Scientific Papers. Series A. Agronomy, Vol. LXVII, No. 2, 2024
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

MANAGEMENT OF FEW MAIN WHEAT DISEASES USING ALTERNATIVE ORGANIC PRODUCTS WITH FUNGICIDE EFFECT – A REVIEW

Mirela PARASCHIVU[1], Milica DIMA[2], Alina Marinela PRIOTEASA[1]

[1]University of Craiova, Faculty of Agronomy, 19 Libertatii Street, Craiova, Romania
[2]Research and Development Station for Plant Culture on Sands Dabuleni, 217 Petre Banita, Dolj County, Romania

Corresponding author email: milicadima@yahoo.com

Abstract

Worldwide the majority of fungal wheat diseases may be controlled chemically, but natural plant products have been shown to exert biological activity against wheat fungal pathogens in vitro and in vivo and can be used as bio-fungicidal products. Natural plant products have a specific mode of action and a confined target range. They are also often harmless to hostile microorganisms, have a shorter shelf life, and provide no residual traits. Frequently included in integrated pest management (IPM) schemes, they are generally less hazardous to humans and the environment than traditional synthetic chemical pesticides. Also, the use of chemical products is limited due to undesirable environmental effects and the emergence of resistant pathogens to fungicides. The major compounds that have been investigated to date include phenols, flavonoids, quinones, terpenes, tannins, alkaloids, lectins, polypeptides, saponins and sterols. These products may have fungicidal or fungistatic activity on plant pathogens or they can create conditions unfavourable for establishment and multiplication of pathogenic microorganisms on host plants. In this study, we have discussed the sensitivity of most important fungal pathogens of wheat against different natural extracts products and essential oils and their main components, together with their modes of action in controlling wheat diseases. The option of replacing fossil oil-based chemicals with plant product formulations fits well with food and agriculture policies directed to the future.

***Key words**: wheat diseases, pathogens, natural products, plant extracts, essential oils.*

INTRODUCTION

In the last decades, organic crops are constantly expanding, and the demand for healthy food, with no chemical residual products, is increasing.

Cereals are one of the most important crops worldwide and they are vital for human consumption and animal feed (Neupane et al., 2022). To feed the estimated 9.8 billion people on the planet by 2050, the supply of cereal food must rise by 70-100% and 2-3% (annually) (Hawkesford et al., 2013; Ray et al., 2013; Tripathi et al., 2016). Maintaining access to safe, disease- and pest-free and affordable agricultural products and raw materials and ensuring sustainable agricultural production are challenges that must be faced in the context of climate changes, which impact both natural and agricultural ecosystems with severe economic consequences (Răduțoiu, 2022; Răduţoiu & Stan, 2022; Răduțoiu, 2023; Velea et al., 2021; Zală, 2021; Zală et al., 2023a). Also, there is serious concern that climate zones will move faster that it is possible for plant populations to track them, which is expected to determine disproportionate extinction of local endemic species (Răduţoiu & Băloniu, 2021; Răduțoiu et al., 2023).

One of the most significant impacts of climate change on cereals is the increase in temperature (Chakraborty & Newton, 2011; Chakraborty, 2013). According to previous studies, over the next 30 years, the earth's average surface temperature will rise at a rate of about 0.2 degrees Celsius every decade (Bernstein et al., 2008). Higher temperatures can lead to heat stress in plants, which can result in reduced yields and increased susceptibility to diseases (Coakley et al., 1999; Paraschivu et al., 2017; Paraschivu et al., 2019; Paraschivu et al., 2021; Paraschivu et al., 2023). For example, a 1°C increase in temperature during wheat cultivation could result in a 3-10% decrease in crop yields (Yao et al., 2012). This is because pathogens, such as fungi and bacteria, thrive in warm and moist conditions, and can infect plants more easily when they are stressed.

In order to control pathogens, the current problems related to the consequences caused by fungal and viral plant diseases along with those caused by agricultural pollution (Bonciu, 2023b; 2023c) require essential changes in plant cropping and breeding technologies (Bonciu, 2023a; Lipianu et al., 2023; Zălă et al., 2023b). One of the most modern such technologies is agricultural biotechnology and genomics (De Souza and Bonciu, 2022a; 2022b), which is able to ensure the creation of varieties and forms of plants with targeted performances: increased productivity and quality, resistance to diseases and tolerance to unfavorable climatic factors. Thus, in the context of increasingly obvious climate change, adapted technological measures are required in all crops in order to prevent the increasingly pronounced influence that weeds, pathogens and pests have on the quantity and quality of production (Matei et al., 2019; 2020; 2022).

Also, other practical way to reduce yield losses is to investigate alternative organic products with fungicide effect. This approach can result in the eco-friendly usage of natural products and other qualities that have minimal adverse effects.

For the past few decades, it is estimated that there are more than 250.000 higher plant species that can be evaluated for their antimicrobial bioactive chemical compounds, especially plant extracts and oils (EOs) (Tegegne and Pretorius, 2007; Shuping and Eloff, 2017; Zaker, 2016). Many plant extracts have demonstrated potent antifungal activity (with MIC values below 1.0 mg/mL) using in vitro assays, but only a few were tested in vivo (Drakopoulos et al., 2020; Seepe et al., 2020). The lack of resources and expertise needed to carry out pertinent in vivo experiments in the field or in a greenhouse remain one of the limiting issues.

Despite of this, medicinal and other plant extracts have attracted attention in the pesticide industry based on their antimicrobial properties due to spectrum of their constituent secondary metabolites such as phenols, polyphenols, flavonoids, glycosides, tannins, alkaloids and other compounds that may inhibit the development of resistance due to the presence of different constituent antimicrobial compounds and their synergisms (Calvo et al., 2011; Mahlo et al., 2010; Mdee et al., 2009; Rishi and Singh, 2003; Sultana et al., 2013). Also, the components with phenolic structures, like carvacrol, eugenol, and thymol, were highly active against the plant pathogens, enhancing plant defence mechanisms against pathogenic microorganisms (Das et al., 2010).

Majority of the researches on bio-active plant extract and essential oils (EOs) emphasized on effect of plant extracts against plant pathogens or diseases. Essential oils contain a mixture of different compounds such as monoterpenes, diterpenes, sesquiterpenes, aliphatic and other aromatic compounds that are volatile in nature (Koul et al., 2008; Nuzhat and Vidyasagar, 2013).They are oily liquids obtained from medicinal plants, herbs, spices and aromatic plant species (parts including the flowers, leaves, barks, roots, seeds, fruits and whole plants) through fermentation, efleurage and steam distillation (Burt, 2004), whereas plant extracts, in contrast are obtained from dried plant products by filtration and evaporation using various solvents (Van de Braak and Leijten, 1999; Wang et al., 2004).

As part of Integrated Pest management (IPM), natural plant products have a narrow target range with specific mode of action, therefore are suitable for a specific target, mostly nontoxic for antagonistic microorganisms, show limited field persistence and have a shorter shelf life and no residual threats (Zaker, 2016).

