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## Allelopathic effect of goosefoot on germination and early stage growth of triticale and radish

### Introduction

Weeds are plants that are very well adapted to growth and development in changing environmental conditions. Their proliferation is a significant and growing problem for agriculture. They have the ability to produce an ample amount of seeds which are characterised by prominent vitality and easy germination. These plants demonstrate a wide range of temperature tolerance and variable soil conditions. They use nutrients in larger quantities than crop plants and they can appear in secondary weed infestation. One example is goosefoot (*Chenopodium album* L.). It is an annual plant that grows to about one meter in height (Paczyńska, 2016). In various classification systems it belongs to the goosefoot family (Chenopodiaceae Vent.) or amaranthus (Amaranthaceae Juss.). *C. album* has been cultivated in Europe since ancient times. In Poland, it occurs in the lowlands as well as in lower mountain regions, and it often grows on the fallow, fields or gardens (Sudnik-Wójcikowska, 2011). Goosefoot has a pile root and is branched. Its stem also branches strongly and sometimes has red discoloration. The whole plant is pubescent (Czubiński, Paradowski, 2014). The leaves take on a diamond shape or are lanceolate, with a serrated edge and a wedge-shaped base. *C. album* begins flowering in July, which can last until November. Its flowers are small and pale green. After flowering, it produces fruit in the form of a small nut with black seeds. Goosefoot seeds can easily adapt to all weather conditions, even retaining their ability to germinate for several years (Klaaßen, Freitag, 2004). This plant is wind-proof and reproduces and develops very quickly, thus taking valuable nutrients and water from crop plants (Domagała-Świątkiewicz, 2007). *C. album* contains vitamins A, B<sub>1</sub>, B<sub>2</sub> and C and microelements. It is also rich in flavonoids, essential

oils, carbohydrates and proteins (Byłka, Kowalewski, 1997; Dutt et al., 2003; Jardim et al., 2008; Usman et al., 2010; Geşiński, Nowak, 2011). Its seeds are abundant in valuable fats and albumins. Shoots, older leaves and seeds contain oxalic acid, saponins, phenols, lignans and alkaloids (Cutillo et al., 2004, 2006; Lavaud et al., 2007; Laghari et al., 2011)

Crop plants and weeds are a community with an additive system of components in which individuals compete for limited resources of the habitat, especially for water, nutrients and light. Competition results in the adjustment and weakening of competing organisms, which manifests as a reduction in the amount of biomass produced, in the size of individual organs and in seed yield. In cases of strong competitive impacts, individuals may even die and be eliminated from the community (Begon et al., 1999). In the literature, the high allelopathic potential of *C. album* is widely discussed (Batish et al., 2006; Jafari, Kholdebarin, 2002; Laghari et al., 2011). Although, Reinhardt et al. (1994) pointed out, this plant did not exert an inhibitory effect on radish germination when milled dry shoot biomass was added to the soil (1% w/w) or when radish seeds were treated with aqueous soil extracts from pots that previously contained mature *C. album* plants. In natural conditions, the allelopathic actions of *C. album* are not only limited to plant-plant interactions. *C. album* plants strongly propagate soil microorganism growth (like *Anabena* genus, a nitrogen-fixing cyanobacteria) and their aqueous extracts can enhance the growth of *Bradyrhizobium japonicum* Kirchner (Vokou et al., 2006).

The aim of the study was to examine the effect of aqueous extracts from dry goosefoot (*Chenopodium album* L.) plants on germination and early stage growth of triticale grains ( $\times$ *Triticosecale* Wittm. ex A.Camus) and radish seeds (*Raphanus sativus* L.). The effect of different percent concentrations of *C. album* extracts on (1) germination index values, (2) percent inhibition of seedling growth, (3) fresh and dry seedling mass, relative water content and percent water content in 7-day triticale and radish seedlings and (4) the degree of cell membrane destabilisation by measuring the electrolyte leakage were determined.

## Material and methods

### Plant material

Triticale ( $\times$ *Triticosecale*) grains and radish (*Raphanus sativus*) seeds were used in the experiment. Goosefoot (*Chenopodium album*) shoots in the vegetative phase were collected in spring 2019, from the southern Poland stand (49°59'10"N 20°03'42"E) and dried in laboratory conditions. Plant material was stored in the dark to avoid photochemical destruction of allelopathic compounds.

### Preparation of extracts

Dry material (goosefoot shoots) was ground in a mortar and distilled water was added, in the following amounts: (I) 0.5% extract: 0.5 g dry material + 95.5 ml distilled water, (II) 1.0% extract: 1 g dry material + 99 ml distilled water, (III) 1.5% extract: 1.5 g dry material + 98.5 ml distilled water and (IV) 2.0% extract: 2 g dry material + 98 ml distilled water. The preparations were left for 24 hours in the dark at approximately 25°C to allow for extraction of the compounds. After one day, the extracts from dry *C. album* plants were strained and stored in a refrigerator at 8°C ± 2°C for the duration of the experiment.

### Seed germination

25 pieces of triticale grains and radish seeds (after washing with running water for 30 minutes, and then 3 times with distilled water) were placed with a sterile tweezer on Petri dishes (Ø 9 cm) covered with a triple layer of filter paper, moistened with 5 ml of the appropriate aqueous extract of *C. album* plants in the concentrations: 0.5%, 1.0%, 1.5% or 2.0%. For the control, distilled water was used. During the experiment, all grains and seeds were placed in the dark, at room temperature. Every 24 h for 7 days the number of germinated grains and seeds was counted. Grains and seeds were considered germinated when their germinal root was equal to half the size of a grain or seed.

