# Effect of cinmethylin (LUXIMO®) in combination with non-chemical measures against *Alopecurus myosuroides* Huds. in winter cereals

## *Einfluss von cinmethylin (LUXIMO®) in Kombination mit nicht-chemischen Verfahren gegen Alopecurus myosuroides Huds. in Wintergetreide*

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## Abstract

Pre-emergence herbicides in winter annual cereals often need to be combined with other weed control tactics to provide sufficient weed control efficacy for the entire growing season. In the present study, the new pre-emergence herbicide cinmethylin for the control of *Alopecurus myosuroides* Huds. in Europe was tested in four field experiments in winter wheat and winter triticale in Southwestern Germany over a period of three years. Treatments with cinmethylin were combined with stubble treatments and delayed drilling of winter annual cereals in a three-factorial block design. Average densities of *A. myosuroides* in the untreated control plots ranged from 38-1233 plants $m^{-2}$. The pre-emergence herbicide Cinmethylin controlled 58-99% of *A. myosuroides* plants until 120 days after sowing. Additive and synergistic effects of cinmethylin and delayed drilling were found for all studies reducing *A. myosuroides* density by more than 90%. Stubble treatments including one and two passes of chisel ploughing, chisel ploughing followed by glyphosate application and conversation stubble tillage with a straw harrow did not result in significant different *A. myosuroides* densities in the following winter cereal crops. Winter wheat and winter triticale grain yields were significantly increased by cinmethylin and delayed drilling. These data underline the benefits of integrated weed management using different weed control tactics.

**Keywords:** Integrated weed management, pre-emergence herbicide, preventive weed control

## Zusammenfassung

Vorauflaufherbizide in Wintergetreide müssen häufig mit anderen Verfahren der Unkrautbekämpfung kombiniert würden, um eine ausreichende Kontrolle der Unkräuter über die gesamte Vegetationsperiode zu erzielen. In der vorliegenden Arbeit wurde das neue Vorauflaufherbizid Cinmethylin zur Bekämpfung von *Alopecurus myosuroides* Huds. in vier Feldversuchen mit Winterweizen und Wintertriticale an Standorten in Südwestdeutschland über drei Jahre getestet. Der Einsatz von Cinmethylin wurde mit Stoppelbehandlungen und Spätsaat von Wintergetreide in dreifaktoriellen Parzellenversuchen kombiniert. Die mittlere Dichte von *A. myosuroides* in den unbehandelten Kontrollen variierte zwischen 38-1233 Pflanzen $m^{-2}$. Cinmethylin bekämpfte 58-99 % der *A. myosuroides* Pflanzen bis zu dem Zeitpunkt von 120 Tagen nach der Saat. In Kombination mit Spätsaat stieg der Bekämpfungserfolg auf mehr als 90 % in allen Versuchen. Die Stoppelbehandlungen hatten keinen Einfluss auf die Dichte von *A. myosuroides*. Die Kornerträge von Winterweizen und Wintertriticale der Behandlungen Cinmethylin mit Spätsaat lagen signifikant über denen der unbehandelten Kontrolle. Die Ergebnisse unterstreichen den Nutzen von integrierten Verfahren der Unkrautkontrolle.

**Stichwörter:** Integrierte Unkrautbekämpfung, Vorauflaufherbizide, vorbeugende Unkrautkontrolle

## Introduction

Cinmethylin is a potential new pre-emergence herbicide to control *Alopecurus myosuroides* Huds. and other grass weeds in cereals and oil-seed rape. Cinmethylin had been developed by Shell chemical company in the 1980ies. It was used in Asia to control grass-weeds in rice (DAYAN, 2003) but so far, it has not been applied in Europe. The mode of action of cinmethylin was recently identified by CAMPE et al. (2018). It inhibits the fatty acid thioesterases (FAT) in the plastid and represent a new mode of action for chemical weed control. Already 2 out of 17 *A. myosuroides* populations tested showed natural resistance to cinmethylin (MESSELHÄUSER et al., 2021a) before the selection within the population using cinmethylin has started. Repeated application of herbicides has selected for many resistant populations of *A. myosuroides* in Western Europe to almost all herbicide modes of action registered for *A. myosuroides* control. More populations were resistant to post-emergence herbicides inhibiting the photosystem II- (PS2), acetyl CoA carboxylase (ACCase)- and acetolactate synthase (ALS) than to pre-emergence her bides (DROBNY et al., 2006; DÉLYE et al., 2007; MENNE et al., 2012; MENNE & HOGREFE, 2012; BAILLY et al., 2012; HEAP, 2014). Therefore, it is expected that resistant populations of *A. myosuroides* to cinmethylin may also be selected after several seasons of LUXIMO® application in winter annual crops.

