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RESPONSE OF CORN SEEDLINGS ON MINT AND CARAWAY ESSENTIAL OILS IN MICROENCAPSULATED FORMULATION

Summary

The aim of this study was to examine the influence of microencapsulated essential oils (EO) of peppermint (Mentha × piperita L.) and caraway (Carum carvi L.) on the initial growth and metabolism of maize (Zea mays L.). Four concentrations EO of caraway and peppermint, i.e. 3, 30, 300 and 3000 mg·L^{-1}, were used. The influence of EO on the energy of germination of seeds, germination coefficient, biometry of seedlings, infection of seedlings by blight, activity of amylases in seeds, electrolyte leakage and efficiency of photosystem II were assessed. The results of an experiment showed that EO only in the highest concentrations have an inhibitory effect on the initial growth of maize. Concentrations in the range of 3-300 mg·L^{-1} do not limit the growth of maize seedlings. The EO in the lowest concentrations have a limiting effect on the pathogenesis of seedling blight caused by microorganisms of the natural seed microbiome. Based on the results, it can be concluded that peppermint and caraway EO have potential as a natural herbicide in the maize protection.
***Key words**: maize, essential oil, peppermint, caraway, germination, seedlings growth*

REAKCJA SIEWEK KUKURYDZY NA MIKROKAPSUŁKOWANE OLEJKI ETERYCZNE Z MIĘTY I KMINKU

Streszczenie

Celem badań było określenie wpływu mikrokapsułkowanych olejków eterycznych (EO) z mięty (Mentha × piperita L.) i kminku (Carum carvi L.) na początkowy wzrost i metabolizm kukurydzy (Zea mays L.). W doświadczeniu wykorzystano cztery stężenia olejku miętowego i kminkowego, tj. 3, 30, 300 i 3000 mg·L^{-1}. Oceniono wpływ EO na energię kiełkowania nasion, współczynnik kiełkowania, biometrię siewek, porażenie zgorzelą siewek, analizę aktywności amylaz w nasionach, wyciek elektrolitów i wydajność fotosystemu II. Na podstawie otrzymanych wyników stwierdzono, że EO tylko w najwyższych stężeniach mają hamujący wpływ na początkowy wzrost kukurydzy. Stężenia w zakresie 3-300 mg·L^{-1} nie ograniczają wzrostu siewek kukurydzy. EO w najniższych stężeniach mają działanie ograniczające patogenezę zgorzeli siewek wywołanej przez mikroorganizmy naturalnego mikrobiomu nasion. Podsumowując, należy stwierdzić, że kukurydza wykazuje mniejszą wrażliwość na zastosowane EO niż chwasty. W związku z tym EO z mięty i kminku mają potencjał jako naturalne herbicydy w ochronie kukurydzy.
***Słowa kluczowe**: kukurydza, olejek eteryczny, mięta, kminek, kiełkowanie, wzrost siewek*

1. Introduction

Essential oils [EO] are very promising substances among natural products, that exhibit a wide range of biological effects [12, 41]. Therefore, they may be a rich source of biocidal substances for agricultural use [39, 43]. EO are natural products of secondary metabolism. EO are usually a multi-component mixture of monoterpene and sesquiterpene compounds and their derivatives [22]. These compounds may have the character of aldehydes, esters, terpenes, ketones, alcohols, lactones, or chemicals containing sulfur or nitrogen, i.e. amines and thiols [8]. Main compounds in EO are highly volatiles with low persistence [27]. Very large diversity of the chemical composition of EO affects on of their biological activity [8, 33]. Therefore, EO with these properties are a good alternative to replacing classic pesticides, mainly natural fungicides and insecticides [1, 14, 20, 23, 25]. These oils are safe to both the environment and the consumers because of their low toxicity and rapid breakdown in the environment [19, 37]. Recently, much attention has been paid to the phytotoxic potential of different EO. Amri et al. [4] demonstrated that more than 80 EO and in excess of 50 constituents has some phytotoxic activity. Due to the structural diversity and complexity of their constituents, EO affect a variety of biochemical and physiological processes in treated plants [4].

The efficacy of field applications of EO depends on several factors, i.e. the developmental stage of the plants, the weather conditions at the time of spraying and the physicochemical properties of the applied mixture [7, 10]. It was shown that EO, such as caraway and peppermint oils, may have herbicidal potential [15, 26]. Both oils contain compounds with high phytotoxic potential, i.e. monooxygenated monoterpenes [33]. Last experiments show that secondary metabolites and chemical compounds existing in extracts or EO of some plants have allelopathic effects on seed germination and seedling growth in studied plants [2, 3, 11, 16, 18, 24, 28, 30, 31, 32]. Because of possible use of EO as natural herbicide in weed controlling, they may be considered as valuable alternatives in organic farming [30].

The aim of this study was to examine the influence of peppermint (*Mentha × piperita* L.) and caraway (*Carum carvi* L.)

