

# THE EFFECT OF FUNGICIDES

## *on the physiological and biochemical state of lupine plants after seed treatment*

**Goal.** To assess the effect of fungicides on the content of chlorophyll and the activity of antioxidant enzymes (peroxidase, catalase) in lupine plants after seed treatment. **Methods.** Laboratory and vegetation studies were carried out in the laboratory of analytical chemistry of pesticides of pesticides of the Institute of Plant Protection. The seeds of yellow lupine (*Lupinus luteus* L., variety Obriy) were treated with combined fungicides from different chemical classes: triazoles (cyproconazole, difenoconazole, tebuconazole, prothioconazole), phenylpyrroles (fludioxonil), carboxamides (carboxin), dithiocarbamates (thiram). Determination of the content of fungicides in plants was carried out using chromatographic methods of analysis. Chlorophyll content, peroxidase and catalase activity were determined by physicochemical methods according to generally accepted methods. **Results.** Fungicides activated the antioxidant systems of plants, depending on their physicochemical properties (in particular, the octanol-water partition coefficient *K<sub>ow</sub>*) and their content in plants (C, mg/kg). An increase in peroxidase activity (up to 89% compared to the control) was established within 30 days, which indicates the activation of antioxidant processes aimed at maintaining oxidative homeostasis in plants. The change in catalase activity under the influence of fungicides was inversely correlated with peroxidase activity, which is explained by the formation of adaptive mechanisms of ROS homeostasis. The high activity of peroxidase, compared to catalase, testifies to the important role of this enzyme in the redox reactions of plant resistance under the influence of fungicides. The total chlorophyll content under the action of fungicides, increased by 6–20%, compared to the control. **Conclusions.** Seed treatment with fungicides affects the course

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of redox reactions in plants, causing changes in the activity of key enzymes. The high activity of peroxidase against the background of fluctuations in catalase activity indicates the direct effect of fungicides on the state of antioxidant systems and the important role of peroxidase in maintaining ROS homeostasis. The stimulatory effect of fungicides on the accumulation of chlorophyll at the initial stages of growth of lupine plants was established, the content of which exceeded the control indicator by 6–20% by development phase. Changes in the activity of antioxidant enzymes (catalase and peroxidase) and the content of chlorophyll can serve as criteria for determining the levels of adaptation of lupine plants to the stress effect of fungicides.

**fungicides; seed treatment; peroxidase; catalase; chlorophyll**

Modern technologies for growing leguminous crops require disease protection systems that are able to timely and reliably control their development and ensure the realization of the genetic potential of the variety/hybrid at all stages of growth and development of cultivated plants. Seed treatment with fungicides is a mandatory method, as it provides an

opportunity to protect plants in the early stages of organogenesis. Fungicides are physiologically active substances, therefore, in addition to their direct action — protection of agricultural crops from pathogens, they also act on the plant itself, affecting the metabolism, physiological and biochemical status of plants, depending on the properties and dose of application [1].

Pesticides, penetrating into plant cells, can affect the oxidative modification of proteins, nucleic acids, lipid oxidation, etc. The general reaction of plants to the action of adverse environmental factors (drought and salinity, low and high temperatures, exposure to heavy metals, pesticides, damage by phytopathogens) is the formation of reactive oxygen species (ROS), which are considered both as markers of stress and as signal mediators (intermediates) necessary for the development of an adaptive response. Protection of plants from the destructive effect of an excess of ROS occurs with the participation of enzymatic and non-enzymatic systems that provide mechanisms of antioxidant protection of plants and maintenance of functional cell activity. The main components of the enzymatic system are superoxide dismutase, catalase, peroxidase, etc. Their activity is controlled genetically and varies significantly in different types of plants and even in individual varieties of the same species [2–4].

In the literature, there are conflicting data on the effect of fungicides on the activity of antioxidant enzymes in plant cells: on the one hand, there is information that indicates an increase in catalase, peroxidase, and superoxide dismutase activity when using fungicides from the triazole and strobilurin classes [5, 6], on the other hand, there is

the results of studies on the lack of activation of enzymes of the antioxidant system due to their use [7, 8]. The dynamics of changes in oxidase activity is a non-specific phenomenon, but reflects all processes associated with the accumulation of ROS and is an indicator of the physiological and biochemical state of plants, resistance to the influence of biotic and abiotic factors.

