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ORIGINAL ARTICLE

Effects of essential oils on mycoflora and winter wheat seed germination

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The mycoflora of winter wheat seed consists of various fungi that differ as to the parasitism rate. Their harmfulness is connected with their phytotoxic action and ability to produce mycotoxins. Assuming that essential oils have an effective antifungal impact, we studied the effectiveness of 13 essential oils which were produced by LLC "Aromatyka", Ukraine (cinnamon, orange, peppermint, rosemary, vervain, ylang-ylang, sandal, fennel, lavender, eucalypt, bergamot, frankincense, and geranium) on securing of a group of fungi from winter wheat seeds. The seed mycoflora of Bogdana variety harvested in 2017-2020, which was grown in the North-Eastern Forest-Steppe zone of Ukraine (Sumy oblast), was analyzed. A fungi complex analysis was made on the media PGA. The impact of essential oils on seed germinating ability and the length of wheat sprouts on the 7th day has been determined. A long-term studying of seed treatment by essential oils showed their effects on mycoflora formation. These plants affected not only the fungi amount but also changed their secure spectrum. The studies admit a negative impact of fungi on seed germination and plant development. The highest seed germination equaled 95% under its treatment with rosemary and orange oils. However, under seed treatment with rosemary oil, there appeared Fusarium sp. and *Bipolaris sorokiniana* (Sacc.) Shoem., which harms seed germination. Orange oil has increased the number of fungi of Penicillium sp. The best results (based on three indices) had sandal oil, under which the fungus colony has increased half, and seed germination equaled 61%, the sprout length was maximal when applying other oils (58.8 mm). The essential oils which fully inhibited seed and fungi development (cinnamon, fennel, vervain, geranium) were determined. The study of two of them as fungicides for treatments at the beginning of wheat flowering proved a similar effect to falcon on the change of the internal seed mycoflora.

Keywords: seed mycoflora, winter wheat, essential oils

Introduction

Intensive chemization of agricultural production harms the environment and human health. Pathogenic organisms cause significant losses of agricultural products every year. A search for alternative ways of protection to reduce the pesticide load is an urgent problem today.

There are 3000 essential oils, from which only 300 are used by people (Burt & Reinders, 2003). The term "essential oil" was first suggested by Swiss scientist Paracelsus von Hohenheim in the 16th century. The earliest records of essential oil production techniques belong to Andalusian doctor Ibn Al-Baitar, though they were used in Shumery and ancient Egypt. The International Organisation for Standardisation (ISO) defines an essential oil as a product received by distillation with water or vapor, mechanic treatment, or dry distillation of natural materials. Essential oils are received from all parts of a plant, more often from grasses and spices, though new sources of these substances (like food and plant waste) are studied nowadays (Macwan et al., 2016; Ravindran & Jaiswal, 2016; Fengfeng et al., 2017; Nazzaro et al., 2017).

Essential oils contain different secondary metabolites that have an allelopathic impact on plants, adversely affect insects and various microorganisms. The researchers consider these oils to be an alternative to pesticides. For this purpose, they are diligently studying them as insecticides (Titouhi et al., 2017), herbicides (Dutra et al., 2020), fungicides (Amini et al., 2016), and acaricides (Ribero et al., 2019). It has also been proved that essential oils affect plant growth and development; that is why in an agrarian sector, they are used as inhibitors (oils inhibit the germination of potato tubers during storage) (Shukla et al., 2019) and stimulate plant growth (Dyadiuchenko et al., 2020). Seed treatment with thyme essential oil increases drought resistance of wheat (Ben-Jabeur et al., 2019).

The wheat seeds contain various microorganisms: fungus, bacteria, viruses. Some of them are phytopathogenic, which is why the seed is a source of infection for them. Fungi are the most studied among phytopathogenic microorganisms. It has been proved that fungus infection occurs in plants growing, most often in flowering. The hyphae appear in the seed which is being formed. The fungi inside the seed are dangerous not only for plants under their germination but also for animals and people because most of them produce mycotoxins. Field and seed infection is controlled in two ways: by spraying plants and treating the seeds with fungicides.

The essential oils from different plants are diligently studied as biofungicides against seed infection. The research on the effects of essential oils of different concentrations on fungi from wheat seeds (Acremonium sp., Alternaria sp., Arhrobotrys sp., Aspergillus sp., Cladosporium sp., Epicoccum sp., Fusarium sp., Penicillium sp., Rhizopus sp., Trichoderma sp. and Ulocladium sp.) in Turkey showed the highest anti-fungi activity of oils from clove and oregano. In Slovenia, the researchers proved thyme oil (*Thymus vulgaris* L.) to have the highest antifungal action on mycelial growth of fungi (*Alternaria alternata* (Fr.) Keissl, *Alternaria infectoria*