Previous findings suggest that plant extracts can work by targeting the plasma membrane in the majority of infections, increasing the permeability of the fungal cell wall, and disrupting the normal actions of the topoisomerase enzymes (Kawakami et al., 2015), while essential oils (EOs) are associated with disruption of the fungal cell wall integrity through the inhibition of chitin and β-glucans synthesis, disruption of the cell membrane, such as by binding to or inhibiting ergosterol biosynthesis, mitochondria dysfunction arising from inhibition of electron transport and respiratory chain proton pumps, cell division inhibition via interference with microtubule polymerization, inhibition of ribonucleic acid, deoxyribonucleic acid or protein synthesis; and efflux pump inhibition (Lagrouh et al., 2017; Seepe et al., 2021). The underlying mechanisms are not clearly understood, but involvement of induced resistance is considered (Fokkema, 1993).

Different previous studies have demonstrated the excellent properties of plant extracts and essential oils for their antimicrobial and antioxidant activities (Celikel and Kavas, 2008; Tajkarimi et al., 2010).

Considering the findings above, a crucial first step toward sustainable crop production is reducing the use of traditional synthetic fungicides in the presence of efficient natural alternatives. Thus, the present paper emphasises in the following subsections, a review of some studies conducted in the past years on antifungal activity of plant extracts and essential oils isolated from plants against the main pathogens in wheat.

NATURAL PRODUCTS AGAINST WHEAT RUSTS

In many wheat-growing areas, one of the most significant constrainer to wheat productivity is *Puccinia triticina* which produces leaf rust. The fungus is able to cause severe yield losses reaching up to 50% (Draz et al., 2015). The severity of the disease depends upon the developmental stage of the plant and its susceptibility of the plant (Duplessis et al., 2021). Usually, the disease management is based on the use of resistant cultivars and application of chemical fungicides, but alternative control methods are required (Barro et al., 2017).

Hassan et al. (1992) reported that rust pustules on the wheat leaves can be reduced with leaf extracts of *Datura stramoniu*. In 2019 Draz et al. have tested five plant extract (i.e. henna, *Lawsonia inermis*; acalypha, *Acalypha wilkesiana*; chinaberry, *Melia azedarach*; pomegranate, *Punica granatum*; and lantana, *Lantana camara)* against leaf rust infection caused by *Puccinia triticina* showing that Infection Coefficient (IC) decreased for all tested variants with values that ranged between 7.5 to 20. The most effective one was the extract of *Lantana camara* with 88.88% efficiency which was very close to the fungicide "diniconazole" (efficiency = 89.92%).

The efficacy of eight plant extracts (garlic, clove, garden quinine, Brazilian pepper, anthi mandhaari, black cumin, white cedar and neem) in controlling leaf rust disease of wheat was investigated *in vitro* and *in vivo* (Shabana et al., 2017). *In vitro*, all treatments inhibited spore germination by more than 93%, while *in vivo* foliar spray application of wheat plants at mature stage with all plant extracts has significantly reduced the leaf rust infection.

The efficiency in the treatment of leaf rust of wheat was examined also for plant leaf extracts of Neem and Moringa at varied concentrations of 50, 100, and 150 ml correspondingly. All treatments decreased fungal growth *in vitro* by greater than 90% (Afzal et al., 2023).

The methanol extracts of henna, lantana, acalypha, chinaberry, and pomegranate exhibited a 100% - inhibition of *P. triticina* spores germination (Elkhwaga et al., 2018).

The aqueous leaf extracts of *Jacaranda mimosifolia* (Bignoniaceae), *Thevetia peruviana* (Apocynaceae) and *Calotropis procera* (Apocynaceae) inhibited *P. triticina* urediniospore germination *in vitro* by strongly stimulated defense-related gene expression and the subsequent accumulation of pathogenesis-related (PR) proteins in the apoplast of inoculated wheat leaves (Naz et al., 2014).

The plant oils could potentially be used alone in organic growing or in rotation with synthetic fungicides in an integrated pest management (IPM) program in the conventional wheat growing. Unlike many fungicides, resistance to plant oils has not been reported yet. In vivo results indicated that the use of plant oils could be also a valid treatment to control infections caused by *P. triticina*. Thus, the efficacy of eight plant oils (castor, corn, cottonseed, linseed, olive, peanut, soybean and sunflower seed oils) was evaluated as possible alternatives to synthetic fungicides for the control of *P. triticina* (Arslan, 2014). The percentage of inhibition in urediniospore germination of all tested plant oils ranged from 0 to 84.9% against *P. triticina*, linseed oil providing the best control at 2.5 % concentration *in vitro* and at 1% concentration *in vivo.*

Stem rust, caused by *Puccinia graminis* f. sp. *tritici*, is one of the three main rusts attacking wheat plants worldwide.

Omara et al. (2020) showed that leaf extract of *Artemisia cina* inhibited spore germination and increased incubation and latent periods in wheat stem rust than other treatments. Also, garlic oil revealed the highest suppression of stem rust severity followed by cinnamon, thyme, onion and clove oils, respectively (Abdel-Kader et al., 2021). According to the report of Uwineza et al. (2018), pennyroyal (*Mentha pulegium*), Atlas cedar (*Cedrus atlantica*) and clove (*Eugenia aromatica*), are potentially effective plant sources against yellow rust caused by *P. striiformis* on wheat.

Wan et al. (2017) underlined that application of the EOs together with resistant cultivars may alleviate this constraint by preventing the emergence of new races.

NATURAL PRODUCTS AGAINST *Fusarium* species IN WHEAT

Fusarium fungal pathogens produce in wheat seedling and head blights leading to devastating economic yield loss in the field and result in a greater impact on food insecurity. Moreover, often in cereal grain samples analysed are found mycotoxins such as deoxyvalenol or vomitoxin (DON), toxin T-2, monoacetoxyscirpenol (MAS), diacetoxyscirpenol (DAS) and nivalenol (NIV), which can produce food intoxications that are manifesting through sickness, vomiting, diarrhoea, headache, abdominal pains, fever, oesophageal cancer, carcinogenesis, mutagenicity and neural tube defects etc. in livestock (Reddy et al., 2010). Thus, beside conventional fungicides using alternative organic products with fungicide effect are required. Seepe et al. (2021) emphasized that he families with high frequencies of evaluated species against *Fusarium* pathogens were *Solanaceae*, followed by *Combretaceae* and *Fabaceae* and *Euphorbiaceae*. Leaf extracts from these plants demonstrated potent *in vitro* activities (minimum inhibitory concentrations <1.0 mg/mL) against nine *Fusarium* species. Often, in cereals, *Fusarium oxysporum* was the most frequently used pathogen, followed by *F. graminearum.*

Velluti et al. (2004) evaluated 37 essential oils (of which lemongrass, cinnamon, clove, palmarosa and oregano) and showed antifungal activity against *Fusarium* sp. Also, the antifungal effect of *Aloe Vera* (syn: *A. barbadensis*) as inhibitor of mycelium growth of *Fusarium oxysporum* was reported (Rodriguez et al., 2005). Kumar et al. (2007) reported *Chenopodium ambrosioides* can inhibit two aflatoxigenic strains of *F. oxysporum* and other fungi, while and essential oil of Peumusboldus was effective against *Fusarium* spp. (Souza et al., 2005). Cheng et al. (2008) investigated the antifungal activity of essential oil from *Calocedrus macrolepis* var. *formosana* and its constituents T-murolol and a-cadinol on the growth of plant pathogenic fungi which also inhibited the growth of *Fusarium oxysporum*. Also, Abo El-Seoud et al. (2005) evaluated essential oils of fennel, peppermint, caraway, eucalyptus, geranium and lemongrass for their antimicrobial activities against *F. oxysporum* and other fungi and found that essential oils of fennel, peppermint and caraway can be used as active ingredients for formulating biocides. The use of essential oils obtained from *Carum carvi*, *Cymbopogon nardus*, *Pelargonium roseum*, *Pimentadioica* and *Thymus vulgaris* was found as effective against mycelium growth *F. oxysporum* (Zabka et al., 2009). Also, Deba et al. (2008) tested the fungitoxic activities of the flower essential oils of *Bidens pilosa* against *Fusarium* spp., while in 2010, Naeini et al. observed anti-*Fusarium* properties of five EO of *Cuminum cyminum* and *Zataria multiflora*.