*Alopecurus myosuroides* is prone of herbicide resistance because of several reasons. Population densities rapidly increased over the past decades due to a shift of cropping systems to higher proportions of winter annual crops and reduced tillage practices (LUTMAN et al., 2013; GERHARDS et al., 2016). Selection pressure is high because herbicides are often sprayed several times within a rotation (ZELLER et al., 2018). Herbicide resistance can spread within agricultural fields and from field to field due to cross-pollination and seed transport with combine harvesters, mainly if contract harvesters were used. Finally, seeds persist in the soil seed bank over a period of up to 8 years (MOSS, 1990; GERHARDS et al., 2016; MOSS, 2017). Those are reasons why *A. myosuroides* became a very problematic weed in Western European winter cereal production causing approximately 20% grain yield losses at densities of 100 plants per $m^{-2}$ (ZELLER et al., 2018; ZELLER et al., 2021).

It is mostly agreed that only integrated weed control strategies including preventive and curative methods of weed control can successfully suppress *A. myosuroides* (LUTMAN et al., 2013; MOSS, 2017). Pre-emergence herbicides are usually not sufficient to provide a critical level of minimum 95% weed control efficacy against *A. myosuroides*, which is necessary to prevent an increase of population densities (MELANDER, 1995; MENEGAT & NILSSON, 2019; MESSELHÄUSER et al., 2021). Among preventive methods, integration of spring crops in winter cereal rotations reduced *A. myosuroides* densities by up to 88%, inversion tillage by 69%, delayed autumn drilling by 50%, selection of competitive crop cultivars and increasing crop density by up to 40% (LUTMAN et al., 2013; ZELLER et al., 2018; ZELLER et al., 2021). Cover cropping, non-selective herbicide application on the stubble and stubble tillage suppressed *A. myosuroides* densities in the fall-to-spring season by more than 90% (SCHAPPERT et al., 2018). Inversion tillage and repeated shallow tillage operations (up to 5 cm depth) after harvesting the previous crop resulted in better *A. myosuroides* suppression than deep stubble tillage of approximately 15 cm depth with a chisel plough. Although chisel ploughing provides better decomposition of crop residues and volunteer seeds, it can induce secondary dormancy of fresh *A. myosuroides* seeds. Shallow stubble tillage operations with a straw harrow prevent secondary dormancy and induce most seeds to germinate (MOSS, 2017; ZELLER et al., 2021). That preventive weed control methods listed above were mostly investigated separately in the previous studies. Few studies have combined preventive and curative methods in multi-factorial experiments (ZELLER et al., 2021). The objectives of this study were to determine the combined effects of stubble treatments, late drilling and the pre-emergence application of cinmethylin on *A. myosuroides* density and winter cereal grain yield. The hypotheses were that i) cinmethylin provided more than 80% weed control efficacy against *A. myosuroides* until the end of the vegetative growth stage (tillering) of winter cereals; ii) that delayed autumn drilling had an additive or synergistic effect on the efficacy of the pre-emergence cinmethylin application; iii) repeated stubble tillage and a combination of chisel ploughing and non-selective herbicide application on the stubble reduced *A. myosuroides* in the following winter cereal compared to reduced stubble tillage.

## Material and methods

### *Experimental sites*

Four field experiments were conducted in winter wheat (2) and winter triticale (2) in Southwestern Germany from autumn 2017 until summer 2020. Three experiments were located at the research station Ihinger Hof (IHO) (48°44'32.5"N 8°55'31.1"E) of the University of Hohenheim and one on a practical farm site in Entringen 48°33'31.1"N 8°57'23.6"E). Climatical conditions were similar at both locations. Temperatures were 1-2 °C higher than the long-term average in all three years. All years were characterized by longer periods of drought in early spring, summer and autumn. In 2017 and 2019, soil was very dry before and shortly after sowing of winter cereals. The soil type at both locations was a parabrown soil containing 41% clay in Entringen and 32% clay at Ihinger Hof. Organic carbon contents ranged from 1.5% at Ihinger Hof to 2.1% in Entringen.

### *Experimental design*

A three factorial randomized complete block design with three repetitions was realized in all four experiments. Each plot had a length of 12 m and a width of 3 m. The first factor was the **stubble treatment** between the harvest of the previous crop and the sowing of the winter cereal. Ploughing is a common stubble tillage practice to incorporate residues of the previous crop. It was applied once in the “reduced” treatment. In one treatment, chisel ploughing was “repeated” four weeks after the first pass to provide better control of emerging weeds and crop volunteers than in the “reduced” treatment. “Conservation” tillage is often applied when problems with soil erosion occurs. It was conducted twice with a straw harrow. In one treatment, chisel ploughing was followed by one application of non-selective herbicides.