E.G. Simmons, *Aspergillus flavus* L., *Epicoccum nigrum* L. and *Fusarium poae* (Peck) Wollenw) of wheat seed mycoflora in vitro (Anžlovar et al., 2017). The effects of savory essential oil (Iran) on wheat infection by *Fusarium oxysporum*, grown in pots under artificial seeds infection with a pathogen, showed a lack of infection control compared to fungicide treatment (Rahimian & Eisvand, 2016). Citral as a component of various essential oils (lemon myrtle, Litsea sp., lemongrass, lemon, eucalyptus) inhibits not only phytopathogens development but also reduces the number of mycotoxins (patulin, aflatoxin, alternariol, and its derivative, alternariol monomethyl ether) (Liang et al., 2015; Wang et al., 2018; Wang et al., 2019).
The antifungal mechanism of essential oils has been already studied: distortion of the cell membrane, changes, and inhibition of fungi cell wall (Wu et al., 2008; Yutani et al., 2011), dysfunction of fungi mitochondria (Chen et al., 2013), the decrease in the amount of nitrogen oxide (Cotoras et al., 2013).
The study aimed to establish the features of seed mycoflora by treatment with essential oils of various plants and to identify their impact on wheat germination.

Methods

The Bogdana variety seeds were grown in the North-Eastern part of the Forest-Steppe region of Ukraine (Sumy oblast, Sumy National Agricultural University (SNAU)). The harvests of 2017-2020 were analyzed. The effects of 13 essential oils produced by LLC "Aromatyka", Ukraine (cinnamon, orange, peppermint, rosemary, vervain, ylang-ylang, sandal, fennel, lavender, eucalypt, bergamot, frankincense, and geranium) have been analyzed. The seeds were being rinsed with flow water for an hour and then doused with sterile water (100ml). Then 1ml of essential oil was added to each container. The seeds were kept in this solution for 2.5 hours. The seeds in control were immersed in sterile water for the same period. The received material was dried on filter paper without rinsing in water and put into Petri dishes (20 in amount) on PGA. Dishes were put into a thermostat where the colonies and seed germination were going on under 22–24 °C for seven days.
The fungi were determined according to mycelia structure as well as to sporulation. As many as 100 seeds were analyzed in each variant. The germination capacity of seeds and the length of wheat sprouts were determined on the 7th day. The effectiveness of winter wheat spraying was tested in the experimental field of a Research and Manufacturing Complex of SNAU. The plants were sprayed with a hand-sprayer one time at the beginning of plant flowering (5.06.2020). It was a small-plot three-fold experiment. Falkon© (Bayer) with a consumption rate of 2ml/1l was used as a standard. The same consumption rate was used for fennel essential oil spraying; the amount of cinnamon essential oil was reduced (1.5ml/1l) because in previous years, we have noted its phytotoxic effect.
The analysis of wheat seeds mycoflora was made after spraying on a media (PGA); after rinsing with water, they were kept in a 1 % solution of potassium permanganate during 1-2 min in order to study an internal composition of seed fungi (Naumova, 1951). The percentage of isolated fungi was calculated basing on the whole amount of secured colonies in a variant. The effect of spraying on the mass of 1000 grains was determined as well.
We used the dispersion analysis to process the data.

Results

The analysis of mycoflora of winter wheat seed from the North-Eastern part of Ukraine started in 2007 and showed a significant quantity of Alternaria sp. Seed germination observation during many years showed no effects of these fungi on wheat seed germination. However, a significant percentage of fungi isolation (*Alternaria tenuissima* (Nees) Wiltshire, *A. alternata*, the complex of species *A. infectoria*, *A. avenicola*, and *A. arborescens*) in grain products anticipate the danger of a significant amount of mycotoxins availability, which is not controlled in Ukraine. So, it was decided to find ways to regulate the number of fungi of Alternaria sp. in winter wheat seed. The analysis of essential oils' effects on the amount of these fungi started in 2017. The seeds were put into a 1% aqueous solution of cinnamon oil for 2.5 h. We showed satisfactory results compared to other substances' effectiveness: the colonies amount reduced by half compared to control (Table 1).

Table 1. Effects of essential cinnamon oil (1% aqueous solution) on the mycoflora of wheat seed harvested in 2017.

Variant	Isolation of fungal colonies, number	Amount of colonies, number	Seed germination, %	Average sprouts length, mm
Control (water)	*Alternaria* sp. 75 *Penicillium* sp. 28 *Cladosporium* sp. 7 *Monilia* sp. 1	111	100	53.8
Cinnamon	*Alternaria* sp. 54 *Penicillium* sp. 3 *Fusarium sporotrichioides* Sherb. 3 *Arthrinium caricicola* Kunze: Fr 1	61	Have not germinated	-
LSD_{05}	*Alternaria* sp. 3.9 *Penicillium* sp. 3.6	4	-	-

The amount of Alternaria sp. has reduced; herewith, most of the isolation fungi were indicated as one species *A. infectoria*, which, contrary to other species, produces only one mycotoxin. In 2017 fungi of Penicillium sp. were second as to determination among mycoflora representatives of wheat seed. The application of essential oil has fully reduced their amount. At the same time was isolated *F. sporotrichioides*, which are the mycotoxins producers. The cinnamon essential oil has not given a chance to seeds to germinate.
In 2018 the spectrum of essential oils was broadened. Different results as to mycoflora changes of winter wheat seed were received (Table 2).

