Control of hoary cress (*Lepidium draba* L.) in strawberry production

Bekämpfbarkeit von Pfeilkresse (Lepidium draba L.) im Erdbeeranbau

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Abstract

The perennial weed hoary cress (*Lepidium draba* (L.) Desv.) is known as a problem weed in viticulture, however it also occasionally occurs in leaf crops, spring and winter cereals, where it typically establishes at the field margins. The weed has an extensive root system and can only be controlled mechanically by repeated hoeing, while in winter cereals, maize and oilseed rape it can be controlled either by synthetic auxins or inhibitors of the acetolactate synthase (ALS). In various special crops, such as strawberry (*Fragaria* x *ananassa* Duch.), these herbicides are not registered. Yet, the rhizome-deriving plants, which emerge in early spring, exert strong competitive pressure on the less competitive strawberry plants. In order to investigate the efficacy of the active ingredients registered for weed control in strawberries (status as of 2019), seeds of hoary cress introduced by compost were collected from a strawberry stand, grown into seed- and rhizome-deriving plants and then treated with the maximum registered field dose rate of the herbicides. For comparison, the herbicides were additionally applied to strawberries, field mustard (*Sinapis arvensis* L.), wild radish (*Raphanus raphanistrum* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.) and field pennycress (*Thlaspi arvense* L.).

In addition to the registered inhibitors of acetyl-CoA synthase (ACCase), the microtubule inhibitors propyzamide and pendimethalin, as well as napropamide-, clopyralid-, dimethenamid-, and flufenacet-containing herbicides did not result in sufficient efficacy on hoary cress. Field application rates of herbicides containing the active ingredients isoxaben (inhibition of cellulose synthesis) and phenmedipham (photosystem II) resulted in efficacy rates of > 70%. The photosystem II inhibitors metamitron and the protoporphyrinogen oxidase (PPO) inhibitor pyraflufen achieved > 90% efficacy on seed-borne hoary cress. Similarly, high efficacy levels were found for the reference weeds. However, phytotoxic damage may occur on strawberries, therefore an application using spray guards is recommended. These results were additionally confirmed in dose-response experiments. However, all treatments of root-borne hoary cress with none of the herbicides mentioned resulted in insufficient control. Therefore, active ingredients registered in strawberries are only suitable for early control of newly introduced seed-borne hoary cress while rhizome-deriving hoary cress plants can only be effectively controlled with herbicides in the following crop.

Keywords: herbicides, hoary cress, *Lepidium draba*, strawberries

Zusammenfassung

Das ausdauernde Wurzelunkraut Pfeilkresse (*Lepidium draba* (L.) Desv.) gilt als problematische Art im Weinbau und kommt gelegentlich in Blattfrüchten, Sommer- und Wintergetreide vor, dort jedoch v.a. an Feldrändern. Das Unkraut verfügt über ein ausgedehntes Wurzelsystem und kann mechanisch nur durch wiederholtes Hacken bekämpft werden, während es in Wintergetreide, Mais und Raps entweder durch einige synthetische Auxine oder Hemmer der Acetolactatsynthase (ALS) kontrolliert werden kann. In vielen Sonderkulturen, wie im Erdbeeranbau, sind diese Herbizide nicht zugelassen. Jedoch übt v.a. die wurzelbürtige Pfeilkresse, die bereits im zeitigen Frühjahr aufläuft, starken Konkurrenzdruck auf die konkurrenzschwachen Erdbeeren aus. Um die Wirksamkeit in Erdbeeren zugelassener herbizider Wirkstoffe

