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The studies on the parasitism of branched broomrape (*Phelipanche ramosa* L.) on some root vegetables from the *Apiaceae* family

Abstract. The studies were conducted in 2020–2022 in Skierniewice, in the greenhouse and in the open. The observations were carried out on carrot (*Daucus carota* L.), parsley (*Petroselinum sativum* (Mill) Fuss.), and celeriac (*Apium graveolens* L. var. *rapaceum* (Mill)). The seeds of tested vegetable crops were sown in a greenhouse, and before sowing, *Phelipanche ramosa* seeds were mixed with the top layer of the substrate for half of the pots. The number and height of *P. ramosa* inflorescence shoots, the number of capsules with seeds in one pot, and the height of vegetable plant's inflorescence shoots were determined in experiments. It was found that tested vegetable crops from *Apiaceae* family can be the host plants for *P. ramosa*. Celeriac appeared to be a better host than carrot and parsley. Inflorescence shoots of carrot and celeriac parasitised with *P. ramosa* were lower than shoots growing without the parasite, but shoots of parsley were higher. The study aimed to determine the possibility of *P. ramosa* parasitizing vegetable crops from *Apiaceae* family, under Polish conditions, and its influence on the plant's morphological features.

Keywords: parasitism, *Phelipanche ramosa*, carrot, parsley, celeriac

INTRODUCTION

Branched broomrape (*Phelipanche ramosa* L. Pomel) is a root-parasitic plant species belonging to the *Orobanchaceae* family [Parker and Riches 1993, Parker 2009]. This plant is known all over the world, especially in countries with a warm or temperate climate. It causes great damage in tomato cultivation in the Mediterranean basin [Qasem and Kasrawi 1995, Qasem 1998, Avdeyev et al. 2003, Haidar and Sidahmed 2006, Joel et al. 2007, Kostoy et al. 2007, Hershenhorn et al. 2009, Disciglio et al. 2016, Gebreegziher et al. 2023], in Chile and other countries of South America [Diaz et al. 2006]. *Phelipanche ramosa* adapts to parasitism on new plants, as exemplified by the large losses in rapeseed yields in France [Zehhar et al. 2003, Gibot-Leclerc et al. 2012, Moreau et al. 2016]. It can also parasitise other plant species, including potatoes, hemp, tobacco [Piwowarczyk 2012], cabbage and celery plants [Zehhar et al. 2003, Qasem and Foy 2007, Gibot-Leclerc et al. 2014, Anyszka et al. 2025]. According to some authors, this parasite can cause from 5% to 100% losses in crop yields [Joel et al. 2007, Schneeweiss 2007], and once it appears, it is very difficult to control. It produces a very large number of small

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seeds, even up to 200,000 per gram [Qasem and Kasrawi 1995, Qasem 1998], which contributes to the increase in the soil seed bank of this species [Moreau et al. 2016]. At the same time, its invasive potential is significant, as all tropical and subtropical countries as well as most countries with a temperate climate are susceptible to its invasion [Mohamed et al. 2006]. The number of seeds depends on the host. Lolas [1994] and Wegmann [2004] report that in tobacco, *P. ramosa* can produce approximately 100 000 seeds per plant, while Zimdahl and Basinger [2024] state that *P. ramosa* can produce even 500 000 seeds. The changes that have been taking place for years due to climate warming may lead in the future to an increased risk of *P. ramosa* infecting other areas and crops. Climate change may affect obligate parasites directly by affecting their physiology, but also indirectly, as a consequence of the impact on host plants and habitats [Piwowarczyk and Kolanowska 2023].

In Poland, *P. ramosa* is observed mainly on tobacco and tomato roots [Borkowski and Dyki 2008, Borkowski et al. 2018], and is most common in the south of the country [Piwowarczyk 2012]. Buschmann [2004] and Piwowarczyk [2012] report that *P. ramosa* can also parasitize on hemp (*Cannabis sativa* L.). The area of hemp cultivation in Poland exceeds 1,500 hectares, which may be important for the spread of *P. ramosa*. Zehhar et al. [2003] found the *P. ramosa* parasitising carrot roots in Morocco, and Qasem and Foy [2007] showed that celeriac is also a good host for this parasite. Except for cultivation crops, *P. ramosa* can also occur on many weed species, e.g., black nightshade (*Solanum nigrum* L.) and bittersweet nightshade (*Solanum dulcamara*), black henbane (*Hyoscyamus niger* L.) from *Solanaceae* family [Haidar and Sidahmed 2006, Borkowski and Dyki 2008], and lesser swine-cress (*Lepidium didymum* L.), from *Brassicaceae* family [Watts et al. 2024]. The presence of weeds as host plants helps *P. ramosa* survive even in the absence of the main host crops [Watts et al. 2024]. In Poland, *P. ramosa* has been observed on *Galinsoga parviflora*, an annual weed species often found in segetal weed communities of cultivated crops, especially vegetable crops [Anyszka et al. 2025].