Table 2. Effects of essential oils (1% aqueous solution) on the microflora of wheat seed, harvested in 2018.

Variant	Isolation of fungal colonies, number	Amount of colonies, number	Seed germination, %	Average sprouts length, mm
Control	*Alternaria* sp. 54 *Penicillium* sp. 12 *Aureobasidium pullulans* (de Bary & Löwenthal) G.Arnaud 16 *Nigrospora oryzae* (Berkeley et Broome) Petch 6 *Monilia* sp. 3 Other fungal colonies 24	115	100	60.4
Orange	*Alternaria* sp. 10 *Penicillium* sp. 63 Other fungal colonies 1	74	95	16.3
Peppermint	*Alternaria* sp. 21 *Penicillium* sp. 10 *Trichoderma* sp. 6 *Monilia* sp. 3 *A. flavus* 1 *Aspergillus niger* Tiegh. 1 Other fungal colonies 3	45	Have not germinated	-
Rosemary	*Alternaria* sp. 40 *Penicillium* sp. 15 *Trichoderma* sp. 5 *Chaetomium* sp. 5 *B. sorokiniana* 4 *Fusarium* sp. 2 Other fungal colonies 30	101	95	43.9
Cinnamon	Have not germinated	-	Have not germinated	-
LSD_{05}	*Alternaria* sp. 3.2 *Penicillium* sp. 3.6 Other fungal colonies 2.8	5.5	4,2	0.7

The amount of fungi colonies germinated from seed under its treatment with aqueous solutions of essential oils was admitted to decrease. In all variants was shown a decrease in the percentage of isolation of Alternaria fungi as compared to control. However, a decrease in the amount of some species caused an increase in the amount or appearance of others. The essential oil from oranges reduced the percentage of isolation of Alternaria sp. up to 10%, but at the same time increasing the number of colonies of Penicillium sp., due to which the length of wheat sprouts decreased.

The oil from peppermint reduced the number of colonies by half, but the wheat seed could not germinate. Rosemary did not significantly reduce the percentage of fungi colonies but affected the spectrum of their species. The sprout length was decreased up to 43.9 mm. The availability of fungi of Alternaria sp. and Penicillium sp. was standard for all variants. Under cinnamon oil application, neither fungi colony nor wheat seed was germinated.

In 2019 *A. pullulans* and Alternaria fungi dominated in a control. Like in 2018, the effects of essential oils from plants on wheat seed mycoflora were different (Table 3).

Table 3. Effects of essential oils (1% aqueous solution) on the mycoflora of wheat seed, harvested in 2019.

Variant	Isolation of fungal colonies, number	Amount of colonies, number	Seed germination, %	Average sprouts length, mm
Control	*A. pullulans* 68 *Alternaria* sp. 41 *Trichoderma* sp. 5 *Penicillium* sp. 3 *N. oryzae* 2 *F. sporotrichioides* 1 Other fungal colonies 15	135	99	62.2
Ylang-ylang	*A. pullulans* 20 *Alternaria* sp. 13 Other fungal colonies 1	34	16	15.0
Sandal	*Alternaria* sp. 3 *A. pullulans* 1 Other fungal colonies 47	51	61	58.8
Eucalypt	*Penicillium* sp. 54 *Alternaria* sp. 2 *A. niger* 1	63	90	49.5

	Other fungal colonies 6			
Vervain	Other fungal colonies 1	1	Have not	-
Cinnamon	Have not germinated	-	germinated	-
Fennel			1	2.0
Lavender			Have not germinated	-
LSD_{05}	-	2.8	4	2.3

In a variant with seed steeping into a 1% aqueous solution of essential oil from vervain, only one colony was registered without sporulation germinated from one seed. None of the wheat seeds germinated. The application of ylang-ylang oil cut the number of colonies is almost four times, only 16% of seeds germinated, and the length of their sprouts on the 7th day equaled 15mm on average. Sandal oil almost completely inhibited colonies *A. pullulans* and Alternaria sp., but the colonies of other fungi germinated without sporulation. Among the variants with the application of essential oils, 61% of seeds had a maximal sprout length. Eucalypt oil caused a significant percentage of isolation of Penicillium sp., which had fewer effects on sprouts length than in 2018 under the application of orange oil. The essential oils from cinnamon, fennel, and lavender prevented the colonies of fungi and wheat seed from germinating. In 2020 after essential oils treat, a more significant amount of colonies germinated from seed than control, except for the variants with the application of cinnamon, geranium, and fennel (Table 4).

