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Effectiveness of pre-sowing fungicide treatment of soybean (*Glycine max* [L.] Merr.) seeds

Eficacia del tratamiento de semillas de soja (*Glycine max* [L.] Merr.) con fungicidas previo a la siembra

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Abstract

A study conducted at Lviv National Environmental University in 2023 examined the effects of nine fungicidal seed treatments on soybean (Ambella® variety) germination, root rot development, and yield. Seed germination energy and capacity were measured using the between-paper method at 5 and 8 days, respectively. Seed-borne infections and root rot pathogens were identified using the blotter method. Root rot incidence was assessed at soybean growth stages BBCH 12, BBCH 13, and BBCH 61. The data were analyzed using Statistica software. The best results were obtained with treatments containing fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at rates of 0.4 ml kg^{-1} and 0.8 ml kg^{-1}, and fludioxonil (25 g L^{-1}) + metalaxyl-M (10 g L^{-1}) at a rate of 1.0 ml kg^{-1}, which led to high seed germination energy (90.5 % - 95.5 %), and capacity (95.5 % - 99.5 %), and yields of 3.53 - 3.59 tons per hectare. Soybean yield for seed treatment with thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1}) at rates of 1.0 ml kg^{-1} and 1.5 ml kg^{-1} reached 3.52 tons and 3.75 tons per hectare, respectively. Overall, fungicide treatments improved both root health and yield of soybean compared to untreated seeds.

Keywords: Disease severity and incidence, root rot, seed germination, seed capacity, yield.

Resumen

Un estudio realizado en 2023 en la Universidad Nacional Ambiental de Lviv examinó los efectos de nueve tratamientos fungicidas en la germinación, el desarrollo de la pudrición de las raíces y el rendimiento de la soja (variedad Ambella®). El estudio comparó semillas tratadas con un grupo de control. Se identificaron infecciones transmitidas por semillas y patógenos de la pudrición de la raíz utilizando el método del papel secante, y la energía y capacidad de germinación de las semillas se midieron a los 5 y 8 días, respectivamente. La incidencia de la pudrición de la raíz se evaluó durante las etapas BBCH 12, BBCH 13 y BBCH 61 de crecimiento de la soja. Los datos fueron analizados utilizando el software Statistica. Los mejores resultados se observaron con tratamientos que contenían fluxapyroxad (250 g L^{-1}) + piraclostrobina (250 g L^{-1}) a tasas de 0.4 ml kg^{-1} y 0.8 ml kg^{-1}, y fludioxonil (25 g L^{-1}) + metalaxil-M (10 g L^{-1}) a una tasa de 1.0 ml kg^{-1}, lo que llevó a una alta tasa de energía (90.5 % - 95.5 %) y capacidad (95.5 % - 99.5 %) de germinación, y rendimientos de 3.53 - 3.59 toneladas por hectárea. El rendimiento de la soja de semillas tratadas con metiltiofanato (250 g L^{-1}) + piraclostrobina (25 g L^{-1}) + fipronil (225 g L^{-1}) a tasas de 1.0 ml kg^{-1}y 1.5 ml kg^{-1} alcanzó 3.52 y 3.75 toneladas por hectárea, respectivamente. En general, los tratamientos fungicidas mejoraron tanto la salud de las raíces como el rendimiento de la soja en comparación con las semillas no tratadas.

Palabras clave: capacidad de germinación, germinación, podredumbre radicular, rendimiento, severidad e incidencia de la enfermedad.

Introduction

Soybean (*Glycine max* [L.] Merr.) is a critical crop for global food security due to its rich protein content, serving as a sustainable alternative to animal protein. The production of plant-based proteins has a significantly lower carbon footprint compared to animal-based ones, reducing emissions by 3 to 80 times, depending on the type of protein and the life cycle assessment methodology used (Thrane *et al.*, 2017). Additionally, soybean, as a leguminous crop, fixes atmospheric nitrogen, making it an excellent preceding crop in rotation systems (Gomes *et al.*, 2017; Nyandoro *et al.*, 2019).

Large-scale cultivation of soybean in Ukraine began after 2010. According to Ukraine's State Statistics Service (UKRSTAT) (2023), soybean planting areas expanded from 0.06 million hectares in 2000 to 1.04 million hectares in 2010, a 17-fold increase. By 2023, this had increased to 1.73 million hectares, a value similar to 2018. This expansion made Ukraine one of the top 10 global soybean exporters (Feed and Grain Staff, 2024). However, the expansion of planting areas and the shortening of crop rotation cycles have contributed to deteriorating phytosanitary conditions in the fields. While soybean cultivation in Ukraine initially required no chemical protection against diseases, today, numerous pathogens have been identified, leading to significant losses in both yield and quality (Pikovskyi and Solomiichuk, 2022).

