotų mažėjimas, miškų naikinimas, didėjantis patogenų aktyvumas kelia grėsmę maisto saugai. Aplinkos pokyčiai veikia augaliją bei gyvūniją, sukeliant nenuspėjamą jų elgesį bei kaitą. Staigūs aplinkos sąlygų pokyčiai augalams kelia abiotinį stresą bei sumažina išlikimo tikimybę. Įvairūs atlikti tyrimai atskleidžia, kad adaptacija, migracija, cheminės sudėties pokyčiai, mutacijos yra augalų išlikimo būdai ateityje. Specialistai sutinka, kad klimato kaita turi pastebimą įtaką žemdirbystei ir sodininkystei, kai keičiantis klimatui paveikiami ne tik augalai, bet ir jų ligas sukeliantys mikroorganizmai. Vieni iš dažniausiai pasitaikančių augalų ligas sukeliančių sukėlėjų yra patogeniniai grybai. Šie patogenai, atsakingi už milžiniškus derliaus nuostolius ir yra vieni didžiausių pavojų maisto saugai. Mokslinėse publikacijose stebėti duomenys atskleidžia, kad CO_2 koncentracijos pokyčiai, nenuspėjami kritulių modeliai veikia ne tik augalus, bet ir jų patogeninius grybus, kurie sukelia derlių naikinančias ligas. Einant laikui šie patogenai išvysto mechanizmus, padedančius prisitaikyti prie kintančių aplinkos sąlygų, ir tampa atsparesni rinkoje esantiems fungicidams. Augalų – šeimininkų kaita, migracija, naujos genetinės linijos, ligų protrūkiai taip pat pastebimi vis dažniau. Supratimas, kaip klimato kaita veikia augalus ir jų ligas sukeliančius patogeninius grybus, turės nemažą įtaką augalų ligų kontrolei ateityje. Dabar plačiai naudojami fungicidai yra gerai žinomi dėl žalingo šalutinio poveikio bei riboto veikimo prieš patogeninius grybus, todėl klimato kaitos akivaizdoje, kai patogenai tampa vis atsparesni cheminei kontrolei, nauji alternatyvios biokontrolės metodai yra vis labiau tiriami ir taikomi.

Raktažodžiai: prisitaikymas, mikroskopiniai grybai, patogenai, CO_2 lygis, temperatūra.

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