### Germination parameters

After 7 days of the experiment, the effect of *C. album* aqueous extracts on the germination capacity of triticale grains and radish seeds was evaluated. A germination index – GI (AOSA, 1983), speed of emergence – SE, seedling vigour index – SVI (Islam et al., 2009), coefficient of the rate of germination – CRG (Chiapusio et al., 1997) and time required for 50% germination – T<sub>50</sub> (Farooq et al., 2006) were assessed.

### Biometric analysis

Triticale and radish seedling length was measured using a calliper with an accuracy of 1 mm. The effect of goosefoot extracts on seedling growth was determined according to Islam and Kato-Noguchi (2012).

### Fresh and dry mass, relative water content and percentage water content

Fresh mass (FM) of triticale and radish seedlings was determined with a balance (Ohaus Adventurer Pro, USA). To obtain the dry mass (DM), the plant material was dried for 48 h at 105°C in a dryer (WAMED SUP 100, Poland) and then weighed. The relative water content (RWC) and the percentage content were determined based on the mass values.

The RWC was determined according to the method described by Mullan and Pi-tragalla (2012). Briefly, an individual seedling was weighed for FM and incubated for 24 h at 25°C in vials with 10 ml distilled water for saturation of plant tissues with water. After the incubation time, the turgor seedling mass (TM) was determined. Then, each was dried at 105°C for 48 h in the laboratory oven (WAMED SUP 100, Poland) and DM weighed. The RWC parameter for every seedling was calculated according to the formula:  $RWC = [(FM - DM) / (TM - DM)] \times 100$ . The percentage of water content (% H<sub>2</sub>O) was determined based on the mass values according to the formula  $\% H_2O = 100 - [(DM \times 100) / FM]$ .

### Electrolyte leakage

Cell membrane permeability was measured by electrolyte leakage in triticale and radish seedlings according to the method used by Możdżeń et al. (2018).

### Statistical analysis

Experimental results were compiled in Microsoft Excel. Additionally, statistical analysis was performed using one-way ANOVA/MANOVA. To assess the significance of differences between the means  $\pm$  SD (n = 3), Duncan's test at  $p \leq 0.05$  was used. The data was analysed with the STATISTICA program (StatSoft, Inc. 2018, Data Analysis Software System, version 13.1).

## Results

### Germination indexes

The germination capacity of triticale grains (*Triticosecale*) from the control group (distilled water) after 2 days was 100%. A similar result was obtained for seeds germinating on the aqueous extracts of dry *Chenopodium album* at a concentration of 0.5%, where the germination capacity after 3 days was 90%. Higher concentrations of goosefoot extracts (1.0%, 1.5% and 2.0%) inhibited the germination of grains. Regardless of the concentration of extracts, the largest number of newly germinated triticale grains was observed on the third day of the experiment. Similar results were observed for radish (*Raphanus sativus*) seeds. The highest percentage of germinated seeds was recorded after 4 days for the control sample and after 6 days for the 0.5% aqueous extracts. With increasing concentrations, a clear reduction in the number of germinated seeds was observed. Radish seeds watered with 2.0% extracts exhibited the lowest germination capacity (Tab. 1 – Appendix 1).

The coefficient of rate of germination (CRG) index for triticale grains slightly decreased compared to control with increasing aqueous goosefoot extract concentrations. The only statistically significant differences observed for this index, for grains,

were between the control and 2.0% extracts. Compared to the control, the CRG for radish seeds clearly decreased in each of the *C. album* extracts used. A significant decrease in the CRG index was demonstrated even at a concentration of 1.0% (Tab. 2 – Appendix 1).

The shortest time needed to reach 50% germinated seeds ( $T_{50}$ ) for triticale and radish seeds was in the control case. For aqueous *C. album* extracts, the  $T_{50}$  values for each of the extracts increased with the concentration of allelopathic compounds (Tab. 2 – Appendix 1). The germination index (GI) reached higher values for radish seeds compared to triticale grains. Regardless of the type of seeds studied, the GI values decreased with increasing concentrations of aqueous *C. album* extracts. Compared to the control, the lowest GI was observed for grains and seeds germinating in Petri dishes saturated with 2.0% goosefoot extracts.

The speed of emergence (SE), regardless of the type of studied seeds, reached its highest values in the control sample (Tab. 2 – Appendix 1). For *C. album* extracts, the SE index values decreased for both triticale and radish seeds with an increase in the concentration of extracts. For radish seeds treated with extracts (1.5% and 2.0% concentrations) a clear inhibition of germination was observed.

Compared to the control, the seed vigour index (SVI), irrespective of the organ and type of seeds, significantly decreased with increasing concentration of *C. album* extracts (Tab. 3 – Appendix 1). The lowest values were observed in seedlings watered with 2.0% extracts.

### Biometric analysis

Biometric analysis of whole triticale and radish seedlings revealed significant inhibition of growth in the presence of aqueous extracts from *C. album* plants (Tab. 4 – Appendix 1; Fig. 1–2 – Appendix 2). Stimulation of seedling growth in relation to control was observed only for radish seedlings watered with 0.5% goosefoot extract. The root length of triticale and radish seedlings was similar in all studied samples. With increasing concentration of allelopathic compounds in aqueous extracts, inhibition of root growth was observed. The exception was for *R. sativus* seedlings watered with 0.5% *C. album* extract, which resulted in a stimulatory effect on the root length of seedlings. The inhibition percentage index of growth (IP), expressed as a percentage of the control value, reached higher positive values for the triticale and radish above-ground organs with increasing concentration of goosefoot extract (Tab. 4 – Appendix 1). The only exception were radish seedlings watered with 0.5% extract; compared to controls, they reached negative values, which indicated stimulation of hypocotyl growth.