The main sources of infection that contribute to reduced soybean yields include diseased seeds, infected plant debris, and contaminated soil (Gupta and Kumar, 2020). Therefore, healthy seeds are essential to maintaining high yields, as various biotic and abiotic factors can affect seed quality (Tsedaley, 2015; Gebeyaw, 2020). Chemical plant protection is typically applied in two ways: pre-sowing seed treatment and fungicide spraying during the vegetative stage. Pre-sowing fungicide treatment is widely used worldwide due to its lower environmental impact compared to field spraying, as it reduces the number of fungicide applications. Seed treatment, unlike spraying plants with fungicides, allows for the protection of seeds and seedlings from soil-borne and seed-borne infections (Lamichhane *et al.*, 2020).

Fungicidal treatment of soybean seeds protects them against both seed-borne and soil-borne fungal pathogens during the early stages of plant development (Navi *et al.*, 2019; Ayesha *et al.*, 2021). Fungicides used in seed treatment, such as pyraclostrobin, metalaxyl, and carbendazim, are primarily absorbed by the cotyledons, with about 15 % being absorbed by the roots, stems, and leaves (Sartori *et al.*, 2020). In soils with low organic matter, fungicide absorption by seedlings increases. These treatments can protect germinating seeds and seedlings for up to 4-5 weeks after sowing (Kazda *et al.*, 2005, as cited in Lamichhane *et al.*, 2020). Pre-sowing seed treatment is particularly beneficial in no-till systems, short crop rotation cycles, and when planting in cold, wet soils (Lamichhane *et al.*, 2020). Gowda *et al.* (2020) demonstrated in their research the effectiveness of soybean seed treatment with fungicides for long-term storage (over 9 months) under high temperatures.

Despite the benefits, some pesticides may have negative effects on plant growth. For example, Kyrychenko *et al.* (2022) found that treatments with fipronil, thiophanate-methyl, and pyraclostrobin inhibited early plant growth, although they did not affect seed germination. Soybeans are susceptible to various fungal diseases, including sudden death syndrome (*Fusarium* spp.), root rot (caused by a complex of fungi) (Kandel *et al.*, 2023), seedling damping-off (*Pythium* spp.) (Navi *et al.*, 2019), downy mildew (*Peronospora manshurica* [Naum.] Syd.), as well as white mold (*Sclerotinia sclerotiorum* de Bary), gray mold (*Botryotinia fuckeliana* Whetzel.), and other molds like *Aspergillus* spp., *Mucor* spp., *Penicillium* spp., and *Rhizopus* spp. (Pikovskyi and Solomiichuk, 2022). Moreover, Sahu *et al.* (2023) identified several fungal species from soybean seeds, including *Aspergillus* spp., *Alternaria* spp., *Cladosporium* spp., *Curvularia* spp., *Rhizopus* spp., and *Fusarium* spp. These seed-borne pathogens can persist as dormant mycelium, spores, or sclerotia mixed with seeds (Hosseini *et al.*, 2023).

Fungicides used for pre-sowing seed treatment must not negatively impact seed germination (Ayesha *et al.*, 2021). The profitability and effectiveness of these treatments depend on factors like soybean variety, soil conditions, planting date, and population density (Rossman *et al.*, 2018).

The aim of this study was to evaluate the effects of pre-sowing soybean seed treatment with six different active substances at varying doses on seed germination energy and capacity, root rot development, and yield.

Materials and methods

The research was conducted in 2023 at Lviv National Environmental University (LNEU). Field experiments were performed at the University's Educational and Research Centre, while laboratory analyses were conducted at the Chair of Genetics, Plant Breeding, and Plant Protection. The experimental site is located at geographic coordinates 49.898185° N, 24.087261° E.

The soil at the experimental plots was dark-grey podzolic light loam, with low humus content (FAO, 2015). The clay content in the topsoil layer was 28.4 %, classifying the soil as light loam. The humus content was 2.26 %, and the pH (KCl) of the 0 - 20 cm soil horizon was 6.10, indicating slightly acidic conditions. Hydrolytic acidity in the arable horizon was low, at 2.60 cmol kg^{-1}. The sum of exchangeable bases was 22.5 cmol kg^{-1}, corresponding to a high level of base saturation. The nitrogen content (Nh) in the 0 - 20 cm soil layer was 73 mg kg^{-1}, phosphorus was 56 mg kg^{-1}, and potassium was 36 mg kg^{-1}.