Different studies emphasized the antifungal activity against *Fusarium oxysporum* of essential oils obtained from plants used in traditional medicine, such as: *Aconitum laeve* Royle (Ranunculaceae) (MIC – Minimum Inhibitory Concentration - value of 300 µg/mL), *Artemisia sieberi* Besser. (Asteraceae) (MIC value of 60 µg/mL), *Bupleurum falcatum* L. (Apiaceae) (MIC of 2 µg/mL), *Cannabis sativa* L. (Cannabidaceae) (Inhibition of 93.58% at 1 µL/mL), *Cinnamomum camphora* (Lauraceae) (inhibition of 49% at 3000 µL/L), *Citrus aurantium* (Rutaceae) (inhibition of 57.75% at 1 µL/mL), *Citrus reticulata* L. (Rutaceae) (inhibition of 70% at 0.15 mL/100 mL), *Cuminum cyminum* (Apiaceae) (MIC value of 72 µg/mL), *Cymbopogon citratus*, Stapf. (Poaceae) (inhibition of 100% at 2500 µL/L), *Cymbopogon nardus* (L.) Rendle (Poaceae) (inhibition of 85.56% at 1 µL/mL), *Echinophora platyloba* DC. (Apiaceae) (inhibition of 51.8% at 1 µL/L), *Eucalyptus* sp. (Myrtaceae) (inhibition of 55.11% at 1500 µL/L), *Foeniculum vulgare* Mill. (Apiaceae) (MIC value of 72 µg/mL), *Helichrysum splendidum* (Thunb.) Less. (Asteraceae) (inhibition of 58% at 3000 µL/L), *Heracleum persicum* Desf. Ex Fischer. (Apiaceae) (MIC value of 530 µg/mL), *Lippia rehmannii* H. Pearson (Verbenaceae) (inhibition of 72% at 500 µL/L), *Matricaria recutita* (L.) syn. (Asteraceae) (inhibition of 56.0% at 62.5 µg/mL), *Melaleuca alternifolia* (Myrtaceae) (MIC value of 0.91 mg/mL), *Mentha spicata* L. (spearmint) (Lamiaceae) (inhibition of 79% at 2000 µL/L), *Nepeta cataria* L. (Lamiaceae) (inhibition of 97.86% at 1 µL/mL), *Ocimum basilicum* L. (Lamiaceae) (inhibition of 74.87% at 1 µL/mL), *Origanum heracleoticum* L. (Lamiaceae) (MIC value of 0.07 mg/mL), *Origanum majorana* L. (Lamiaceae) (inhibition of 59.36% at 1 µL/mL), *Origanum vulgare* L. (Lamiaceae) (MIC value of 50 µg/mL), *Pelargonium roseum* L. (Geraniaceae) (inhibition of 85.56% at 1 µL/mL), *Mentha piperita* L. (Lamiaceae) (MIC value of 1.50 µg/mL), *Pimenta dioica* (L.) Merr. (Myrtaceae) (inhibition of 100% at 1 µL/mL), *Pimpinella anisum* L. (Apiaceae) (MIC value of 120 µg/mL), *Rosa damascena* P. Mill. (Rosaceae) (MIC value of 0.29 mg/mL), *Rosmarinus officinalis* (rosemary) (Lamiaceae) (MIC value of 410 µg/mL), *Salvia sclarea* L. (Lamiaceae) (inhibition of 58.82% at 1 µL/mL), *Satureja hortensis* L. (Lamiaceae) (MIC value of 0.14 mg/mL), *Silene armeria* L. (Caryophyllaceae) (MIC value of 500 µg/mL), *Stachys pubescens* Ten. (Lamiaceae) (MIC value of 1 µg/mL), *Syzigium aromaticum* L. (Myrtaceae) (Inhibition of 83% at 250 µL/L), *Thymus daenensis* Celak. (Lamiaceae) (MIC value of 4 µg/mL), *Thymus kotschyanus* Boiss. & Hohen. (Lamiaceae) (MIC value of 0.5 µg/mL), *Thymus kotschyanus* Boiss. & Hohen. (Lamiaceae) (MIC value of 75 µg/mL), *Thymus vulgaris* L. (Lamiaceae) (MIC value of 0.14 mg/mL), *Xylopia aethiopica* (Dunal) A. Rich. (Annonaceae) (MIC value of 3000 ppm), Zataria multiflora Boiss. (Lamiaceae) (MIC value of 66 µg/mL) (Ahmad and Beg, 2001; Chutia et al., 2009; Da Cruz Cabral et al., 2013; Khosravi et al., 2020; Manganyi et al., 2015; Moghaddam et al., 2015; Mohammadi et al., 2024; Naeini et al., 2010; Stević et al., 2014; Tegang et al., 2018; Zabka et al., 2009).

In 2007 Singh et al. reported 100% effect of Cinnamon leaf oil against *Fusarium graminearum.* Also, other studies emphasized the antifungal effect of *Curcuma longa* L. (Zingiberaceae) (MIC value of 2450 µg/mL), *Eucalyptus* sp. (Myrtaceae) (inhibition of 55.11% at 1000 µL/L) and *Zhumeria majdae* Rech. f. & Wendelbo (Lamiaceae) (inhibition of 75.11% at 1000 µL/L) against *Fusarium graminearum* (Davari and Ezazi, 2017; Kumar et al., 2016).

The results also showed that the essential oils (Eos) of anise, cinnamon, spearmint and thyme have more effect in decreasing fungal growth and mycotoxins production in wheat grains. At 5% (v/v) concentration, sweet basil EO totally inhibited mycelial growth and prevented aflatoxin production, showing that the oil's minimum inhibitory concentration (MIC) is less than or equivalent to 5% (Atanda et al., 2007).

According to Ferreira et al. (2018), the EO of *Zingiber officinale* reduced biosynthesis of the mycotoxin dioxynivalenol (DON) and ergosterol at concentrations of 500 and 1000 g/ml, respectively. According to Kumar et al., 2016, the EO of *Curcuma longa* totally suppressed formation of zearalenone (ZEA) and reduced fungal biomass at concentrations of 3500 and 3000 mg/ml, respectively.