### Fresh and dry mass, relative water content and percentage water content

The aqueous extracts from *C. album* plants had an inhibitory effect on the FM values of triticale and radish seedlings. Compared to the control sample, when the concentration of the extracts increased, a significant decrease in the mass values was observed. The lowest values for this parameter were found in seedlings watered with 2.0% extract. The exception was radish seedlings treated with 0.5% extract, which showed a significant increase in FM, compared to control seedlings (Tab. 5).

The DM of triticale seedlings reached different values depending on the concentration of the extract. Compared to the control, the highest values were found in seedlings watered with 0.5% extract and the lowest for seedlings grown in Petri dishes with 1.0% and 2.0% goosefoot extract. In the case of radish seedlings, DM increased for each extract concentration, in relation to the control (Tab. 5).

**Tab. 5.** Fresh and dry masses, percentage water content and relative water content of triticale (*Triticosecale* Wittm. ex A.Camus) – (A) and radish (*Raphanus sativus* L.) – (B) seedlings watered with the aqueous extracts of *Chenopodium album* L. shoots in different concentrations (0.5%, 1.0%, 1.5%, 2.0%) and control conditions

Parameter	Concentration of aqueous extracts [%]									
	Control		0.5		1.0		1.5		2.0	
	A	B	A	B	A	B	A	B	A	B
FM	0.2531a ±0.03	0.0988b ±0.02	0.2196ab ±0.07	0.1587a ±0.01	0.1813b ±0.03	0.0673c ±0.03	0.1699c ±0.02	0.0283d ±0.02	0.1018d ±0.01	0.0197e ±0.005
DM	0.0251c ±0.00	0.0028d ±0.001	0.0796a ±0.06	0.0050a ±0.00	0.0227c ±0.01	0.0043b ±0.00	0.0577b ±0.08	0.0025d ±0.00	0.0267c ±0.01	0.0039c ±0.002
WC	90.09a ±0.29	97.10a ±0.47	57.88de ±39.07	96.83a ±0.66	87.52ab ±1.51	92.80a ±2.65	68.20d ±39.01	90.82a ±2.61	73.80c ±4.67	78.05b ±17.19
RWC	79.61a ±8.89	58.50b ±15.00	60.73bc ±29.84	70.51a ±3.61	66.74b ±6.23	57.64b ±12.44	50.54c ±29.93	75.28a ±53.29	60.82bc ±14.87	51.77b ±35.39

mean values ±SD (n = 3) in row marked with letters a, b, c differ significantly according to Duncan's test at  $p \leq 0.05$ ; FM – fresh mass [g], DM – dry mass [g], WC – water content [%], RWC – relative water content [%]

The total water content of triticale seedlings decreased significantly when extract concentration increased, compared to the control values (Tab. 5). In the case of radish seedlings, the values for this parameter changed slightly. In seedlings watered with 2.0% extract, a significant decrease in the water content was found. The RWC in the tested triticale seedlings decreased with the increasing extract concentration, compared to the control. For radish seedlings, the values for this parameter differed depending on the interaction with allelopathic compounds concentrated in aqueous extracts from *C. album*.

## Electrolyte leakage

The electrolyte leakage measurements revealed an increase in cell membrane destabilisation under the influence of goosefoot extracts (Fig. 3). Regardless of the type of seedling, a statistically significant increase in electrolyte leakage occurred along with increasing extract concentration. The highest degree of cell membrane disorganisation was found for triticale and radish seedlings treated with 2.0% *C. album* extract.

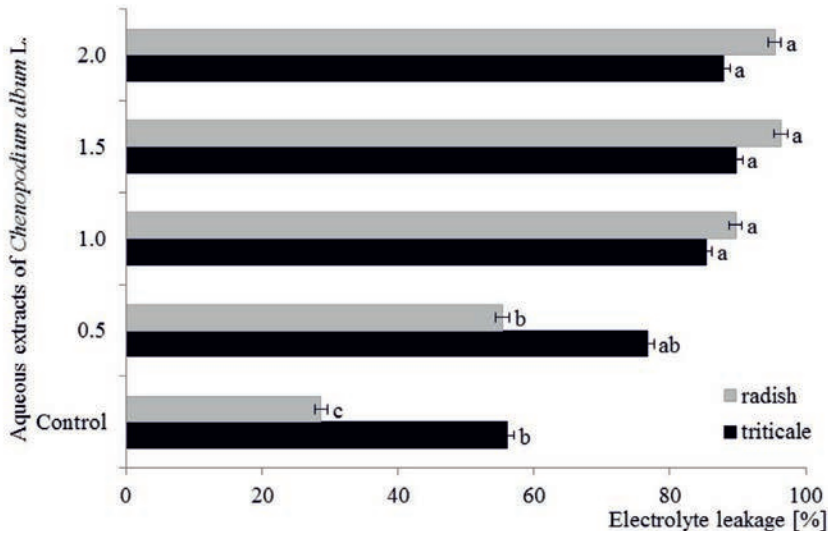


Fig. 3. Electrolyte leakage from cell membranes of triticale (*Triticosecale* Wittm. ex A. Camus) and radish (*Raphanus sativus* L.) seedlings watered with the aqueous extracts of *Chenopodium album* L. shoots in concentrations 0.5%, 1.0%, 1.5%, 2.0% and control conditions; mean values  $\pm$ SD ( $n = 3$ ) marked with letters a, b, c differ significantly according to Duncan's test at  $p \leq 0.05$

## Discussion

Seed germination is a complex process that includes both catabolic and anabolic reactions and biochemical transformations. It consists of processes occurring inside the seed that lead to the activation of the embryo (Nonogaki et al., 2010). The germination is controlled by external (environmental) and internal (genetic and hormonal) factors realised as a function of time. The exogenous factors include water, temperature and light (Benech-Arnold et al., 2000). The endogenous factors are hormones, growth and development regulators, and reactive oxygen species content. In addition, various chemical substances that occur in nature, e.g. nitrogen oxides, butenolide derivatives (Janas et al., 2010), glyconitrile (Downes et al., 2013) and allelopathic compounds secreted by neighbouring plants (Zandi et al., 2018, 2019; Puła et al., 2020) have impact on germination.