(Stand 2019) zu untersuchen, wurden in einem Erdbeerbestand Samen von durch Kompost eingeschleppter Pfeilkresse geerntet, zu samen- und wurzelbürtigen Pflanzen herangezogen und anschließend mit der jeweils maximal zugelassenen Feldaufwandmenge verschiedener Herbizide behandelt. Zum Vergleich wurden die Herbizide zusätzlich auf Ackersenf (*Sinapis arvensis* L.), Hederich (*Raphanus raphanistrum* L.), Hirtentäschel (*Capsella bursa-pastoris* (L.) Medik.) und Ackerhellerkraut (*Thlaspi arvense* L.) appliziert. Neben den zugelassenen Hemmern der Acetyl-CoA-Synthase (ACCase), führten auch die Mikrotubulihemmer Propyzamid und Pendimethalin, sowie Napropamid-, Clopyralid-, Dimethenamid-P- und Flufenacethaltige Herbizide zu keiner ausreichenden Wirkung. Die Feldaufwandmenge von Herbiziden mit den Wirkstoffen Isoxaben (Hemmung der Cellulosesynthese) und Phenmedipham (Photosystem II) führten zu Wirkungsgraden von > 70 %. Die Hemmer des Photosystems II, Metamitron, sowie der Hemmer der Protoporphyrinogen-Oxidase (PPO) Pyraflufen erzielten > 90 % Wirkung auf samenbürtige Pfeilkresse. Ähnlich hohe Wirkungsgrade wurden für die Vergleichsunkräuter festgestellt. Wobei an den Erdbeeren Phytotoxschäden entstehen können, sodass eine Applikation mit Spritzschutz empfehlenswert ist. Diese Ergebnisse konnten zusätzlich in Dosis-Wirkungsversuchen bestätigt werden. Jedoch führte die Behandlung wurzelbürtiger Pfeilkresse bei keinem der genannten Wirkstoffe zu ausreichender Kontrolle, sodass in Erdbeeren registrierte Herbizide lediglich zur zeitigen Bekämpfung neu eingeschleppter, samenbürtiger Pfeilkresse geeignet sind und wurzelbürtige Pfeilkresse ausschließlich in der Folgekultur effektiv mit Herbiziden bekämpft werden kann.

Stichwörter: Erdbeeren, Herbizide, *Lepidium draba*, Pfeilkresse

Introduction

The neophyte hoary cress (*Lepidium draba* (L.) Desv., syn. *Cardaria draba*) is a perennial cruciferous plant and originated as a steppe plant in western Asia. Although it was first described in Germany as early as in 1728, it has only appeared as an arable weed since the second half of the 20th century. It established primarily on base-rich, moderately dry sites with medium to heavy soils (HOLZNER & GLAUNINGER, 2005; PARTZSCH et al., 2006). There, the approximately 20-60 cm tall plant develops an extensive root system that accounts for approximately 76% of the total biomass and largely extends below the bottom of the plow (MILLER et al., 1994; PARTZSCH et al., 2006). In this context, roots on which adventitious shoots occur can form as well as shoots from depths greater than 30 cm. Because of its low growth and consequently its limited ability to compete for light, hoary cress is only slightly to moderately competitive in most arable crops (HOLZNER & GLAUNINGER, 2005). In addition, the species spreads by seed. In many specialty crops, which have low competition, like strawberries, hoary cress, which emerges in early spring, exerts strong competitive pressure. In addition, the weed can allelopathically inhibit a variety of different crops (QASEM, 1994; KIEMNEC & MCINNIS, 2002). However, due to its strong regenerative ability, hoary cress can only be controlled mechanically by repeated hoeing, possibly in combination with herbicides over a long period of time. While acetolactate synthase (ALS) inhibitors are approved for weed control in winter cereals, corn and oilseed rape they cannot be used in strawberries to control hoary cress. The range of herbicides approved in strawberry production is narrow, and in addition to the stage of development of the strawberry, the cropping system, cultivar and soil type must be considered for an herbicide application. For example, soil herbicides are only approved for use in open field cultivation, while pyraflufen-containing products must be applied with a spray guard. If this species has been newly introduced to a field, weed control must be adapted to this troublesome weed. To evaluate the chemical control options for hoary cress, herbicides recommended in 2019 for perennial strawberry production were evaluated for their potential to control hoary cress in comparison to field mustard (*Sinapis arvensis* L.), wild radish (*Raphanus raphanistrum* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), and field pennycress (*Thlaspi arvense* L.).