NATURAL PRODUCTS AGAINST SPOT BLOTCH IN WHEAT

Spot blotch (SB), a devastating disease of wheat in warmer growing areas of the world, is caused by *Bipolaris sorokiniana* (teleomorph *Cochliobolus sativus*). The pathogen is capable of producing toxins like helminthosporol and sorokinianin and can infect leaves, stems, roots, rachis, and seeds (Roy et al., 2023). Briquet et al. (1998) reported that helminthosporol affects membrane permeability, thereby inhibiting mitochondrial oxidative phosphorylation, the photophosphorylation in chloroplasts, and the proton pumping across the plasma membrane, as well as β-1,3-glucan synthase activity. Also, sorokinianin compound shows inhibitory activity on seed germination (Nakajima et al., 1998).

The susceptibility to the pathogen increases around Zadoks' growth stage DC 56 (three-quarters of the inflorescence emerged) and fungal infection accelerates leaf senescence at later growth stages (Dehne and Oerke, 1985).

On a worldwide scale, yield losses in wheat caused by *B. sorokiniana* (16-25%, whereas under severe epidemic condition it may reach up to 80%) indicate the need to search for alternative strategies for disease control (Joshi and Chand, 2002; Saari, 1998). One of the promising strategies is using alternative organic products with fungicide effect.

Plant extract from different species has been used to control spot blotch of wheat by encouraging lignification in host cell wall, reducing penetration of pathogen and enhancing wound healing in hosts (Hossain et al., 2016; Soylu, 2008).

Magar et al. (2020) reported that, *in vitro* experiment, different botanical extracts (neem (*Azadirachta indica*), garlic (*Allium sativum*), eucalyptus (*Eucalyptus globolus*), bojho (*Acorus calamus*) and asuro (*Justicia adhatoda*) in different concentrations (5%, 10% and 15%) inhibited the mycelial growth of fungus significantly. The mycelial growth inhibition of *Bipolaris sorokiniana* increased gradually with increased concentration of the extracts. The highest mycelial growth inhibition percentage was found by the application of garlic clove extract (52.85%) at 15% which was followed by bojho extract (52.48%) at 15% concentration. Similar results have been reported by several authors working with different botanical extracts (Yadav et al., 2015; Yasmin, 2016)

Different concentration of the oil of ginger, eucalyptus, clove, sesame and neem were evaluated *in vitro* for their antifungal effect against *B. sorokiniana.* The highest inhibition was observed by the application of clove oil, followed by garlic oil at 55.27% and 51.45% respectively, at a concentration of 3000 ppm (Debsharma et al., 2021). Yasmin (2016) reported that ginger extract inhibited the mycelial growth of *B. sorokiniana* up to 38.35% at 15% concentration, which suggested the antifungal activity of the extract. Similar findings were reported also by other authors (Hasan et al., 2005; Raveau, 2020). Other two essential oils were evaluated at a concentration of 0.31 µl/ml for *Origanum compactum* and 1.25 µl/ml for *Thymus satureioides* (Zahraoui et al., 2024). *Thymus satureioides* was found to be more effective than *Origanum compactum*, reducing the infection rate of B. *sorokiniana* by 52% and improving productivity by 50%. However, the results showed that both essential oils significantly reduced disease severity by 48% and increased grain yield by an average of 25% across all varieties used. The results confirm previous findings obtained by El Ajjouri et al. (2008), who have demonstrated that *Thymus satureioides* by his bioactive compound carvacrol or cymophenol (a phenolic monoterpenoid) is among the most active essential oils against fungi. Carvacrol can destabilize the cytoplasmic membrane and act as a proton exchanger, reducing the pH gradient across the cytoplasmic membrane. The resulting collapse of the proton motive force and depletion of the ATP pool eventually leads to cell death (Ultee et al., 2002). It is also possible that the action of the carvacrol to be modulated by other minor molecules of other compounds, suck us P-cymene that makes carvacrol being more easily transported into the cells (Ultee et al., 2002).

Considering previous findings and the potential of plant extracts and essential oils to reduce infection rates caused by *B. sorokiniana*, they deserve further studies to explore their antifungal properties and evaluate the long-term effectiveness of the treatment.

NATURAL PRODUCTS AGAINST POWDERY MILDEW IN WHEAT

Powdery mildew in wheat caused by the obligate parasite *Blumeria graminis* f. s. *tritici* is one of the first recognized wheat diseases, widely distributed with significant global incidents over the last four decades, but more damaging in cool, wet climates and semi-arid areas (Morgounov et al., 2012). The disease is ranked sixth out of the ten most important fungal diseases of wheat and the 8th highest yield loss contributor of wheat globally (Dean et al., 2012; Savary et al., 2019). Grain yield reduction, which results from plant infection by pathogen, can reach 15-20%, and in the case of severe infection, can reach 50% or more (Jaczewska-Kalicka, 2006).

Use of chemical fungicides for controlling powdery mildew in wheat has led scientists to look for alternative antifungal substances such as plant extracts and essential oils that are safer than synthetic products, biodegradable in nature and non-polluting. However, little work has been done about the fungistatic effect of natural extracts on Powdery mildew in wheat.

Choi et al. (2004) reported that the extract of *Rumex acetosella* roots reduced development of powdery mildew. Even extracts prepared from oak bark (*Quercus robur* L.), *Reynoutria sacchaliensis* L., curcuma (*Curcuma longa* L.), and ginger (*Zingiber officinale* Roscoe) were effective against powdery mildew on the winter wheat (Vechet et al., 2005).

Also, Schuster et al. (2010) obtained good results using plant extract from *Glycyrrhiza glabra*. Natural extract from the roots of Chinese rhubarb (*Rheum officinale*) proved its high efficiency for controlling powdery mildew (Yang et al., 2008). Thus, according to a histological analysis, this substance inhibited the germination of conidia, accelerated appressorium deformation prior to the pathogen infecting wheat (*Triticum aestivum*) cells, and decreased the length and number of secondary haustoria following infection, among other effects on *Blumeria graminis in vivo*.

Uwineza et al. (2018) showed that Powdery mildew disease was completely controlled by 1.25 ml/L concentration of essential oils of *Mentha pulegium*, *Eugenia aromatica* and *Cedrus atlantica*.

These findings indicate that even natural compounds could provide long-term protection against powdery mildew in wheat.

CONCLUSIONS

Studies on the antifungal activity of botanical extracts to protect plants from diseases have received much attention lately. Thus, many reports approve the efficacy of natural products of plants in controlling fungal growth and mycotoxin production demonstrating that plant extracts and essential oils contain a high concentration of bioactive and antioxidant substances. Investigating the use of plant-based fungicides to reduce yield losses in cereals is a workable strategy that can also result in the environmentally eco-friendly usage of natural products and serve as a rich source of natural compounds with a variety of fungicidal and other qualities that have little negative effects. Furthermore, field studies under natural conditions would be necessary to thoroughly examine the effect of these plant extracts and essential oils in understanding the reaction of wheat pathogens and host-pathogen relationship.