The early-maturing soybean variety Ambella® (developed by SAATBAU LINZ eGen, Austria) was used in the experiment. The preceding crop in the experimental plots was winter wheat.

Soybean was sown in plots measuring 10 × 2.3 m, with a row spacing of 20 cm, and four replications per treatment. The sowing rate was 500 000 seeds per hectare. The mineral fertilizer NPK 15-15-15 (N.P.K.) was applied at a rate of 100 kg ha^{-1} at sowing. Ammonium sulfate ([NH4]2SO4) was applied at a rate of 80 kg ha^{-1} at the BBCH 61 growth stage.

Pre-sowing seed treatment (dressing with a slurry formulation) of soybean seeds was conducted using various active substances and compared to an untreated control (UTC) (Table 1).

Seed germination energy and capacity after fungicide treatment were evaluated using the between paper method at two moments: 5 days for germination energy and 8 days for germination capacity. A total of 400 seeds (four replicates of 100 seeds each) were tested for each experimental variant. Germination energy and capacity were expressed as the percentage of normal seedlings observed after 5 and 8 days, respectively (Turnipseed, 2013). Seed and root infections were assessed using the blotter method (Vishunavat *et al*., 2023), with seeds incubated in Petri dishes for 7 days at 20 ± 2 °C under white light in a 12-hour light/dark cycle. Pathogen identification was performed microscopically.

Table 1. Experimental variants of soybean seed treatment

Variant	Active substances	Rate (ml kg^{-1})
UTC	untreated control	–
XP0.3	fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1})	0.3
XP0.4	fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1})	0.4
XP0.8	fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1})	0.8
TPF1.0	thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1})	1.0
TPF1.5	thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1})	1.5
FMS1.0	fludioxonil (25 g L^{-1}) + metalaxyl-M (37.5 g L^{-1}) + sedaxane (50 g L^{-1})	1.0
TMF1.2	thiabendazole (25 g L^{-1}) + metalaxyl-M (20 g L^{-1}) + fludioxonil (150 g L^{-1})	1.2
FM1.0	fludioxonil (25 g L^{-1}) + metalaxyl-M (10 g L^{-1})	1.0
P0.4	prothioconazole (300 g L^{-1})	0.4

In the field trial, sowing was carried out on May 4th. Seedlings began emerging on May 15th, with full emergence observed by May 21st. Weed control was achieved using the herbicides bentazone (870 g kg^{-1}) at 2.0 kg ha^{-1}, thifensulfuron-methyl (500 g kg^{-1}) at 6.0 g ha^{-1} (on May 31st), and quizalofop-P-ethyl (50 g L^{-1}) at 1.5 L ha^{-1} (on June 6th) during the BBCH 12 growth stage. Additional herbicide treatments were applied on July 15th during the BBCH 13 stage.

Root lesions from rot pathogens were assessed by determining disease incidence and severity. Root samples were collected from 25 plants per plot, taken consecutively from two adjacent rows at four different locations within each plot during the BBCH 12, BBCH 13, and BBCH 61 growth stages. Disease incidence was calculated as the percentage of infected plants, while disease severity was assessed using a 0-5 scale, where 0 indicated healthy roots and 5 indicated complete root rot (Brown and Kean, 1997). The disease severity index was expressed using a generally accepted formula and expressed as the percentage of infected root area: disease severity index (%) = (sum [class frequency × rating class score]/ [(total number of plants) × (maximum disease index)] × 100).

Harvesting was conducted separately for each plot using a Sampo plot combine with a cutting width of 1.5 m. The grain yield was expressed in tons per hectare (t ha^{-1}).

Descriptive statistics were used to assess root rot severity and incidence, and the results were visualized using Box and Whisker Plots. Root rot infection across the variants was evaluated using a t-test for independent samples, with a significance level of $p<0.05$, and yield was evaluated using a Duncan's multiple range test ($p<0.05$). Correlation analysis was conducted to identify relationships between disease severity, incidence, and yield. All data were analyzed using Statistica software, version 14.0.1.25.

Results

In the laboratory experiment, the germination energy (5 days) and capacity (8 days) of treated and untreated soybean seeds were evaluated using the between paper method (Table 2).