Material and methods

Plant material

For the trial, seeds of hoary cress plants were harvested from a strawberry field in Lower Saxony and from a roadside in Frankfurt, Hessen, in order to obtain sufficiently large quantities for the trials. In addition, seeds of comparative species were acquired. Field mustard was obtained from Herbiseed (Reading, UK) while wild radish, shepherd's purse and field pennycress were obtained from Appels Wilde Samen (Darmstadt, Germany).

Efficacy tests with different herbicides in the greenhouse

The plants were preplanted in seed trays and each five plants were transplanted at the cotyledon stage per 9 cm pot filled with a 3:3:1 mixture of compost, potting soil (Hawita, Vechta, Germany) and sand. In addition to the untreated control three replicate pots were sprayed for each treatment, stage and species. The application was carried out with a laboratory sprayer with an ES 90-04 nozzle (Lechler, Metzingen, Germany) at three bar. Afterwards, the pots were randomized and after a growth period of 21 days the fresh weight of the above ground mass of the plants was determined. In addition to the herbicide screening (Tab. 1), five herbicides with the best efficacies were applied to hoary cress plants for a dose-response trial with the rates displayed in Table 2. A 1:3 dilution series was chosen to cover a wide range of dose rates. The plants were grown, treated and harvested as described above. Furthermore, rhizomes of hoary cress were potted as described above with three pots per treatment. As the first leaves emerged, they were sprayed with the maximum registered field rate displayed in g active ingredient (a.i.) ha^{-1} (Tab. 1). The plants were treated and harvested as described above. All experiments were repeated.

Table 1 Herbicide application rates used in the active ingredient screening with five different weed species in the cotyledon stage and rootstock-derived hoary cress (*Lepidium draba* (L.) Desv.)

Tabelle 1 *Herbizidaufwandmengen im Wirkstoffscreening mit fünf Unkrautarten im Keimblattstadium, sowie wurzelbürtiger Pfeilkresse* (Lepidium draba *(L.) Desv.)*

Trade name	**Active ingredient**	**g a.i. ha^{-1}**	**Water volume in L ha^{-1}**
Betsana SC	160 g phenmedipham L^{-1}	960	300
Cadou SC	500 g flufenacet L^{-1}	150	300
Spectrum	720 g dimethenamid-P L^{-1}	1008	400
Devrinol FL	450 g napropamide L^{-1}	1125	600
Fusilade Max	107 g fluazifop + 125 g butyl ester L^{-1}	137	300
Select 240 EC	240 g clethodim L^{-1}	180	300
Agil-S	100 g propaquizafop L^{-1}	75	300
Vivendi 100	100 g clopyralid L^{-1}	120	300
Flexidor	500 g isoxaben L^{-1}	100	300
Goltix Gold	700 g metamitron L^{-1}	1400	300
Quickdown	24.2 g pyraflufen L^{-1}	19	300
Stomp Aqua	455 g pendimethalin L^{-1}	1593	300
Kerb Flo	400 g propyzamide L^{-1}	500	400

Table 2 Herbicide concentrations used for dose-response assays with hoary cress (*Lepidium draba* L.). The field rates are indicated with asterisks

***Tabelle 2** Herbizidkonzentrationen für Dosis-Wirkungsversuche mit Pfeilkresse* (Lepidium draba *L.). Die Feldaufwandmengen sind mit Sternchen gekennzeichnet*

Trade name	**Concentration of a.i. in the formulated product**	**Dose rates of a.i. in g ha^{-1}**					
Betasana SC	160 g phenmedipham L^{-1}	-	960.0*	320.0	106.7	35.6	0
Quickdown	24.2 g pyraflufen L^{-1}	-	19.4*	6.5	2.12	0.7	0
Goltix Gold	700 g metamitron L^{-1}	-	1400.0*	466.6	155.5	51.9	0
Spectrum	720 g dimethenamid-P L^{-1}	3024.0	1008.0*	336.0	112.0	37.3	0
Flexidor	500 g isoxaben L^{-1}	300.0	100.0*	33.3	11.1	3.7	0