This research carried out on *C. album* confirms that, during germination, grains and seeds become sensitive to allelopathic compounds (Vokou et al., 2006; Valizadeh, Mirshekari, 2011; Konieczna et al., 2018). The germination capacity of triticale grains and radish seeds from the control sample was identical to the sample treated with 0.5% *C. album* aqueous extract. Meanwhile, in other shoot extracts it turned out that the higher the concentration of allelopathic substances the smaller the number of germinated grains and seeds (Tab. 1–2 – Appendix 1). For GI values, a similar result was observed. It reached higher values for radish seeds, compared to triticale grains. In the control groups, the highest values of SE index were observed. The lowest SE values were observed for grains and seeds treated with allelochemical compounds that had accumulated in the 1.5% and 2.0% extracts (Tab. 2 – Appendix 1).

For CRG, values clearly decreased with increasing concentration of aqueous *C. album* extract, compared to the control sample (Tab. 2 – Appendix 1). The SVI reached its lowest values for seedlings watered with 2.0% shoot extract, regardless of the type of organ and seeds (Tab. 3 – Appendix 1). Similar observations in terms of inhibition of seed germination in the presence of aqueous extracts from *C. album* shoot for *Raphanus sativus* L. were observed by e.g. Mallik et al. (1994) and Konieczna et al. (2019). Different degrees of seed sensitivity to allelopathic compounds may result from the size of diaspores and the thickness of seed coats (Sołtys et al., 2012). According to Vaughn and Spencer (1993), large-sized seeds show higher stress tolerance. Możdżeń and Rzepka (2016) and Mazur (2019) confirmed the important protective role of seed coat in the germination and early stages of growth of *Vicia faba* L. and *Phaseolus vulgaris* L. The mechanism of action of allelopathic compounds on seed germination is also associated with disturbances in the phytohormonal balance, slowing down the activation of spare materials, as well as the induction of oxidative stress (Krasuska et al., 2014).

Biometric analysis of underground and above-ground organs of triticale and radish seedlings revealed that aqueous extracts from *C. album* shoots inhibited their growth, as the concentration of allelopathins in the extracts increased (Tab. 4 – Appendix 1). The exception turned out to be radish seedlings watered with 0.5% extracts. This extract stimulated their growth, compared to seedlings from the control. Most likely contained in the leaves and stems of *C. album*, nitrates, among others phenols, saponins and alkaloids, negatively affected the germination and early stages of growth of triticale and radish seeds (Cutillo et al., 2004, 2006; Lavaud et al., 2007; Czubiński, Paradowski, 2014).

Allelopathic substances inhibit cell division and cell lengthening by limiting proton transport from the cytoplasm to the apoplast (Burgos et al., 2004). They reduce the uptake of micro and macroelements by changing the hydraulic conductivity of cell membranes. One of the first effects of allelopathic compounds at a cellular level is to



reduce the transmembrane electrochemical potential of cell membranes. Membrane depolarisation causes disturbances in the transport of anions and cations, which is associated with increased permeability of these structures. Under stress conditions, (1) inhibition of phosphorus, potassium, magnesium and nitrate ion intake, (2) modification of membrane proteins, (3) lipid oxidation by the presence of free radicals due to the reduction of catalase and peroxidase activity and (4) disorders in the functioning of channels, membrane conveyors and proton pumps occur. Damage to the cell membranes depends on, among other things, the concentration and solubility of allelopathic substances and the pH of the environment (Einhellig, 2004). In the experiment, differences in the electrolyte leakages from triticale and radish seedlings proved that allelopathic compounds released from goosefoot shoots clearly increased the degree of cell membrane destabilisation (Fig. 3).

Studies on the allelopathic properties of *C. album* showed that the presence of goosefoot reduced the quantity and quality of various crop plant species (Kropff et al., 1992; Salam et al., 2014). For example, in *Zea mays* L., *Glycine max* (L.) Merr., *Solanum* L. section *Lycopersicon* (Mill.) Wettst., *Avena* L., *Hordeum* L., *Medicago* L., and *Beta vulgaris* L. subsp. *vulgaris*, at a density of 172 to 300 plants per m<sup>2</sup>, goosefoot caused crop losses from 6 to 58% (Staniforth, Lovely, 1964; Sibuga, Bandeen, 1980; Shurtleff, Coble, 1985; Torner et al., 1995; Ngouajio et al., 1999). Dyck and Liebman (1995) attributed uncontrolled *C. album* populations to as much as 59% reduction in yields. In tomato cultivation, goosefoot caused a 36% reduction in the quality of marketable fruit (Bhowmik, Reddy, 1988). For barley yield, changes from 23 to 36% were attributed to its competition with *C. album* plants (Conn, Thomas, 1987). *C. album* caused an approximate 60% reduction in grain yield during the oat growing season and a 23% reduction in lucerne biomass yield (Lapointe et al., 1985). This study also confirmed a negative effect of *C. album* extract on the masses and water content of triticale and radish seedlings (Tab. 5). A decrease in mass accumulation was observed with increasing extract concentration, regardless of the type of seeds. Only for radish seedlings was an increase in the DM value for each of the extract concentrations found.