Fungicide treatments XP0.4, XP0.8, and FM1.0 exhibited the highest germination energy (90.5 %-95.5 %), while the TPF1.0 treatment had the lowest value (17.0 %). Most variants achieved germination capacities between 91.0 % and 99.5 %, with the exception of TPF1.5.

Under laboratory conditions, fungal species from *Fusarium* spp. and *Rhizoctonia* spp., as well as fungus-like organisms from *Pythium* spp., were isolated from the soybean seeds used in the experiment.

In field conditions, root lesions were observed at growth stages BBCH 12 (Figure 1), BBCH 13, and BBCH 61.

Lesions, tissue darkening, and root constrictions caused by rot pathogens were observed. Additionally, visually observations indicated poorer root development in the UTC variant, which exhibited the highest disease incidence (72.5 %) and severity (14.8 %) at BBCH 12 (Figure 2). Significant differences in disease severity were observed between the UTC and the treated variants XP0.4, TPF1.5, and FMS1.0, as well as between the following pairs: XP0.4 and TPF1.0, TPF1.0 and TPF1.5, and TPF1.0 and FMS1.0 (p<0.05).

A Box and Whisker Plot analysis showed a wide variance in disease incidence, particularly in the TPF1.0 variant, while the variance in disease severity was the smallest among all treatments.

At BBCH 13 (Figure 3), disease severity in UTC plants increased to 24.1 %, while disease incidence rose to 95%. Among treated seeds, disease severity ranged from 7.4 % to 17.8 %, and disease incidence ranged from 57.5 % to 87.5 %.

Using the t-test for independent samples, statistically significant differences were detected in disease severity between the UTC variant and the following variants: XP0.3, XP0.4, XP0.8, TPF1.0, TPF1.5, FMS1.0, TMF1.2, and FM1.0. Additionally, significant differences were observed between the following pairs of variants: XP0.4 and TPF1.0, XP0.4 and TMF1.2, XP0.4 and FM1.0, XP0.8 and FM1.0, TPF1.5 and FM1.0, and FMS1.0 and FM1.0. Regarding disease incidence, significant differences were found between the UTC and XP0.8 variants, UTC and TPF1.5, and XP0.8 and TMF1.2.

At BBCH 13 growth stage, the greatest variation in disease severity indices was observed in variant P0.4. Additionally, a significant amplitude in disease incidence indices was detected in variants XP0.3, XP0.4, and P0.4, as shown by Box and Whisker Plot analysis.

At BBCH 61, disease incidence and severity decreased across all variants due to the reduction in the proportion of infected root tissue and the die-off of severely affected plants. Disease incidence ranged from 10.0 % to 87.5 %, with UTC having the highest values. The largest decreases in disease incidence were in XP0.3 and XP0.8. Disease severity ranged from 1.0 % to 24.0 %, with the highest severity recorded in the UTC and the lowest in XP0.3 and XP0.8. The final observation showed a reduction in the amplitude of severity indices across all variants, except for UTC, TPF1.0, and TMF1.2 (Figure 4).

To identify the causal organisms of soybean root rot, samples with lesions were collected from each variant. Incubation of these samples in Petri dishes using the blotter method (Figure 5, Figure 6) allowed the detection of fungi such as *Alternaria* spp., *Fusarium* spp., *Rhizoctonia* spp., and fungus-like organisms *Aphanomyces* spp. and *Pythium* spp.

Soybean yield varied from 3.16 to 3.75 tons per hectare, with the highest yield in TPF1.5 and the lowest in TMF1.2 (Figure 7).

Box and Whisker Plot analysis indicated that the TPF1.5 treatment exhibited the greatest yield amplitude and also achieved the highest overall yield. Statistical analysis revealed significant yield differences between treated and untreated variants

Table 2. Germination energy and germination capacity of soybean seeds under laboratory conditions

Variant	Germination energy (%)	Germination capacity (%)
UTC	46.0^{a}	97.5^{ab}
XP0.3	78.5^{b}	97.5^{ab}
XP0.4	90.5^{c}	99.5^{a}
XP0.8	95.5^{c}	95.5^{abc}
TPF1.0	17.0^{d}	91.0^{cd}
TPF1.5	45.5^{a}	87.5^{d}
FMS1.0	29.0^{e}	93.0b^{cd}
TMF1.2	65.5^{f}	99.5^{a}
FM1.0	91.0^{c}	97.0^{abc}
P0.4	70.0^{bf}	99.0^{ab}

UTC: Untreated control. Based on Duncan's multiple range test (p<0.05). Data analyzed using Statistica software, version 14.0.1.25.