In the previous years, a decrease in the percentage of Alternaria fungi was registered, but in 2020 in the variants with the application of essential oils, more colonies germinated. It can be explained that species A. arborescens dominated on control, and other variants dominated *A. avenicola*. The essential oils reduced the amount of one Alternaria species, which dominated the investigation of previous years. The application of bergamot oil caused a maximal amount of fungi colonies among all variants and harmed wheat seed germination. Seed treatment with frankincense and eucalypt oils resulted in a significant amount of secured Mucorales species. The eucalypt oil, like last year, caused an increase in the amount of Penicillium sp. These oils harmed seed germination. Seed treatment with frankincense oil caused the least impact on the number of fungal colonies. The application of lavender oil prevented the seed from germinating but stimulated the germination of many fungi colonies, which did not coincide with the investigation results last year when no fungus was isolated. This fact indicates the need for many years of research into the effects of essential oils on the seed mycoflora. The fennel and cinnamon oils proved their effectiveness. The application of geranium oil demonstrated a similar reaction (Fig. 1).

Table 4. Effects of essential oils (1% aqueous solution) on the mycoflora of wheat seed, harvested in 2020.

Variant	Isolation of fungal colonies, number	Amount of colonies, number	Seed germination, %	Average sprouts length, mm
Control	*Alternaria* sp. 62 *Trichothecium roseum* (Pers.) Link 22 *Trichoderma* sp. 12 *Acremoniella atra (Corda) Sacc.* 10 *Penicillium* sp. 8 *Mucor* sp. 1 Other fungal colonies 20	135	97	72.3
Bergamot	*Alternaria* sp. 84 *Tr. roseum* 26 *Trichoderma* sp. 21 *A. flavus* 11 *Penicillium* sp. 5 Other fungal colonies 8	155	9	25.5
Frankincense	*Alternaria* sp. 77 *Mucor* sp. 10 *Tr. roseum* 24 *A. atra* 13 *Trichoderma* sp. 10 *Penicillium* sp. 8 Other fungal colonies 4	136	78	54.2
Lavender	*Alternaria* sp. 70 *Tr. roseum* 32 *A. flavus* 18 *Trichoderma* sp. 12 *Penicillium* sp. 6 *Acremonium* sp. 1 Other fungal colonies 15	154	Have not germinated	-
Eucalypt	*Alternaria* sp. 65 *Mucor* sp. 10 *Tr. roseum* 28 *Penicillium* sp. 21 *Trichoderma* sp. 12 *A. niger* 1	136	79	43.5
Cinnamon	Have not germinated	-	Have not germinated	-
Geranium				
Fennel				

LSD_{05}	*Alternaria* sp. 7.4 *Tr. roseum* 4.3 *Trichoderma* sp. 3.6 *Penicillium* sp. 2.9	3.1	3.3	0.9

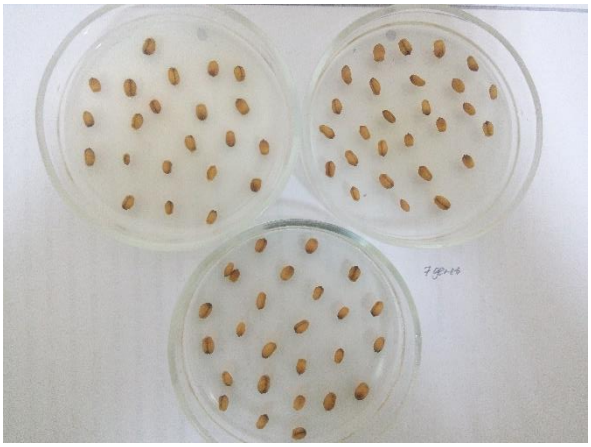

Fig 1. Non-germinated wheat seeds without fungal colonies on the 7th day after treatment with cinnamon, fennel, and geranium oils (2020).

The reason for further studying the effectiveness of essential oils for spraying was their complete suppression of seed mycoflora. As an etalon, the plants were treated with Falkon© at the beginning of flowering wheat. The analysis of the impact of plants spraying with essential oils on the inner mycoflora of wheat seed showed results similar to the fungicide (Table 5).

Table 5. Effects of spraying on inner mycoflora formation of winter wheat seed and 1000 seeds mass (SNAU, 2020).