EO on maize (*Zea mays* L.) in seeds germination, seedlings growth and some aspects of early plants physiology.

2. Methodology

2.1. Characteristics of essential oils

The EO of caraway (*Carum carvi* L.) and peppermint (*Mentla* × *piperita* L.) were used in the present study. The EO of caraway fruits herb was purchased from the Avicenna Oil company (Wrocław, Poland). The EO of peppermint was prepared on industrial scale by the Hoffmann Aroma company (Zamysłowo, Poland). The final content of caraway or peppermint EO in the microcapsules was measured by hydrodistillation method (20 g of microcapsules and 60 mL of water) for 3 h using Clevenger-type apparatus. The volume of separated EO was multiplied by the specific density of the microcapsules, which was determined by the pycnometer method.

The chemical composition of the EO in the microcapsules was analysed by gas chromatography-mass spectrometry (GC-MS) using a Trace GC Ultra apparatus (Thermo Electron Corporation, Milan, Italy) equipped with a flame ionization detector (FID) and MS DSQ II detector. A simultaneous GC-MS/FID analysis was performed using an MS-FID splitter (SGE, Analytical Science).

The chemical analysis showed that the microcapsules contained 7.5 % caraway EO and 12.5 % peppermint EO. The caraway EO was composed of d-limonene (40 %) and carvone (60 %). The peppermint oil was composed of menthone (21 %) and menthol (53 %).

2.2. Experiment design

The experiment was performed on the maize (*Zea mays* L.) cv. Ronaldinio. The seeds were obtained from the Experimental Station of the University of Agriculture in Prusy, near Krakow (Poland). They were characterized by a weight of 1000 grains (WTG) amounting to around 380.25 g. 11-cm diameter glass Petri dishes were lined with a Whatman filter paper (sterilized at 121°C, 25 min) moistened with 5 ml of the oils solution and distilled water as control. Four concentrations of caraways and peppermints EO, i.e. 3, 30, 300 and 3000 $mg \cdot L^{-1}$, were used. The solutions were prepared prior to the experiment. Then, 25 seeds were uniformly placed in each dish. Three replications were used for each treatment. All Petri dishes were randomly placed in a growth chamber. Plants were grown for the first three days in the darkness and then in plastic pots filled with perlite exposed to light (200 $\mu mol\ m^{-2}\ s^{-1}$ PPFD, at temperature of 25/20ºC day/night.). Plants were monitored daily and moistened with EO solutions and water as needed.

Macroscopic evaluation of germination of maize seeds was performed. Seed germination energy - the percentage of sprouted seeds after 24 h was calculated. Seed germination degree - germination coefficient was evaluated visually for the length of the hypocotyl seeds, where: 1 - no sprout, 2 hypocotyl length up to 1 cm, 3- hypocotyl length over 1 cm. The germination coefficient was calculated after 92 h according to the formula:

$$V = \frac{n1 \times 1 + n2 \times 2 + n3 \times 3}{N},$$

where: V = germination coefficient, nx = a number corresponding to each hypocotyl length estimation, N = total number of seeds.

Shoot and root lengths were measured for each treatment and control after one week (Ist term of experiment) and two weeks (IInd term of experiment). The percentage share of seedlings infected (seedlings with lesions covering more than 50% of the seedling area, including plants completely destroyed) by naturally occurring microorganisms that cause seedlings blight was also calculated [29]. In the assessment of the infection, an additional variant of control was used - standard chemical surface sterilization of seeds with sodium hypochlorite.

After 24 hours of the experiment, 3 grains were taken from each replicate, which were then frozen at -70° C. The operation was repeated after 48 hours and 72 hours. The collected grain was then used to analyze the activity of amylases and protein content during germination of seeds. During growth in pots electrolyte leakage and the PSII efficiency were measured.

Leave pieces collected from each treatment were placed into vials containing 10 cm^3 of ultrapure water (one piece per vial), and shaken (100 rpm) at 20°C. After 24 h, electrical conductivity (E1) was measured using a conductometer (CI 317, Elmetron, Poland). The vials with samples were boiled for 5 minutes and shaken again for 24 hours as above. Then conductivity was measured again and the obtained values represented total ion content (E2) (E2) in the leave pieces. Membrane permeability was expressed as the percentage of total EL [17]. All measurements were performed for 10 biological replicates.

The amylases activity in the seeds was measured after 24, 48 and 72 hours of treatment. Seeds collected from each treatment were homogenised in 0.1 M phosphate buffer (pH 7.0), and then centrifuged at 16,000× g for 5 min. A sample of tissue extract (70 µl) was added to 630 µl of phosphate buffer (pH 7.0) and shaken with 35 µL of 2% Lugol's reagent and 70 µL of 0.5% soluble starch solution. Absorbance was recorded for 5 minutes at 595 nm using an Ultrospec 2100 Pro spectrophotometer (Amersham Biosciences, Little Chalfont, UK). Protein content was determined according to Bradford [9] using bovine serum albumin (BSA) as a standard. All measurements were performed for 6 biological replicates.