Statistical analysis

All data were analyzed using in R statistical software (version 4.0.0, (R Foundation for Statistical Computing). Initially, the Shapiro-Wilk test for normality was used. Statistical differences between treatments were then evaluated using the Wilcoxon rank-sum test. Additionally, dose-response analyses including the calculation of 95% confidence intervals were conducted using the three-parameter log-logistic model included in the packages 'drc' (RITZ et al., 2015).

Formula 1 Log-logistic function for dose-response analysis with 0 as lower asymptote.

***Formel 1** Log-logistische Funktion für Dosis-Wirkungsanalysen mit 0 als untere Asymptote.*

$$f(x) = 0 + \frac{d - 0}{1 + \exp(b(\lg(x) -)}$$

Results and discussion

In this study, the chemical control potential of hoary cress, a problem weed in strawberry production, was investigated in comparison with four reference weeds. The investigations have shown that only the PPO inhibitor pyraflufen and the photosystem II-inhibitor metamitron were able to reduce the biomass of hoary cress grown from seed with by over 90% (Fig. 1A). Both herbicides can be applied after the harvest of strawberries. In the dose-response trial, only in the case of metamitron, a control rate of over 90% was achieved. This was indicated by an ED_{90}-value of 77.9% with a standard error of 57.8 of the maximum registered field rate (1090.6 g of active ingredient per ha). In the case of pyraflufen, 141.3% ± 94.0 of the field rate (27.4 g of active ingredient per ha) were necessary for the same rate of biomass reduction. Therefore, these herbicides are absolutely insufficient for practical use. For dimethenamid-P, phenmedipham and isoxaben, which achieved comparatively good results with > 70% fresh weight reduction in the active ingredient screening, with ED_{90}-value of 1738, 673 and 592 were calculated (Fig. 2B). This indicates insufficient weed control, although the effectiveness in the field may differ from the observations in the greenhouse. However, based on the calculated 95% confidence intervals, the differences were statistically significant in the case of pyraflufen and metamitron compared to dimethenamid-P. Generally, the five herbicides mentioned achieved the best control successes on the reference weeds, whereby the wild radish was somewhat more difficult to control as only with the field application rate of pyraflufen reduce the of the biomass by more than 90% (Fig. 1B-E). Despite low efficacy levels, a partial effect was observed with all herbicides except in the case on treatment of wild radish with napropamide, which is in any case no longer approved. Although, these effects were not statistically significant in all cases, the results are generally in line with other herbicide studies with cruciferous plants (KLINGENHAGEN, 2014).