The second factor was the **drilling time** of winter cereals including an early date from late September until mid of October and a late date three to six weeks later from the end of October until early December.

The third factor was the **weed control method** in winter cereals including a pre-emergence application of LUXIMO® in the full recommended field rate of 0.66 l $ha^{-1}$ (495 g a.i. $ha^{-1}$ cinmethylin) and an untreated control. Cinmethylin was applied five days after sowing with a plot sprayer (Schachtner-Gerätetechnik, Ludwigsburg, Germany), which was calibrated for a volume of 200 l $ha^{-1}$ and a speed of 3.6 km $h^{-1}$. Broadleaved weed species were controlled in all plots with synthetic auxins in spring.

### *Assessments*

Density of *A. myosuroides* was determined 45 and 120 DAS. In the figures, data of the second counting are presented. *A. myosuroides* plants were counted in a 0.1 m² frame randomly placed four times in each plot. Grain yield was measured in a 1.5 m x 12 m strip in the center of each plot with a plot harvester (Wintersteiger, Elite 3, Ried im Innkreis, Austria). Grain weights were transformed to a homogenous water content of 14%.

### *Statistical analysis*

For data analysis, the statistical software R (Version 3.6.2, RStudio Team, Boston, MA, USA) was used. Prior to ANOVA, the data were checked for homogeneity of variance and normal distribution of residuals. If necessary, data were square root transformed to homogenize variances and to normalize the distribution. In the figures, back transformed means are shown. In the ANOVA, stubble treatment, sowing date and herbicide treatment were included as fixed effects. Multiple mean comparison tests were performed using the Tukey HSD-Test at a significance level of $\alpha \leq 0.05$.

## Results

### *Effects of treatments on* **Alopecurus myosuroides** *density*

At IHO 2018, moderate infestation rate of *A. myosuroides* density with 38 plants $m^{-2}$ were measured in the early sown and untreated plots. Delayed drilling resulted in average *A. myosuroides* density of 11 plants $m^{-2}$, which corresponds to a 71% reduction. Cinmethylin controlled 97% of *A. myosuroides* plants. At Entringen 2019, the three-way interaction of stubble treatment, sowing date and weed control was significant. Densities in the control plots were very high and ranged from 872 to 1233 plants $m^{-2}$ after early sowing and 464 to 996 plants $m^{-2}$ after late sowing at the second sampling date 120 DAS. Delayed drilling early December reduced *A. myosuroides* density to an average of 11 plants $m^{-2}$. Cinmethylin application provided an additive effect to late drilling. Densities in all treatments sprayed with cinmethylin were less than 2 plants $m^{-2}$, which amounted in 98-99% *A. myosuroides* control efficacy (WCE). In the IHO 2019 experiment, only the factor weed control showed significant effects. Delayed autumn drilling slightly reduced *A. myosuroides* densities with an average of 199 plants $m^{-2}$ compared to 241 plants $m^{-2}$ for the early sowing date. At IHO 2020, delayed autumn drilling and cinmethylin application significantly reduced *A. myosuroides* density. Infestation rates in the early sown control plots were considerably high with an average of 282 plants $m^{-2}$. Delayed drilling reduced *A. myosuroides* density to 101 plants $m^{-2}$ (64% WCE). Densities in treatments sprayed with cinmethylin were 114 plants $m^{-2}$ in the early sown plots and 24 plants $m^{-2}$ after delayed drilling (Fig. 1). WCE of cinmethylin increased from 58% in the early sowing date to 91% after delayed drilling. Therefore, cinmethylin application provided a synergistic effect to late drilling.