Efficiency of photosystem II was estimated by means of chlorophyll *a* fluorescence with a Plant Efficiency Analyzer (PEA) (Hansatech Ltd. King's Lynn, UK). The measurements were carried out after a 30 min adaptation of leaves to darkness. Phenomenological energy fluxes were calculated as following: energy absorption by antennas (ABS/CS = Fm); energy flux for trapping (energy transferred to a reaction center) (TR_0/CS = Fv/Fm (ABS/CS)); energy flux for electron transport ($ET_0/CS = (F_v/F_m)\ (1\text{-}V_J)$ Fm); energy dissipation (energy loss as heat) (DI_0/CS = (ABS/CS)-(TR_0/CS)), where CS is the cross-section of the sample [38]. The measurements of leaf PSII efficiency were performed on the youngest fully developed leafs in 10 replications (1 leaf per replication).

2.3. Statistical Analyses

The collected data were analyzed using a two-way ANOVA (STATISTICA 12 software, StatSoft, Tulsa, OK, USA). Means and standard errors were calculated. Comparisons of the treatments were carried out according to Duncan's multiple range test at $p < 0.05$.

3. Results and discussion

Our results showed that EO does not have a statistically significant effect on energy of germination of seeds of *Z. mays* after 24 h (Fig. 1). However, there is a tendency to limit this process, especially after treatment of seeds with peppermint oil in concentration 30 mg·L^{-1} and 3000 mg·L^{-1}. Energy of germination was in the range of 64-78%.

On the basis of a 3-point scale, the germination coefficient was calculated, which took into account the amount of sprouted seeds and the length of individual sprouts (Fig. 2). The lowest germination coefficient compared to control was obtained in maize treated with peppermint EO in concentration 3000 mg·L^{-1}. Among of all treatments, the highest germination coefficient was obtained in maize treated with caraway EO in 3 mg·L^{-1} and peppermint EO in 30 mg·L^{-1} but it was not statistically significant compared to the control. It can be concluded that maize reacts negatively to high concentrations, while low concentrations may even stimulate its germination.

Evaluation of the seedling morphology of maize following treatment with EOs indicated that both oils in low concentrations not have statistically significant effect on length of shoots and roots compared to control (Fig. 3 and 4).

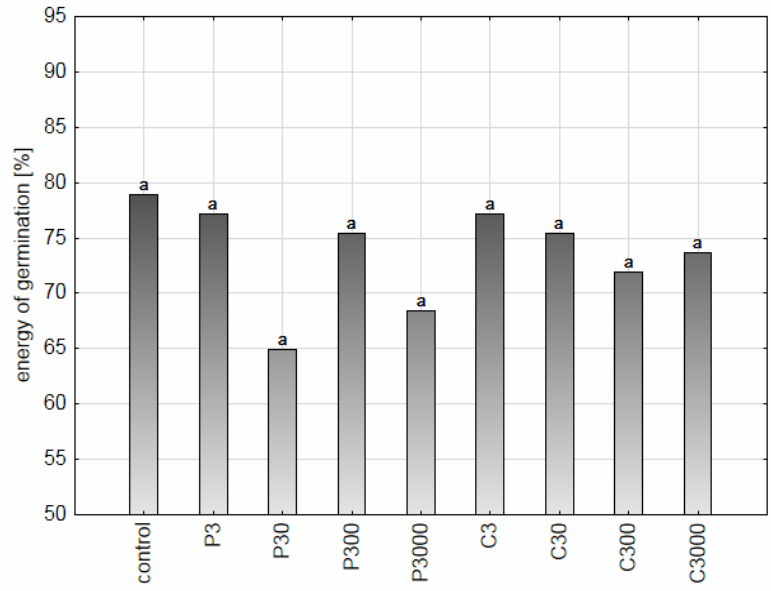

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Fig. 1. Effect of peppermint and caraway essential oil in tested concentrations on the energy of germination of maize seeds. Abbreviations for all figures: P – EO of peppermint (*Mentla × piperita* L.), C – EO of caraway (*Carum carvi* L.); 3, 30, 300, 3000 – concentration of EO [mg·L^{-1}]. Values marked with the same letters do not differ significantly at α=0.05

Rys. 1. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na energię kiełkowania nasion kukurydzy. Skróty dla wszystkich rysunków: P – EO miętowy (Mentla × piperita L.), C – EO kminkowy (Carum carvi L.); 3, 30, 300, 3000 – stężenia olejków [mg·l^{-1}]. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