In the near future, increased interest will be observed in alternative fungicides because of their safe status as they can be easily decomposed, nature friendly and nonphytotoxic. Thus, discovering sustainable, safe and effective control strategies for controlling crop diseases remains imperative towards achieving the second goal, amongst others, of the Sustainable Development Goals (SDGs), which is “to end hunger, achieve food security and improved nutrition and promote sustainable agriculture’’.

REFERENCES

Abdel-Kader, M. M., El-Gamal, N. G., Khalil, M. S., El-Mougy, N. S., El-Sayed, A. E. K. B. (2021). Potentiality of some essential oils and algae extract spray treatments on suppressing wheat stem rust severity under field conditions. *Archives of Phytopathology and Plant Protection*, 54 (19-20), 2407-2422.

Abo-El- Seoud, M.A., Sarhan, M.M., Omar, A.E. and Helal, M.M. (2005). Bioside formulation of essential oils having antimicrobial activity. *Archives of Phytopathology and Plant Protection*, 38, 175-184.

Afzal, S., Tariq, M. A., Khanum, A., Haroon, A., Hussain, M. A., Batool, M., Samreen, S. (2023). Grasp of wheat leaf rust through plant leaves extract and bioagent as an eco-friendly measure. *Journal of King Saud University-Science*, *35*(2), 102452.

Ahmad, I., Beg, A.Z. (2001). Antimicrobial and phytochemical studies on 45 Indian medicinal plants against multi-drug resistant human pathogens. *J. Ethnopharmacol*ogy, 74, 113–123.

Arslan, U. (2014). Efficacy of plant oils on the control of bean rust and wheat leaf rust. *Fresenius Environmental Bulletin*, 23, 9a, 2259-2265.

Atanda, O.O., Akpan, I., Oluwafemi, F. (2007). The potential of some spice essential oils in the control of *A. parasiticus* CFR 223 and aflatoxin production *Food Control*, 18 (5), pp. 601-607, 10.1016/j.foodcont.2006.02.007

Barro, J.P., Forte, C.T., Trentin, D., Scariot, M., Milanesi, P.M. (2017) Effectiveness of different fungicide formulations and number of applications in controlling wheat leaf rust. *Summa Phytopathologica* 43(4):276–280. https://doi.org/10.1590/0100-5405/174240

Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., Riahi, K. IPCC (2008). *Climate Change 2007: Synthesis Report*; IPCC: Geneva, Switzerland, 2008.

Bonciu, E. (2023)a. Genetic transformation in agriculture: the real chance for ensuring worldwide sustainable food security. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, Vol. *23*(1): 73-80.

Bonciu, E. (2023)b. Clastogenic potential of some chemicals used in agriculture monitored through the allium assay. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, Vol. *23*(3): 63-68.

Bonciu, E. (2023)c. Some sustainable depollution strategies applied in integrated environmental protection management in agriculture. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, Vol. *23*(3): 69-76.

Calvo, M.A., Arosemena, E.L., Shiva, C., Adelantado, C. (2011). Antimicrobial activity of plant natural extracts and essential oils. In Science against Microbial Pathogens: *Communicating Current Research and Technological Advances*; Méndez-Vilas, A., Ed.; FORMATEX: Barcelona, Spain, pp. 1179–1185.

Celikel, N., Kavas, G. (2008). Antimicrobial properties of some essential oils against some pathogenic microorganisms. *Czech Journal of Food Sciences*, 26, 174–181.

Chakraborty, S. (2013). Migrate or evolve: options for plant pathogens under climate change. *Global Change Biology*, 19(7), 1985-2000.

Chakraborty, S. & Newton, A.C. (2011). Climate change, plant diseases and food security: an overview. *Plant Pathology*, 60(1), Special Issue: Climate Change and Plant Diseases, 2-14.

Cheng S.S, Liu J.Y, Chang E.H and Chang S.T. (2008): Antifungal activity of cinnamaldehyde and eugenol congeners against wood-rot fungi. *Bioresource Technology*, 99, 5145"5149.

Choi, J.H, Brummer, E., Stevens, D.A. (2004) Combined action of micafungin, a new echinocandin, and human phagocytes for antifungal activity against Aspergillus fumigatus. *Microbes and Infection,* 6, 383–389.

Coakley, S.M., Scherm, H., Chakraborty, S. (1999). Climate change and plant diseases management. *Annual Review of Phytopathology*, 37, 399-426.

Chutia, M., Bhuyan, P.D., Pathak, M.G., Sarma, T.C., Boruah, P. (2009). Antifungal activity and chemical composition of *Citrus reticulata* Blanco essential oil against phytopathogens from North East India, LWT. Journal of *Food Science and Technology,* 42, 777–780.

Davari, M., Ezazi, R. Chemical composition and antifungal activity of the essential oil of *Zhumeria majdae*, *Heracleum persicum* and *Eucalyptus* sp. against some important phytopathogenic fungi. *Journal of Medical Mycology,* 27, 463–468.

Da Cruz Cabral, L., Pinto, V.F., Patriarca, A. (2013). Application of plant derived compounds to control fungal spoilage and mycotoxin production in foods. *International Journal of Food Microbiology*, 166, 1–14.

Das, K., Tiwari, R.K., Shrivastava, D.K. (2010). Techniques for evaluation of medicinal plant products as antimicrobial agent: current methods and future trends. *Journal of Medicinal Plants Research*, 4, 104-111.

De Souza, C.P., Bonciu, E., 2022a, Progress in genomics and biotechnology, the key to ensuring food security. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(1), 149-157.

De Souza, C.P., Bonciu, E., 2022b, Use of molecular markers in plant bioengineering. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(1), 159-166.

Dean, R., Van Kan, J.A., Pretorius, Z.A., Hammond-Kosack, K.E., Di Pietro, A., Spanu, P.D., Rudd, J.J., Dickman, M., Kahmann, R., Ellis, J. (2012).The top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology*, 13, 414–430.

Deba, F., Xuan, T.D., Yasuda, M., Tawata, S., (2008). Chemical composition and antioxidant, antibacterial and antifungal activities of the essential oils from Bidenspilosa Linn. var. Radiata. *Food Control*, 19, 346–352.

Debsharma, R., Islam, S., Debnath, D., Chakraborty, S., Mahapatra, S. (2021). Efficacy study of some botanical oils against spot blotch disease (Bipolaris sorokiniana) of wheat under In-vitro condition. *International Journal of Chemical Studies*, 9(1), 3022-3028.

Dehne, H.W., Oerke, E.C. (1985) Investigations on the occurrence of *Cochliobolus sativus* on barley and wheat. Vol. 2. Infection, colonization, and damage to stem and leaves. *Journal of Plant Diseases and Protection*, 92, 606–617.

Drakopoulos, D., Kägi, A., Gimeno, A., Six, J., Jenny, E., Forrer, H.R., Musa, T., Meca, G., Vogelgsang, S. (2020). Prevention of *Fusarium* head blight infection and mycotoxins in wheat with cut-and-carry biofumigation and botanicals. *Field Crop Research,* 246, 107681.