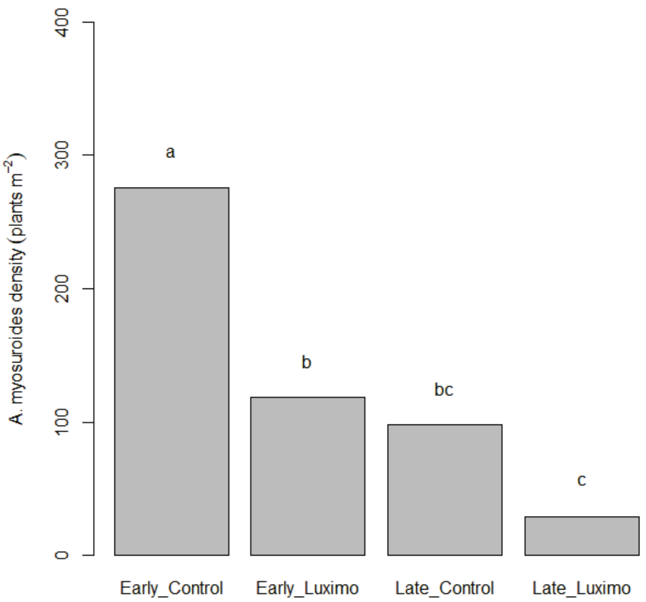


**Figure 1** Effects of delayed autumn drilling and LUXIMO® (cinmethylin) treatment on the average *Alopecurus myosuroides* density (plants $m^{-2}$) at Ihinger Hof (IHO) in winter wheat 2020.

***Abbildung 1*** *Einfluss von Spätsaat und LUXIMO® (cinmethylin) auf die mittlere Dichte (plants m-2) von* Alopecurus myosuroides *am Standort Ihinger Hof (IHO) in Winterweizen 2020.*

### *Effects of treatments on cereal grain yields*

In the IHO 2018 experiment, delayed autumn drilling in combination with cinmethylin application significantly increased winter wheat yield compared to early sowing and untreated controls. The cinmethylin treatment after delayed sowing resulted in a grain yield of 7.1 t $ha^{-1}$ compared to 6.3 t $ha^{-1}$ for the early sown treatments and 6.0 t $ha^{-1}$ for the late drilled control plots. Grain yield in Entringen 2019 was only affected by weed control treatment. The application of cinmethylin increased the average grain yield to 9.4 t $ha^{-1}$ compared to 7.0 t $ha^{-1}$ for the untreated control (Fig. 2).

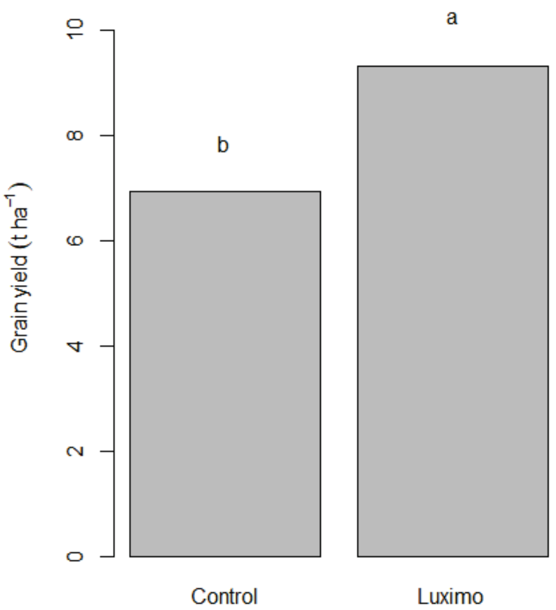


**Figure 2** Effect of LUXIMO® (cinmethylin) treatment on the average winter triticale grain yield (t $ha^{-1}$) at Entringen in 2019.

***Abbildung 2*** *Einfluss von LUXIMO® (cinmethylin) auf den mittleren Kornertrag (t $ha^{-1}$) von Wintertriticale am Standort Entringen in 2019.*

At IHO 2019, no significant effects of stubble treatment, sowing date and weed control on grain yield were observed. The average grain yields amounted 5.5 t $ha^{-1}$ to 8.5 t $ha^{-1}$ in the control plots and 8.5 t $ha^{-1}$ to 10.1 t $ha^{-1}$ in the LUXIMO®treatments. Yields were slightly higher after delayed sowing compared to the early sowing. Among the stubble treatments, reduced tillage resulted in slightly higher yields compared to the other treatments. Grain yields at IHO in 2020 were influenced by sowing date and weed control. Late drilling achieved 2.5 t $ha^{-1}$ higher grain yields than early sowing and the application of cinmethylin also increased grain yields by 2.5 t $ha^{-1}$ compared to the untreated control.

## Discussion

The results in this study proofed the first hypothesis that WCE of cinmethylin against *A. myosuroides* exceeded 80%. On average, WCE was 88% ranging from 58-99%. Data of WCE were similar to other pre-mergence herbicides commonly used against *A. myosuroides* in winter cereals, such as flufenacet, pendimethalin, prosulfocarb and diflufenican and combinations of those (MENNE et al., 2012; MENEGAT & NIELSSON, 2019; MESSELHÄUSER et al., 2021). However, WCE of pre-emergence herbicides varied stronger between years and sites than post-emergence herbicides (MESSELHÄUSER et al., 2021). Pre-emergence herbicides showed lower WCE especially under dry conditions and high clay and organic matter contents. Activity of pre-emergence herbicides is often not long enough to provide effective weed until the end of tillering of winter cereals, which can be as long as 150 DAS (KUDSK & KRISTENSEN, 1992). Therefore, pre-emergence herbicides often need to be combined with other weed control tactics.