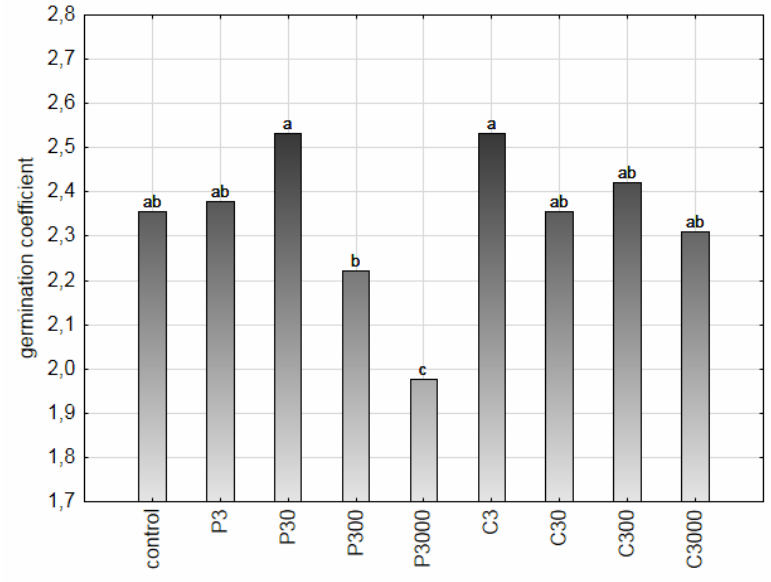

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Fig. 2. Effect of peppermint and caraway essential oil in tested concentrations on the germination coefficient of maize seeds. Values marked with the same letters do not differ significantly at α=0.05

Rys. 2. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na współczynnik kiełkowania nasion kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

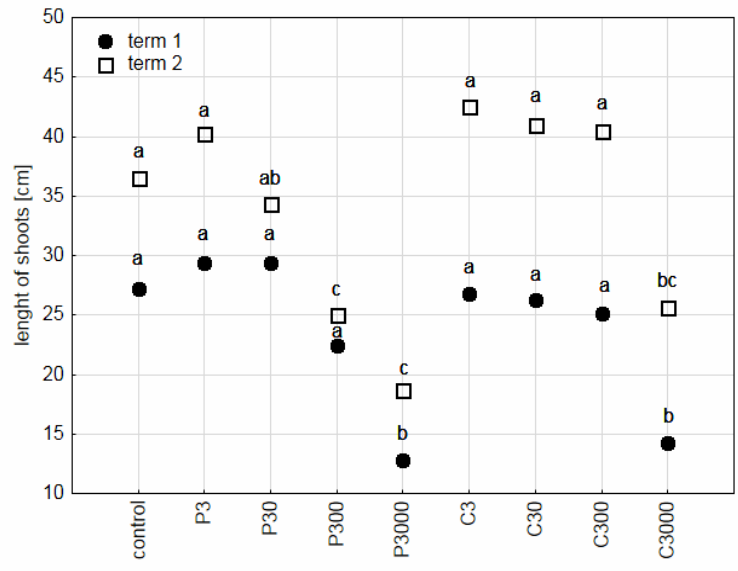

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Fig. 3. Effect of peppermint and caraway essential oil in tested concentrations on the length of shoots of maize seedlings. Values marked with the same letters do not differ significantly at α=0.05

Rys. 3. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na długość pędów siewek kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

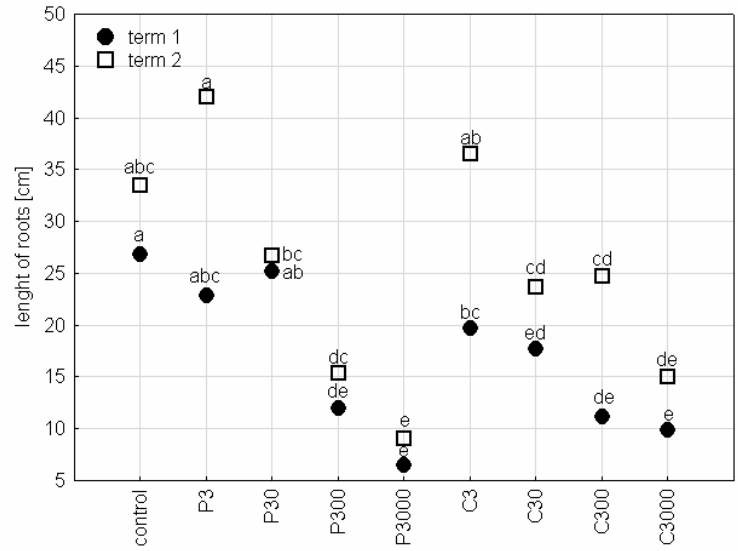

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Fig. 4. Effect of peppermint and caraway essential oil in tested concentrations on the length of roots of maize seedlings. Values marked with the same letters do not differ significantly at α=0.05

Rys. 4. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na długość korzeni siewek kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

EO of peppermint and EO of caraway in concentration 3000 mg·L^{-1} inhibited the length of shoots and roots compared to the control in Ist term of experiment. The treated roots were almost 4 times shorter in comparison to control roots. Similar results were obtained for the second term of the experiment - the oils used only in the highest concentrations caused inhibition of shoots and roots length.

