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SHORT COMMUNICATION

The possibility of using potassium octadecanoate ($C_{17}H_{35}COOK$) in protection of broadleaf and conifer tree plantations against damages caused by cervids

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ABSTRACT

The study on the potential use of potassium octadecanoate ($C_{17}H_{35}COOK$) in the protection of silver fir, Scots pine and sessile oak against browsing and bark stripping by cervids on ten 0.1 ha study plots in the Jeleśnia and the Radomsko Forest Districts during the autumn and winter season 2021 and 2022 was carried out. Naturally regenerated trees *Abies alba*, *Pinus sylvestris*, and *Quercus petraea* were treated with potassium soap and Cervacol Extra PA repellent. For each tree species four study plots were established where 200 trees (100 treated by repellent and 100 untreated) selected randomly were tested. Moreover, at one plot, as a pilot study where early thinning was performed prior, an additional 60 Scots pines were left as browsing trees to evaluate the protective effect of potassium stearate. Damage inspections on research plots were carried out twice per month by checking the extent and degree of damages. Potassium octadecanoate protected best on the older Scots pine plantation, since it had a significant impact on the trees protection in relation to pines free from repellent. In the case of natural regenerated fir trees, a significantly higher percentage of damaged trees protected with Cervacol Extra PA was found compared to silver fir trees protected with the use of potassium octadecanoate. At the sessile oak plots protected with both tested repellents, no significant differences were found in the extent and degree of damage to trees. It was shown that potassium octadecanoate persists on protected plants maintaining an intense odour and durability during storage over the winter period. Considering the satisfactory results and the original research profile (besides ecological character of the substance), it is recommended to continue field experiments with the use of potassium octadecanoate in protecting forest plantations and natural regenerated stands against damage caused by cervids. Further research could consider enrichment of the substance composition with a quartz sand as well as increase the number of experimental plots and their distribution in various regions of the country.

KEY WORDS

bark stripping, browsing, ecological substances, forest protection, game management, potassium soap, repellents

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Introduction

Damages caused by cervids are one of the main biotic threats in silver fir *Abies alba* Mill. and Scots pine *Pinus sylvestris* L. stands in Poland. Especially saplings which are within height range of deer feeding are particularly sensitive to damage caused by game (Szukiel, 2001; Ślusarski, 2020). In the years 2015-2019 in Poland, the area of trees of different species damaged by game amounted to 152,811.07 ha of which as much as 37% of the damage was economically significant (Ślusarski, 2019). The reason for this phenomenon is the very high level of red deer *Cervus elaphus* L. and roe deer *Capreolus capreolus* L. population over the last 10 years (Panek and Budny, 2015), which was estimated to be 265,621 *C. elaphus* individuals in 2020 and 886,442 *C. capreolus* (BDL, 2022). These values are many times higher than the average number of deer in other European countries (Putman and Moore, 1998; Dzięciołowski, 2011). Similarly, in recent years the increase in deer numbers has been noticed in the USA, Canada (Côté *et al.*, 2004), New Zealand (Fraser *et al.*, 2000) and Japan (Iijima *et al.*, 2023), where abundant deer browsing (Rooney and Waller, 2003; Filazzola *et al.*, 2014; Pinchot *et al.*, 2022) has caused severe economic losses in the forest economy (Gill, 1992; Conover *et al.*, 1995; Ward *et al.*, 2004). The proper game management and deer population reduction allow the recovery of vegetation communities (Jenkins and Howard, 2021).

A significant problem, apart from the number of animals, is the age and gender structure of the population which translates into its feeding habits (swarms with a large number of young individuals are characterized by increased nutritional demand and nutritional imitation of feeding) and intensification of damage to forests. Observed climate changes and the accompanying increase in air temperature, mild winters, and shortening of the snow cover period limit natural selection of individuals and increase the survival of Cervidae (Post *et al.*, 1999; Dzięciołowski, 2011; Spake *et al.*, 2020). Other factors contributing to the intensification of damage to forests caused by deer include incorrect hunting management, *i.e.* the use of an inappropriate proportion of food in the game's diet and year-round feeding with high-energy food thereby increasing the reproductive potential of animals. Anthropopressure and the associated fragmentation of forest areas which hinder the migration of animals have a significant impact on the level of damage to forests caused by game (Szukiel and Nasiadka, 1994; Mathisen *et al.*, 2018; Borowski *et al.*, 2020; Jenkins and Howard, 2021).

The basis for protective measures to reduce damage to forests caused by cervids are the results of an inventory of the animal population and the damage caused by them which is carried out annually in April and May. The available solutions for protecting tree stands against damage caused by game include biological, mechanical and chemical methods. The latter includes the use of repellents (mostly classified as synthetic chemicals), *i.e.* agents that deter animals from valuable parts of forest stands through scent, taste, mechanical or complex effects (Szukiel, 2001). Repellents are widely used in Europe due to their high effectiveness in the protection of trees (Bergquist and Örlander 1996; Stutz *et al.*, 2019) and also in North American countries like the USA (Nolte, 1998; Redick *et al.*, 2020). On the other hand, protecting crops with repellents, although a procedure that brings positive results, has certain limitations in practice related to weather conditions or the animals' habituation to a given substance (MacGowan *et al.*, 2004; Węgorek, 2005; Iijima and Oka, 2023). Previous studies have shown that repellents are sometimes effective in protecting planted trees (Andelt *et al.*, 1994; Conover *et al.*, 1995; El Hani and Conover, 1997; Nolte, 1998) and other times not (Elmeros *et al.*, 2011). Furthermore, even when dense repellents are applied frequently, they cannot protect 100% of planted trees (Ward and

Williams, 2010). The use of repellents in the form of chemical protection is not very effective (Cislerová, 2001). Regular reapplication of repellents is laborious and does not achieve lasting effects (Stutz, 2019).