The intense and negative allelopathic effect of goosefoot extracts on triticale grains and radish seeds most likely resulted from the type of extracts used in the experiment. Leaves are organs that accumulate the largest amount of allelopathic compounds, and roots contain the lowest concentration (Kryzeviciene, Paplauskiene, 2004).

Goosefoot is a common weed in Poland. In limiting *C. album*, regular care of arable land in connection with simultaneous prevention of weed control is important. Otherwise, *C. album* plants left without interference quickly cover large areas (even eliminating crop species), will use the nutrients intended for the crop plants and sharply increase their seed bank in the soil. This problem especially affects plants cul-

tivated in wide rows, such as maize, sugar beets and potatoes. The weed economic thresholds determine the number of weed plants per unit area at which the crop yield loss will be greater than the total costs of the plant protection treatments. For maize, the threshold is 2 pcs of *C. album* per m<sup>2</sup> and for sugar beet 5 plants per 30 m in a row (*The threshold of pests...*, 2020).

In cereal crops (both spring and winter forms), besides the negative potential from released allelochemicals and competition for nutrients, the timing of the appearance of goosefoot is also problematic because *C. album*'s ability to germinate occurs during the entire growing season and this weed may yield seeds several times. Additionally, due to the fact that these seeds hold moisture well, even small numbers per 1 ha may disturb the long-term storage of grain. Determination of such weed thresholds is quite difficult due to many factors that occur (e.g. the moment of weed appearance in relation to the developmental stage of the crop, weather and soil conditions and the actual prices of plant protection treatments) (Rola et al., 2013).

However, research conducted by Valizadeh and Mirshekari (2011) suggests that the *C. album* threshold for rapeseed may be 4–8 pcs per m<sup>2</sup> (coverage of rapeseed in the terms of LAI drops from 3 to 1.5). The lack of selective herbicides, which at the same time could control the occurrence of goosefoot and be harmless to plants (Kucharski, Sekutowski, 2007) means that only regular mechanical treatments help in reducing the occurrence of goosefoot in crop fields. If necessary, chemical weed control is used along with areas adjacent to them, e.g. wasteland, ditches, paths and areas prepared for growing plants. It is also important to clean the equipment used for sowing seeds and harvesting plants, fertilise the soil only with well-spread manure and use good quality seed that is free from weed seed contamination (Domagała-Świątkiewicz, 2007).

Although the controversy around the phenomenon of allelopathy has not yet been unequivocally resolved, the negative effect of one plant on other neighbouring individuals remains an indisputable fact (Gniazdowska, 2007). Weston (2005) emphasised that all plants contain allelochemical substances with different structures and functions. The germination and early growth analyses carried out have revealed the allelopathic effects of *C. album* extracts at various concentrations, which similarly interfere with the metabolism of grains and seeds and indicate the need for further research. Poonia et al. (2015) emphasized that attention should be paid to *C. album* not only as a bothersome weed but as a source of functional nutrients and useful medicinal properties. However, this species is a good host for many dangerous crop pests (*Agrotis segetum* Denis & Schiffermüller, *Aphis fabae* Scop., *Delia radicum* L., *Heterodera schachtii* Schmidt, *Silphida latreille* Latreille) and the host of some pathogens that cause viral diseases (e.g. beet mosaic, hepatitis jaundice (Abe, Tamada, 1986). *C.*

*album* was also reported to be the host of a new plant disease caused by the fungus *Stagonospora atriplicis* (Westend.) Lind in New Zealand (McKenzie, Dingley, 1996).

## Conclusion

- (1) The results presented in this paper confirm the allelopathic properties of aqueous extracts of dry goosefoot (*Chenopodium album*). Based on the observations, an inhibitory effect of allelopathic compounds released from *C. album* shoots on the GIs of triticale grains ( $\times$ *Triticosecale*) and radish seeds (*Raphanus sativus*) was found.
- (2) Biometric analysis of triticale and radish seedlings demonstrated a significant inhibition of growth in the presence of aqueous extracts from dry *C. album* shoots.
- (3) With an increasing concentration of *C. album* extracts, the FM values of 7-day triticale and radish seedlings were decreased. The DM and the percentage of water content values changed, depending on the type of seed and the concentration of goosefoot shoot extract.
- (4) The negative effect of *C. album* was confirmed by the electrolyte leakage detected from triticale and radish seedlings cells. With increasing allelopathic substances in the shoot extracts, an increase in water-ion balance disorders in the studied seedlings was observed.

## Conflict of interest

The authors declare no conflict of interest related to this article.

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## Appendix 1

**Tab. 1.** Percentage of germinated triticale grains (*×Triticosecale* Wittm. ex *A.Camus*) – (A) and radish seeds (*Raphanus sativus* L.) – (B) watered with the aqueous extracts of *Chenopodium album* L. shoots in different concentrations (0.5%, 1.0%, 1.5%, 2.0%) and control conditions