The research hypothesis assumed that *P. ramosa* can parasitize on the roots of some root vegetables from *Apiaceae* family in Poland, and its harmfulness varied. This study aimed to determine the possible risk of *P. ramosa* parasitism on carrot (*Daucus carota* subsp. *sativus*), parsley (*Petroselinum sativum* (Mill) Fuss.) and celeriac (*Apium graveolens* var. *rapaceum*) roots, in Polish conditions, and its influence on the plant's morphological features.

MATERIALS AND METHODS

The experiments were conducted in 2020–2022 in Skierniewice, Poland, in the greenhouse and in the open. The studies on parasitism of branched broomrape (*Phelipanche ramosa* L. Pomel) on the roots of three vegetable species: carrot (*Daucus carota* L.), cv. Nerac F_1, parsley (*Petroselinum sativum* (Mill) Fuss.), cv. Eagle and celeriac (*Apium graveolens* L. var. *rapaceum* (Mill)), cv. Maxim was determined.

The experiments were set up in a greenhouse, with five replicates, and after six weeks, the pots were moved to an open area (uncovered vegetation hall). Seeds of tested vegetable crops were sown into 5-liter pots filled with a substrate containing 75% podzolic soil and 25% peat. For each crop, five pots were prepared containing the vegetable seeds alone (control) and five pots containing both the vegetable seeds and *P. ramosa* seeds. To each pot, 12 seeds of the tested vegetable species (host plants) were sown, and *P. ramosa* seeds were added to half of the pots at a rate of approximately 0.01 g per pot (1–2 thousand seeds). Pots for sowing *P. ramosa* were partially filled with substrate, and the top layer of the substrate was mixed with *P. ramosa* seeds and then put into the pots. *P. ramosa* seeds were collected in the previous year while conducting the test with tomatoes. Seeds were stored in a paper bag at room temperature. A small number of seeds were used for sowing due to their small mass and size. Seeds of all plant species were sown into pots on May 15, 2020 (experiment I), July 22, 2021 (experiment II), and May 31, 2022 (experiment III).

After emergence, the small seedlings of vegetable plants were thinned to 6 plants per pot. During the summer, the plants were fertilised (once a month) with a multi-component fertiliser and systematically watered until constant humidity was achieved. During experiments, the tested plants were sprayed against pests and diseases, with plant protection products officially approved in Poland, according to the principles of integrated plant protection. In October of each year, the pots were moved for the winter to the greenhouse, where the temperature did not drop below 5°C, and during sunny weather slightly exceeded 10°C.

In the experiments, the number of pots with *P. ramosa* inflorescence shoots, the number of *P. ramosa* shoots per pot and their height, the number of capsules with seeds per pot, and the height of inflorescence shoots of vegetable plants were determined. *Phelipanche ramosa* emerges unevenly, therefore for each vegetable plant species, the number of pots in which *P. ramosa* inflorescence shoots emerged from the soil at a given date was determined. In each experiment, observations were conducted on five dates, depending on the term of shoot emergence. The results are presented in Table 1.

The number of *P. ramosa* inflorescence shoots in pots was determined 4–5 times in each experiment, between 105 and 375 days after sowing. Observations were made in the year the experiment was established and the following year, depending on the intensity of shoot emergence. Observations of the number of inflorescence shoots emerging from the soil also determine the timing of *P. ramosa*. Observations in the year following the experiment were possible because the pots were stored in an unheated greenhouse during the winter. Five observations were made for each plant, depending on the occurrence of the parasite, and the results are presented in Table 2.

The height of *P. ramosa* inflorescence shoots was determined 2–3 times in each experiment, based on measurements of the three tallest shoots in each pot. In the experiment established in 2020, measurements were taken 210 and 346 days after sowing, in the experiment established in 2021, after 311 and 342 days, and in the experiment established in 2022, after 135, 166, and 188 days. The results for the tallest shoot are presented in Table 3. The number of capsules with seeds, produced by *P. ramosa*, was determined in an experiment started in 2020 and 2021, between 344 and 382 days after sowing. The number of fully developed capsules with seeds in each pot was determined, the average value per pot was calculated, and the mean for two years was presented in Table 3.