Due to the restrictions introduced in the EU in 2009 regarding the use of chemicals in the natural environment (Article 14 of Directive 2009/128/EC of October 21, 2009 establishing a framework for community action for the sustainable use of pesticides [Journal of Laws EU Office L 309 of 24/11/2009, p.71] and Regulation No. 1107/2009 of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC [Journal of Laws. EU Office L 309 of 24/11/2009, p. 1]) and the resulting obligation to comply with the principles of integrated plant protection at the beginning of 2014 (Głowacka, 2013a, b; Kurrer, 2021), the search for alternative and environmentally friendly substances and methods of forest protection against damage caused by cervids has become highly important (Gerhardt *et al.*, 2013; Bernacka *et al.*, 2015). These include the use of agents of natural origin such as potassium octadecanoate ($C_{17}H_{35}COOK$), which is commonly known as potassium stearate, could be taken into consideration. Potassium octadecanoate is based on plant acids with the addition of potassium alkali. The agent has a greasy consistency, light brown color, and an intense smell that is unfamiliar in forest ecosystems. Potassium soap is biodegradable and water-soluble and has been approved for use in organic farming in the European Union. This compound is widely used in horticulture to combat mites from the spider mite family (Acari, Tetranychidae), insects from the aphid superfamily (Hemiptera, Aphidoidea) (Tartanus *et al.*, 2019) and common fungal diseases such as gray mold caused by the pathogen Staphylococcus gray *Botrytis cinerea* Pers. (Ascomycota, Sclerotiniaceae) among others (Mazik, 2016; Przybylak, 2020). In turn, American scientists (Gills and Raupp, 1989; Miller, 1989) drew attention to the possibility of using potassium stearate to reduce the occurrence of harmful foliophagous insects especially in the event of the appearance of an alien invasive species.

Potassium stearate as a detergent is considered a safe, effective and low toxicity alternative to more toxic pesticides as it is non-toxic to animals and birds, and therefore has many advantages when compared to other insecticides. Other detergents such as dish and clothes washing detergents are far too harsh to use on plants because of various additives in them. Therefore, some soaps and detergents, even though they are poor insecticides, have additives in them that may be phytotoxic and some plants might be sensitive to soap and may be injured by it. From tree species taxa sensitive plants include hawthorn *Crataegus* spp., cherry *Prunus* spp., plum *Prunus* spp., horse chestnut *Aesculus hippocastanum* L., mountain ash *Sorbus* spp., and Japanese maple *Acer palmatum* Thunb. It has been reported that conifer species may be sensitive to soap but only under drought conditions. It is also known that the water quality used during insecticidal soap treatment has an impact on the effectiveness of treatment. Presence of calcium, magnesium and iron in water solution cause the fatty acids to precipitate out of the solution causing the soap to be ineffective (Cranshaw, 2008). Furthermore, other authors have reported the impact of high temperatures (above 32°C) or the application of soap insecticides in full sun to cause damage to plants. High temperatures and high humidity may increase plant stress, and therefore higher sensitivity to soap insecticides (Ubl and Munnerlyn, 2021). However, the common use of repellent Cervacol Extra PA in Europe may also cause significant phytotoxic effects that were confirmed in Scots pine and Norway spruce *Picea abies* (L.) Karst. seedling protection (Bergquist and Örlander, 1995).

Therefore, the use of potassium stearate as natural, safe to plants and additive-free to protect silvicultural crops against browsing by cervids may be an interesting alternative to currently used synthetic repellents. It has been assumed that the presence of a foreign substance in the natural environment which is unknown to animals will contribute to the protection of forest crops and young forests by reducing the nutritional attractiveness of plants. With the above in mind, an attempt was made to verify the following hypotheses: (i) protecting trees with potassium stearate will significantly reduce the size and degree of damage caused by game, (ii) the effectiveness of tree protection using potassium octadecanoate, a substance of natural origin unknown to animals, will be higher than the effectiveness of tree protection using traditional repellents of synthetic origin. Therefore, the aim of the research was to assess the effectiveness of the use of potassium octadecanoate in protecting silver fir, Scots pine and common oak young trees as well as a comparison of its effectiveness in reducing damage caused by animals as compared to reference trees and the use of the commonly used repellent Cervacol Extra PA.

Materials and methods

Experiment design. The research was carried out in the mountain area (from January 21 to April 1, 2021) of Jeleśnia Forest District, Romanka Górna Forest Division (N: 49.6064, E: 19.2593), comp. 250g and in the lowland area (from November 26, 2022 to March 26, 2023) of Radomsko Forest District, Masłowice Forest Division (N: 51.1132, E: 19.7674), comp. 95f, 97d, 98d, 99f, and 114a (Fig. 1) which are area where damages caused by red deer and roe deer recur every year. The number of cervids in the Romanka forest area was 42 deer and 43 roe deer based on the inventory by the 'Jeleń' Hunting Association in Sopotnia Wielka on 23 February 2021, while in the Masłowice forest area was 26 deer and 102 roe deer according to the deer inventory prepared by the Hunting Association 'Cietrzew' in Krery on 10 April 2022.