One of the important criteria for evaluating the reactions of a plant organism to stressors of various nature, including pesticides, the state of the pigment complex can also serve as an excess of ROS can lead to a number of destructive processes: photooxidation of chlorophyll, peroxidation of lipids and sulfhydryl groups of proteins of chloroplast membranes, disruption of the structure of chloroplast DNA, etc. [9–12]. In addition, plant pigments are also one of the effective mechanisms of counteracting phytotoxic effects at the cellular level, therefore, the dynamics of changes in their content is one of the indicators of the physiological state of plants, a characteristic of photosynthetic activity and the potential ability of agricultural crops to form a harvest [13, 14]. In the literature, there is evidence of both positive [15] and negative [16] effects of fungicides on the photosynthetic apparatus of plants. The positive effect of fungicides on the pigment complex of plants is considered by scientists from the standpoint of their stimulating effect on the processes of pigment synthesis and the formation of a light-absorbing complex, as well as the protective effect of these compounds against the premature destruction of chlorophylls [17].

Today, the question of the mechanism of the effect of fungicides on antioxidant metabolism, the content of photosynthetic pigments, and their role in determining the level of such an effect on the productivity of agricultural crops is actively studied and discussed [18–21], however, certain aspects of physiological and biochemical changes remain unclear and require further research detailed studies.

Therefore, the aim of the research was to evaluate the effect of fungi-

cides on the content of chlorophyll and the activity of oxidoreductase enzymes (peroxidase, catalase) in lupine plants during seed treatment.

**Research methodology.** Laboratory and vegetative studies were carried out in the laboratory of analytical chemistry of pesticides of the Institute of Plant Protection of the National Academy of Sciences. The seeds of yellow lupine (*Lupinus luteus* L, variety Obriy) were treated with combined fungicides of different chemical classes (triazoles, phenylpyrroles, carboxamides, dithiocarbamates) according to the following options:

1. Control (without treatment);
2. Carboxin, 500 g a.i./t + thiram, 500 g a.i./t;
3. Cyproconazole, 13 g a.i./t + fludioxonil, 38 g a.i./t;
4. Cyproconazole, 9 g a.i./t + difenoconazole, 45 g a.i./t;
5. Prothioconazole, 50 g a.i./t + tebuconazole, 30 g a.i./t.

Research was conducted during April-May in compliance with the requirements of the vegetation method. The plants were grown in plastic vessels (soil grey, gilded with a humus content of 2.2%, pH 6.1) under natural light and temperature. The experiment was repeated four times. The selection of plant samples was carried out at intervals of 5 days (after the emergence of seedlings).

Determination of the content of fungicides in plants was carried out using the Algorithm of chemical-analytical monitoring of pesticides

[22]. Chlorophyll content and peroxidase activity (EC. 1.11.1.7) were determined colorimetrically, and catalase (EC. 1.11.1.6) was determined titrimetrically according to generally accepted methods [23, 24]. Statistical processing of the obtained data was carried out by methods of dispersion analysis using Microsoft Office Excel.

**Research results.** The nature of the effect of active substances on the intensity of physiological and biochemical processes in general, and the activity of enzymatic systems of antioxidant protection (catalase, peroxidase) in particular, is determined by their physicochemical properties (by the value of the hydrophobicity coefficient  $\log K_{ow}$ ) and their content in plants (C, mg/kg). The content of fungicides in plants decreases during the growing season and depends on the rate of their application, which determines the initial amount (initial toxic potential) of the pesticide (Fig. 1).

Based on the results of research, different sensitivity of peroxidase to the studied fungicides was recorded. So, on the 10th day after sowing (seedling emergence phase) in variants using combinations of triazole-based active substances: difenoconazole + cyproconazole (content in plants 0.58 mg/kg + 0.28 mg/kg) and prothioconazole + tebuconazole (0.92 mg/kg + 0.35 mg/kg) peroxidase activity was the highest – 13% and 17% compared to the control, respectively (Figs. 1, 2). Whereas, when using a combination of cypro-