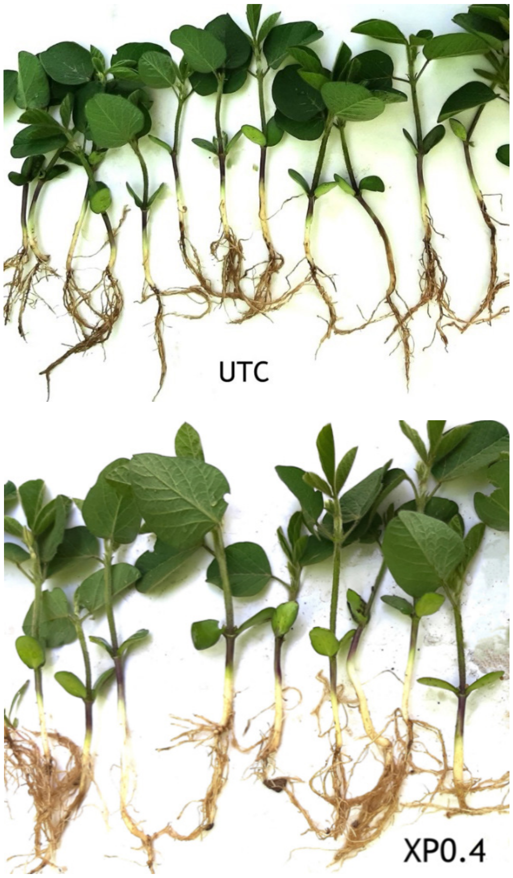

Figure 1. Soybean plants in the experiment (growth stage BBCH 12).

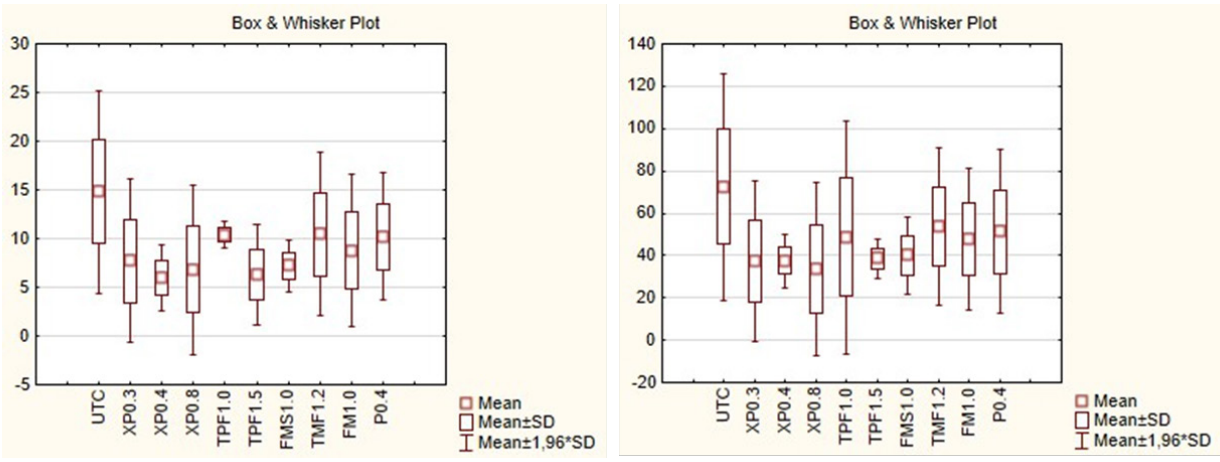

Figure 2. Statistical indices of root rot development on soybean at BBCH 12 growth stage (left: disease severity [%], right: disease incidence [%]), based on data analyzed using Statistica software, version 14.0.1.25.