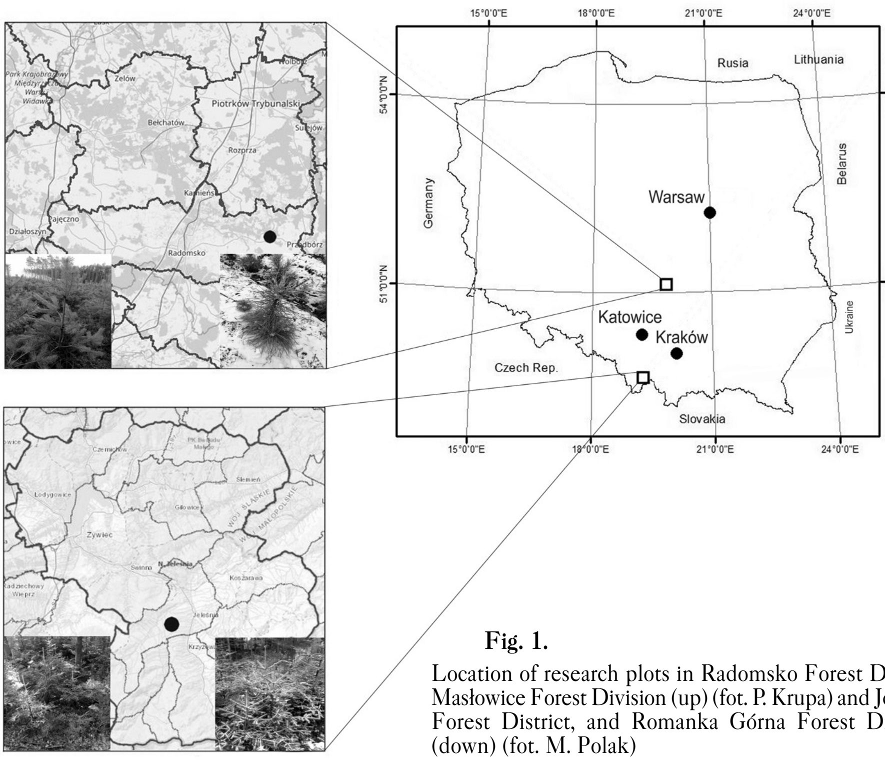

Fig. 1.
Location of research plots in Radomsko Forest District, Masłowice Forest Division (up) (fot. P. Krupa) and Jeleśnia Forest District, and Romanka Górna Forest Division (down) (fot. M. Polak)

The subject of the research was the natural regenerated trees of silver fir in sapling and self-sown tree phases (Jeleśnia Forest District) and trees aged 2-5 years for Scots pine and 4-7 years for sessile oak *Quercus petraea* (Matt.) Liebl. in the Radomsko Forest District. Four 0.1 ha, rectangular (Radomsko Forest District), and renewal cones 100 m apart (Jeleśnia Forest District) research areas were established in both forest districts.

Research plots with silver fir (designated J1-J4) were located in a Natura 2000 area (PLB24002, PLH240006 Beskid Żywiecki). In the upper forest layer there were 90 year old silver fir (50% share in the area) and 70 year old (20% share in the area) and 90 year old Norway spruce (30% share in the area). The growth consisted of 15-year-old common beech *Fagus sylvatica* L., Norway spruce and silver fir constituting respectively 60%, 20% and 10% of the species composition, while the 6-year-old layer of growth included silver fir (70%), Norway spruce (20%) and common beech (10%). The trees in the study areas grew in a fresh mountain forest with a water-protective function developed on leached brown soil.

The study areas with Scots pine (named R1 and R4) and sessile oak (named R2 and R3) were located in the Widawka Valley Protected Landscape Area (PL.ZIPOP.1393.OCHK.272) in subdivisions 95f (area no. R1; 3.44 ha) and 97d (area no. R4; 3.77 ha). This area included 2-year-old cultivation of Scots pine (80% share in the area) growing in a wet mixed forest habitat developed on gley-podzolic soil in the first case and in a fresh coniferous forest habitat on arenosol soil in the second case. In the study area R3 (subdivision: 98d; 0.99 ha), there was 5-year-old pines (80% share in the area) and 7-year-old sessile oaks (10% share in the area) growing in a fresh mixed coniferous forest habitat on rusty podzolic soil. In subdivision 99f (research area R2; 2.38 ha) there were 2- and 3-year-old pine trees (70% share) and 4-year-old sessile oak trees (10% share in the area) observed in a fresh mixed coniferous forest habitat on rusty soil podzolic.

As a part of additional pilot studies conducted in the Radomsko Forest District, the impact of Scots pine tree protection with the use of potassium soap against bark stripping of standing trees (area R5) and felled browsing trees (area R6) was recorded. Area R5 was older 5-year-old trees in subdivision 98d (description above). In turn, research area R6 (subdivision 114a; 2.76 ha) was characterized by the presence of a 48-year-old Scots pine stand with water-protective functions, an admixture of 48-year-old silver birch, and the local occurrence of Norway spruce and alder black *Alnus glutinosa* (L.) Gaertn. in a fresh coniferous forest habitat developed on rusty podzolic soil. The understory layer included common buckthorn *Frangula alnus* Mill., Norway spruce, mountain ash *Sorbus aucuparia* L., sessile oak and American bird cherry *Prunus serotina* L.