Aqueous extracts [%]	Days [24h]														
	1		2		3		4		5		6		7		
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
Control	80 a	80 a	96 a	84 a	96 a	96 a	96 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
	±1.58	±0.84	±0.89	±0.84	±0.71	±1.14	±0.55	±0.55	±0.00	±0.45	±0.00	±0.45	±0.00	±0.00	±0.00
0.5	68 ab	60 ab	80 ab	64 ab	96 a	80 a	96 a	92 a	100 a	96 a	100 a	100 a	100 a	100 a	100 a
	±0.71	±1.14	±0.89	±1.30	±2.07	±2.28	±1.64	±1.92	±0.00	±1.30	±0.00	±0.45	±0.00	±0.45	±0.00
1.0	40 b	8 c	44 b	12 b	64 b	16 b	68 b	20 b	72 b	28 b	76 b	44 b	80 b	44 b	44 b
	±1.14	±1.14	±0.84	±1.48	±2.97	±1.52	±2.07	±1.52	±1.52	±1.52	±1.22	±2.41	±1.30	±2.49	±1.30
1.5	36 b	0 c	40 b	8 b	56 b	8 c	60 b	16 b	64 b	28 b	68 b	32 bc	76 b	40 b	40 b
	±1.14	±0.00	±0.84	±0.71	±2.07	±1.14	±2.59	±0.84	±2.59	±1.14	±2.30	±0.89	±2.17	±0.84	±0.84
2.0	20 c	0 c	28 c	8 b	52 b	8 c	56 bc	16 b	56 b	20 bc	60 bc	24 c	60 bc	28 c	28 c
	±1.14	±0.00	±1.30	±1.30	±3.05	±1.14	±2.68	±1.14	±2.97	±1.48	±3.85	±2.07	±3.85	±2.07	±2.07

mean values ±SD (n = 3) marked letter (a, b, c) in columns differ significantly according to Duncan's test at p < 0.05

**Tab. 2.** The germination parameters of triticale grains (*×Triticosecale* Wittm. ex *A.Camus*) – (A) and radish seeds (*Raphanus sativus* L.) – (B) watered with the aqueous extracts of *Chenopodium album* L. shoots in different concentrations (0.5%, 1.0%, 1.5%, 2.0%) and control conditions

Aqueous extracts [%]	CRG		T <sub>50</sub>		GI		SE	
	A	B	A	B	A	B	A	B
Control	24.34 a	24.12 a	0.35 b	0.35 cd	58.74 a	59.42 a	80.00 a	80.00 a
0.5	23.70 a	22.98 ab	0.59 ab	0.67 a	53.74 a	55.42 ab	68.00 b	60.00 b
1.0	22.56 ab	19.72 b	0.67 a	0.59 ab	34.71 b	36.30 b	50.00 c	18.18 c
1.5	22.42 ab	18.44 bc	0.66 a	0.63 a	31.16 b	32.57 b	47.37 d	0.00 d
2.0	21.90 b	19.12 b	0.65 a	0.40 c	23.78 c	27.17 c	33.33 e	0.00 d

the germination index (GI), speed emergence (SE), the coefficient rate germination (CRG) index and the time needed to reach 50% of germinated seeds (T<sub>50</sub>); mean values (n = 3) marked letter (a, b, c) in columns differ significantly according to Duncan's test at p < 0.05

**Tab. 3.** Seed vigour index (SVI) triticale (*×Triticosecale* Wittm. ex *A.Camus*) – (A) and radish (*Raphanus sativus* L.) – (B) seedlings after 7 days of germination on the aqueous extracts of *Chenopodium album* L. shoots in different concentrations (0.5%, 1.0%, 1.5%, 2.0%) and control conditions

SVI	Concentration of aqueous extracts [%]									
	Control		0.5		1.0		1.5		2.0	
	A	B	A	B	A	B	A	B	A	B
Underground organ	98.40 a	96.00 a	90.00 ab	64.80 b	53.25 b	10.91 c	39.74 c	3.50 d	5.67 d	12.50 e
Aboveground organ	114.40 a	49.60 d	99.60 b	80.60 b	76.75 c	72.27 c	95.26 b	19.50 e	23.67 d	6.07 f
Whole seedlings	212.80 a	145.60 a	189.60 b	145.40 a	130.00 c	83.18 b	135.00 c	23.00 c	29.33 d	18.57 d