The second hypothesis that delayed autumn drilling had an additive or synergistic effect on the efficacy of the pre-emergence cinmethylin application was proofed by the data. WCE against *A. myosuroides* was always higher than 90% after the combination of late drilling and cinmethylin application few days after sowing. Combined effects were additive in 2018 and 2019 and synergistic in 2020. This underlines the benefits of integrated weed management using chemical and non-chemical weed control tactics.

## References

CAMPE, R., E. HOLLENBACH., L. KÄMMERER et al., 2018: A new herbicidal site of action: Cinmethylin binds to acyl-ACP thioesterase and inhibits plant fatty acid biosynthesis. Pesticide Biochemistry and Physiology **148**, 116–125.

DÉLYE, C., Y. MENCHARI, J.-P. GUILLEMI, et al., 2007: Status of black grass (*Alopecurus myosuroides*) resistance to acetyl-coenzyme A carboxylase inhibitors in France. Weed Research **47**, 95–105.

GERHARDS, R., J. DENTLER, C. GUTJAH, et al., 2016: An approach to investigate the costs of herbicide-resistant *Alopecurus myosuroides*. Weed Research **56**, 407–414.

LUTMAN, P.J.W., S.R. MOSS, S. COOK et al., 2013: A review of the effects of crop agronomy on the management of *Alopecurus myosuroides*. Weed Research **53**, 299–313.

MELANDER, B., 1995: Impact of drilling date on *Apera spica-venti* L. and *Alopecurus myosuroides* Huds, in winter cereals. Weed Research **35**, 157–166.

MENEGAT, A., A.T.S. NILSSON, 2019: Interaction of Preventive, Cultural, and Direct Methods for Integrated Weed Management in Winter Wheat. Agronomy **9**, 564.

MENNE, H.J., C. HOGREFE, 2012: Impact of multiple resistance mechanisms in black-grass (*Alopecurus myosuroides* Huds.) populations on the of cereal herbicides. Julius-Kühn-Archiv **1**, 65–74.

MENNE, H.J., B. LABER, D. KERLEN et al., 2012: Effectiveness of flufenacet in controlling resistant black-grass (*Alopecurus myosuroides* Huds.) – comparison of glasshouse and field trial results. Julius-Kühn-Archiv **1**, 401–408.

MESSELHÄUSER, M.H., A.I. LINN, A. MATHES et al., 2021a: Development of an Agar Bioassay Sensitivity Test in *Alopecurus myosuroides* for the Pre-Emergence Herbicides Cinmethylin and Flufenacet. Agronomy **11**, 1408.

MESSELHÄUSER, M.H., M. SAILE, B. SIEVERNICH et al., 2021b: Effect of cinmethylin against *Alopecurus myosuroides* Huds. in winter cereals.Plant, Soil and Environment **67**, 46–54.

MOSS, S.R., 1990: The seed cycle of *Alopecurus myosuroides* in winter cereals: a quantitative analysis. In: Europe an Weed Research Society, Helsinki, Finland, June 1990, 27-35.

MOSS, S.R., J.H. Clarke, 1994: Guidelines for the prevention and control of herbicide-resistant black-grass (*Alopecurus myosuroides* Huds.). Crop Protection **13**, 230–234.

MOSS, S.R., 2017: Black-grass (*Alopecurus myosuroides*): Why has this weed become such a problem in Western Europe and what are the solutions? Outlooks on Pest Management **28**, 207–212.

SCHAPPERT, A., M.H. MESSELHÄUSER, M. SAILE, et al., 2018: Weed Suppressive Ability of Cover Crop Mixtures Compared to Repeated Stubble Tillage and Glyphosate Treatments. Agriculture **8**, 144.

ZELLER, A.K., Y.I. KAISER, R. GERHARDS, 2018: Suppressing *Alopecurus myosuroides* Huds. in rotations of winter annual and spring crops. Agriculture **8**, 91.

ZELLER, A.K., Y.I. ZELLER, R. GERHARDS, 2021: A long-term study of crop rotations, herbicide strategies and tillage practices: Effects on *Alopecurus myosuroides* Huds. abundance and contribution margins of the cropping systems. Crop Protection **145**, 105613.