Draz IS, Abou-Elseoud MS, Kamara AM, Alaa-Eldein Omaima A, El-Bebany AF (2015). Screening of wheat genotypes for leaf rust resistance along with grain yield. *Annals of Agricultural Sciences* 60(1):29–39. https://doi.org/10.1016/j.aoas.2015.01.001

Draz, I.S., Elkhwaga, A.A., Elzaawely, A.A. (2019). Application of plant extracts as inducers to challenge leaf rust of wheat. *Egyptian Journal of Biological Pest Control* 29, 6 https://doi.org/10.1186/s41938-019-0109-9

Duplessis, S., Lorrain, C., Petre, B., Figueroa, M.,Dodds, P.N.,Aime, M.C. (2021). Host Adaptation and

Virulence in Heteroecious Rust Fungi. *Annual Review of Phytopathology*, 59 (1), 403-422.

El Ajjouri M., Satrani B., Ghanmi A., Amarti F. (2008). Antimicrobial activity of essential oils extracted from medicinal plants against the pathogenic microorganisms: A review. *Issues in Biological Sciences and Pharmaceutical Research*, 2, 1-7.

Elkhwaga, A. A., Elzaawely, A. A., Draz, I., Ismail, A. A., & El-Zahaby, H. M. (2018). Potential of some plant extracts in controlling wheat leaf rust caused by Puccinia triticina Eriks. *Environment, Biodiversity and Soil Security*, 2, 95-102.

Ferreira, F.M.D., Hirooka, E.Y., Ferreira, F.D., Silva, M.V., Mossini, S.A.G., Machinski, M. Jr. (2018). Effect of *Zingiber officinale* Roscoe essential oil in fungus control and deoxynivalenol production of *Fusarium graminearum* Schwabe *Vitr. Food Additives and Contaminants*.: Part A, 35 (11), 2168-2174, 10.1080/19440049.2018.1520397

Fokkema, N.J. (1993). Opportunities and problems of control of foliar pathogens with microorganisms *Journal of Pesticide Science*, 37, 411-416.

Hasan, M.M., Chowdhury, S.P., Alam, S., Hossain, B., Alam, M.S. (2005). Antifungal effects of plant extracts of seed-borne fungi of wheat seed regarding seed germination, seedling health and vigour index. *Pakistan Journal of Biological Sciences.* 8(9), 1284-1289.

Hassan, I., Nasir, M.A., Haque, M.R. (1992). Effect of different plant extract on brown rust and yield of wheat. *Journal of Agricultural Research,* 30, 127-31.

Hawkesford, M.J., Araus, J.L., Park, R., Calderini, D., Miralles, D., Shen, T., Zhang, J., Parry, M.A. (2013). Prospects of doubling global wheat yields. *Food and Energy Security,* 2, 34–48.

Hossain, M.M., Hossain, I., Khalequzzaman, K.M. (2016) Biological control of leaf blight of wheat caused by Bipolaris sorokiniana. *Bulletin of the Institute of Tropical Agriculture*, Kyushu University 39: 43-51.

Joshi, A.K., Chand, R. (2002). Variation and inheritance of leaf angle, and its association with spot blotch (Bipolaris sorokiniana) severity in wheat (*Triticum aestivum*). *Euphytica* 124, 283-91.

Jaczewska-Kalicka, A. (2006). Phytosanitary condition of winter wheat grown in a conventional and ecological system. *Zeszyty Naukowe Akademii Rolniczej we Wrocławiu Rolnictwo* LXXXVII, 540, 187–193.

Kawakami, K., Inuzuka, H., Hori, N., Takahashi, N., Ishida, K., Mochizuki, K., Ohkusu, K., Muraosa, Y., Watanabe, A., Kamei, K. (2015). Inhibitory effects of antimicrobial agents against *Fusarium* species. *Medical Mycology*, 53, 603–611.

Khosravi, A.R., Shokri, H., Saffarian, Z. (2020). Anti-fungal activity of some native essential oils against emerging multidrug resistant human non dermatophytic moulds. *Journal of Herbal Medicine*, *23*, 100370.

Koul, O., Walial, S., Dhaliwal, G.S. (2008). Essential Oils as Green Pesticides: Potential and Constraints. *Biopesticides. International, 4*, 63–84.

Kumar, R., Mishra, A.K., Dubey, N.K., Tripathi, Y.B., (2007). Evaluation of Chenopodiuambrosioides oil as a potential source of antifungal, antiaflatoxigenic and antioxidant activity. *International Journal of Food Microbiology*, 115: 159–164.

Kumar, K.N., Venkataramana, M., Allen, J.A., Chandranayaka, S., Murali, H.S., Batra, H.V. (2016). Role of *Curcuma longa* L. essential oil in controlling the growth and zearalenone production of *Fusarium graminearum*, LWT. *Food Science and Technology*, 69, 522–528.

Lagrouh, F., Dakka, N., Bakri, Y. (2017). The antifungal activity of Moroccan plants and the mechanism of action of secondary metabolites from plants. *Journal of Medical Mycology,* 27, 303–311.

Lipianu, S., Zală, C.R., Istrate, R., Manole, M.S., Ciontu, C. (2023). Research on the protection of rapeseed crop against diseases, weeds and pests. *Scientific Papers. Series A. Agronomy*, Vol. LXVI (1), 399-405.

Magar, P. B., Baidya, S., Koju, R., Adhikary, S. (2020). In-vitro evaluation of botanicals and fungicides against Bipolaris sorokiniana, causing spot blotch of wheat, 296-305.

Mahlo, S.M., McGaw, L.J., Eloff, J.N. (2010). Antifungal activity of leaf extracts from South African trees against plant pathogens. *Crop Protection*, 29, 1529–1533.

Manganyi, M.C., Regnier, T., Olivier, E.I. (2015). Antimicrobial activities of selected essential oils against *Fusarium oxysporum* isolates and their biofilms. *South African Journal of Botany*, 99, 115–121.

Matei, Gh., Vlăduț V.N., Petrescu E., Dodocioiu A.M., Popa D. (2019). *Efficiency of some herbicides on grain sorghum crop*. *ISB INMA TECH' 2019 Agricultural and Mechanical Engineering*, 870-875.

Matei, Gh., Vlăduț, V., Dodocioiu, A.M., Toader, M. (2020). Study regarding the optimization of grain sorghum cultivation technology in the context of sustainable agriculture. *Scientific Papers. Series A. Agronomy*, Vol. LXIII, No. 2, 145-152.

Matei, Gh., Popescu, C.V., Paraschivu, M., Călin Sălceanu, C., Roșculete, E. (2022). Efficacity evaluation of some anti-drift agents in the conditions of Caracal plain, Romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development* Vol. 22, Issue 4, 411-418.

Mdee, L.K., Masoko, P., Eloff, J.N. (2009). The activity of extracts of seven common invasive plant species on fungal phytopathogens. *South African Journal of Botany*, 75, 375–379.

Moghaddam, M., Taheri, P., Pirbalouti, A.G., Mehdizadeh, L. (2015). Chemical composition and antifungal activity of essential oil from the seed of *Echinophora platyloba* DC. Against phytopathogens fungi by two different screening methods, LWT. Journal of *Food Science and Technology*, 61, 536–542

Mohammadi, A., Nazari, H., Imani, S., Amrollahi, H. (2014). Antifungal activities and chemical composition of some medicinal plants. *Journal of Medical Mycology*, 24, e1–e8.