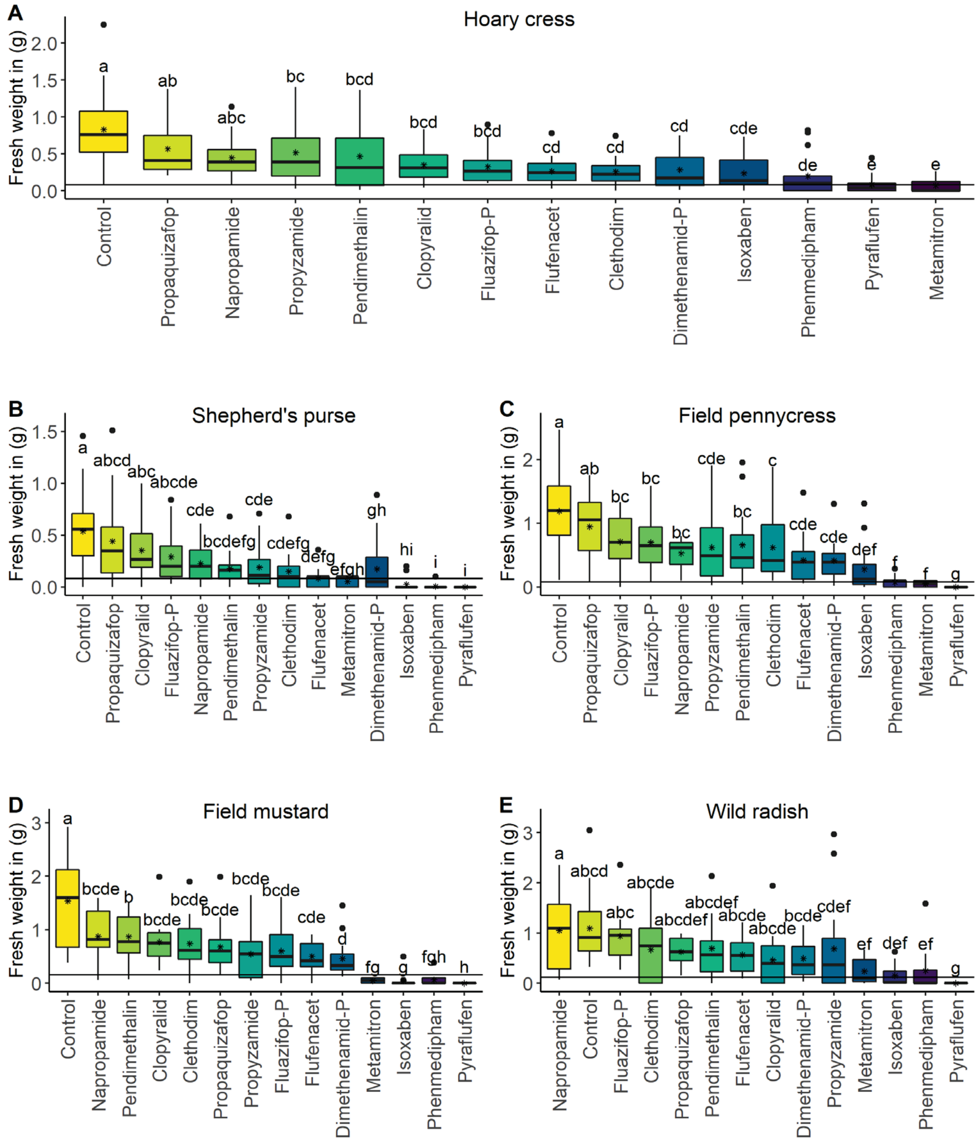

Figure 1 Fresh weight of A) hoary cress (*Lepidium draba* L. Desv.), B) of shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), C) of field pennycress (*Thlaspi arvense* L.), D) of field mustard (*Sinapis arvensis* L.), and E) of wild radish (*Raphanus raphanistrum* L.) 28 days after treatment with different herbicides. Statistical differences are indicated with different letters (p<0.05) and 90% fresh weight control relative to the untreated control are indicated by a horizontal black line.

***Abbildung 1** Frischgewicht von A) Pfeilkresse* (Lepidium draba *L.) B) Hirtentäschel* (Capsella bursa-pastoris *(L.) Medik.), C) Ackerhellerkraut* (Thlaspi arvense *L.), D) Ackersenf* (Sinapis arvensis *L.), und E) Hederich* (Raphanus raphanistrum *L.) 28 Tage nach der Behandlung mit verschiedenen Herbiziden. Statistische Unterschiede sind mit unterschiedlichen Buchstaben angegeben (p<0.05). Die Kontrolle von 90 % des Frischgewichts im Vergleich ist durch eine horizontale schwarze Linie gekennzeichnet.*