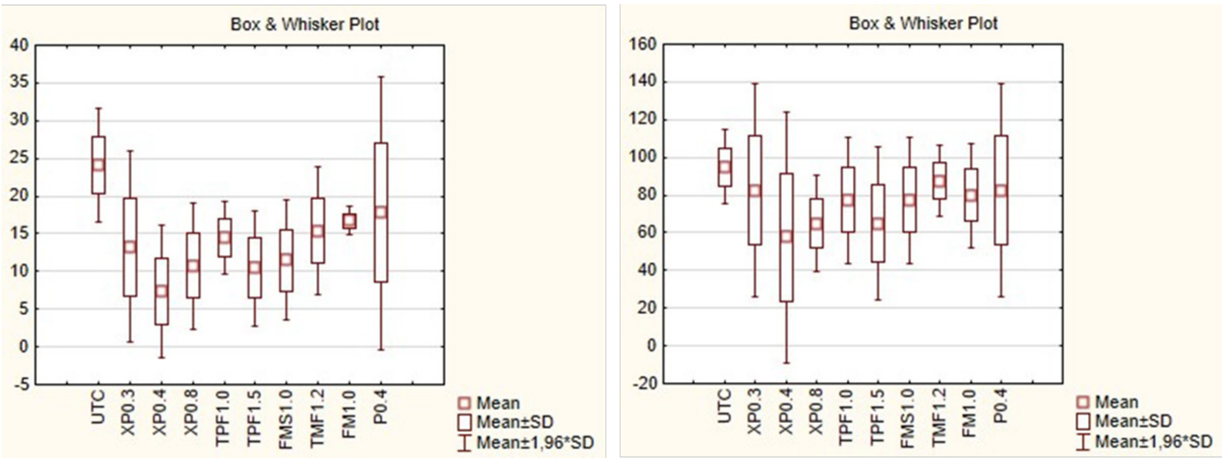

Figure 3. Statistical indices of root rot development on soybean at BBCH 13 growth stage (left: disease severity [%], right: disease incidence [%]), based on data analyzed using Statistica software, version 14.0.1.25.

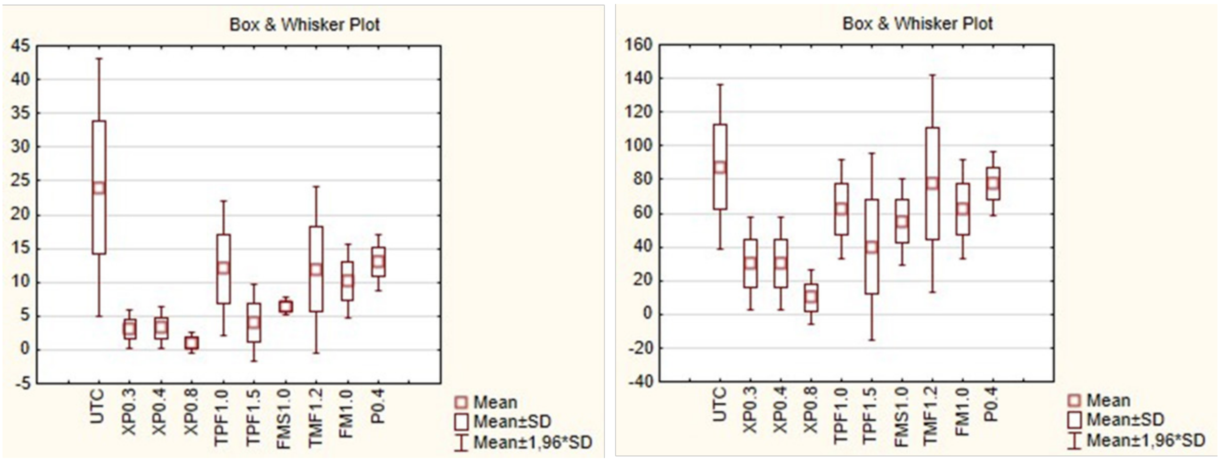

Figure 4. Statistical indices of root rot development on soybean at BBCH 61 growth stage (left: disease severity [%], right: disease incidence [%]), based on data analyzed using Statistica software, version 14.0.1.25.

Figure 5. Parts of soybean roots with rot lesions after 7 days of incubation (1 = UTC; 2 = XP0.3; 3 = XP0.4; 4 = XP0.8; 5 = TPF1.0; 6 = TPF1.5; 7 = FMS1.0; 8 = TMF1.2; 9 = FM1.0; 10 = P0.4).

Figure 6. Morphological structures of fungi from the genus *Fusarium* spp. on infected root samples (left) and under the microscope (400x magnification) (right).