Variant	Isolation of fungal colonies, %	Mass of 1000 grains, g
Control	*Alternaria sp.*62.7 *Tr. roseum* 11.7 *A. atra* 7.4 *Mucor sp.* 3.7 *F. poae* 1.6 *Rh. Stolonifer* 1.2 Other fungal colonies 11.7	38.16
Falkon	Alternaria sp. 25.9 A. pullulans 10.7 Tr. roseum 13.4 Cladosporium sp. 1.8 Penicillium sp. 0.9 Other fungal colonies 47.3	39.54
Cinnamon	Alternaria sp. 35.6 A. pullulans 17.8 Cladosporium sp. 4.2 Tr. roseum 0.9 Penicillium sp. 0.9 A. niger 0.9 Other fungal colonies 39.7	32.8
Fennel	Alternaria sp. 34.8 A. pullulans 20.7 Cladosporium sp. 5.4 Tr. roseum 3.3 A. niger 1.1 B. sorokiniana 1.1 Other fungal colonies 33.6	36.66
LSD_{05}	*Alternaria* sp. 2.6 *Tr. roseum* 0.6 Other fungal colonies 0.7	0.4

Spraying has significantly decreased the amount of Alternaria fungi, changed the spectrum of fungi, which had an insignificant secure percentage, increased the number of fungi without sporulation, and caused the appearance of *A. pullulans*. Wheat treatment with essential oils solutions resulted in the decrease of the amount of *Tr. roseum*, as well as in the sporadical appearance of dangerous species: *A. niger* and *B. sorokiniana*. Spraying with preparations affected the mass of 1000 seeds. This index increased in a variant with Falkon spraying and decreased in a variant with essential oils treatment.

Discussion

Most investigations on studying the antifungal impact of essential oils were conducted under conditions in vitro, and their effectiveness as to a broad spectrum of fungi was achieved and proved. The essential oils of medium concentration *Zataria multiflora* Boiss., *Cuminum cyminum* L., *Foeniculum vulgare* Mill., Pinaceae, and *Heracleum persicum* Desf. ex Fisch. fully inhibited ten non-toxic (*Fusarium solani* (Mart.) Sacc. and *Fusarium oxysporum* Schlecht.) and 11 toxicogenic (*Fusarium verticillioides* (Sacc.) Nirenberg, *F. poae* and *Fusarium equiseti* (Corda) Sacc.) fungi isolates (Naeini et al., 2010).

However, essential oils from different plants had different impacts on fungi. As follows from Ayala-Zavala et al. (2009), the essential oil from peppermint has to inhibit A. flavus and A. niger's development. In our investigation, on the contrary, it provoked the germination of sporadical colonies of these fungi. The effectiveness of orange peel oil against *A. alternata* and *Alternaria dauci* (JG Kühn) JW Groves & Skolko, which germinated from carrot seed (in vivo), was proved while studying the effectiveness of extractions and essential oils from different plants (Lima et al., 2016). The antifungal effects of orange peel oil are attributed to the availability of monoterpene citrine, which has manifested the ability to inhibit the growth of mycelium *A. alternata* in vitro (Marostica et al., 2007). In our investigation, the orange essential oil has also reduced the amount of Alternaria colonies and provoked a high percentage of Penicillium sp isolation fungi. Cinnamon essential oil under conditions in vitro, by 100% has inhibited the growth of phytopathogenic fungi *F. oxysporum*, *Cylindrocarpon destructans* (Penz.) Penz. & Sacc., *Botrytis cinerea* Fr., *Colletotrichum gloeosporioides*, *Rhizoctonia solani* Kühn), except *F. solani*, its inhibition percentage equaled 66.59% (Ma et al., 2019). Our results have also shown a 100% fungi inhibition, but under conditions in vivo. The essential oils from fennel seed and leaves inhibited all tested phytopathogenic fungi' mycelia growth: Alternaria sp., *Pencillium expansum* L., *R. stolonifer, Fusarium oxysporum* f. sp. *albedinis* and, *Aspergillus brasiliensis* (Sellam et al., 2015). The results of our investigation proved a 2-year prolonged inhibition of germination of fungi colonies from wheat seed after its treatment with fennel oil.

It is more difficult to study the essential oils' effects not on separate species but a complex, especially seed mycoflora. The analysis on the impact of 6 essential oils (*Melissa officinalis* L., *Salvia officinalis* L., *Coriandrum sativum* L., *Thymus vulgaris* L., *Mentha piperita* L., *Cinnamomum zeylanicum* L.) on the mycoflora of wheat seed showed a decrease in the amount of fungi colonies on the 5th day. However, on the 22nd day, the inhibiting effects decreased. A significant amount of Alternaria fungi was admitted in all variants under oils application. Fungi of Cladosporium sp. have germinated in a variant with sage and coriander, Aspergillus sp. – with coriander and peppermint. The highest fungicide effects were admitted in balm mint and thyme oils. The cinnamon essential oil has effectively reduced the amount of fumonisin (Sumalan et al., 2013).

Our investigation showed the negative impact of essential oils on seed germination and wheat sprouting peculiarities. Some adverse effects on seed germination and sprouts length were established when analyzing the effects of rosemary and oregano oils (in different concentrations) on five wheat varieties' germination abilities. This fact was explained by many monoterpenes, which, according to the previous data (Dudai et al., 2004), are powerful inhibitors of wheat seed germination. When the concentration of essential oils increased, the inhibition increased as well. The rosemary oil had less negative impact than oregano oil (Atak et al., 2016). The analysis of essential oils in insecticides' function was combined with their effects on seed germination *Triticum durum* Desf. The bergamot, fennel, and lavender oils decreased seed germination by 70% (Rossi et al., 2012). In our investigation, these oils have completely prevented seed germination *T. aestivum* L.