In research plots J1 and J4 in the Jeleśnia Forest District and R1 and R2 in the Radomsko Forest District, the trees (100 trees on each research plot) were protected with potassium octadecanoate while those in plots J2 and J3 in the Jeleśnia Forest District and R3 and R4 in the Radomsko Forest District with the traditional repellent Cervacol Extra PA. Concurrently in each study area 100 unprotected trees, which constituted a reference sample, were left untreated (Table 1). In the case of natural regeneration of fir trees, each of the substances protecting plants against animals was applied to the trees on the same date (15 January 2021) by applying it with a glove onto the main shoot and one side shoot. In the case of pine seedlings, the needles around the top bud were lubricated, and in the case of oak seedlings the upper part of the top shoot was protected. In plot R5, 100 trees protected against bark stripping with potassium octadecanoate were located in one row, while the row of 100 trees constituting the reference sample was ten meters away from the protected plot. The protection consisted of lubricating the pine whorls which were at risk of bark stripping. In study area R6, after early thinning 60

Scots pine trees were left to be browsing trees of which half were protected with potassium octadecanoate. The protected trees were selected randomly and were located on both sides of the logging trail. The remaining thirty trees constituted the reference sample (Table 1). Potassium octadecanoate was applied to interwhorls with thin bark. The treatment in the Radomsko Forest District was applied on 26 November 2022.

The protection procedure was performed on dry trees and seedlings during a rainless day at an above zero air temperature. Protection with potassium octadecanoate was repeated during the first three inspections as the substance naturally washed off over time due to its solubility in rain. The Cervacol Extra PA repellent was applied once and remained after it dried out on the protected plants for the duration of the research. The specification of the substances used in the experiment presented is in Table 2.

At each study area the occurrence of damage caused by cervids with two-weeks intervals (often enough to register damage as well as to account for the possible repellent influence of human odor which could impact on the study results) was inventoried to assess the number of damaged trees and the degree of tree damage. The degree of tree browsing caused by cervids was assessed using the classification introduced be Szukiel (2001) as follows:

– I degree: shoot and apical bud not damaged, side shoots gnawed, loss of up to 50% of needles or leaves on the main shoot and side shoots,

Table 1.
The study design with the number of trees treated (T) with selected protective substance (P – potassium octadecanoate, C – Cervacol Extra PA) and untreated (UT) at study plots

Locality – tree species	1	2	3	4	5	6
	Seedling stand – browsing protection				Sapling stand – bark stripping protection	Browsing trees
Radomsko – Oak		T(P) – 100 UT – 100	T(C) – 100 UT – 100			
Radomsko – Pine	T(P) – 100 UT – 100			T(C) – 100 UT – 100	T(P) – 100 UT – 100	T(P) – 30 UT – 30
Jeleśnia – Fir	T(P) – 100 UT – 100	T (C) – 100 UT – 100	T (C) – 100 UT – 100	T(P) – 100 UT – 100		

Table 2.
Specification of repellents intended to protect silver fir, Scots pine and sessile oak trees against damage caused by cervids

Repellent type	Cervacol Extra PA	Potassium octadecanoate $C_{17}H_{35}COOK$
Form	The paste ready to use	Consistency thick and oily
Consumption of agent	2.0-5.0 kg/1000 seedlings for 2-5 year old deciduous and coniferous trees (protection against browsing)	Approximate consumption as for Cervacol Extra PA
Date of application	Autumn and winter period	Autumn and winter period
Temperature of application	Above 0°C, no rain	Above 0°C, no rain
Number of treatments	1	1 or 2 due to resistance on plants
Price (included tax)	108 PLN (5 kg)*	93,65 PLN (5 kg)**

Price given according to company prices of: *Production-Service-Commercial Plant of State Forests in Olsztyn, available from: https://zpuh.olsztyn.lasy.gov.pl/repelenty, ** 'Dalfa' Manufacturing Company, available from: https://dalfa.pl

– II degree: browsing or breaking of the main shoot. Healthy buds or at least one side shoot remain in the undamaged lower part. Missing apical bud, most of the side buds damaged, loss of most of the needles or leaves,
– III degree: browsing or breaking of the main shoot. The lower remaining part lacks buds and side shoots. Grade I and II damage systematically repeated in subsequent years.

In case of tree bark stripping, the level of damages was assigned to one of three following degrees (Szukiel, 2001):
– I degree: superficial, one-sided damage to the cortex up to $^1/_3$ tree circumference,
– II degree: patchy or intermittent stripping of the bark up to $^1/_2$ tree circumference,
– III degree: stripping of the bark above half of the tree's circumference.

A total of 1,860 trees were analyzed including 800 silver firs, 660 Scots pine and 400 sessile oak specimens (Table 1).

Statistical analyses. The significance of differences in the level of browsing damage and regeneration of silver fir, Scots pine and sessile oak as well as bark stripping in the stand and older Scots pine stands which depended on the protective substance used was analyzed using the chi-square test. First, the compliance of the distribution of variables with the normal distribution was checked using the Shapiro-Wilk test. Then, using the chi-square test the relationships between trees treated with a particular substance and unprotected trees was determined in each study area. Statistical inference was performed assuming a significance level of $\alpha \leq 0.05$ for the characterized statistical tests. The analysis of compliance of the distribution of variables with the normal distribution and the chi-square test were performed using TIBCO Statistica™ 13.3 software (Statsoft, 2017).

