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European ground squirrels in backyard gardens: identifying and mitigating agricultural conflicts with an endangered species

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Abstract

European ground squirrels in backyard gardens: Identifying and mitigating agricultural conflicts with an endangered species. The European ground squirrel faces potential extinction in various countries, with populations decreasing throughout the entire range. Particularly in the Czech Republic, the mosaic landscape of private backyard gardens is now a vital habitat for the species. However, information regarding crop risks and effective, non-invasive measures for conflict mitigation are almost inexistent. To address this, we conducted field experiments examining the risk of damage for 18 common crops in backyard gardens, and tested non-invasive physical barriers to protect small plots. Our research reveals that simple fences are highly effective in safeguarding susceptible crops, particularly in areas with a high squirrel density. These findings contribute to the development of more species-specific, ecologically-based management plans and help create a sustainable future for the European ground squirrel.

Key words: *Spermophilus citellus*, Crop damages, Sustainability, Preventive measures, Rodent control, Human-wildlife conflict

Resumen

La ardilla terrestre europea en los huertos privados: detectar y mitigar los conflictos agrícolas con una especie en peligro de extinción. La ardilla terrestre europea se enfrenta a su posible extinción en varios países, ya que sus poblaciones están disminuyendo a lo largo de todo su rango de distribución. Particularmente en la República Checa, el paisaje en mosaico formado por pequeños huertos privados es hoy un hábitat vital para la especie. Sin embargo, casi no existe información sobre los riesgos que suponen las ardillas para los cultivos ni sobre medidas eficaces y no invasivas para mitigar los conflictos. Para abordar esta situación, realizamos experimentos de campo para examinar el riesgo de daño en 18 cultivos comunes en los huertos privados y estudiamos la eficacia de las barreras físicas no invasivas para proteger parcelas pequeñas. Los resultados muestran que instalar simples cercas es una forma muy eficaz de proteger los cultivos susceptibles, en particular en zonas con una alta densidad de ardillas. Estos resultados contribuyen a la elaboración de planes de manejo más específicos para la especie y más basados en su ecología, y ayudan a lograr un futuro duradero para la ardilla terrestre europea.

Palabras clave: *Spermophilus citellus*, Daños en cultivos, Sostenibilidad, Medidas preventivas, Control de roedores, Conflictos entre los humanos y la fauna silvestre

Introduction

How do we approach the conservation of an endangered species when its occurrence would directly affect farmers and backyard garden owners? This conflict is an example of one of the hardest challenges in conservation: ensuring healthy ecological levels for an endangered species without seriously conflicting with human interests (Aplin and Singleton 2003, Hein et al 2015). The European ground squirrel *Spermophilus citellus* (Linnaeus 1766) is a ground dwelling sciurid, endemic to Central and South-Eastern Europe, whose populations are in serious decline across most of their range (Hegyeli 2020). The main reason for this decline is the loss and degradation of its natural habitats: short-grass steppe, and similar semi-natural habitats, such as pastures and meadows, based on traditional agricultural practices (Grulich 1960, Kryštufek 1993, Hegyeli 2020). These habitats have been disappearing across the whole of Europe due to the intensification of agriculture, farmland consolidation, and the abandonment of grasslands, with the result being overgrown and scrubby habitats (Kryštufek 1993, Stoate et al 2009, Emmerson et al 2016, Hegyeli 2020). European ground squirrel populations are currently relegated to small islands within the species' remaining habitats, and to suitable artificial habitats such as airfields, camping grounds and other such sites with regularly mowed lawns (Matějů et al 2011, Hegyeli 2020, Matějů and Matoušová 2020, Rammou et al 2022). Traditional mosaic landscapes, based on private backyard gardens and small farms, are still in use in some areas, and provide one of the few remaining quality habitats for ground squirrels (Janák et al 2013, Matějů and Matoušová 2020).