Previous studies have referenced that EO can inhibit or delay seed germination and inhibit seedling growth, especially in the highest concentrations [4]. De Almeida et al. [15] studied the effect of EO on model plants i.e. *Lepidium sativum, Lactuca sativa* and *Raphanus sativus.* EOs were applied at the following doses: 2.5, 1.25, 0.625, 0.25, 0.125 and 0.06 µg·mL^{-1}. The germination of *L. sativum* was drastically affected by a 2.5 µg·mL^{-1} dose of EO of balm, caraway, hyssop, thyme and vervain, with a 100% inhibition. Almost all oils, except anise, basil and fennel, inhibited by 100% the germination of *R. sativus*, at the highest dose tested. Vervain, balm, caraway and oregano EO totally inhibited germination of *L. sativa* at doses of 1.25 and 2.5 µg·mL^{-1}. Rolli et al. [33] assessed the inhibition of *Solanum lycopersicum* germination by 25 EO in an in vitro test. They ranked peppermint oil as having medium activity (66.4% inhibition). De Fao [16] studied activity of rue EO on *R. sativus* germination and radicle growth in light and darkness in concentrations from 62.5 to 500 mg·mL^{-1}. The oil inhibited both germination and radical elongation of *R. sativus* seeds, in a dose-dependent manner, with the effect being significantly more effective in the dark. Germination was inhibited by 60 and 77%, respectively in light and in darkness, at the highest

concentration tested (500 mg·mL^{-1}) and by 30–49% at lowest one (62.5 mg·mL^{-1}).

EOs have strong phytotoxic activity to weed seed germination, therefore, may be regarded as potential source of bioherbicides. Cavalieri and Caporali [13] showed an inhibitory effect of peppermint and lavender oils against the germination of seven weeds. Each EO was tested at 4 concentrations in controlled conditions (germination chamber: 0.2, 0.6, 1.8, 5.4 mg·L^{-1}) and in semicontrolled condition (green house: 5.4, 21.6, 86.4, 345.6 mg·L^{-1}). It was shown that the inhibition ability does not differ among the oil types but it depends on their concentration. The germination rate decreased with increasing concentrations of EO. In controlled conditions, the highest concentrations (1.8 and 5.4 mg·L^{-1}) totally inhibited the seed germination. EO also reduced the seed emergence in green house (semi-controlled condition). At highest concentration (345.6 mg·L^{-1}) the germination of *Amaranthus retroflexus* was inhibited by 100%, 84% and 82% with cinnamon, lavender and peppermint EO, respectively. In turn, *Sinapis arvensis* seed germination was inhibited in the range of 57-78% by tested oils. *Lolium perenne* was inhibited by 57% by the cinnamon, 53% by peppermint and 48% by lavender EO. Caraway oil was the most effective among ten EOs tested against the germination of seven weed seeds [5]. Rahimi et al. [30] showed that both ethanol and EO with wild mint, coriander, fennel, green cumin and caraway prevented seed germination of *Vicia villosa*. Also all EOs and ethanol decreased *Lathyrus annuus* germination compared with control. All EOs except for the fennel EO were more effective on inhibiting *Lathyrus annuus* germination than ethanol. Azizi et al. [6] reported that black cumin and cumin EO inhibited the germination of *Bromus tectorum*, *Centura ovina* and *Descurainia sophia*, especially at high concentration. Saharkhiz et al. [34] demonstrated that germination rate and seedling length of *L. perenne*, *Festuca arundinacea* and *Cynodon dactylon* were significantly reduced by EO obtained from carom seeds, cumin, rosemary and Shirazi thyme. The highest effect was observed at 300 and 400 µl·L^{-1}. Moreover, the impact of Shirazi thyme EO on seed germination and seedling growth was most effective - 100% inhibition when compared with other tested EO.

In our study, compared with the control group, seedlings treated with EO of peppermint and caraway at 3000 mg·L^{-1} were characterized by a smaller contribution of the number of maize leaves in Ist term of experiment. In contrast, EO in concentrations 3-300 mg·L^{-1} did not have a significant impact compared to the control (Fig. 5). Synowiec et al. [40] showed that the highest doses of microencapsulated EO (peppermint, caraway and calamus) caused the greatest decrease in the number and dry weight of the tested weeds. In turn, the maize shoots were significantly less sensitive to the microcapsules compared to the roots.

Our study showed lowest infection of seedlings caused by blight after treating the seeds with peppermint and caraway EO in concentration 3 mg·L^{-1} and effect was the same like chemical stylization with sodium hypochlorite (Fig. 6). These results indicate that the EO in the lowest concentrations may have a limiting effect on the pathogenesis of seedling blight caused by microorganisms of the natural seed microbiome.