Results

During the study period the extent of damage caused by game browsing amounted to 14.8% in fir regeneration stands (research plots J1-J4) and 23.5% in oak stands (research plots R2-R3). In the case of bark stripping in older pine trees (research plot R5) and forest stands with felled browsing trees (research plot R6), it was at the level of 28.0%. No damage in Scots pine trees was detected (research plots R1, R4) (Table 3).

The share of fir and oak trees damaged by browsing and previously protected with natural and artificial repellents constituted only 7.0% and 9.5% of the total number of trees observed, respectively (Fig. 2A, B). In the older Scots pine plantation (research plot R5), over half of the trees in the reference plot were damaged due to bark stripping, while the protected trees were only slightly affected (2.5% of the analyzed trees) (Fig. 2C). In the stand with felled browse trees (research plot R6), 40.0% of the analyzed trees were damaged due to bark stripping by cervids which included 21.7% of the trees protected with potassium octadecanoate (Fig. 2D). In cultivated stands of Scots pine that were protected against browsing by use of both potassium octadecanoate (research plot R1) and Cervacol Extra PA repellents (research plot R4), no damage caused by cervids was observed, thus no results of analyses have been presented. Taking into account the variation of the substance used to protect fir trees and sessile oak trees against browsing, potassium octadecanoate showed a greater advantage with a 13% reduction in the number of trees with traces of damage compared to Cervacol Extra PA. Moreover, this difference turned out to be statistically significant (χ^2=13.63, p=0.002). However, in the case of oak seedlings, the variation of the substance used in the test plots turned out to be of negligible importance as compared to the level of registered damage (χ^2=0.56, df=1, p=0.451) (Fig. 3).

Table 3.

Number of selected tree species damaged and undamaged by game with or without protection variant at study plots in Jeleśnia Forest District (J1-J4) and Radomsko Forest District (R1-R4)

No. of plot	Repel-lent*	No. of protected trees [indiv.]					No of unprotected trees [indiv.]				
		not da-maged	I° da-mage	II° da-mage	III° da-mage	Total	not da-maged	I° da-mage	II° da-mage	III° da-mage	Total
						Fir					
J1	P	94	1	0	5	100	85	4	0	11	100
J2	C	84	0	15	1	100	76	0	19	5	100
J3	C	88	0	1	11	100	86	0	0	14	100
J4	P	89	0	5	6	100	79	0	6	15	100
						Oak					
R2	P	81	0	13	6	100	66	0	21	13	100
R3	C	85	0	9	6	100	74	0	19	7	100
						Pine					
R1**	P	100	0	0	0	100	100	0	0	0	100
R4**	C	100	0	0	0	100	100	0	0	0	100
R5	P	95	1	1	3	100	49	18	12	21	100
R6	P	17	6	3	4	30	19	3	2	6	30

*Repellent: P – potassium octadecanoate, C – Cervacol Extra PA
**Lack of damages caused by game

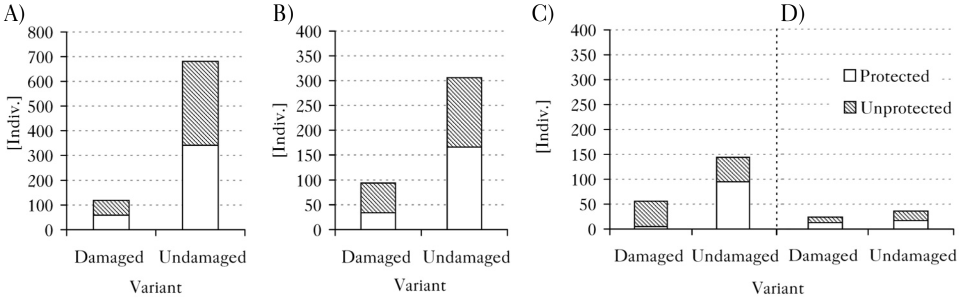

Fig. 2.

Comparison of the number of damaged and undamaged trees of silver fir *Abies alba* (A), sessile oak *Quercus petraea* (B) and Scots pine *Pinus sylvestris* (C) – bark stripping in older crop; (D) – bark stripping by cervids in stand with felled trees in the research area

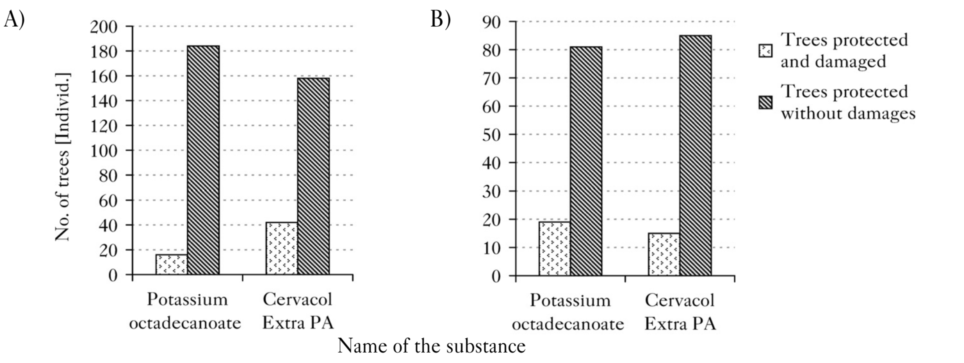

Fig. 3.