The height of inflorescence shoots of the tested vegetable species was determined in experiments conducted in 2020/2021 and 2021/2022. Inflorescence shoots were measured in each pot 358 and 327 days after sowing, respectively, and the average shoot height was calculated for each plant. The results were presented on Figure 1A and 1B.

The results were statistically analysed by analysis of variance, using Statistica Program v. 13.0 (Statsoft Inc.). The Newman-Keuls test ($p = 0.05$) was used to compare the significance of the means.

The study aimed to determine the possible risk of *P. ramosa* parasitizing vegetable crops from *Apiaceae* family, under Polish conditions, and its influence on morphological features.

RESULTS

The seeds of the tested vegetable crops and *P. ramosa* were sown at different times. The sowing date did not affect the germination and emergence of vegetable seeds. *Phelipanche ramosa* shoots appeared at different times. The first shoots of *P. ramosa*, over the years, appeared 105 days after celeriac sowing, 110 days after carrot sowing, and 117 days after parsley sowing (Table 1).

In the pots with carrots, the first *P. ramosa* shoots appeared at 110 days after sowing in the experiment started in 2020, at 342 days after sowing in the experiment started in 2021, and they did not appear at all in the experiment carried out in 2022 (Table 1). In the experiment started in 2020, the shoots of *P. ramosa* appeared the earliest in the pots with carrot, compared to other tested crops. The share of pots with *P. ramosa* shoots between 110 and 144 days after sowing ranged from 20% to 80%, depending on the observation date. After 340 days from sowing, *P. ramosa* shoots were observed in fewer pots than after 186 days after sowing (Table 1), because old shoots withered and dried and were removed from pots, and new ones appeared after the next 21 days. In the experiment started in 2021, the shoots of *P. ramosa* in carrots appeared only in 1 pot, and there were few of them, while in the experiment carried out in 2022, no *P. ramosa* shoots were visible at all observation dates.

In parsley, *P. ramosa* shoots appeared at 117 days after sowing in the experiment started in 2020, and were visible at all the next observation dates, but they were not observed in subsequent years. In celeriac, *P. ramosa* shoots were observed in all experiments. The first shoots in the experiment started in 2020, appeared 186 days after sowing, in the experiment started in 2021, after 293 days, and in the experiment carried out in 2022, after 105 days (Table 1).

In all years of the study, the largest number of *P. ramosa* shoots was found in celeriac (Table 2). In the experiments started in 2020, the number of *P. ramosa* shoots, after 375 days from sowing, was on average 15.6, in the experiment started in 2021, after 342 days from sowing, it was 10.4, and in the experiment conducted in 2022, after 188 days from sowing, it was 12.8 shoots. In carrot, in the experiment started in 2020, *P. ramosa* shoots appeared at all observation terms and in 2021, at 342–356 days after sowing, while the number of shoots was small. In parsley, there were a few *P. ramosa* shoots that appeared only in the experiment started in 2020, and were not observed in subsequent years. Although they were higher and produced more capsules with seed than in carrots (Tables 2 and 3).

Table 1. The number of pots with *Phelipanche ramosa* shoots in vegetable crops from *Apiaceae* family

Cultivated plant	The number of pots with *P. ramosa* shoots (pcs.)														
	Experiments – years														
	2020/2021					2021/2022					2022				
	Days after sowing the seeds (DAS)*														
	110	117	144	186	340	160	293	311	327	342	105	120	127	135	188
Carrot	1	2	4	4	2	0	0	0	0	1	0	0	0	0	0
Parsley	0	2	3	2	2	0	0	0	0	0	0	0	0	0	0
Celeriac	0	0	0	3	5	0	2	3	5	5	1	2	3	4	4

* Observation dates: experiment 2020/2021 – DAS = 110 (2.09.2020), 117 (9.09.2020), 144 (9.10.2020), 186 (17.11.2020), 340 (20.04.2021), experiment 2021/2022 – DAS = 160 (29.12.2021), 293 (11.05.2022), 311 (29.05.2022), 327 (14.06.2022), 342 (29.06.2022), experiment 2022 – DAS = 105 (13.09.2022), 120 (28.09.2022), 127 (5.10.2022), 135 (13.10.2022), 188 (5.12.2022)

Table 2. The number of *Phelipanche ramosa* inflorescence shoots in the pots with vegetable crops from *Apiaceae* family