Morgounov, A., Tufan, H.A., Sharma, R., Akin, B., Bagci, A., Braun, H.J., Kaya, Y., Keser, M., Payne, T.S., Sonder, K. (2012). Global incidence of wheat rusts and powdery mildew during 1969–2010 and durability of resistance of winter wheat variety Bezostaya 1. *European Journal of Plant Pathology*, 132, 323–340.

Naeini, A., Ziglari, T., Shokri, H., Khosravi, A.R., 2010. Assessment of growth-inhibiting effect of some plant essential oils on different Fusarium isolates. *Journal de Mycologie Médicale/Journal of Medical Mycology* 20, 174–178.

Nakajima, H., Toratsu, Y., Fujii, Y., Ichinoe, M. and Hamasaki, T. (1998). Biosynthesis of sorokinianin, a phytotoxin of Bipolaris sorokiniana: Evidence of mixed origin from the sesquiterpene and TCA pathways. *Tetrahedron Letters*, 39, 1013–1016.

Naz, R., Bano, A., Wilson, N. L., Guest, D., & Roberts, T. H. (2014). Pathogenesis-related protein expression in the apoplast of wheat leaves protected against leaf rust following application of plant extracts. *Phytopathology*, *104*(9), 933-944.

Neupane, D., Adhikari, P., Bhattarai, D., Rana, B., Ahmed, Z., Sharma, U., Adhikari, D. (2022). Does Climate Change Affect the Yield of the Top Three Cereals and Food Security in the World? *Earth*, 3, 45-71. https://doi.org/10.3390/earth3010004

Nuzhat, T.; Vidyasagar, G.M. Antifungal investigations on plant essential oils. A review. (20130. *International Journal of Pharmacy and Pharmaceutical Sciences, 5*, 19–28.

Omara, R.I., Essa, T.A., Khalil, A.A. (2020). A case study of non-traditional treatments for the control of wheat stem rust disease. *Egyptian Journal of Biological Pest Control* 30, 83 https://doi.org/10.1186/s41938-020-00284-3

Paraschivu, M., Cotuna, O., Olaru, L.,Paraschivu, M. (2017). Impact of climate change on wheat-pathogen interactions and concerning about food security. *Research Journal of Agricultural Science*, 49(3), 87-95.

Paraschivu, M., Cotuna, O., Paraschivu, M., Olaru, L. (2019). Effects of interaction between abiotic stress and pathogens in cereals in the context of climate change: an overview. *Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series* XLIX (2), 413-424.

Paraschivu, M., Matei, Gh., Cotuna, O., Paraschivu, M., Drăghici, R. (2021). Reaction of rye cultivars to leaf rust (P. recondita f. sp. secalis) in the context of climate change in dry area in southern Romania. *Scientific Papers. Series A. Agronomy*, Vol. LXIV (1), 500-507.

Paraschivu, M., Cotuna, O., Sărățeanu, V., Matei, Gh. Drăghici, R., Prioteasa, A.M. (2023). Assessment of leaf rust (*P. recondita* f. sp. secalis) attack in marginal areas in Southern Romania. *Scientific Papers. Series A. Agronomy,* Vol. LXVI, No.2, 2023, 330-338.

Raveau, R., Fontaine, J., Lounès-Hadj Sahraoui, A. (2020). Essential oils as potential alternative bio control products against plant pathogens and weeds: A review. *Foods*, 9(3):365.

Ray, D.K., Mueller, N.D., West, P.C., Foley, J.A. (2013). Yield trends are insufficient to double global crop production by 2050. *PLoS ONE*, 8, e66428.

Răduțoiu, D. & Băloniu, L. (2021). Invasive and potentially invasive alogen plants in the agricultural crops of Oltenia. *Scientific Papers. Series B, Horticulture.* LXV, 1, 782-787.

Răduțoiu, D. (2022). The economic importance of the spontaneous flora within Oltenia Plain, Romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development* 22 (1), 561-568.

Răduțoiu, D. & Stan, I. (2022). Vegetation damage to agricultural crops in Oltenia, Romania. *Scientific Papers. Series B, Horticulture*. LXVI, 885-892.

Răduțoiu, D. (2023). The economic importance of the Spontaneous flora in the area of the Piedmont and Subcarpathian Hills of Oltenia, Romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, Vol.23 (3), 768-775.

Răduțoiu, D., Băloniu, L., Stan, I. (2023). Natura 2000 Habitats from Oltenia affected by invasive and potentially invasive species (I). *Scientific Papers. Series B. Horticulture*, Vol. LXVII, No. 1, 827-832.

Reddy, K.R.N., Nurdijati, S.B., Salleh, B. (2010). An overview of plant-derived products on control of mycotoxigenic fungi and mycotoxins. *Asian Journal of Plant Sciences,* 9, 126.

Rishi, K., Singh, R. (2003). Chemical components and insecticidal properties of Bakain (*Melia azedarach* L.)-A review. *Agricultural Revolution*, 24, 101–115.

Rodríguez, D. Jasso de, Hernández-Castillo, D, Rodríguez-García, R , Angulo-Sanchez, J. L. (2005). Antifungal activity in vitro of Aloe verapulp and liquid fraction against plant pathogenic fungi. *Industrial Crops and Products.* 21, 81-87.

Roy, C., He, X., Gahtyari, N.C., Mahapatra, S., Singh, P.K. (2023). Managing spot blotch disease in wheat: Conventional to molecular aspects. *Frontiers in Plant Science* 14:1098648. doi: 10.3389/fpls.2023.1098648.

Saari, E.E. (1998) Leaf blight diseases and associated soilborne fungal pathogens of wheat in south and southeast Asia. In: Helminthosporium Blights of Wheat: Spot Blotch and Tan Spot (Duveiller, E., Dubin, H.J.,Reeves, J. and McNab A., eds). Mexico, D.F., Mexico: CIMMYT, pp. 37–51.

Savary, S., Willocquet, L., Pethybridge, S.J., Esker, P., McRoberts, N., Nelson, A. (2019). The global burden of pathogens and pests on major food crops. *Nature Ecology and Evolution*, 3, 430–439.

Schuster, C., Konstantinidou-Doltsinis, S., Schmitt, A. (2010). Glycyrrhiza glabra extract protects plants against important phytopathogenic fungi. *Communications in Agricultural and Applied Biological Sciences* 75(4), 531-40.

Seepe, H.A., Lodama, K.E., Sutherland, R., Nxumalo, W., Amoo, S.O. (2020). In vivo antifungal activity of South African medicinal plant extracts against *Fusarium* pathogens and their phytotoxicity evaluation. *Plants*, *9*, 1668.

Seepe, H.A., Nxumalo, W., Amoo, S.O. (2021). Natural Products from Medicinal Plants against Phytopathogenic *Fusarium* Species: Current Research Endeavours, Challenges and Prospects. *Molecules*, 26 (21), 6539. https://doi.org/10.3390/molecules26216539

Shabana, Y.M., Abdalla, M.E., Shahin, A.A., El-Sawy, M.M., Draz, I.S., Youssif, A.W. (2017). Efficacy of plant extracts in controlling wheat leaf rust disease caused by Puccinia triticina. *Egyptian Journal of Basic and Applied Sciences.* 4 (1), 67-73.