The percentage share of silver fir *Abies alba* (A) and sessile oak *Quercus petraea* (B) trees with traces of cervid damages depending on the applied protective substance in the research areas

Analyzing browsing the degree of damage in natural regeneration fir stands and oak stands, it was shown that the predominance of II and III degrees resulting in 'significant damage' to forests have been observed regardless of the tree protection variant used. In total, degree II damage constituted 38.6% of the total registered damage in the case of fir and 66.0% in the case of oak, while degree III damage constituted 57.1% and 34.0%, respectively. It was found that the number of trees with the highest degree of damage reached the highest value (47.1% in fir stands and 62.5% in oak stands) in unprotected trees, and the lowest in the case of stands protected with potassium octadecanoate (16.2% in fir stands and 18.7% in oak stands). Moreover, in regenerated fir stands, the use of a natural repellent (potassium octadecanoate) (research plots J1, J4) compared to an artificial repellent (Cervacol Extra PA) (research plots J2, J3) turned out to be effective in reducing damage to important trees by almost 82.0% which is four times more in the case of degree II and 69.4% which is more than twice in the case of degree III (Fig. 4A, B).

Protection of Scots pine trees with the use of potassium octadecanoate against bark stripping damage (research plot no. R5) was effective in reducing damage in all degrees ranging from 87.5% in degree III to 95.0% in degree I. However, this effect was not confirmed in the pine stand in which the felled trees were left after harvesting (research plot R6) (Fig. 4C, D).

No significant correlation was found between the number of damaged trees that were protected using Cervacol Extra PA or unprotected (χ^2=0.01, p=0.920). However, statistically significant (χ^2=14.95, p=0.000) almost three times higher significant damages (degrees II and III altogether) were confirmed for silver fir trees treated with Cervacol Extra PA (research plots no. J2, J3) compared to the ones protected with potassium octadecanoate (research plots no. J1, J4). The situation was different in oak trees where no statistically significant differences (χ^2=0,57, p=0.451) were noted in the number of trees protected with natural (research plot R2) or artificial repellents (research plot R3). It was demonstrated that the level of significant browsing and bark stripping damages reached always higher than 30.0% in Scots pine stands with felled trees to 26.0% in sessile oak trees that had no protective treatments applied compared to trees protected using potassium octadecanoate. Furthermore, with the exception of the Scots pine stand with felled trees these effects were statistically significant (Table 4).

Discussion

Forests in Poland are under constant pressure from various factors that generate economically measurable losses. In recent years, the vast majority of harmful factors affecting forests are related

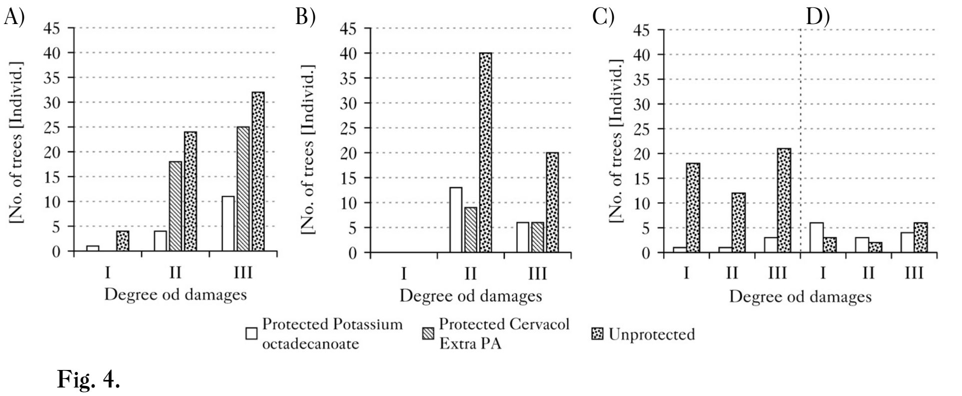

Fig. 4.

The quantitative share of silver fir *Abies alba* (A), sessile oak *Quercus petraea* (B), and Scots pine *Pinus sylvestris* (C) – bark stripping in older crop; (D) – bark stripping by cervids in stand with felled trees relative to degrees of damage in the research areas

Table 4.

Number of silver fir *Abies alba* and sessile oak *Quercus petraea* trees damaged by cervid browsing and Scots pine *Pinus sylvestris* trees damaged by cervid bark stripping at a significant level as well as chi-square test results for the significance of differences depending on the type of applied protective substance

Protective variant	Tree species							
	Silver fir		Sessile oak		Scots pine[1]		Scots pine[2]	
	[Indiv.]	[%]	[Indiv.]	[%]	[Indiv.]	[%]	[Indiv.]	[%]
Cervacol Extra PA	42[a]	36.8	15[a]	16.0	–	–	–	–
Potassium octadecanoate	16[b]	14.0	19[a]	20.2	4[a]	10.8	7[a]	46.7
Reference	56[a]	49.2	60[b]	63.8	33[b]	89.2	8[a]	53.3
Total	114	100	94	100	37	100	15	100