As show in Fig. 7, in Ist term, a significant increase in electrolyte leakage was observed in the leaves of EO treated plants, while the greatest increase, reaching a value of 26-27%, was noted under the influence of EO of peppermint in concentration 300 mg·L^{-1}, EO of caraway 30 mg·L^{-1} and 3000 mg·L^{-1}. The significantly higher disintegration of cellular membranes observed in the first period compared to control was inhibited in the second observation period, when the electrolyte leakage with maize did not differ from the control. Earlier study reports that EO and their constituent inhibit weeds and some plants through electrolyte leakage. In the leaf tissues of *Echinochloa crus-galli* and *Calyptronoma occidentalis* treated with artemisia EO [21], observed a dose-dependent increase in electrolyte leakage. Singh et al. [36] observed that oil from lemon eucalyptus caused severe electrolyte leakage from disks of *Parthenium hysterophorus*. Tworkoski [42] reported that EO from summer savory, red thyme, clove, and cinnamon cause rapid electrolyte leakage in *Taraxacum officinalis* leaf.

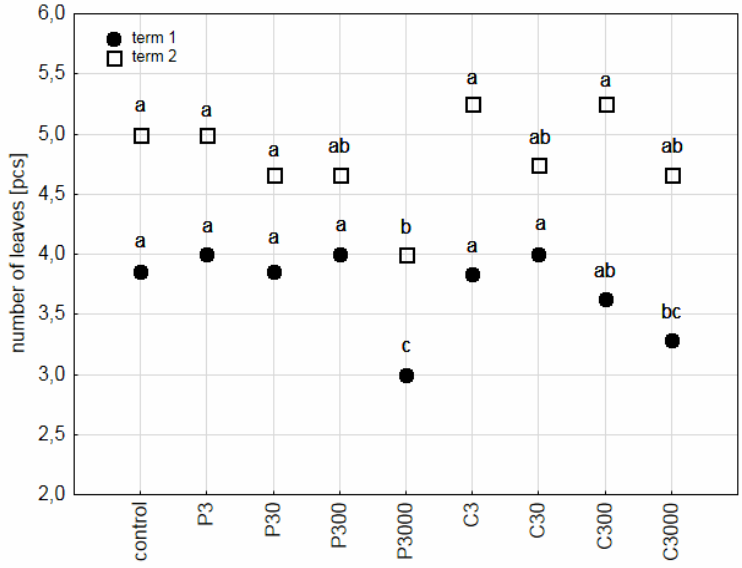

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Fig. 5. Effect of peppermint and caraway essential oil in tested concentrations on the number of leaves of maize. Values marked with the same letters do not differ significantly at α=0.05

Rys. 5. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na liczbę liści kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

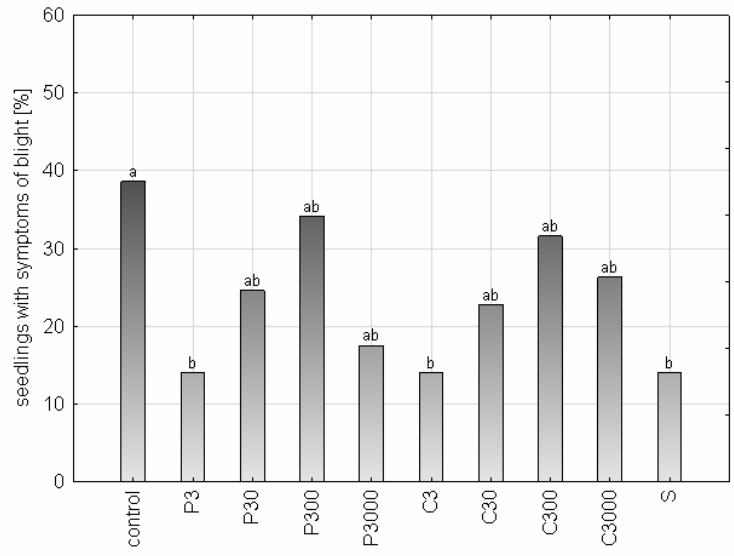

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Fig. 6. Effect of peppermint and caraway essential oil in tested concentrations and sodium hypochlorite on the infection of seedlings by blight. Abbreviation: S – standard chemical sterilization of seeds using 10% sodium hypochlorite. Values marked with the same letters do not differ significantly at α=0.05

Rys. 6. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach oraz podchlorynu sodu na porażenie siewek zgorzelą. Skrót: S – standardowa chemiczna sterylizacja nasion z użyciem 10% podchlorynu sodu. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