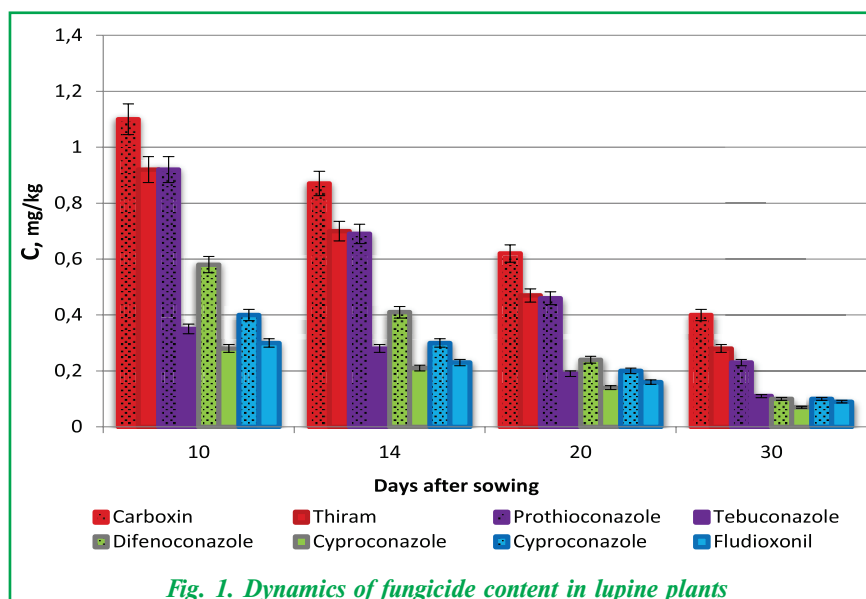


Fig. 1. Dynamics of fungicide content in lupine plants

conazole and fludioxonil (phenylpyrrole class), the enzyme activity was 15% lower than the control. Such a multidirectional regulatory effect can be determined both by the chemical class of compounds and by the features of their translocation and transformation processes in plants. The obtained results confirm the established regularities [25].

There is an assumption that the amount of absorption of active substances during seed germination is directly proportional to the lipophilicity of compounds (by the value of  $\log K_{ow}$ ) [26]. Accordingly, the triazoles cyproconazole, prothioconazole, difenoconazole and tebuconazole, as lipophilic ( $\log K_{ow}$  3.09–4.4), water-soluble compounds (15–300 mg/l), are well absorbed by seeds and translocated acropetally (systemic action). While fludioxonil, as a lipophilic compound ( $\log K_{ow}$  4.12), is well absorbed by seeds, however, due to its low solubility in water (1.8 mg/l), it moves very slowly through the vascular system of the plant, so it exhibits a slight stress effect during the same period time. When using the combination of carboxin (carboxamide class) + thiram (dithiocarbamate class), despite the significant rate of application, their content on the 10th day after sowing is 1.1 mg/kg and 0.92 mg/kg, respectively, while the peroxidase activity at variant exceeded the control by only 5%: carboxin ( $\log K_{ow}$  2.3) – locally penetrates the seed, is immobile in the plant; thiram ( $\log K_{ow}$  1.73) – almost does not penetrate

into the seeds, is practically not soluble in water, which can explain the recorded insignificant effect on the activity of the enzyme.