Ground squirrels are predominantly herbivorous, feeding on wild grass, roots, leaves, fruits, seeds and flowers, and a variety of agricultural crops when available (Grulich 1960, Herzig-Straschil 1976, Ružić 1978, Dănilă 1984, Leššová 2010, Arok et al 2021). In the past, when the species was abundant and widely distributed, they were considered an agricultural pest, to the point of being subjected to nationwide control measures, as in Serbia and Macedonia, for example (Gradojević 1928, Ružić-Petrov 1950). Paid rewards were even offered for its killing, such as in rural areas of Austria or Czechoslovakia (Brinkmann 1951, Grulich 1960). In Czechoslovakia, Grulich (1960) mentions an occasion in 1949, in the Valtice municipality area, where 14,000 individuals were culled by locals, without any noticeable effect on the ground squirrel population. Nowadays, due to the endangered status of the ground squirrel and the small size of its populations across all of its range, conflicts with landowners are rare and localised, but if conservation efforts are successful (Janák et al 2013, Matějů and Matoušová 2020), we might expect them to increase both in number and severity.

Among the few existing studies about the diet of the European ground squirrel, despite its reputation as a pest, only Grulich (1960) mentions the conflict of ground squirrels with agriculture, focusing only on large, commercial farming, such as the cultivation of grain and fodder fields. Knowledge of the interaction between ground squirrels and suburban gardens is lacking. Similarly, our only knowledge about the control of the damage caused by European ground squirrels is based on their previous status as a pest (Grulich 1960), so there are virtually no studies on the effectiveness of non-invasive methods to prevent potential damage from European ground squirrels to agriculture. Hence, our study had two aims. The first of these was to identify the risks of damage to the most commonly cultivated crops in backyard gardens in the Czech Republic. To this end, we designed an experimental setup that mirrored a typical backyard garden environment. We provided wild ground squirrels unrestricted access to small plots with crops typically grown in Czech backyard gardens. Our second aim was to identify an efficient strategy to protect small plots in backyard gardens using a minimum amount of materials and effort. We conducted long-term experiments on small garden plots to evaluate the efficacy of simple physical barriers. To design the most effective and practical barrier using the least amount of materials, we sought to answer the following questions: 1) will ground squirrels access a plot that is enclosed by fencing on the sides, but not on the top? and 2) will they intentionally dig under a barrier to access a protected plot?

Methods

Study site

To assess the potential damages to crops commonly cultivated by backyard garden owners in the Czech Republic, we set experimental plots during 2021 and 2022 in an apricot orchard in the outskirts of Hrušovany u Brna (49° 2' 19'' N 16° 35' 39'' E), a village in Brno-Country District in the South Moravian Region of the Czech Republic. The orchard is located in the centre of a ground squirrel colony monitored since 2008 (AOPK ČR 2008). The area covered by this population (42 ha) is a mosaic of small orchards (28 %), vineyards (26 %), ploughed and crop fields (26 %), gardens (5 %), and other grassy habitats (15 %). This diverse environment provides ground squirrels with a variety of food sources, including grass, fruits, fruit stones, nuts in orchards, and various crops in the fields.

The experimental orchard (0.6 ha) is surrounded by a woven-wire fence with a 10 cm opening that allows ground squirrels to enter and exit but prevents larger herbivores such as European hares *Lepus europaeus* and roe deer *Capreolus capreolus*, abundant in the area, from getting in. Within the orchard, lines of trees on ploughed ground alternate with 2 m wide patches of grass. Adjacent lands include grassy vegetation with fruit trees and alfalfa and wheat fields providing additional food sources for ground squirrels. Ground squirrels residing in or visiting the experimental orchard are often observed moving between these areas.

The ground squirrel population in this locality was estimated at 350 individuals in 2021 and 400 individuals in 2022 (Matějů and Brzobohatá 2022). Ground squirrels dig and inhabit burrow systems for refuge and hibernation (Ružić 1978, Lagaria and Youlatos 2006). Counting these burrows is a common method to obtain a proxy of the occurrence and abundance of ground dwelling mammals as there is a correlation between the number of active burrows and density of individuals (Biggins et al 1993, Hubbs et al 2000, McDonald et al 2011, Janák et al 2013). We counted all the ground squirrels' burrow openings in the experimental orchard, resulting in a density of 310 holes/ha in 2022. The estimated number of ground squirrels burrowing within the orchard was approximately 40 individuals.

Testing damage risks for the most common crops

We planted 18 varieties of crops in 37 small plots (1 x 2 m) between the trees of the orchard (see table 1). The size of the experimental plots reflected the typical size of backyard garden plots in the area. We followed the local crop-planting calendar and adhered to recommended care guidelines for each species, including regular watering and weeding. We selected the most common and easiest to grow crops, taking into account local traditions and regional availability. The choice of using seeds or seedlings was also influenced by the availability of these resources. These plots were left unprotected, except for the fence surrounding the entire orchard.