[1]Older crop; [2]A stand with leftover felled trees
For each tree species values marked with the same letter indicate no statistically significant differences at the level $\alpha \leq 0.05$

to the rapidly changing climate and the occurrence of weather anomalies. The result of these events are damages to the forest ecosystem which disrupts the established production process and negatively affects its effectiveness (Partyka, 1990; Miścicki, 1998; Rooney and Waller, 2003). The functioning of forest ecosystems is also inseparable from the presence and pressure of biotic factors, among which herbivorous mammals cause damage at all levels of the forest ecosystem (Jezierski, 1996; Fuchs *et al.*, 2021). However, the presence of game in forests is associated with properly functioning sustainable forest management. Nevertheless, due to the lack of self-regulating mechanisms in game populations as well as the lack of predators, forest game management activities are necessary. In spite of this, the numbers of large game in Polish forests continues to increase which may threaten the sustainability of forests (Mikoś, 2012; Milewski, 2018). Thus, establishing trees in forest stands is connected with their active protection against deer. These costs are increasing due to the increasing number of Cervidae and the need to rebuild the structure of forest stands from coniferous to deciduous species every year (Piskonowicz *et al.*, 2007; Balik *et al.*, 2016,). In situations where damage caused by game becomes cyclical, it leads to the cessation of tree growth and loss of biomass which inevitably leads to the formation of shrub-like trees and deterioration in the quality of timber (Halls, 1975; Szukiel, 2001). However, the character of forest damage caused by deer is variable in time and space (Jędrzejewska *et al.*, 1997). The most common tree damage occurs in periods of limited food availability, *i.e.* winter and early spring. Tree damage resulting from browsing and striping in the growing season is a rarer phenomenon and most likely associated with a deficiency of mineral nutrients in ruminants (Nasiadka and Lipski, 2006). One of the basic methods of protecting trees against browsing by game in managed forests is the use of synthetic repellents. These agents with either an odoriferous, taste, physical, or complex action become tolerable to deer over time. Therefore, it is essential to change these agents to other previously unused ones or introduce new agents unknown to game animals. Cervacol Extra PA followed by Emol 5, Emol 10 and Wam Extra PA are the most commonly used repellents in forest tree protection against browsing in Poland. These agents cover the leaves of tree protection surfaces for many months, reducing the photosynthetic area and potentially having an adverse effect on tree health. Furthermore, the current doctrine of forest protection practice which requires using integrated methods and limitations in the use of chemical agents, requires the search for other environmentally friendly solutions. Therefore, in view of the need to find new ecologically friendly agents to protect trees against game browsing which do not reduce the photosynthetic area, this study attempts to determine the possibility of using potassium octadecanoate, a naturally occurring substance, to protect European silver fir, Scots pine, sessile oak, and European beech against browsing by deer. The proposed substance is fully ecologically friendly and biodegradable, soluble in water, and has a strong, foreign scent in the ecosystem. However, until now potassium octadecanoate has not been used in forest protection against Cervidae, thus its effectiveness remains unknown as well as its impact on game animals and protected trees. The impact of this substance on the behavior and feeding habits of deer is also unknown. Studies that examined the possibility of using potassium octadecanoate in tree protection against damage caused by deer showed that in the Jeleśnia Forest District the size of damage in natural silver fir cultivation was low at only 15%. This result may have been influenced by the exceptionally favorable winter weather conditions for game animals in the 2020/2021 season. The strongest pressure on woody plants from game animals usually occurs in winter and early spring when there is a lack of alternative food sources. Bark stripping and browsing of trees during the growing season are more rare and most likely associated with a deficiency of mineral nutrients in ruminants (White, 2019). Therefore, the impact of game animals on forest trees varies depending on their trophic behavior (Jezierski, 1996). The caloric demand of game animals increases in mid-March and is associated with the end of the gestation period in females, the approaching lactation period, and the growth of young offspring (Giebel and Węgorek, 2005). The results of this research indicate differences in the number of damaged unprotected and protected trees. In the case of European silver fir, Scots pine and sessile oak, more unprotected trees were damaged than those protected with repellent. Among the damaged trees, the rate of damage for European silver fir was (50.42%), Scots pine (77.50%), sessile oak (63.83%), while unprotected trees accounted for the majority of damage. The protective effect of potassium octadecanoate on Scots pine was most effective in the 5-year-old plantation, where only 5% of protected trees were damaged as compared to the control where damage reached 51%. In conclusion, it seems justified to recommend the use of potassium octadecanoate as a fully economic and ecologically friendly alternative to synthetic repellents to protect trees. Its effectiveness should be confirmed after several years of use as game animals may intentionally avoid trees treated with this substance in the forest. The use of potassium stearate, a new foreign substance in the forest ecosystem, can be successfully applied to protect plants against browsing until the scale of damages increases. It should also be taken into consideration the possible enrichment of the substance composition with quartz sand that might increase the efficiency of the protection effect due to its additional physical repellent interaction with Cervidae.

Conclusions

- Potassium octadecanoate protected the cultivation of 5-year-old Scots pine best as it positively affected the reduction of damage to protected trees compared to unprotected ones.
- The protection of common fir using repellent Cervacol Extra PA and potassium stearate did not significantly affect the reduction of damage from game on research plots.
- No significant differences in the size of damage and degree of damage to oak trees from game were observed in the stands protected by potassium octadecanoate and Cervacol Extra PA.
- The substance being tested had the weakest impact in Scots pine stands on the amount of damage from game during the study conducted with the remaining harvested felled pine trees. However, only degree I of damage predominated among the protected, felled trees.
- The low level of damage to young trees and the lack of significant differences in the number of damaged trees between unprotected and protected ones treated with the tested substances did not allow for the verification of the hypothesis regarding the significant impact of potassium stearate on the reduction in amount and degree of damage to regenerated trees.