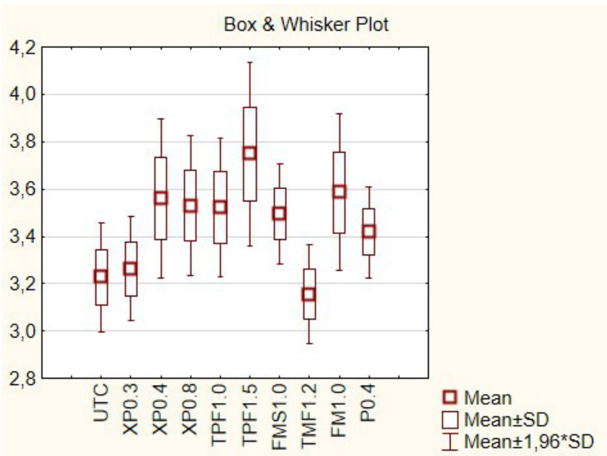

Figure 7. Soybean yield in tons per hectare (data analyzed using Statistica software, version 14.0.1.25).

Table 3. Comparison of soybean yields in the experiment

Variant	Yield (t ha^{-1})	Statistical group
TMF1.2	3.16	a
UTC	3.23	ab
XP0.3	3.26	ab
P0.4	3.42	bc
FMS1.0	3.50	c
TPF1.0	3.52	cd
XP0.8	3.53	cd
XP0.4	3.56	cd
FM1.0	3.59	cd
TPF1.5	3.75	d

Based on Duncan's multiple range test ($p<0.05$). Data analyzed using Statistica software, version 14.0.1.25.

(Table 3). In particular, statistically significant differences were observed between the UTC variant and all other variants, except TMF1.2, XP0.3, and P0.4. Additionally, significant differences were observed among the fungicide-treated variants, particularly between XP0.3 and the following: FMS1.0, TPF1.0, XP0.8, XP0.4, FM1.0, and TPF1.5. Statistically significant differences were also found between TMF1.2 and the variants P0.4, FMS1.0, TPF1.0, XP0.8, XP0.4, FM1.0, and TPF1.5, as well as between TPF1.5 and both P0.4 and FMS1.0.

Additionally, a moderate inverse correlation (r= -0.64) was found between root rot severity and yield at BBCH 12, while a strong inverse correlation (r= -0.77) was observed between disease incidence and yield at BBCH 13. These correlations were statistically significant ($p<0.05$).

Discussion

Fungi *Fusarium* spp., and *Rhizoctonia* spp., and fungus-like organisms *Pythium* spp. were isolated under laboratory conditions from the seeds of the soybean variety Ambella® used in the experiment.

In the laboratory experiment, higher levels of germination energy were observed in soybean seeds subjected to pre-sowing treatment with pesticides containing the active substances fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at application rates of 0.4 ml kg^{-1} and 0.8 ml kg^{-1} (XP0.4 and XP0.8), as well as fludioxonil (25 g L^{-1}) + metalaxyl-M (10 g L^{-1}), at 1.0 ml kg^{-1} (FM1.0). The germination capacity indices of these variants were high, but the highest capacity in the experiment was for the variant treated with fungicides containing the active substances fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at the application rate of 0.4 ml kg^{-1} (XP0.4), as well as thiabendazole (25 g L^{-1}) + metalaxyl-M (20 g L^{-1}) + fludioxonil (150 g L^{-1}), at 1.2 ml kg^{-1}. Seed treatment with the active substances fluxapyroxad and thiabendazole showed the highest seed germination rates. These results are consistent with the results of Radzikowska *et al.* (2022) in pre-sowing treatment of maize seeds with succinate dehydrogenase inhibitors (like fluxapyroxad), and Hameed *et al.* (2019) in pre-sowing treatment of wheat seeds with different benzimidazoles (like thiabendazole).

Inhibitory action on soybean seed germination both after 5 and 8 days was detected in variants with pre-sowing treatment with preparations with the active substances thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1}) at the rates of 1.0 ml kg^{-1} (TPF1.0) and 1.5 ml kg^{-1} (TPF1.5). According to Nan (1995), thiophanate-methyl enhances the germination of sainfoin seeds, whereas Junior *et al.* (2019) reported that it has no effect on soybean seed germination. Seed treatment with pyraclostrobin has been shown to stimulate soybean growth, as noted by Li *et al.* (2020). In contrast, Triques *et al.* (2021) found that fipronil had no significant effect on the germination of treated sugarcane seeds, while Stevens *et al.* (1999) reported that fipronil disrupted the germination of rice seeds. The reduced soybean seed germination rates observed in these treatment variants can be attributed to the presence of fipronil in the formulation.