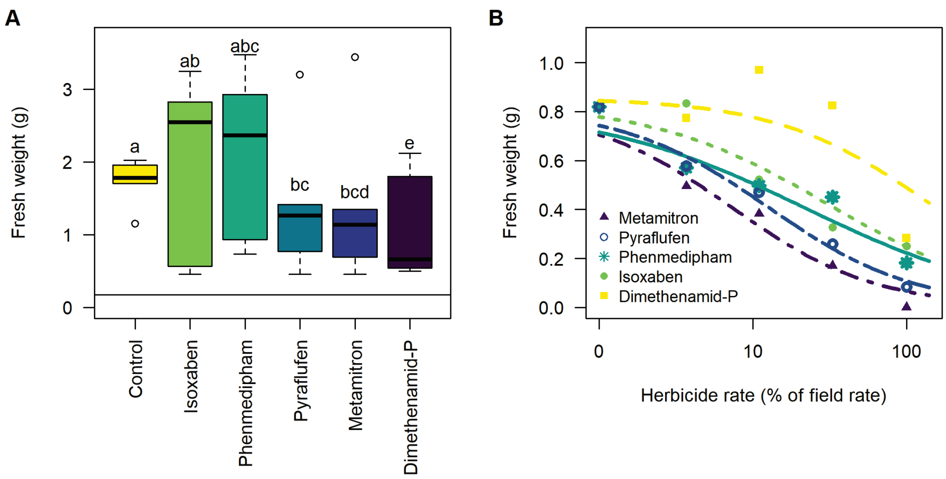

Figure 2 A) Fresh weight of hoary cress (*Lepidium draba* L. Desv.) grown from creeping rootstocks 28 days after treatment with different herbicides. Statistical differences are indicated with different letters (p<0.05) and 90% fresh weight control relative to the untreated control are indicated by a horizontal black line. B) Response of hoary cress to different dose rates of metamitron, pyraflufen, phenmedipham, isoxaben and dimethenamid-P 28 days after treatment.

Abbildung 2 *A) Frischgewicht von Pfeilkresse* (Lepidium draba *L. Desv.) auf kriechenden Wurzelstöcken 28 Tage nach der Behandlung mit verschiedenen Herbiziden. Die statistischen Unterschiede sind mit unterschiedlichen Buchstaben angegeben (p<0.05) und die Kontrolle von 90 % des Frischgewichts im Vergleich ist durch eine horizontale schwarze Linie gekennzeichnet. B) Wirkung verschiedener Dosierungen von Metamitron, Pyraflufen, Phenmedipham, Isoxaben und Dimethenamid-P auf Pfeilkresse 28 Tage nach der Behandlung.*

In case of the graminicides propaquizafop, fluazifop and clethodim, this partial effect may be due to the fact that many Brassicaceae species express the eukaryotic ACCase, in addition to the prokaryotic ACCase in the chloroplast. Orthologs of the eukaryotic ACCase are the targets of ACCase inhibitors in grasses (KONISHI et al., 1996; SCHULTE et al., 1997). Partial effects of these less effective herbicides could contribute to the control success in a combined approach of mechanical and chemical control when controlling other weeds. In fact the combination of partial effects may be the only way to limit the damage by this perennial weed, as our experiments with hoary cress derived from root material have demonstrated that chemical control of established patches of this weed is not possible as the plants recover quickly (Fig. 1A). In that regard, mowing down the inflorescences in the production year can at least prevent the spread of seeds and covering the seeds with straw may even hinder the germination of this light-dependent germinators. A consequent prevention of seed production may effectively reduce the hoary cress seeds as they mostly decay within five years (PARTZSCH et al., 2006). However, to control hoary cress effectively in the long term, either intensive hoeing and tillage over a long period of time is necessary or the use of herbicides approved in other crops. This includes the use of synthetic auxins like MCPA or 2,4-D and ALS-inhibitors like metsulfuron in winter cereals (KNUTSON & RANSOM, 1998), imazamox in correspondingly tolerant oilseed rape (LAUFER et al., 2014) or glyphosate before the next crop (WATERHOUSE & MAHONEY, 1983). A combined approach of mechanical and chemical control may be particularly effective (JACOBS, 2007). Finally, the investigation of pelargonic acid, which was recently approved in strawberries, could be interesting for the control of problematic weeds in this crop, even if this contact herbicide may be inferior to the systemic active ingredients mentioned for the control of hoary cress.

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