Testing physical barriers

We conducted 13 long-term tests to evaluate the effectiveness of simple physical barriers (table 1). For this purpose, we used woven-wire, metal-framed fences with dimensions of 1 x 1 x 0.5 m and a mesh size of 1 cm (fig. 1s in supplementary material) to protect seven crop varieties across nine plots: cauliflower (n = 1), broccoli (n = 1), lettuce (n = 1), kohlrabi (n = 2), peas (n = 1), beans (n = 2), and cabbage (n = 1). Additionally, we tested four plots (one each of cabbage, kohlrabi, cauliflower, and broccoli) by enclosing them on all sides, including the top, using cold frames: small greenhouses measuring 2 x 0.5 x 0.5 m (fig. 4s in supplementary material). For all tests, we used seedlings to provide immediate visual and olfactory stimuli for the squirrels. The fences and cold frames were firmly planted approximately 4 cm deep into the soil. Both protected and unprotected plots were continuously monitored by camera traps (Bunaty Mini full HD, ScoutGuard Predator). Additionally, we conducted weekly in-person inspections of each plot, carefully monitoring crop growth progression and noting any observable incidents of consumption. We allowed each experimental crop to grow until: a) it was completely consumed, b) it was ready to harvest, or c) the seeds were not sprouting after 4 weeks. We then counted the number of surviving plants or seeds, if any, and compiled our data from direct observations and camera traps to identify the location of the damage in the plants or seeds, and to estimate the speed of such damage.

Among those crops planted as seedlings we next compared the number of plants that reached the harvesting stage in the protected group with the number that reached this stage in the unprotected groups. Finally, within the protected crops, we identified any potential cases of top breaching or digging under the protection.

All analyses were performed using R Statistical Software, v4.2.2 (R Core Team 2022), and data were processed using the package *Tidyverse* (Wickham et al 2019).

Results

Testing damage risks for the most common crops

The results of our experimental tests of damage to crops are summarised in table 1. Ground squirrels completely damaged most of the tested plots, except for those planted with leek and onion. Corn was only partially consumed once it sprouted. Potatoes also grew to reach the harvest stage, and their tubers were untouched in 2021. In 2022, however, the vegetative parts of the potato plants were partially consumed and the tubers were bitten.

Seedlings of lettuce, kohlrabi, cauliflower, cabbage, celery, and broccoli were all eaten between one and five days after being planted according to the timestamps of our camera traps and/or our in-person controls. From the camera trap footage we were unable to calculate the actual time of sprouting after seeds were planted but through our weekly in situ inspections we were able to ascertain whether plants had been consumed since the last visit. The larger seeds (peas, beans, sunflowers) were dug out and consumed. Small seeds, such as carrots or radish, survived until sprouting, and were then promptly consumed.

We did not observe any other animals consuming plants, either directly or in our camera traps, and there were no signs of other rodents.

Testing physical barriers

Crop yields were significantly higher in protected plots than in non-protected plots (table 2, Mann-Whitney U test, $W = 4.5$, $p < 0.001$, effect size 0.81). Both wire-woven fences and cold frames were successful in preventing damage to the crops and the harvesting stage was reached in all such cases (n = 13, table 3). Diggings under the protection were detected in 23 % (n = 3) of all trials. In these cases, our direct observations and videos showed that ground squirrels took advantage of two cold frames and a fence that were installed on mounds. The elevated beds enabled rainwater reveal the edges of the frames, thus indicating to the ground squirrels where to dig to access the crops (fig. 2s in supplementary material). However, when the structures were firmly attached to level ground without elevation, ground squirrels did not exhibit intentional digging behaviour and failed to access the crops (fig. 3s in supplementary material). In the trials where only the sides of the plot were protected (fences, n = 9, table 3), we observed a juvenile ground squirrel inside the plot on one occasion, seemingly having fallen in. However, it showed no interest in the plants (video 1s in supplementary material), which eventually grew to the harvest stage.

Discussion

The results from our first experiment, testing unprotected common species cultivated in backyard gardens, demonstrated a significant risk to most types of crops, with the squirrels completely consuming almost all types of plants, except leek and onion, within a short period after planting. Seedlings were promptly consumed, whereas those planted as seeds prompted

Table 1. List of crops and their vulnerability to ground squirrels in experimental unprotected plots (1 x 2 m), plots protected with cold frames (2 x 0.5 x 0.5 m) and plots protected with wire fences (1 x 1 x 0.5 m): PlM, planting method; PrM, protection method; NP, number of plants/plot; NH, number of harvested plants.