Field observations revealed that untreated seeds (control) suffered more root rot damage, while plants treated with fungicides had better-developed root systems during the BBCH 12 and BBCH 13 growth stages. This enhanced root development can be attributed to the stimulant properties of fluxapyroxad, thiabendazole, and thiophanate methyl, as well as the reduced incidence of root rots resulting from fungicide treatments.

Laboratory analysis revealed the presence of *Alternaria* spp., *Fusarium* spp., and *Rhizoctonia* spp. fungi, as well as fungus-like organisms *Aphanomyces* spp. and *Pythium* spp. in the infected soybean roots.

The progression of root rot in soybean plants treated with the studied seed treatments gradually intensified, reaching the highest levels at the BBCH 13 growth stage, with disease incidence ranging from 57.5 % to 87.5 %, and disease severity from 7.4 % to 17.8 %. The notable increase in root rot development at the BBCH 13 stage can be attributed to the diminishing efficacy of the seed treatment preparations over time, as the protective effect of such treatments typically lasts for an average time of 14 - 20 days (Kyrychenko *et al.*, 2022).

At the BBCH 61 growth stage, a decrease in root rot development was observed across all experimental variants. The most significant reduction was noted in the variant using the active substances fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) for the seed treatment at a rate of 0.8 ml kg^{-1}. The reduction in root rot infection can be attributed to the die-off of severely infected plants, as well as to the decreased susceptibility of mature plants to the disease.

Root rot had a significant impact on soybean yield in the experiment. A strong correlation was observed between yield and the disease development index at the BBCH 12 growth phase, as well as between yield and the disease prevalence index at BBCH 13.

Significantly higher yields can be achieved in soybean seeds with pre-sowing treatment with fungicides using following active substances (in comparison with untreated seeds): fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at the rates of 0.4 ml kg^{-1} or 0.8 ml kg^{-1} (XP0.4 and XP0.8); thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g l^{-1}) at 1.0 ml kg^{-1} or 1.5 ml kg^{-1} (TPF1.0, TPF1.5); fludioxonil (25 g L^{-1}) + metalaxyl-M (37.5 g L^{-1}) + sedaxane (50 g L^{-1}) at 1.0 ml kg^{-1} (FMS1.0); fludioxonil (25 g L^{-1}) + metalaxyl-M (10 g L^{-1}) at 1.0 ml kg^{-1} (FM1.0); and prothioconazole (300 g L^{-1}) at 0.4 ml kg^{-1} (P0.4). The soybean yield in these variants ranged from 3.42 to 3.75 tons per hectare. The highest yield in the experiment was observed in the variant treated with the active substances thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1}) at the rate of 1.5 ml kg^{-1} (TPF1.5).

When seed treatment preparations with the active substances fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at a rate of 0.3 ml kg^{-1} (XP0.3) and thiabendazole (25 g L^{-1}) + metalaxyl-M (20 g L^{-1}) +

fludioxonil (150 g L^{-1}) at a rate of 1.2 ml kg^{-1} (TMF1.2) were applied, soybean yield did not significantly differ from the control, where seed treatments were not used. The yield in these variants was 3.16 - 3.26 tons per hectare.

Conclusions

The use of fungicidal seed treatments with the active substances fluxapyroxad (250 g L^{-1}) + pyraclostrobin (250 g L^{-1}) at a rate of 0.4 ml kg^{-1} increased seed germination energy and germination capacity. Using these active substances at a rate of 0.8 ml kg^{-1}, as well as fludioxonil (25 g L^{-1}) + metalaxyl-M (10 g L^{-1}) at a rate of 1.0 ml kg^{-1}, ensures high seed germination energy. When using these treatments, soybean yield was among the highest in the experiment. The preparation with thiabendazole (25 g L^{-1}) + metalaxyl-M (20 g L^{-1}) + fludioxonil (150 g L^{-1}) at a rate of 1.2 ml kg^{-1} (TMF1.2) also resulted in the highest germination capacity observed in the experiment. However, the soybean plants treated with this preparation had some of the highest levels of root rot infection and the lowest yield in the experiment. The use of the active substances thiophanate methyl (250 g L^{-1}) + pyraclostrobin (25 g L^{-1}) + fipronil (225 g L^{-1}) at rates of 1.0 ml kg^{-1} (TPF1.0) and 1.5 ml kg^{-1} (TPF1.5) negatively affected soybean seed germination parameters (17.0 % - 45.5 % for germination energy, and 87.5 % - 91.0 % for germination capacity). However, the treatments resulted in high yield (3.52 - 3.75 tons per hectare). The reasons for this require further research.

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