Cultivated plant	Average number of *P. ramosa* shoots in one pot												
	2020/2021				2021/2022				2022				
	Days after sowing (DAS)*												
	110	144	319	375	311	327	342	356	105	127	135	166	188
Carrot	0.4	3.2	2.2	2.5	0	0	0.3	0.6	0	0	0	0	0
Parsley	0	1.0	2.0	1.6	0	0	0	0	0	0	0	0	0
Celeriac	0	0	7.2	15.6	4.0	7.8	10.4	10.4	0.2	2.8	3.8	11.8	12.8

* Observation dates: experiment 2020/21 – DAS = 110 (2.09.2020), 144 (6.10.2020), 319 (30.03.2021), 375 (25.05.2021), experiment 2021/22 – DAS = 311 (29.05.2022), 327 (14.06.2022), 342 (29.06.2022), 356 (13.07.2022), experiment 2022 – DAS = 105 (13.09.2022), 127 (5.10.2022), 135 (13.10.2022), 166 (13.11.2022), 188 (5.12.2022)

The height of *P. ramosa* shoots depends on the year and date of observation (Table 3). In the experiment started in 2020, the height of *P. ramosa* shoots in pots with parsley and celeriac differed slightly, while in carrots, it was clearly lower. The highest shoots were observed in the pots with celeriac, in an experiment carried out in 2022. After 166 and 188 days of vegetation, their height was 23 cm (Table 3). The height of the shoots is related to the host plant and weather conditions. October was warm and sunny, which stimulated the growth of *P. ramosa* in the shade of densely leafed celeriac. Both tall and lower shoots flowered abundantly and produced seeds. Capsules with seeds appeared on the shoots, having already reached 1 cm above the ground. *P. ramosa* shoots grown in the pots with carrots were the lowest and produced the fewest capsules with seeds (Table 3). In the experiment carried out in 2022, *P. ramosa* plants were not visible in carrot and parsley, and intensive development of this parasite in pots with celeriac was noted. This experiment was completed in December 2022; hence, there is no data from the spring of the next year.

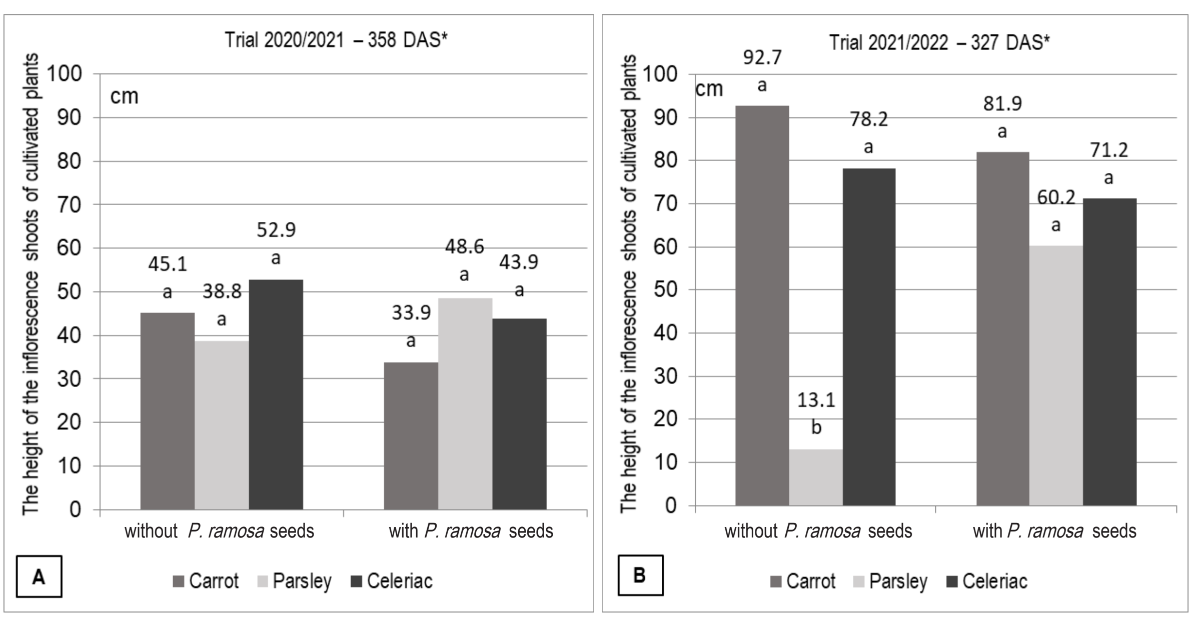
The differences between the height of inflorescence shoots of vegetable crops, growing in the presence and without of *P. ramosa*, were noted as trends, and were not always statistically significant (Figure 1A, B). In the experiment started in 2020, the height of inflorescence shoots of celeriac and carrot, at 322 days after sowing (April 2, 2021), grew without *P. ramosa* (control) was comparable to the shoots grown with the presence of *P. ramosa*. Later, a increase in the height of inflorescence shoots growing without *P. ramosa* was observed. After 358 days from sowing, in the experiment started in 2020, and after 327 days in the experiment started in 2021, the inflorescence shoots of carrot and celeriac grew without *P. ramosa* (control) were higher, in comparison to those growing in the presence of *P. ramosa*. A trend toward reduced growth of inflorescence shoots of carrots and celeriac grown in the presence of *P. ramosa* was observed, suggesting a potential harmful effect of this parasite. *Phelipanche ramosa* develops on the roots of host plants in the soil, therefore even if this parasite is not visible above the soil surface, its negative impact on the host plants may be revealed. In carrot and celeriac, no differences were found in the timing of inflorescence shoots emergence between the plants grown in the presence and without *P. ramosa*.