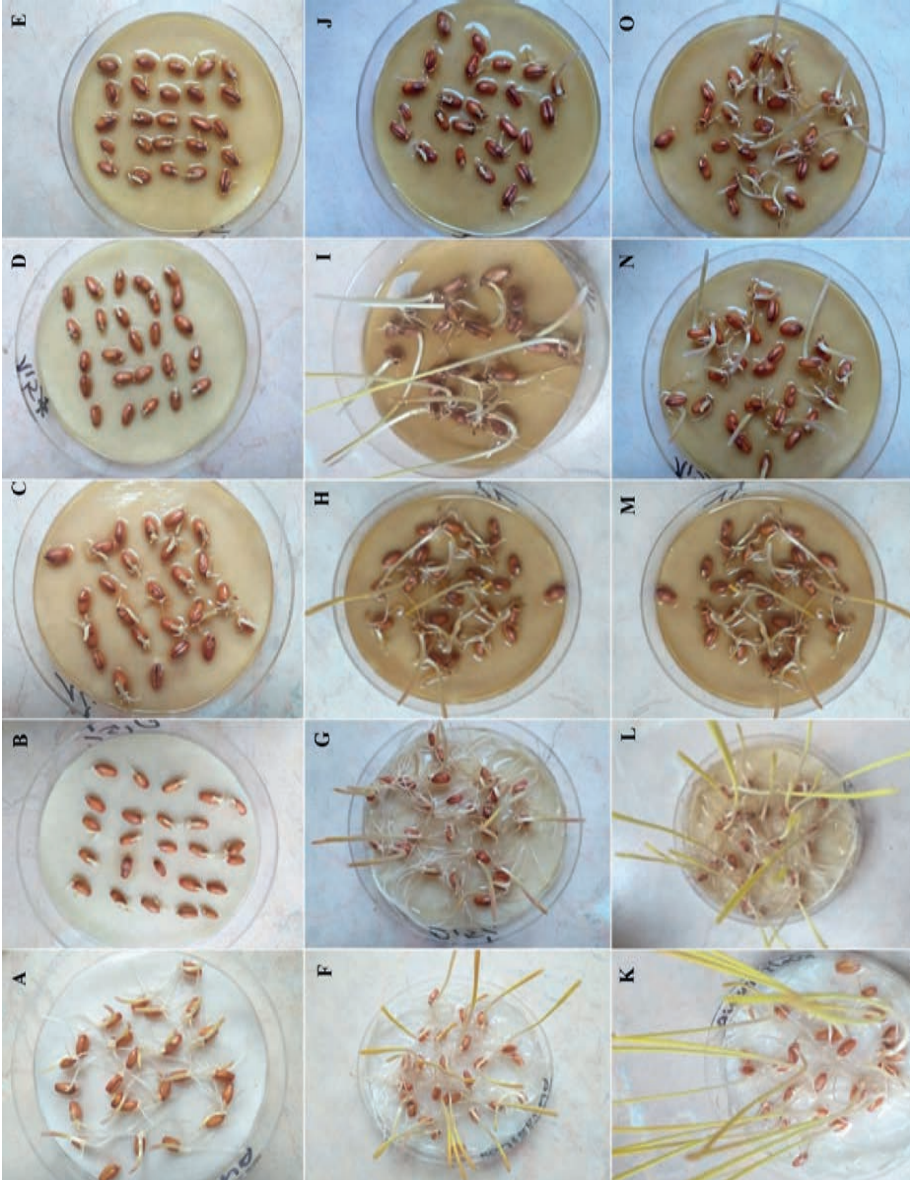
mean values (n = 3) in row marked with letters a, b, c differ significantly according to Duncan's test at p ≤ 0.05

**Tab. 4.** Length and inhibition percentage (IP) of growth (expressed as a percentage of control) of triticale (*×Triticosecale* Wittm. ex A. Camus) and radish (*Raphanus sativus* L.) seedlings germinated on the aqueous extracts of *Chenopodium album* L. shoots in different concentrations (0.5%, 1.0%, 1.5%, 2.0%) and control conditions

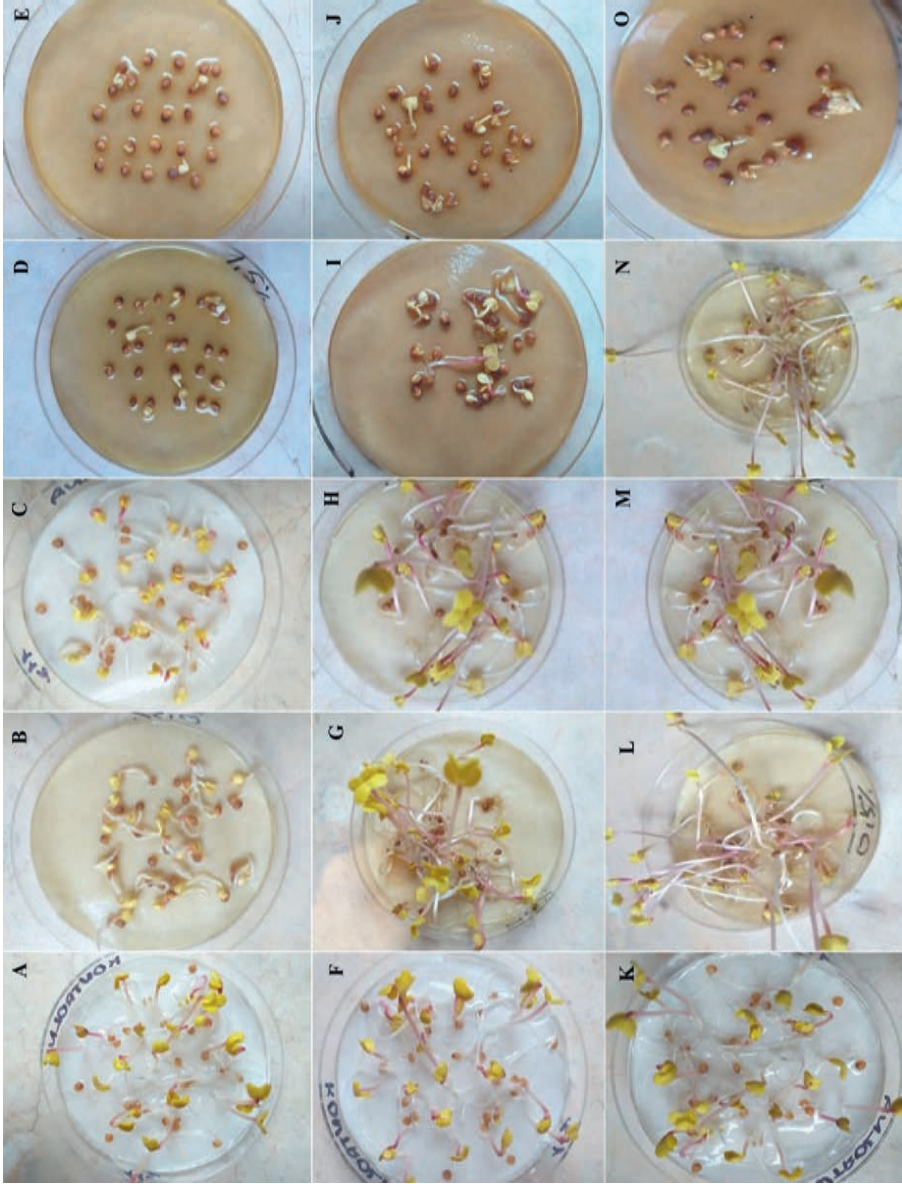
Organs	Concentration of aqueous extracts [%]									
	Control		0.5		1.0		1.5		2.0	
	[mm]	[mm]	IP%	[mm]	IP%	[mm]	IP%	[mm]	IP%	
Triticale										
Underground parts	98.4 a ±1.90	90.0 a ±2.37	6.31	42.6 b ±0.52	55.89	30.2 c ±0.91	68.87	3.4 d ±0.15	96.64	
Aboveground parts	114.4 a ±1.21	99.6 a ±1.65	12.97	61.4 b ±2.09	46.79	72.4 c ±1.36	36.76	14.2 d ±0.80	87.35	
Whole seedlings	212.8 a ±2.52	189.6 a ±3.83	104.20	104.0 b ±2.10	51.15	102.6 b ±2.14	51.72	17.6 c ±0.79	91.57	
Radish										
Underground parts	49.6 a ±4.15	6.48 b ±0.92	-9.06	4.8 c ±0.87	93.83	1.4 d ±0.30	98.14	3.5 c ±0.29	94.39	
Aboveground parts	96.0 a ±0.43	8.06 c ±2.03	-64.20	31.8 b ±0.30	35.85	7.8 c ±0.09	84.45	1.7 d ±0.17	96.51	
Whole seedlings	14.56 a ±4.43	14.54 a ±2.88	-19.25	3.66 b ±0.93	72.55	0.92 c ±0.38	93.21	0.52 c ±0.19	96.07	