Tabla 1. *Lista de cultivos y de su vulnerabilidad ante las ardillas terrestres en parcelas experimentales no protegidas (1 x 2 m), parcelas protegidas con invernaderos (2 x 0,5 x 0,5 m) y parcelas protegidas con cercas de alambre (1 x 1 x 0,5 m): PlM, método de plantación; PrM, método de protección; NP, número de plantas/parcela; NH, número de plantas cosechadas.*

Plot	Plant	Scientific name	Year	PlM	PrM	NP	NH	Damage location	Speed of damage
1	Bean	*Phaseolus vulgaris*	2021	Seeds	No	20	0	Seeds and mature parts	Immediate
2	Bean	*Phaseolus vulgaris*	2021	Seeds	No	20	0	Seeds and mature parts	Immediate
3	Bean	*Phaseolus vulgaris*	2022	Seeds	No	16	0	Seeds and mature parts	Immediate
4	Bean	*Phaseolus vulgaris*	2022	Seeds	No	32	0	Seeds and mature parts	Immediate
5	Bean	*Phaseolus vulgaris*	2022	Seedlings	Wire fence	27	16	No ddamage	NA
6	Beet	*Beta vulgaris vulgaris*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
7	Beet	*Beta vulgaris vulgaris*	2021	Small seeds	no	Not counted	0	Green parts	Upon sprouting
8	Broccoli	*Brassica oleracea* var. italica	2021	Seedlings	Cold frame	12	9	No damage	NA
9	Broccoli	*Brassica oleracea* var. italica	2021	Seedlings	No	12	0	Seedling	Within 5 days
10	Broccoli	*Brassica oleracea* var. italica	2021	Seedlings	Wire fence	9	8	Seedling	Within 5 days
11	Cabbage	*Brassica oleracea* var. *capitata*	2021	Seedlings	Cold frame	9	9	Seedling	Within 5 days
12	Cabbage	*Brassica oleracea* var. *capitata*	2021	Seedlings	No	21	0	Seedling	Within 5 days
13	Cabbage	*Brassica oleracea* var. *capitata*	2021	Seedlings	No	10	0	Seedling	Within 5 days
14	Cabbage	*Brassica oleracea* var. *capitata*	2021	Seedlings	Wire fence	9	8	No damage	NA
15	Carrot	*Daucus carota sativus*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
16	Cauliflower	*Brassica oleracea* var. *botrytis*	2021	Seedlings	Cold frame	12	12	No damage	NA
17	Cauliflower	*Brassica oleracea* var. *botrytis*	2021	Seedlings	No	21	0	Seedling	Within 5 days
18	Cauliflower	*Brassica oleracea* var. *botrytis*	2021	Seedlings	No	10	0	Seedling	Within 5 days
19	Cauliflower	*Brassica oleracea* var. *botrytis*	2021	Seedlings	Wire fence	9	9	No damage	NA
20	Celery	*Apium graveolens*	2021	Seedlings	No	10	0	Seedling	Fast (26 hrs)
21	Corn	*Zea mays*	2021	Seeds	No	20	0	Leaves	Within 10 days
22	Corn	*Zea mays*	2021	Seeds	No	20	10	Leaves	Within 10 days
23	Kohlrabi	*Brassica oleracea* var. *gongylodes*	2021	Seedlings	Cold frame	18	0	Seedling	Within 5 days
24	Kohlrabi	*Brassica oleracea* var. *gongylodes*	2021	Seedlings	No	21	0	Seedling	Within 5 days
25	Kohlrabi	*Brassica oleracea* var. *gongylodes*	2021	Seedlings	Wire fence	21	19	No damage	NA
26	Kohlrabi	*Brassica oleracea* var. *gongylodes*	2022	Seedlings	Wire fence	12	10	No damage	NA
27	Kohlrabi	*Brassica oleracea* var. *gongylodes*	2022	Seedlings	Wire fence	10	8	No damage	NA
28	Leek	*Allium porrum*	2021	Small seeds	No	Not counted	33	Leaves	Around 30 days
29	Lettuce	*Lactuca sativa*	2021	Seedlings	No	20	0	Seedling	Fast (between 20 and 50 hours)
30	Lettuce	*Lactuca sativa*	2021	Seedlings	No	13	0	Seedling	Fast (between 20 and 50 hours)
31	Lettuce	*Lactuca sativa*	2021	Seedlings	Wire fence	9	9	No damage	NA
32	Onion	*Allium cepa*	2021	Bulb	No	22	21	Leaves	Around 30 days
33	Onion	*Allium cepa*	2021	Bulb	No	27	24	Leaves	NA
34	Onion	*Allium cepa*	2021	Bulb	No	24	19	Leaves	NA
35	Parsley	*Petroselinum crispum*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
36	Pea	*Pisum sativum*	2021	Seeds	No	30	0	Seeds and mature parts	Immediate
37	Pea	*Pisum sativum*	2021	Seeds	No	30	0	Seeds and mature parts	Immediate
38	Pea	*Pisum sativum*	2022	Seeds	No	32	0	Seeds and mature parts	Immediate
39	Pea	*Pisum sativum*	2022	Seeds	No	32	0	Seeds and mature parts	Immediate
40	Pea	*Pisum sativum*	2021	Seeds	No	30	0	Seeds and mature parts	Immediate
41	Pea	*Pisum sativum*	2022	Seeds	Wire fence	15	8	No damage	NA
42	Potato	*Solanum tuberosum*	2021	Bulb	No	10	10	No damage	NA
43	Potato	*Solanum tuberosum*	2021	Bulb	No	10	10	No damage	NA
44	Potato	*Solanum tuberosum*	2022	Bulb	No	10	10	Tubers and plants	Around 30 days
45	Potato	*Solanum tuberosum*	2022	Bulb	No	10	10	Tubers and plants	Around 30 days
46	Radish	*Raphanus sativus*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
47	Radish	*Raphanus sativus*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
48	Spinach	*Spinacia oleracea*	2021	Small seeds	No	Not counted	0	Green parts	Upon sprouting
49	Spinach	*Spinacia oleracea*	2021	Small seeds	No	Not counted	0	Green Parts	Upon sprouting
50	Sunflower	*Helianthus annuus*	2021	Seeds	No	Not counted	0	Seeds	Immediate