Conclusions

A long-standing studying of wheat seed treatment with essential oils has shown their impact on seed mycoflora formation. The essential oils affected not only the fungi amount but also changed the spectrum of their isolation. A decrease in the amount of fungi colonies was admitted in 2017-2019, but in 2020 their amount increased. The amount of Alternaria fungi decreased under the application of essential oils during the first three years, but in the last year of investigation, their amount increased due to species change. The species *A. arborescens* dominated in control, and *A. avenicola* dominated variants with the application of oils. The investigation failed to determine the effective essential oil for seed mycoflora regulation. The more the colonies amount decreased, the worse the seed germinated. In all variants, these substances inhibited plant germination and development. The highest seed germination equaled 95% under its treatment with rosemary and orange oils. Sandal oil had the best results (according to three indices), when the colonies amount decreased by half, seed germination equaled 61%, and the sprout length was maximal among all essential oils (58.8mm).

The essential oils which completely inhibited the seed and fungi development (cinnamon, fennel, vervain, geranium) have been determined. The analysis of two of them in the function of fungicides, under treatment at the beginning of wheat flowering, proved to have a similar Falkon© impact on the changes of an internal seed mycoflora. However, fennel and cinnamon essential oils decreased the mass of 1000 grains as compared to control.

References

Amini, J., Farhang, V., Javadi, T., & Nazemi, J. (2016). Antifungal effect of plant essential oils on controlling Phytophthora species. The plant pathology journal, 32(1), 16–24. https://doi.org/10.5423/PPJ.OA.05.2015.0091

Anžlovar, S., Likar, M., & Koce, J. (2017). Antifungal potential of thyme essential oil as a preservative for storage of wheat seeds. Acta Bot. Croat., 76 (1), 64–71. https://doi.10.1515/botcro-2016-0044

Atak, M., Mavi, K., & Uremis, I. (2016). Bio-herbicidal effects of oregano and rosemary essential oils on germination and seedling growth of bread wheat cultivars and weeds. Romanian Biotechnological Letters, 21 (1), 11149–11159.

Ayala-Zavala, J. F., Gonzalez-Aguilar, G. A., & Del Toro-Sànchez, L. (2009). Enhancing safety and aroma appealing of fresh-cut fruits and vegetables using the antimicrobial and aromatic power of essential oils. Concise reviews and hypotheses in food science. J. Food Sci, 74, 84–91. https://doi.10.1111/j.1750-3841.2009.01294

Ben-Jabeur, M., Vicente, R., López-Cristoffanini, C., Alesami, N., Djébali, N., Gracia-Romero, A., Serret, M. D., López-Carbonell, M., Araus, J. L., & Hamada, W. (2019). A Novel Aspect of Essential Oils: Coating Seeds with Thyme Essential Oil induces Drought Resistance in Wheat. Plants (Basel, Switzerland), 8(10), 371. https://doi.org/10.3390/plants8100371

Bezpal'ko, V.V., Stankevych, S.V., Zhukova, L.V., Zabrodina, I.V., Turenko, V.P., Horyainova, V.V., Poedinceva, A.A., Batova, O.M., Zayarna, O.Yu., Bondarenko, S.V., Dolya, M.M., Mamchur, R.M., Drozd, P.Yu., Sakhnenko, V.V., Matsyura, A.V. (2020). Pre-sowing seed treatment in winter wheat and spring barley cultivation. Ukrainian Journal of Ecology, 10(6), 255-268. https://doi.org/10.15421/2020_291

Bezpal'ko, V.V., Zhukova, L.V., Stankevych, S.V., Ogurtsov, Yu.H., Klymenko, I.I., Hutians'kyi, R.A., Fesenko, A.M., Turenko, V.P., Zabrodina, I.V., Bondarenko, S.V., Batova, O.M., Golovan, L.V., Klymenko, I.V., Poedinceva, A.A., Melenti, V.O. (2019). Ecologically safe methods for presowing treatment of cereal seeds. Ukrainian Journal of Ecology, 9(3), 189-197. https://doi.org/10.15421/2019_729

Burt, S. A., & Reinders, R. D. (2003). Antibacterial activity of selected plant essential oils against *Escherichia coli* O157:H7. Lett. Appl. Microbiol., 36, 162–167. https://doi.10.1046/j.1472-765X.2003.01285.x

Chen, Y., Zeng, H., Tian, J., Ban, X., Ma, B., & Wang, Y. (2013). Antifungal mechanism of essential oil from *Anethum graveolens* seeds against *Candida albicans*. J. Med. Microbiol., 62, 1175–1183. https://doi. 10.1099/jmm.0.055467-0