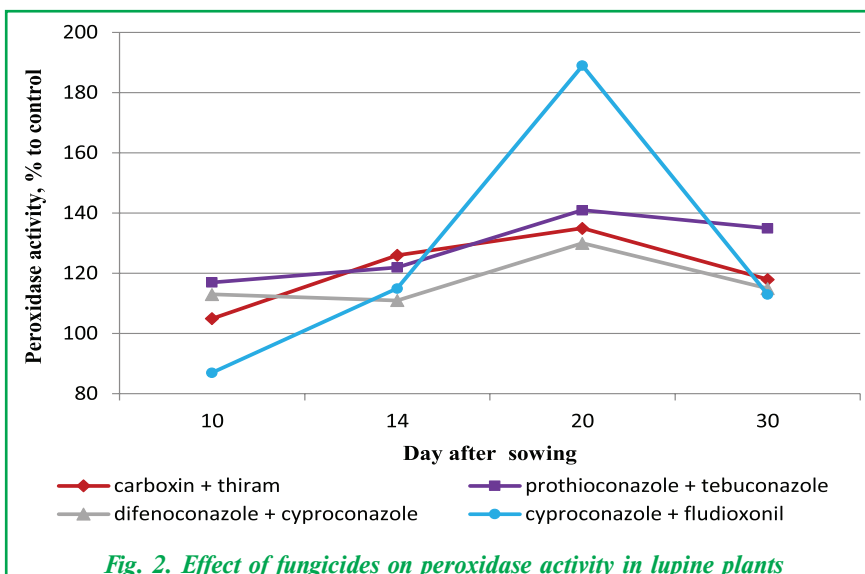
Until the phase of 3–4 leaves (20th day after sowing), the activity of the enzyme in plants on all variants gradually increased, on average, by 1.2–1.4 times, which may be caused by an increase in de novo enzyme synthesis, changes in the ratio between peroxidase isoforms and/ or accumulation of enzyme substrates that induce its synthesis. A rapid and significant increase in enzyme activity in the cyproconazole + fludioxonil variant (98% to the control) compared to the cyproconazole + difenoconazole variant (30% to the control) may indicate the cumulative prolonged stress effect of fludioxonil itself. By the 30th day (phase of 7–8 leaves), against the background of a decrease in the initial content of fungicides by 3–6 times, the activity of peroxidase in all variants decreased, compared to the previous phase of research, but exceeded the corresponding indicator of control by 11–35%, therefore, the treatment seeds with the studied fungicides induces a sufficiently high level of peroxidase activity for 30 days, which indicates the activation of antioxidant processes aimed at maintaining oxidative homeostasis in plant cells.

The change in the activity of catalase, which, as a rule, is inversely correlated with the activity of peroxidase, under the influence of the studied fungicides, differed

significantly by variant. The maximum activity of the enzyme on the 10th day after sowing was recorded in the variant using the combination of difenoconazole + cyproconazole (46% compared to the control), while in the remaining variants the catalase activity was 13–31% below the control level (Fig. 3).

Subsequently, when using the combination of cyproconazole + difenoconazole for two decades, a tendency to a steady decrease in enzyme activity was observed, which probably indicates a shift in the pro-oxidant-antioxidant balance in the direction of increasing the generation of ROS in the form of peroxides. In the cyproconazole + fludioxonil variant, the maximum activity of catalase (36% compared to the control), as well as peroxidase, was recorded on the 20th day, which may indicate the synergism of the action of these enzymes in the process of detoxification of excess ROS. By the 30th day, the activity of the enzyme decreased to the control level, which is probably explained by the fact that during this period the stabilization of detoxification processes took place, as a result of which the amount of formed ROS decreased. Low activity of catalase (13–50% lower than control) during 20 days when using the combination of tebuconazole + prothioconazole may be caused by the competitive action of peroxidase, the activity of which increased during this period. In the carboxin + thiram variant, up to the 14th day, catalase activity increased, showing a certain synergy with peroxidase, and further changes can be explained by the «antagonism» of peroxidase and the formation of adaptation mechanisms to maintain ROS homeostasis.

The results of our research show that the studied fungicides caused different degrees of activation of the antioxidant system, which determined different levels of peroxidase and catalase activity in plants. A rather high activity of peroxidase, compared to catalase within 30 days after sowing, indicates a more significant role of this enzyme in redox reactions of plant resistance under the influence of fungicides, which is confirmed by literature data [18].