Table 2. Comparison of different protection methods on harvest output for crops planted as seedlings. Mean harvest indicates the mean number of plants reaching the harvesting stage for each category: NP, total number of plots; MH, mean harvest; SE, standard error.

Tabla 2. Comparación de la producción de la cosecha entre los diferentes métodos de protección de los cultivos sembrados con plantones. "Mean Harvest" indica la media de plantas que alcanzaron la fase de cosecha respecto de cada categoría: NP, número total de parcelas; MH, cosecha media; SE, error estándar.

Protection method	NP	MH	SE
Total protected	13	9.62	1.24
~Wire fence	9	10.56	1.36
~Cold frame	4	7.50	2.60
Total unprotected	9	0.00	0.00

Table 3. Summary of results for the long-term physical barrier tests. Intentional digging was detected in three out of 13 tested infrastructures (23 %). An apparently unintentional top side breaching was detected only once during both tested seasons, in one out of the nine plots with unprotected top sides: ID, intentional digging TB, top side breaching.

Tabla 3. Sumario de los resultados para las pruebas de largo plazo con las barreras físicas. Las ardillas excavaron de forma intencionada bajo tres de las 13 protecciones (23 %). Detectamos sólo un caso durante las dos temporadas en el que un juvenil de ardilla pareció haber entrado por arriba de forma inintencionada, en uno de los nueve cercados sin la parte superior protegida: ID, excavación inintencionada; TB, ruptura del lado superior.

Protection type	N = 13	ID	TB
Cold frame	4	3 (23 %)	NA
Fence	9		1 (11 %)*

different behaviours. Large seeds such as peas *Pisum sativum*, beans *Phaseolus vulgaris* and sunflowers *Helianthus annuus* were dug out and consumed. Smaller seeds remained untouched, perhaps undetected, until sprouting, and then most of them were consumed when young and tender, except for leek *Allium orrum*, which was only nibbled at and showed negligible damage. Damage to onion plants *Allium cepa* was also negligible. The leaves of corn *Zea mays* were only partially eaten but the cobs did not develop.