Chuprina, Yu.Yu., Klymenko, I.V., Havva, D.V., Golovan, L.V., Buzina, I.M., Titova, A. Ye., Mikheev, V.H., Zabrodina, I.V., Stankevych, S.V. (2020). The level of adaptability of perspective samples of soft and durum spring wheat in Ukrainian forest-steppe. Ukrainian Journal of Ecology, 10(6), 12-22. https://doi.org/10.15421/2020_251

Cotoras, M., Castro, P., Vivanco, H., Melo, R., & Mendoza, L. (2013). Farnesol induces apoptosis-like phenotype in the phytopathogenic fungus *Botrytis cinerea*. Mycologia, 105, 28–33. https://doi.10.3852/12-012

Dudai, N., Ben-Ami, M., Chaimovich, R., & Chaimovitsh, D. (2004). Essential oils as allelopathic agents: bioconversion of monoterpenes by germinating wheat seeds. Acta Hort, 629, 505–508.

Dutra, Q. P., Christ, J. A., Carrijo, T. T. et al. (2020). Phytocytotoxicity of volatile constituents of essential oils from *Sparattan thelium* Mart. species (Hernandiaceae). Sci Rep., 10, 12213. https://doi.org/10.1038/s41598-020-69205-6

Dyadiuchenko, L., Taranenko, V., Muraviev ,V., & Dmitrieva, I. (2020). The study of natural essential oils as growth regulators of winter wheat. BIO Web of Conferences, 21, 6. https://doi.org/10.1051/bioconf/20202100023

Fengfeng, W., Yamei, J., Xueming, X., & Na. Y. (2017). Electrofluidic pretreatment for enhancing essential oil extraction from citrus fruit peel waste. J. Clean. Prod., 159, 85–94.

Gentosh, D.T., Kyryk, M.M., Gentosh, I.D., Pikovskyi, MY., Polozhenets, V.M., Stankevych, S.V., Nemerytska, L.V., Zhuravska, I.A., Zabrodina, I.V., Zhukova, L.V. (2020). Species compositions of root rot agents of spring barley. Ukrainian Journal of Ecology, 10 (3), 106-109. https://doi.org/10.15421/2020_141

Horiainova, V.V., Turenko, V.P., Bilyk, M.O., Stankevych, S.V., Zhukova, L.V., Batova, O.M., Martynenko, V.I., Kucherenko, Ye.Yu., Zviahintseva, A.M. (2020). Species composition, morphological and biological peculiarities of leaf pathogens of spring wheat. Ukrainian Journal of Ecology, 10(3), 115-120. https://doi.org/10.15421/2020_143

Karaca, G., Bilginturan, M., & Olgunsoy, P. (2017). Effects of some plant essential oils against fungi on wheat seeds. Indian Journal of Pharmaceutical Education and Research, 51, 385–388. https://doi.org/10.5530/ijper.51.3s.53

Liang, D.; Xing, F.; Selvaraj, J.N.; Liu, X.; Wang, L.; Hua, H.; Zhou, L.; Zhao, Y.; Wang, Y., & Liu, Y. Inhibitory effect of cinnamaldehyde, citral, and eugenol on aflatoxin biosynthetic gene expression and aflatoxin B1 biosynthesis in *Aspergillus flavus*. J. Food Sci. 2015, 80, M2917–M2924.

Lima, C., Rentschler, L., Bueno, J., & Boaventura, A. (2016). Plant extracts and essential oils on the control of *Alternaria alternata, Alternaria dauci* and on the germination and emergence of carrot seeds (*Daucus carota* L.). Ciência Rural., 46. 764–770. https://doi.10.1590/0103-8478cr20141660

Ma, Y., Chen, Ch., Li, Q., Wang, W., Xu, F., Cheng, Y., & Dong, X. (2019). Fungicidal activity of essential oils from *Cinnamomum cassia* against the pathogenic fungi of panax notoginseng diseases. Chem. Biodiversity, 16 (11). https://doi.org/10.1002/cbdv.201900416

Macwan, S. R., Dabhi, B. K., Aparnathi, K. D., & Prajapati, J. B. (2016). Essential oils of herbs and spices: their antimicrobial activity and application in preservation of foods. Int. J. Curr. Microbiol. Appl. Sci., 5, 885–901. https://doi.10.20546/ijcmas.2016.505.092

Marostica, J., Mário, R. , & Pastore, G. M. (2007). Biotransformation of limonene: a review of the main metabolic pathways. Quím. Nova [online], 30 (2), 382–387. https://doi.org/10.1590/S0100-40422007000200027

Naeini, A., Ziglari, T., Shokri, H., & Khosravi, A. R. (2010). Assessment of growth-inhibiting effect of some plant essential oils on different Fusarium isolates. J Mycol Med., 20, 174–178. https://doi.10.1016/j.mycmed.2010.05.005

Naumova, N. A. (1951). Analysis of seeds for fungal and bacterial infection. Moscow; Leningrad: Selkhozgiz, 140 p.