**Fig. 2. Effect of fungicides on peroxidase activity in lupine plants**

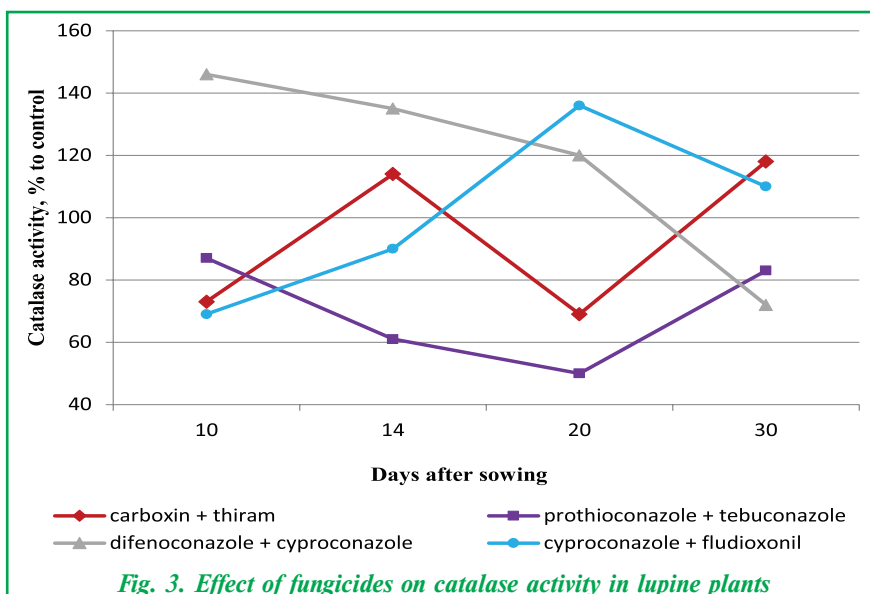


Fig. 3. Effect of fungicides on catalase activity in lupine plants

The content of chlorophyll is an important indicator that reflects the capacity of the development of the photosynthetic apparatus. The total content of plastid pigments significantly depended on the vegetation period of the crop: from  $1.07 \pm 0.03 - 1.22 \pm 0.04$  mg/g per 10 days (seedling phase) to  $4.69 \pm 0.12 - 5.77 \pm 0.11$  mg/g — on the 30th day (phase 7–8 leaves). When treating lupine seeds with combinations based on triazoles: prothioconazole + tebuconazole, cyproconazole + difenoconazole, and cyproconazole + fludioxonil, the chlorophyll content in leaves on the 10th day exceeded the control by 6, 9, and 14%, respectively (Fig. 4). By the 30th day, the content of green pigments gradually increased and exceeded the corresponding indicator of the control by 16, 19 and 20%, respectively. When using the combination of carboxin + thiram, the content of chlorophyll by developmental phases exceeded the control by 12–9%, and starting from the 14th day, a tendency to decrease its content was observed.

Research by Radzikowska D. et. al. [27] showed an increase in the intensity of photosynthesis and the efficiency of photochemical reactions during the treatment of spring barley seeds with fludioxonil, triticonazole, a combination of tebuconazole and prothioconazole. Data from Kur'yat V.G. testify that during the treatment of vegetable nightshade crops with tebuconazole,

the mesostructure of the leaves is rearranged and the content of chlorophylls increases [28]. In the work of Yüzbaşıoğlu E., it was established that the treatment of tomatoes with thiram contributed to the increase in the activity of peroxidase, catalase, and chlorophyll content [29].

Therefore, data from literary sources confirm the results obtained by us of the stimulating effect of fungicides on the activity of antioxidant enzymes (peroxidase, catalase) and the content of chlorophyll, and the degree of this manifestation differed according to the variants, depending on the nature of the effect of the active substances.

### CONCLUSIONS

Seed treatment with fungicides affects the course of redox reactions

in plants, causing changes in the activity of key enzymes. The high activity of peroxidase against the background of fluctuations in catalase activity indicates the direct effect of fungicides on the state of antioxidant systems and the important role of peroxidase in maintaining ROS homeostasis. The stimulatory effect of fungicides on the accumulation of chlorophyll at the initial stages of growth of lupine plants was established, the content of which exceeded the control indicator by 6–20% by development phase. Changes in the activity of antioxidant enzymes (catalase and peroxidase) and the content of chlorophyll can serve as criteria for determining the levels of adaptation of lupine plants to the stress effect of fungicides.

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**Conflict of interest:** the authors declare no conflict of interest.

### REFERENCES

1. Kots S.Ya., Pavlyshche A.V. (2021). Vykozystannia funhitsydiv v intehrovanykh systemakh zakhystu roslyn ta yikh vplyv na fiziolohebiokhimichni protsesy za inokuliatcii yii nasinnia bulbochkovomy bakteriiamy. [The use of fungicides in integrated plant protection systems and their influence on physiological and biochemical processes during seed inoculation with nodule bacteria.] *Fiziologhiia roslyn i henetyka*, [Plant physiology and genetics], 53(1), 3-28. <https://doi.org/10.15407/frg2021.01.003> (in Ukrainian).
2. Kolupaev Yu.E., Karpets Yu.V. (2019). Ak-