With the exception of celery *Apium graveolens* these results coincide with the few specific mentions in the existing literature regarding damages caused by European ground squirrels (Grulich 1960, Herzig-Straschil 1976). In our test, the celery seedlings we used were quickly consumed by ground squirrels, contradicting the owner of a nearby garden who claimed to be unaffected by these animals and successfully grew celery without any protective measures. There could be several reasons for this discrepancy, such as timing or place of planting, density of ground squirrels, and even individual preference. Perhaps celery, with its sharp taste and smell, stringy texture, and poor nutritional value, might not be the first choice for a ground squirrel in the presence of more attractive alternatives.

Farmers in the area identified potatoes as a vulnerable crop (personal communication). We planted potatoes in two separate years, with opposite results. Ground squirrels did not consume any part of the plant in our 2021 experiments. However, in 2022 they nibbled some tubers and pruned the vegetative parts of the plant, although they did not consume these completely during our experiments. Potato plants, members of the Solanaceae family, contain glycoalkaloids. These compounds may be involved in protecting the plant against phytopathogens as they can be toxic to humans and, to a lesser degree, to rodents (Willimott 1933, Maga and Fitzpatrick 1980, Friedman 2006). Their presence could help to explain why ground squirrels seem to consider potato plants only partially palatable and why they did not consume this crop in our 2021 experiments. In 2022, however, a severe drought severely limited the availability of sources of water. Ground squirrels, originally a steppe species, obtain most of their water through their food (Grulich 1960), and potato plants were probably some of the few water sources left during the drought. This hypothesis, shared by farmers living in the area, could explain why, both in our experimental plots and in neighbouring fields, ground squirrels resorted to biting tubers and potato stems despite the availability of other food sources such as seeds or ripe wheat. The specific effect of glycoalkaloids on the European ground squirrel is unknown, but we did not observe any sick or dead individuals near any potato field. Given the high value farmers give to this crop and the fact that ground squirrels seem to prefer other vegetables, any effective measure to protect potato plants should be a strategic priority in future conservation plans. A measure worth trying could be as simple as providing ground squirrels with a water source. We confirmed that ground squirrels drink water directly when an artificial water dispenser is provided in the field, but the effectiveness of this measure remains to be tested.

We conducted the study in an area with one of the highest densities of European ground squirrels within the Czech Republic. In this situation, farmers and gardeners face a very limited choice regarding what they can grow without protection, and our results confirm that their complaints are justified. Naturally, lower densities of animals could differ significantly in their potential damage to crops and the speed at which this occurs. Similarly, our tests were designed to replicate typical, small, backyard garden plots (1 x 2 m). In larger plots, particularly for taller densely growing plants, such as grain, sunflower, or corn, the damage tends to be localised around the edges of the plantation as the ground squirrels –like some other species– do not dare venture deep inside the fields, according to Grulich (1960) and to our own unpublished data and (Canavelli et al 2012, Senar et al 2016).

Our results confirm a clear risk of conflict between ground squirrels and owners of backyard gardens, highlighting the need for prevention and mitigation measures.

In the past, the methods employed were largely invasive, involving poisons, guns, and deadly traps (Grulich 1960, Turček 1964). Nowadays, toxicants are still considered the most effective and frequently used tool to control close relatives of the ground squirrel, such as the California ground squirrel *Otospermophilus beecheyi* in the US (Baldwin et al 2014). Back in Europe, any lethal or harmful method would be illegal to use against the European ground squirrel, given its status as an endangered species. Nevertheless, multiple poisons are still easily accessible and frequently used against other rodents, particularly voles, with the legal consent of authorities (Aulicky et al 2022). Many concerned gardeners would not hesitate to use rodenticides, knowingly or unknowingly, on an endangered species like the European ground squirrel. Furthermore, if not monitored and managed, human wildlife conflicts can exert sufficient social and economic pressure to drive poor political management decisions, despite scientific evidence (Ferreira et al 2012). Hence, it is imperative to investigate accessible, non-lethal, and effective alternatives if we want to avoid the use of invasive methods. In our second experiment we tested the effectiveness of simple, inexpensive physical barriers to protect backyard garden plots. Results revealed that these simple barriers effectively mitigated crop damage, increasing crop yields significantly, particularly when installed correctly on level ground.