Table 3. The number of capsules with seeds and the height of the highest shoot of *Phelipanche ramosa* in vegetables crops from Apiaceae family

Cultivated plant	The number of capsules with seeds in one pot (2020–2022)	The height of the highest shoot of *Phelipanche ramosa* [cm]						
		Experiments – years						
		2020/2021		2021/2022		2022		
		Days after sowing (DAS)*						
	DAS 344-382	210	346	311	342	135	166	188
Carrot	2.1 [a]	9	3	–	3	–	–	–
Parsley	7.1 [a]	13	11	–	–	–	–	–
Celeriac	179.5 [b]	11	10	5	8	13	23	23

The same letters within column indicate no differences according to Newman-Keuls test at $p = 0.05$.
* Observation dates: experiment 2020/2021 – DAS = 210 (11.12.2020), 346 (26.04.2021), experiment 2021/2022 – DAS = 311 (29.05.2022), 342 (29.06.2022), experiment 2022 – DAS = 135 (13.10.2022), 166 (13.11.2022), 188 (5.12.2022)

Figure 1. Height of inflorescence shoots of vegetable crops, growing without and with *Phelipanche ramosa*, (A) at 358 DAS in 2020/2021 and (B) 327 DAS in 2021/2022



The same letters within figure indicate no differences according to Newman-Keuls test, at $p = 0.05$.
* DAS – days after sowing

Significant differences in the height of parsley inflorescences shoots were observed. Inflorescence shoots of parsley grown in the presence of *P. ramosa* were taller than those grown without the parasite (control). These differences were particularly evident in the experiment begun in 2021, during observations conducted 327 days after sowing. In this experiment, in the third decade of May (May 25, 2022), 307 days after sowing, only two inflorescence shoots exceeding 20 cm in height were observed in parsley grown without *P. ramosa* (control), whereas in the presence of *P. ramosa*, 11 shoots reaching 100 cm in height were observed, and these shoots were already beginning to flower. Such differences in the height of parsley inflorescence shoots may likely be because P. ramosa, under conditions of incomplete vernalization of parsley, stimulates the growth of inflorescence shoots. The vernalization process was described by Zurzycki and Michniewicz [1985], Kopcewicz and Lewak [1998, 2002]. This process is the effect of low temperatures of 0–10°C, which triggers the sprouting and flowering of biennial plants. Vernalization is influenced by plant age, day length, light intensity, gibberellin, ABA, kinetin, vitamin E, as well as other factors such as parasitism by *P. ramosa*.

DISCUSSION

Studies by many authors have shown that *P. ramosa* can parasitise many crop species and some weed species, but not all plants are good hosts for this parasite. *P. ramosa* seeds germinate only in the presence of germination stimulants released by the host plants [Bouwmeester et al. 2003, Cardoso et al. 2011]. In favourable thermal conditions and the presence of a good host, *P. ramosa* appears earlier and develops intensively, producing seeds.