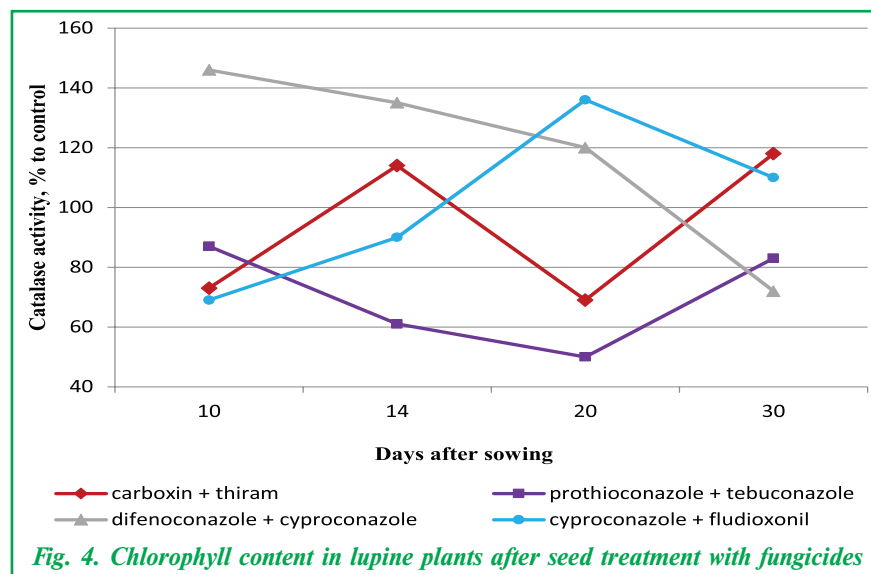


Fig. 4. Chlorophyll content in lupine plants after seed treatment with fungicides

tyvnye formy kysloroda, antyoksydanty i ustoi- chyvost rastenyi k deistviyu stressorov. [Reactive oxygen species, antioxidants and plant resistance to stressors]. Kyiv: Lohos, 277 p. (in Russian).

3. Demidchik V. (2015). Mechanism of oxidative stress in plants: from classical chemistry to cell biology. *Environmental and Experimental Botany*, 109, 212–228. <https://doi.org/10.1016/j.envexpbot.2014.06.021>

4. Kolupaev Yu.E., Karpets Yu.V. (2014). Aktivnye formy kysloroda i stressovyy signaling u rastenyi. [Reactive oxygen species and stress signaling in plants]. *Ukrainian biochemical journal*, 86(4), 18–35. [http://nbuv.gov.ua/UJRN/BioChem\\_2014\\_86\\_4\\_4](http://nbuv.gov.ua/UJRN/BioChem_2014_86_4_4). (in Russian).

5. Yue-Xuan Wu, Andreas von Tiedemann. (2001). Physiological Effects of Azoxystrobin and Epoxiconazole on Senescence and the Oxidative Status of Wheat. *Pesticide Biochemistry and Physiology*, 71(1), 1–10. DOI:10.1006/pest.2001.2561.

6. Esteves Amaro A.C., Pereira Ramos A.R., Macedo A.C. et. al. (2018). Effects of the fungicides azoxystrobin, pyraclostrobin and boscalid on the physiology of Japanese cucumber. *Scientia Horticulturae*, 228, 66–75. <https://doi.org/10.1016/j.scienta.2017.10.016>

7. Zavorotna T.A., Rudenko S.S., Panchuk I.I. (2018). Vplyv funghitsydiv na aktyvnist peroksydaz u Arabidopsis thaliana. [Effect of fungicides on the activity of peroxidases in Arabidopsis thaliana]. *Biologichni systemy, [Biological Systems]*, 10(2), 119–124. (in Ukrainian).

8. Debona D., Rodrigues F.A. (2016). A Strobilurin fungicide relieves Bipolaris oryzae-induced oxidative stress in rice. *Journal of Phytopathology*, 164(9), 571–581. DOI:10.1111/jph.12481

9. Dehshiri O., Paknyat H. (2014). Evaluation of Oilseed Rape Genotypes (Brassica napus L.) Based on Chlorophyll and Carotenoids Contents and Antioxidant Enzymes under Drought Stress Conditions. *Journal of Crop Production and Processing*, 3(10), P. 69–77.