- The use of potassium stearate as a natural, environmentally safe substance in forest protection against game may be an alternative to synthetic compounds, especially in protected forest areas.
- It was found that a significantly higher percentage of protected trees treated with Cervacol Extra PA were damaged compared to protected silver firs treated with potassium soap.
- Based on the results, it is not possible to unambiguously determine the significance of the impact of the tested preparation on the amount and degree of damage to sessile oak and Scots pine trees.
- The observed lack of intensive activity by game in Scots pine stands may be due to the short duration of snow cover during the year of the research, the poor health of the trees, and the small distance between the research and agriculturally developed areas.
- Potassium octadecanoate, as an ecologically friendly substance, has appropriate physicochemical properties that allow for its use in plant protection as it remains on the protected trees for a longer period of time while maintaining its intense, specific odour. Additionally, it retains suitable to use for one year of storage, and it does not remain on the leaves in the further vegetative period as a result of rainfall, thus not limiting the photosynthetic surface of plants.
- Considering the satisfactory results and the pioneering nature of the research, continued analysis is recommended on the use of potassium octadecanoate in protecting crops from browsing and young stands from bark stripping by game in future autumn-winter periods. This should involve increasing the number of experimental plots and their distribution in various environmental conditions in different regions of the country.
- Based on research results obtained, it is recommended to take into consideration the possibility of enriching the potassium octadecanoate substance composition with a quartz sand that might significantly increase the efficiency of the protection effect against game damages due to its repellent additional physical interaction.

Authors' contributions

B.B. – contributed to the conception of research, design, and with M.K. investigation of the study; M.K. – statistical analysis; B.B. and M.K. – manuscript editing. Authors contributed to the manuscript revision, read, and approved the submitted version.

Conflicts of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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STRESZCZENIE

Możliwość wykorzystania oktadekanianu potasu ($C_{17}H_{35}COOK$) w ochronie upraw drzew liściastych i iglastych przed szkodami powodowanymi przez jeleniowate

Możliwości zastosowania stearynianu potasu jako repelentu w ochronie jodły pospolitej, sosny zwyczajnej i dębu bezszypułkowego przed zgryzaniem i spałowaniem oceniano na 10 powierzchniach badań o wielkości 0,1 ha każda w nadleśnictwach Jeleśnia i Radomsko (ryc. 1) w sezonie jesienno-zimowym 2021-2022. Podejmując badania, sformułowano następujące hipotezy: (i) zastosowanie stearynianu potasu w ochronie drzew znacząco zmniejszy rozmiar i stopień uszkodzeń spowodowanych przez zwierzynę płową; (ii) skuteczność ochrony drzew przy użyciu oktadekanianu potasu, substancji o naturalnym pochodzeniu, nieznanej dotychczas zwierzynie, będzie wyższa niż skuteczność ochrony drzew za pomocą powszechnie stosowanych repelentów o syntetycznym pochodzeniu, na przykładzie środka Cervacol Extra PA (tab. 1). Celem badań była więc ocena skuteczności zastosowania stearynianu potasu w ochronie młodych drzew *Abies alba* Mill., *Pinus sylvestris* L. i *Quercus petraea* (Matt.) Liebl., a także porównanie skuteczności preparatu w redukcji szkód powodowanych przez zwierzynę płową względem drzew referencyjnych i zabezpieczonych repelentem Cervacol Extra PA – stosowanym w ochronie upraw leśnych przed zgryzaniem. Doświadczenie terenowe założono na 4 powierzchniach, na których przetestowano 200 losowo wybranych drzew. Ponadto na jednej z powierzchni, jako badania pilotażowe, zabezpieczono oktadekanianem potasu 60 drzew zgryzowych sosny zwyczajnej, które pozostawiono na powierzchni badań po wcześniejszym pozyskaniu sosny w ramach trzebieży. W trakcie prowadzonych 2 razy w miesiącu inwentaryzacji szkód oceniano rozmiar i stopień uszkodzeń w 3-stopniowej skali (ryc. 4). Stwierdzono, że stearynian potasu najlepiej ochraniał przed uszkodzeniami ze strony jeleniowatych starszą plantację sosny zwyczajnej, w odróżnieniu od drzew wolnych od zabezpieczenia (ryc. 2 i 4). W przypadku naturalnie odnawiających się jodeł pospolitych stwierdzono znacznie wyższy procent uszkodzonych drzew chronionych środkiem Cervacol Extra PA, niż miało to miejsce u jodeł chronionych stearynianem potasu (ryc. 3 i 4; tab. 2). Dla dębu bezszypułkowego nie zaobserwowano istotnych różnic w rozmiarze i stopniu uszkodzeń drzew zabezpieczonych repelentami (ryc. 4; tab. 2). Wykazano, że stearynian potasu w okresie ochrony wydziela intensywny zapach i wykazuje trwałość na zabezpieczanych roślinach. Biorąc

pod uwagę zadowalające wyniki i oryginalny profil badawczy oraz ekologiczny charakter zastosowanej w zabezpieczaniu drzew substancji, rekomenduje się kontynuację badań terenowych z wykorzystaniem stearynianu potasu w ochronie upraw leśnych przed uszkodzeniami powodowanymi przez jeleniowate, uwzględniając wzbogacenie składu preparatu o piasek kwarcowy, zwiększenie liczby powierzchni badań i ich lokalizację w różnych regionach kraju. Wykorzystanie stearynianu potasu w ochronie lasu przed zwierzyną, jako naturalnej i ekologicznej oraz bezpiecznej dla środowiska przyrodniczego substancji, może stanowić alternatywę dla dotychczas stosowanych związków syntetycznych.