The date of appearance of the first inflorescence shoots of *P. ramosa* in different crop species varied. In the studies, being the subject of this paper, the first shoots of *P. ramosa* appeared 105–117 days from sowing the seeds of the tested vegetable species. It was found that in tobacco, in warm climates, *P. ramosa* plants emerge at approximately 45 to 55 days [Lolas 1994, Wegmann 2004]. In Chinese cabbage, the first inflorescence shoots of *P. ramosa* appeared 97–102 days after planting [Anyszka et al. 2025]. In earlier experiments carried out with tomato [Borkowski and Dyki 2008], the first inflorescence shoots of *P. ramosa* appeared 62–74 days from planting the plants and showed vigorous growth [Borkowski et al. 2018]. It should be assumed that tomato roots produce more strigolactones, substances that stimulate the germination of *P. ramosa* seeds near the host roots [Akiyama and Hayashi 2006, Cardoso et al. 2011 Fernandez-Aparicio et al. 2011]. In addition, the tomato is grown from seedlings, therefore its root system was already developed, and earlier produced stimulants, so *P. ramosa* seeds had faster contact with the tomato roots. The date of appearance of the first shoots of *P. ramosa* may indicate which plant is a better host for this parasite. The presented results show that *P. ramosa* develops better on the roots of celeriac than carrot and parsley. Good hosts are also tomato [Disciglio et al. 2016] and tobacco [Wegmann 2004]. *Phelipanche ramosa* can also appear on the roots of *Galinsoga parviflora* [Anyszka et al. 2025], but this weed is rather a poor host.

The growth and development of *P. ramosa*, determined by the number of shoots produced and the number of capsules with seeds, depends on the availability of assimilates produced by the host plant, which the parasite can use through the root system [Buschmann 2004, Akiyama and Hayashi 2006, Dzierżyńska 2007] and a connection called haustoria. *Phelipanche ramosa*, like other broomrapes (*Orobanche* and *Phelipanche* spp.), during its underground life cycle, undergoes processes of germination, haustorial differentiation from the radicle, haustorial penetration of the host, and formation of a vascular connection with the host [Fernández-Aparicio et al. 2011]. It also affects the height of the *P. ramosa*. In the presented experiments, a different number of *P. ramosa* shoots was found in the tested vegetable species, as well as in individual years. The largest number of shoots, as well as the highest inflorescence shoots, were obtained in celeriac.

The study results show the varied impact of *P. ramosa* on the tested vegetable crops, with the timing of its entry into the plant being particularly important. The harmfulness of *P. ramosa* is greater if the parasite attacks the host plant in the earlier growth phase, and it is most severe when *P. ramosa* flowers and sets the seeds [Gibot-Leclerc et al. 2012, Borkowski et al. 2018]. *P. ramosa* can also parasitise some weed species like *Solanum nigrum* L., *Galinsoga parviflora* Cav., *Hyoscyamus niger* L., *Datura* *stramonium* L. [Vouzounis and Americanos 1998, Haidar and Sidahmed 2006, Anyszka et al. 2025], therefore it allows survival in the absence of host plant.

The height of carrot and celeriac inflorescence shoots was lower in the pots with *P. ramosa*, while in parsley, in pots without parasites. Such a difference in the height of parsley inflorescence shoots may likely be because *P. ramosa*, under conditions of incomplete vernalization of parsley, stimulates the growth of inflorescence shoots. The vernalization process was described by Zurzycki and Michniewicz [1985], Kopcewicz and Lewak [1998, 2002]. This process is the effect of low temperatures of 0–10°C, which triggers the sprouting and flowering of biennial plants. Vernalization is influenced by plant age, day length, light intensity, gibberellin, ABA, kinetin, vitamin E, as well as other factors such as parasitism by *P. ramosa.*

Climate change, particularly global warming, may increase the harmful effects of *P. ramosa*. In France, *P. ramosa* has already been shown to reduce the yields of celeriac cultivation [Gibot-Leclerc et al. 2014]. Based on the studies presented, it is reasonable to assume that in the future, *P. ramosa* could also become a significant pest of celeriac in Poland. This concern is supported by *P. ramosa* ability to produce numerous shoots, abundant flowers, and set seeds when it grows in proximity to celeriac.

CONCLUSIONS

It was found that *P. ramosa* can parasitize on the roots of carrots, parsley, and celeriac. The differences between tested plant species were observed in the time of appearance of the first *P. ramosa* inflorescence shoots, the number of the shoots, as well as in growth, flowering, and fruiting. *Phelipanche ramosa* produced the most inflorescence shoots in the pots with celeriac, and these shoots flowered abundantly and set seeds. The results indicate that celeriac is a better host for *P. ramosa* than carrot and parsley.

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