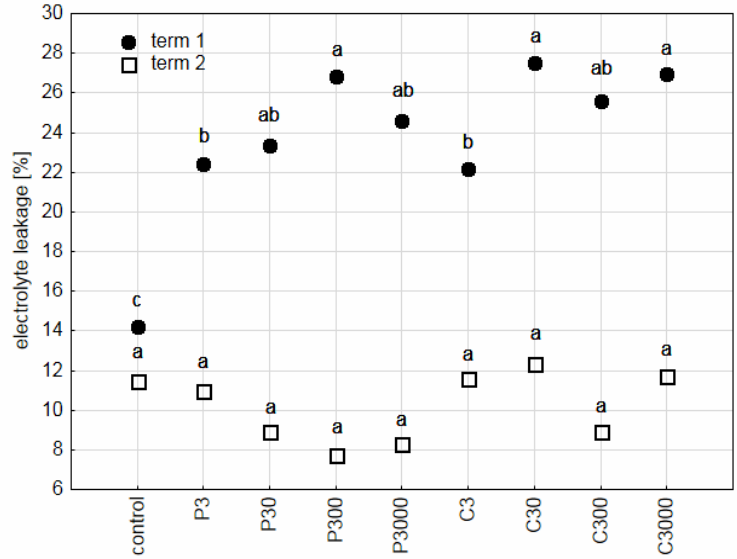

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Fig. 7. Effect of peppermint and caraway essential oil in tested concentrations on the electrolyte leakage of leaves of maize. Values marked with the same letters do not differ significantly at α=0.05

Rys. 7. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na wyciek elektrolitów z liści kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

The influence of tested EO on amylases activity showed Fig. 8. Amylases activity in seeds was lower than control in all EO treatment after 24 h of treatment. The highest concentrations caused the strongest inhibition of tested parameter. The initial inhibition of amylase activity was short-lived, however and at the 3rd observation term, EO of peppermint in concentrations 3 mg·L^{-1} and EO of caraway in 30 mg·L^{-1} caused higher amylases activity.

Values for the specific energy fluxes calculated per CS (ABS/CS), energy flux for trapping (energy transferred to reaction centre) (TR_0/CS), energy flux for electron transport (Et_0/CS), the trapping of photons by the antenna system (Di_0/CS), density of the active reaction centers per CS_0 (RC/CS_0) and number of active reaction centers (RC/CS_m) in plants cultured in the presence of EO of peppermint was lower than control in Ist term of experiment (Fig. 9A). In IInd term, only EO of peppermint in 3000 and 300 mg·L^{-1} statistically significant decreased ABS/CS and RC/CS_m, respectively (Fig. 9B). In turn, caraway EO in the lowest concentrations statistically significant decreased Et_0/CS and RC/CS_m and ABS/CS (Fig. 10A and 10B). Synowiec et al. [40] showed that the maltodextrin and microencapsulated EO of peppermint, caraway and calamus at the highest doses decreased the relative chlorophyll content of the leaves in maize. The application of *Artemisia* EO on weed plants caused losses in chlorophyll concentrations in the leaves [21]. Singh et al. [35] demonstrated that citronellol, citronellal, cineole and linalool reduced chlorophyll concentrations in the leaves of *C. occidentalis*.