Shuping, D.S.S., Eloff, J.N. (2017). The use of plants to protect plants and food against fungal pathogens: A review. *African Journal of Traditional, Complementary and Alternative Medicines*, 14, 120–127.

Singh, G, Maurya, S., Lampasona, M.P., Catalanb, C.A.N. (2007). A comparison of chemical, antioxidant and antimicrobial studies of cinnamon leaf and bark volatile oils, oleoresins and their constituents. *Food and Chemical Toxicology*. 45(9), 1650-1661.

Souza, E.L.d, Lima, E.d.O., Freire, K.R.d.L., Sousa, C.P.D. (2005). Inhibitory action of some essential oils and phytochemicals on the growth of various moulds isolated from foods. *Brazilian Archives of Biology and Technology* 48, 245–250.

Soylu, S. (2008) Mechanisms of Disease Resistance in Plants against Phytopathogens. In: Biochemical Responses of Plants to Invaders, edn. *Research Signpost,* Kerala, India. 33-48

Stević, T., Berić, T., Šavikin, K., Soković, M., Gođevac, D., Dimkić, I., Stanković, S. (2014). Antifungal activity of selected essential oils against fungi isolated from medicinal plant. *Industrial Crops and Products*, 55, 116–122.

Sultana, S., Akhtar, N., Asif, H.M. (2013). Phytochemical screening and antipyretic effects of hydro-methanol extract of Melia azedarach leaves in rabbits. *Bangladesh J. Pharmacol*, 8, 214–217.

Tajkarimi, M., Ibrahim, S., Cliver, D.O. (2010). Antimicrobial herb and spice compounds in food. *Food Control,* 21, 1199–1218.

Tegang, A.S., Beumo, T.M.N., Dongmo, P.M.J., Ngoune, L.T. (2018). Essential oil of *Xylopia aethiopica* from Cameroon: Chemical composition, antiradical and in vitro antifungal activity against some mycotoxigenic fungi. *Journal of King Saud University Science*, 30, 466–471.

Tegegne, G., Pretorius, J.C. (2007). In vitro and in vivo antifungal activity of crude extracts and powdered dry material from Ethiopian wild plants against economically important plant pathogens. *BioControl*, *52*, 877–888.

Tripathi, A., Tripathi, D.K., Chauhan, D., Kumar, N., Singh, G. (2016). Paradigms of climate change impacts on some major food sources of the world: A review on current knowledge and future prospects. *Agriculture, Ecosystems and Environment*, 216, 356–373.

Ultee, A., Bennik, M.H.J., Moezelaar, R. (2002). The phenolic hydroxyl group of carvacrol is essential for action against the food-borne pathogen Bacillus cereus. *Applied and Environmental Microbiology*, 68, 1561-1568.

Uwineza, M.S., Yousfi, B.E.,Lamiri, A. (2018). An alternative control of yellow rust on bread wheat with essential oils of *Mentha pulegium*, *Eugenia aromatica*, and *Cedrus atlantica* (July) International Conference on Advanced Intelligent Systems for Sustainable Development, Springer, Cham (2018), 54-61, 10.1007/978-3-030-11878-5_6

Van de Braak, S.A.A.J., Leijten, G.C.J.J. (1999). Essential Oils and Oleoresins: A Survey in the Netherlands and other Major Markets in the European Union; CBI, Centre for the Promotion of Imports from Developing Countries: Rotterdam, The Netherlands, p. 116.

Vechet, L., Martinkova, J., Sindelarova, M., Burketova, L. (2005). Compounds of natural origin inducing winter wheat resistance to powdery mildew (Blumeria graminis f. sp. tritici). *Plant Soil and Environment*, 51(10), 468.

Velea, L., Bojariu, R., Burada, C., Udristioiu, M.T., Paraschivu, M., Burce, R.D. (2021). Characteristics of extreme temperatures relevant for agriculture in the near future (2021-2040) in Romania. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering*. X, p.70-75.

Velluti, A., Marín, S., Gonzalez, P., Ramos, A.J., Sanchis, V., (2004). Initial screening for inhibitory activity of essential oils on growth of *Fusarium verticillioides*, *F. proliferatum* and F. *graminearum*-based agar media. *Food Microbiology* 21, 649–656.

Wan, A., Wang, X., Kang, Z., Chen, X. (2017). Variability of the stripe rust pathogen, *Strip Rust*, 35-154, 10.1007/978-94-024-1111-9_2

Wang, W., Ben-Daniel, B. H. and Cohen, Y. (2004). Control of plant diseases by extracts of Inula viscosa. *Phytopathology*, 94, 1042-1047.

Yadav, B., Singh, R., Kumar, A. (2015). Management of spot blotch of wheat using Fungicides, Bio-agents and Botanicals. *African Journal*, 10(25), 2494-2500.

Yang, X., Yang, L., Yu, D., Ni, H. (2008). Effects of physcion, a natural anthraquinone derivative, on the infection process of *Blumeria graminis* on wheat. *Canadian journal of plant pathology*, 30(3), 391-396.

Yao, F., Huang, J., Cui, K., Nie, L., Xiang, J., Liu, X., Wu, W., Chen, M., Peng, S. (2012). Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. *Field Crops Research* 126, 16–22.

Yasmin, S. (2016). In vitro evaluation of botanical extracts against some soil and seed borne fungi of economic importance. *Journal of Agriculture and Ecology Research International*, 1-11.

Zabka, M., Pavela, R., Slezakova, L., (2009). Antifungal effect of Pimentadioica essential oil against dangerous pathogenic and toxinogenic fungi. *Industrial Crops and Products* 30, 250–253.

Zahraoui, E. M., Ramzi, A., Habybellah, W., El Yousfi, B., Boukachabine, K. (2024). Alternative control of helminthosporium leaf spot on wheat using essential oils of Origanum compactum and Thymus satureioides. *Moroccan Journal of Agricultural Sciences*, *5*(1), 63-69.

Zaker, M. (2016). Natural Plant Products as Eco-friendly Fungicides for Plant Diseases Control- a Review. *The Agriculturists* 14(1), 134-141.

Zală, C.R. (2021). First report of loose smut-*Ustilago syntherismae* (Schweinitz) Peck on *Digitaria sanguinalis* (L.) Scop. In Bucharest-Romania. *Scientific Papers. Series A. Agronomy*, Vol. LXIV, No. 1, 632-640.

Zală, C.R., Manole, M-S., Istrate, R., Ciocoiu, E., Țurcan, D. (2023a). Preliminary research on soil microflora and macrofauna in the experimental field Moara Domnească, *Scientific Papers. Series A. Agronomy*, Vol. LXVI, No. 1,190-196.

Zală, C.R., Cotuna, O., Paraschivu, M., Istrate, R., Mali-Sanda Manole, M.S. (2023b). Research on the effectiveness of some fungicides and insecticides in combating of some diseases and pests of rape in Cristian commune - Brașov County. *Romanian Agricultural Research*, 40, First Online: February, 2023. DII 2067-5720 RAR 2023-107.