minus (-) values of IP indicates growth stimulation, and plus (+) values of IP indicates growth inhibition; mean values (n = 3) in row marked with letters a, b, c differ significantly according to Duncan's test at p ≤ 0.05





**Fig. 1.** Radish seedlings (*Raphanus sativus* L.) on the 3<sup>rd</sup> (A–E), 5<sup>th</sup> (F–J) and 7<sup>th</sup> (K–O) day of germination watered with aqueous extracts of goosefoot (*Chenopodium album* L.) shoots and distilled water: A, F, K – control (distilled water); B, G, L – 0.5% extract; C, H, M – 1% extract; D, I, N – 1.5% extract; E, J, O – 2% extract (Photo: K. Lipniak)



**Fig. 2.** Triticale seedlings ( $\times$ *Triticosecale* Wittm. ex *A. Camus*) on the 3<sup>rd</sup> (A–E), 5<sup>th</sup> (F–I) and 7<sup>th</sup> (K–O) days of germination watered with aqueous extracts of goosefoot (*Chenopodium album* L.) shoots and distilled water: A, F, K – control (distilled water); B, G, L – 0.5% extract; C, H, M – 1.5% extract; D, I, N – 1.5% extract; E, J, O – 2% extract (Photo. K. Lipniak)

## Abstract

The aim of this study was to investigate the effect of aqueous extracts from *Chenopodium album* L. on germination and early stages of triticale grains (*×Triticosecale* Wittm. ex A.Camus) and radish seeds (*Raphanus sativus* L.). Germination indexes, fresh and dry mass, water content and electrolyte leakage were measured. Studies revealed the different germination capacity of triticale grains and radish seeds, where increased concentrations of allelopathins in aqueous *C. album* extracts significantly inhibited seedling growth for both species. The extracts had an inhibitory effect on the growth of seedling fresh mass. An increase in dry mass of radish seedlings was demonstrated for each of the extracts and, for triticale seedlings, only at concentrations of 0.5% and 1.5%. Water content in triticale and radish seedlings varied depending on the concentration of allelopathins in the extract. With increasing concentrations of *C. album* extract, regardless of seedling type, a statistically significant increase in electrolyte leakage was observed.

**Key words:** fresh and dry mass, seed germination indexes, electrolyte leakage, relative water content

**Received:** [2020.03.16]

**Accepted:** [2020.05.25]

## Allelopatyczny wpływ komosy białej na kiełkowanie i wczesne stadia wzrostu pszenżyta i rzodkiewki

### Streszczenie

Celem pracy było zbadanie wpływu wyciągów wodnych z *Chenopodium album* L. na kiełkowanie oraz wczesne stadia wzrostu ziarniaków pszenżyta (*×Triticosecale* Wittm. ex A.Camus) i nasion rzodkiewki (*Raphanus sativus* L.). Wyznaczono wskaźniki kiełkowania, świeżą i suchą masę, zawartość wody oraz wyciek elektrolitów. Badania wykazały różną zdolność kiełkowania ziaren pszenżyta i nasion rzodkiewki – wraz ze wzrostem stężeń substancji allelopatycznych zawartych w wodnych ekstraktach z *C. album* obserwowano znaczne zahamowanie wzrostu siewek obydwu gatunków. Wodne wyciągi hamowały przyrost świeżej masy siewek. Natomiast przyrost suchej masy siewek rzodkiewki wykazano przy każdym z ekstraktów, a dla pszenżyta jedynie w stężeniach 0,5% i 1,5%. Zawartość wody w siewkach pszenżyta i rzodkiewki była zróżnicowana, w zależności od stężenia allelopatin w ekstrakcie. Wraz ze wzrostem stężenia ekstraktów *C. album*, niezależnie od rodzaju siewek, zaobserwowano statystycznie istotny wzrost wycieku elektrolitów.

**Słowa kluczowe:** świeża i sucha masa, wskaźniki kiełkowania nasion, wyciek elektrolitu, względna zawartość wody

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