10. Souahi H. (2021). Impact of lead on the amount of chlorophyll and carotenoids in the leaves of Triticum durum and T. aestivum, Hordeum vulgare and Avena sativa. *Biosystems Diversity*, 29(3), 207–210. doi:10.15421/012125

11. Esteban R., Barrutia O., Artetxe U. et al. (2015). Internal and external factors affecting photosynthetic pigment composition in plants: a meta-analytical approach. *New Phytologist*, 206, 268–280. doi: 10.1111/nph.13186

12. Ashraf M., Harris P.J.C. (2013). Photosynthesis under stressful environments: An overview. *Photosynthetica*, 51(2), 163–190. DOI: 10.1007/s11099-013-0021-6.

13. Serrano I., Audran C., Rivas S. (2016). Chloroplasts at work during plant innate immunity. *Journal of Experimental Botany*, 67(13), 3845–3854. doi:10.1093/jxb/erw088

14. Miller G., Suzuki N., Ciftci-Yilmaz S., Mittler R. (2010). Reactive oxygen species homeostasis and signalling during drought and salinity stresses. *Plant, Cell & Environment*, 33(4), 453–467. doi: 10.1111/j.1365-3040.2009.02041.x

15. Rajasekar M., Rabert G.A., Manivanan P. (2016). The effect of triazole induced photosynthetic pigments and biochemical constituents of Zea mays L. (Maize) under drought stress. *Applied Nanoscience*, 6, 727–735. <https://doi.org/10.1007/s13204-015-0482-y>

16. Petit A.-N., Fontaine F., Vatsa P. et al. (2012). Fungicide impacts on photosynthesis in crop plants. *Photosynth Res*, 111, 315–326. DOI:10.1007/s11120-012-9719-8

17. Mykhalska L.M., Sanin O.Iu., Tretiakov V.O. (2020). Vplyv elementiv zhyvlennia ta funghitsydiv na vmist khlorofilu v lystkakh vysokoproduktyvnykh sortiv pshenytsi ozymoi. [Effect of nutrients and fungicides on chloro-

phyll content in leaves of high-yielding winter wheat varieties]. *Fiziolohiia roslyn i henetyka, [Plant physiology and genetics]*, 52(6), 538–549. doi: <https://doi.org/10.15407/frg2020.06.538> (in Ukrainian).

18. Shahid M., Ahmed B., Zaidi A., Khan M.S. (2018). Toxicity of fungicides to Pisum sativum: a study of oxidative damage, growth suppression, cellular death and morpho-anatomical changes. *RSC Adv.*, 8(67), 483–498. doi: 10.1039/c8ra03923b

19. Dias M.C. (2012). Phytotoxicity: An Overview of the Physiological Responses of Plants Exposed to Fungicides. *Journal of Botany*, 2012. <https://doi.org/10.1155/2012/135479>

20. Gurpreet Singh, Harkamal Kaur Sahota. (2018). Impact of benzimidazole and dithiocarbamate fungicides on the photosynthetic machinery, sugar content and various antioxidative enzymes in chickpea. *Plant Physiology and Biochemistry*, 132, 166–173. DOI: 10.1016/j.plaphy.2018.09.001

21. Liu. R., Li J., Zhang L. et al. (2021). Fungicide Difenoconazole Induced Biochemical and Developmental Toxicity in Wheat (Triticum aestivum L.). *Plants*, 10, 2304. <https://doi.org/10.3390/plants10112304>

22. Borzykh O.I., Panchenko T.P., Chervyakova L.M., Havryliuk L.L. (2020). Alhorytm khimiko-analitychnoho monitorynhu pestytsydiv (Metodychni rekomendatsii). [Algorithm of chemical and analytical monitoring of pesticides (Methodological recommendations)]. <https://doi.org/10.36495/UDC631.95alhorytm/IZR2020> (in Ukrainian).

23. Pochynok H.N. (1976). Metody biokhimicheskogo analiza rastenyi. [Methods of biochemical analysis of plants]. Kyiv: Naukova dumka. 336 p. (in Russian).

24. Gorodnyi M.M. (Ed.) (2005). Agrokhimichnyy analiz: pidruchnyk. [Agrochemical analys.]. Kyiv: Aristej. 468 p. (in Ukrainian).

25. Borzykh O., Tsurkan O., Chervyakova L., Panchenko T. (2020). Effect of fungicides on the enzymatic activity of the antioxidant system and the chlorophyll content in lupine plants during seed dressing. [Vplyv funghitsydiv na fermentatyvnu aktyvnist antyoksydantnoi systemy ta vmist khlorofilu v roslynakh liupynu za protruennia nasinnia]. *Karantyn i zakhyst roslyn, [Quarantine and Plant Protection]*, (7-9), 3–6. <https://doi.org/10.36495/2312-0614.2020.7-9.3-6> (in Ukrainian).