Our tests aimed to answer two main questions: 1) will the ground squirrels breach into the plots from the top side if we do not protect it? and 2) will they purposely dig under barriers to get access to the plots? Our videos and direct observations confirm that European ground squirrels do climb up fences, but at least intentionally, they seemed unable to climb down to the inside of the barrier once they reached the top. Nevertheless, a close relative species, Richardson's ground squirrels *Spermophilus richardsonii*, have been documented to climb over wire mesh (Witmer et al 2012). In our tests, ground squirrels were able to dig a hole under some of the fences, but they did so only on three occasions when the rain had uncovered part of the lower end of the barrier edge. Most often, ground squirrels appeared in our videos and images actively exploring around the barrier, searching for an existing entrance, but if the barrier (fence or cold frame) stayed firmly attached to the ground, they did not show any intentional digging behaviour, suggesting that they lack this spatial ability. We only monitored the experiments in person once a week, so we were unable to prevent these effects of erosion, but for a garden owner it would be easy to monitor and repair these vulnerabilities before the ground squirrels could take advantage of them. On a few occasions, ground squirrels dug diagonal holes directly under the plots, but there were no exit holes in the plots and the plants remained untouched, supporting the hypothesis that their digging is unintentional. Even if unintentional, ground squirrels could dig up an exit and appear in the protected plot by chance. Witmer et al (2012) proposed using a pea-sized gravel-filled trench. They reported that this worked successfully as a below ground barrier against Richardson's ground squirrels, and could be used in specific situations, such as surrounding a fenced garden or a larger plot.

It could be argued that it would only be a matter of time until squirrels learn to dig purposefully or climb over a fence. Our experiments were conducted during the season when young ground squirrels are most inquisitive and likely to explore their surroundings, and the experiments also covered the full cycle of planting, growing, and harvesting of multiple crops, for two seasons. Despite those favourable circumstances, we did not observe any signs of purposeful digging. Perhaps the negative effect of hibernation in memory retention and learning abilities (Millesi et al 2001) hinders squirrels from effectively building upon any acquired knowledge from the previous year.

We did not test electric fences. Even though they are commonly and effectively used for large animals such as cattle or deer (Mason 1998), they are not considered a practical solution for rodents due to their limited effectiveness and high cost (Shumake et al 1979, Marsh 1994), particularly in the case of small farm owners, for whom the value of the crop would not justify the purchase of such a device. Specific, custom designs might be effective (Witmer et al 2012), but at least in Europe, currently available commercial devices are aimed at larger animals, and field tests in Slovakia have demonstrated that European ground squirrels can cross them easily (Katerina Tuhárska, pers. comm.).

In conclusion, our results show that high densities of European ground squirrels have the potential to enter into conflict with the interests of people with backyard gardens and small farm owners. European ground squirrels consume most varieties of common crops cultivated on small farms, with the exception of the Allium family. Some habitat or environmental modifications, such as providing water during drought periods, might reduce the risk for the least attractive crops for the ground squirrels, such as potatoes. Physical barriers can be successful and cost-effective, and should be part of ecologically-based rodent management plans (Singleton et al 1999, Aplin and Singleton 2003). Combined with targeted outreach actions, such as informational local events or publication of informational brochures (Poledníková and Poledník 2023), these measures could help to minimise future conflicts and avoid the related social and economic pressure for more immediate responses such as lethal control, which could dramatically set back the conservation of any endangered species.

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Author contributions
LP, KP and FMG designed the study. LP, KP and FMG collected field data. FMG and KP analysed the data. FMG wrote the manuscript with significant input from all co-authors. All authors read and approved the final manuscript.

Conflicts of interest
No conflicts declared

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Supplementary material

Fig. 1s. Woven-wire, metal-framed fence.

Fig. 1s. *Cerca de alambre.*

Fig. 2s. Intentional digging after the rain uncovered the bottom of the fence.

Fig. 2s. *Excavación intencionada después de que la lluvia haya dejado al descubierto la parte inferior de la cerca.*

Fig. 3s. Holes under the fence, with no exit inside the protected plot. The plants grew untouched to harvest stage.

Fig. 3s. *Agujeros debajo de la cerca que no tienen salida dentro la parcela protegida. Las plantas crecieron intactas hasta la fase de cosecha.*

Fig. 4s. Cold frame.

Fig. 4s. *Invernadero.*

Video 1s. Young European ground squirrel inside a fenced experimental plot, when he partially inadvertently fell inside. He does not show interest in planted crops, but figures out how to get out.

Accessible at: https://youtu.be/NaOEouK3kDI