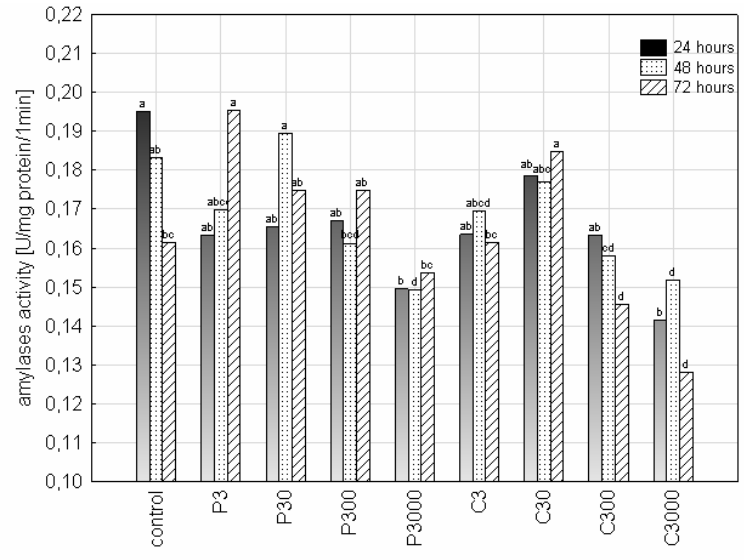

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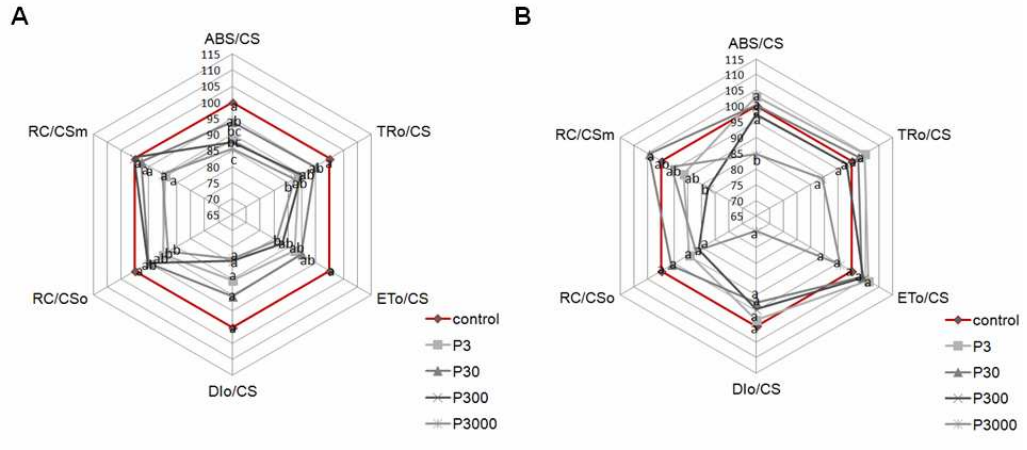
Fig. 8. Effect of peppermint and caraway essential oil in tested concentrations on the amylases activity in seeds of maize. Values marked with the same letters do not differ significantly at α=0.05

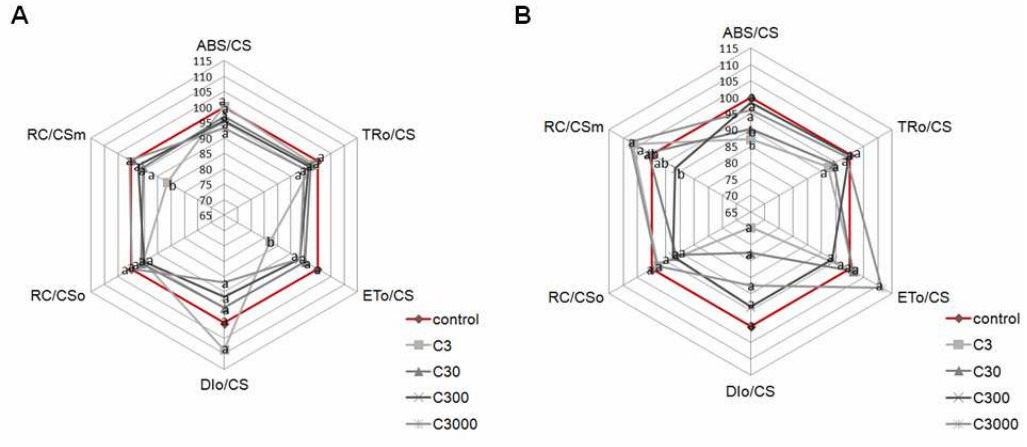
Rys. 8. Wpływ miętowego i kminkowego olejku eterycznego w testowanych stężeniach na aktywność amylaz w ziarnach kukurydzy. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05



Source: own work / Źródło: opracowanie własne

Fig. 9. Effect of peppermint essential oil in tested concentrations on the efficiency of photosystem II in Ist (A) and IInd (B) term of experiment. Values marked with the same letters do not differ significantly at α=0.05

Rys. 9. Wpływ miętowego olejku eterycznego w testowanych stężeniach na wydajność fotosystemu II w I (A) i II (B) terminie doświadczenia. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05



Source: own work / Źródło: opracowanie własne

Fig. 10. Effect of caraway essential oil in tested concentrations on the efficiency of photosystem II in Ist (A) and IInd (B) term of experiment. Values marked with the same letters do not differ significantly at α=0.05

Rys. 10. Wpływ kminkowego olejku eterycznego w testowanych stężeniach na wydajność fotosystemu II w I (A) i II (B) terminie doświadczenia. Wartości oznaczone tymi samymi literami nie różnią się istotnie statystycznie na poziomie α=0,05

4. Conclusions

1. Only the highest concentration of peppermint and caraway essential oils from tested (3000 mg·L^{-1}) causes a significant decrease in germination and initial growth of maize seedlings.
2. Concentrations of peppermint and caraway essential oils in the range of 3-300 mg·L^{-1} do not limit the growth of maize seedlings.
3. The peppermint and caraway essential oils in concentrations (3 mg·L^{-1}) may have a limiting effect on the pathogenesis of seedling blight caused by microorganisms of the natural seed microbiome.
4. The observed increased disintegration of cell membranes of maize seedlings under the influence of all concentration tested was temporary and after the following week this parameter did not differ from the control.
5. EO from peppermint at concentrations 3 and 30 mg·L^{-1}, reduced the activity of amylases after 24 hours but increased their activity after 72 hours of seeds germination.
6. Maize is not sensitive to low concentrations of peppermint and caraway essential oils unlike the weeds as indicated in the literature.

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