26. Felipe Fadel Sartori, Rodrigo Floriano Pimpinato, Valdemar L Tornisielo et al. (2020). Soybean seed treatment: how do fungicides translocate in plants? *Pest Management Science*, 76(7), 2355–2359. <https://doi.org/10.1002/ps.5771>

27. Radzikowska D., Grzanka M., Kowalczewski P.L. et al. (2020). Influence of SDHI seed treatment on the physiological conditions of spring barley seedlings under drought stress. *Agronomy*, 10(5), 731. <https://doi.org/10.3390/agronomy10050731>

28. Kuryata V.H., Rogach V. V., Buina O.I. et al. (2017). Impact of gibberelic acid and tebuconazole on formation of the leaf system and functioning of donor – acceptor plant system of solanaceae vegetable crops. *Regulatory Mechanisms in Biosystems*, 8(2), 162–168. <https://doi.org/10.15421/021726>

29. Yüzbaşıoğlu E. (2020). Effect of fungicide pretreatment on lipid peroxidation, antioxidant enzyme systems and proline accumulation in tomato (Lycopersicon esculentum Mill.) leaves under high temperature stress. *Turkish Journal of Botany*, 44(6), Article 2, 604–617. <https://doi.org/10.3906/bot-2004-79>

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### Вплив фунгіцидів на фізіолого-біохімічний стан рослин люпину за протруєння насіння

**Мета.** Оцінити вплив фунгіцидів на вміст хлорофілу та активність антиоксидантних ферментів (пероксидаза, каталаза) у рослинах люпину за протруєння насіння. **Методи.** Лабораторні й вегетаційні дослідження проводили в лабораторії аналітичної хімії пестицидів Інституту захисту рослин НААН. Насіння люпину жовтого (*Lupinus luteus* L., сорт Обрій) протруювали комбінованими фунгіцидами з різних хімічних класів: триазолі (ципроконазол, дифеноконазол, тебуконазол, протіоконазол), фенілпіролі (флудиоксоніл), карбоксаміди (карбоксин), дитіокарбама ти (тирам). Вміст фунгіцидів у рослинах визначали, використовуючи хроматографічні методи аналізу. Вміст хлорофілу, активність пероксидази та каталази визначали фізико-хімічними методами за загальноприйнятими методиками. **Результати.** Фунгіциди активували антиоксидантні системи рослин, залежно від їх фізико-хімічних властивостей (зокрема коефіцієнта розподілу октанол-вода  $K_{ow}$ ) та вмісту в рослині (С, мг/кг). Встановлено зростання пероксидазної активності (до 89% щодо контролю) впродовж 30-ти діб, що свідчить про активацію антиоксидантних процесів, спрямованих на підтримання окиснювального гомеостазу в рослинах. Зміна активності каталази під впливом фунгіцидів обернено пропорційно корелювала з активністю пероксидази, що пояснюється формуванням адаптаційних механізмів гомеостазу АФК. Висока, порівняно з каталазою, активність пероксидази свідчить про вагомий вплив цього ферменту в окисно-відновних реакціях стійкості рослин за впливу фунгіцидів. Загальний вміст хлорофілу за дії фунгіцидів зростав на 6–20%, порівняно із контролем. **Висновки.** Протруєння насіння фунгіцидами впливає на перебіг окисно-відновних реакцій у рослинах, викликаючи зміни активності ключових ферментів. Висока активність пероксидази на тлі коливань каталазної активності свідчить про пряму дію фунгіцидів на стан антиоксидантних систем та важливу роль пероксидази в підтриманні гомеостазу АФК. Встановлено стимулюючий вплив фунгіцидів на накопичення хлорофілу на початкових етапах росту рослин люпину, вміст якого за фазами розвитку перевищував показник контролю на 6–20%. Зміни активності антиоксидантних ферментів (каталази та пероксидази) та вмісту хлорофілу можуть слугувати критеріями для визначення рівнів адаптованості рослин люпину до впливу стресової дії фунгіцидів.

**фунгіциди; протруєння; пероксидаза; каталаза; хлорофіл**

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