Nazzaro, F., Fratianni, F., Coppola, R., & Feo, V. (2017). Essential Oils and antifungal activity. Pharmaceuticals (Basel, Switzerland), 10 (4), 86. https://doi.org/10.3390/ph10040086

Rahimian, F., & Eisvand, H. R. (2016). Effects of savory essential oil on germination parameters of Fusarium infected seeds of wheat (Triticum aestivum L.). Iranian Journal of Plant Physiology, 6 (3), 1745-1750.

Ravindran, R., & Jaiswal, A. K. (2016). Exploitation of food industry waste for high-value products. Trends Biotechnol., 34, 58–69. https://doi.org/10.1016/j.tibtech.2015.10.008

Ribero, N. C., da Camara, C. A. G., Melo, J. P. R., & de Moraes, M. M. (2019). Acaricidal properties of essential oils from agro-industrial waste products from citric fruit against *Tetranychus urticae*. J. App. Entom., 143, 731. https://doi.org/10.1111/jen.12642

Rossi, E., Cosimi, S., & Loni, A. (2012). Bioactivity of essential oils from Mediterranean plants: insecticidal properties on *Sitophilus zeamais* and effects on seed germination. Journal of Entomology, 9, 403–412. https://doi.org/10.3923/je.2012.403.412

Sellam, K., Bammou, M., Ramchoun, M., Bouhlali, E. D. T., Jaiti, F., Nassiri, L., & El Rhaffari, L. (2015). Antifungal potential of the seed and leaf *Foeniculum vulgare* mill essential oil in liquid and vapor phase against phytopathogenic fungi. Journal of Applied Pharmaceutical Scienc., 5, 50–54. https://doi.10.7324/JAPS.2015.501108

Shukla, S., Pandey, S. S., Chandra, M., Darokar, M. P., & Karla A. (2019). Application of essential oils as a natural and alternate method for inhibiting and inducing the sprouting of potato tubers. Food Chem., 284, 171–179. https://doi.org/10.1016/j.foodchem.2019.01.079

Sumalan, R. M., Alexa, E., & Poiana, M. A. (2013). Assessment of inhibitory potential of essential oils on natural mycoflora and Fusarium mycotoxins production in wheat. Chemistry Central journal, 7(1), 32. https://doi.org/10.1186/1752-153X-7-32

Titouhi, F., Amri, M., Messaoud, C., Haouuel, S., Youssfi, S., Cherif, A., & Jemaa, F. J. M. B. (2017). *Bruchus rufimanus* (Coleoptera: Chrysomelidae) and the extended side-effects on their natural enemies. J. Stored Prod. Res., 72, 11. https://doi.org/10,1016/jspr.2017.02.07

Turenko, V.P., Bilyk, M.O., Zhukova, L.V., Stankevych, S.V., Zayarna, O.Yu., Lukhanin, I.V., Oleynikov, Ye.S., Batova, O.M., Goryainova, V.V., Poedinceva, A.A. (2019). Dependence of species composition and development of root rots pathogens of spring barley on abiotic factors in the Eastern Forest-Steppe of Ukraine. *Ukrainian Journal of Ecology, 9*(2), 179-188.

Wang, L., Jiang, N., Wang, D., & Wang, M. (2019). Effects of essential oil citral on the growth, mycotoxin biosynthesis and transcriptomic profile of *Alternaria alternata*. Toxins, 11 (10), 553. https://doi.org/10.3390/toxins11100553

Wang, Y., Feng, K., Yang, H., Zhang, Z., Yuan, Y., & Yue, T. (2018). Effect of cinnamaldehyde and citral combination on transcriptional profile, growth, oxidative damage and patulin biosynthesis of *Penicillium expansum*. Front. Microbiol., 9, 597. https://doi.org/10.3389/fmicb.2018.00597

Wu, X. Z., Cheng, A. X., Sun, L. M., & Lou, H. X. (2008). Effect of plagiochin E, an antifungal macrocyclic bis (bibenzyl), on cell wall chitin synthesis in *Candida albicans*. Acta Pharmacol. Sin., 12, 1478–1485. https://doi.org/10.1111/j.1745-7254.2008.00900.x

Yutani, M., Hashimoto, Y., Ogita, A., Kubo, I., Tanaka, T., & Fujita, K. (2011). Morphological changes of the filamentous fungus *Mucor mucedo* and inhibition of chitin synthase activity induced by anethole. Phytother. Res., 25, 1707–1713. https://doi.org/10.1002/ptr.3579

Zhukova, L.V., Stankevych, S.V., Turenko, V.P., Bezpal'ko, V.V., Zabrodina, I.V., Bondarenko, S.V., Poedinceva, A.A., Golovan, L.V., Klymenko, I.V., Melenti, V.O. (2019). Root rots of spring barley, their harmfulness and the basic effective protection measures. Ukrainian Journal of Ecology, 9(2), 232-238.

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