Differential sensitivity of locally naturalized *Panicum* species to 4-hydroxyphenyl pyruvate dioxygenase and acetolactate synthase-inhibiting herbicides

Differentielle Sensitivität von lokal naturalisierten Panicum-Arten gegenüber 4-Hydroxyphenylpyruvat-Dioxygenase und Acetolactat- Synthase hemmenden Herbiziden

Benny De Cauwer*, Tim Geeroms, Sofie Claerhout, Dirk Reheul and Robert Bulcke

Ghent University, Faculty of Bioscience Engineering, Department of Plant Production, Coupure Links 653, BE-9000 Gent, Belgium
*Corresponding author, Benny.Decauwer@UGent.be

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Abstract

One of the possible reasons for the expansion of the alien panicoid grasses *Panicum schinzii* (Transvaal millet), *Panicum dichotomiflorum* (Fall panicum) and *Panicum capillare* (Witchgrass) in maize fields in Belgium might be a lower sensitivity to post-emergence herbicides acting against panicoid grasses, in particular those inhibiting 4-hydroxyphenyl pyruvate dioxygenase (HPPD) and acetolactate synthase (ALS). Dose-response pot experiments were conducted in the greenhouse to evaluate the effectiveness of five HPPD-inhibiting herbicides (sulcotrione, mesotrione, isoxaflutole, topramezone, tembotrione) and two ALS-inhibiting herbicides (nicosulfuron, foramsulfuron) for controlling naturalized Belgian populations of *P. schinzii, P. dichotomiflorum* and *P. capillare.* In another dose-response pot experiment, sensitivity of five local *P. dichotomiflorum* populations to HPPD-inhibitors and nicosulfuron was investigated. Finally, the influence of growth stage at time of herbicide application on efficacy of topramezone and nicosulfuron for *Panicum* control was evaluated. Large interspecific differences in sensitivity to HPPD-inhibiting herbicides were observed. *Panicum schinzii* was sensitive (i.e., required a three-fold lower dose than maximum authorized field dose to achieve 90% reduction in biomass) to tembotrione but moderately sensitive (i.e. required maximum field dose) to topramezone and poorly sensitive (i.e. required three-fold higher dose than maximum field dose) to mesotrione and sulcotrione. However, P. dichotomiflorum, a species that morphologically closely resembles *P. schinzii*, was sensitive to mesotrione and topramezone but moderately sensitive to tembotrione. *Panicum capillare* was sensitive to sulcotrione and topramezone, moderately sensitive to tembotrione and poorly sensitive to mesotrione. All Panicum species were sensitive to low doses of nicosulfuron and foramsulfuron. Naturalized *Panicum dichotomiflorum* populations exhibited differential herbicide sensitivity profiles. All species tested showed a progressive decrease in sensitivity to topramezone and nicosulfuron with seedling age. A satisfactory post-emergence control of *Panicum* species in the field will require appropriate choice of herbicide and dose, as well as a more timely application (i.e. before weeds reach the four leaves stage).

Keywords: Bioassay, herbicide sensitivity, leaf stage, nicosulfuron, panicoid grasses, triketone

Zusammenfassung

Einer der möglichen Gründe für die rasche Ausbreitung der standortfremden Unkrauthirsen *Panicum schinzii* (Glattblättrige Hirse), *Panicum dichotomiflorum* (Gabelästige Rispenhirse) und *Panicum capillare* (Haarästige Rispenhirse) in Maisfeldern in Belgien könnte eine geringere Empfindlichkeit gegenüber Nachauflaufherbiziden sein, insbesondere 4-Hydroxyphenylpyruvat-Dioxygenase (HPPD)- und Acetolactat-Synthase (ALS)-Hemmer. Dosis-Wirkungs-Experimente wurden im Gefäßversuch im Gewächshaus durchgeführt, um die Wirksamkeit von fünf HPPD-inhibierenden Herbizidwirkstoffen (Sulcotrione, Mesotrione, Isoxaflutole, Topramezone, Tembotrione) und zwei ALS-inhibierenden Herbizidwirkstoffen (Nicosulfuron, Foramsulfuron) gegen naturalisierte belgische Populationen von *P. schinzii*, *P. dichotomiflorum* und *P. capillare* zu beurteilen. In einem weiteren Dosis-Wirkungs-Topf Experiment wurde die Empfindlichkeit von fünf lokal eingewanderten *P. dichotomiflorum*-Populationen gegenüber HPPD-Inhibitoren und Nicosulfuron untersucht. Schließlich wurde der Einfluss des Blattstadiums zum Zeitpunkt der Herbizid-Anwendung auf Wirksamkeit von Topramezone und Nicosulfuron für Panicum-Bekämpfung ausgewertet. Große interspezifische Unterschiede in der Empfindlichkeit gegenüber HPPD-inhibierenden Herbiziden wurden beobachtet. *Panicum schinzii* war empfindlich gegenüber Tembotrione aber mäßig empfindlich gegenüber Topramezone und leicht empfindlich gegenüber Mesotrione und Sulcotrione. Dagegen war P. dichotomiflorum empfindlich gegenüber Mesotrione und Topramezone aber mäßig empfindlich gegenüber Tembotrione. Panicum capillare war empfindlich gegenüber Sulcotrione und Topramezone, mäßig empfindlich gegenüber Tembotrione und leicht empfindlich gegenüber Mesotrione. Alle Panicum-Arten waren empfindlich gegenüber niedrigen Dosen von

Nicosulfuron und Foramsulfuron. Eingebürgerte Panicum dichotomiflorum-Populationen zeigten differentielle Herbizid-Empfindlichkeitsprofile. Alle untersuchten Arten zeigten eine fortschreitende Abnahme der Empfindlichkeit gegenüber Topramezone und Nicosulfuron mit zunehmendem Blattstadium. Eine befriedigende Nachauflaufbekämpfung von Panicum-Arten in Maisäckern benötigt eine angemessene Wahl von Herbizid und Dosis sowie eine rechtzeitige Anwendung (das heißt vor dem Vierblattstadium).

Stichwörter: Biotest, Blattstadium, Herbizidempfindlichkeit, Nicosulfuron, Triketone, Unkrauthirsen

Introduction

The boom of maize (*Zea mays* L.) cultivation in Flanders (Belgium) that started ca. four decades ago created optimal conditions for the establishment of permanent populations of many panicoid weed grasses (e.g. *Panicum* spp., *Echinochloa* spp., *Setaria* spp., *Digitaria* spp.) in and around maize fields (VANDERHOEVEN *et al.*, 2007). Although the toolbox for weed control in maize contains an impressive variety of herbicides with different molecular modes of action (SANTEL, 2009), newly introduced and naturalizing panicoid grasses continuously complicate appropriate choice of herbicides and their dosages.

Until recently the *Panicum* species *Panicum schinzii* Hack. (Transvaal millet, native to South Africa), *P. dichotomiflorum* Michx. (Fall panicum, native to North and South America) and *P. capillare* L. (Witchgrass, native to North America) were completely overlooked in Belgium. Since 1970, these species have gradually spread and are now locally naturalized and abundant in and along maize fields, particularly on sandy soils (HOSTE and VERLOOVE, 2001; VAN LANDUYT *et al.*, 2006). *P. dichotomiflorum* and *P. schinzii* are morphologically hard to distinguish, particularly at early growth stages. One of the possible reasons for its expansion into maize fields, besides e.g. the lack of crop rotation (VANDERHOEVEN *et al.*, 2007), might be a lower sensitivity to post-emergence (POST) maize herbicides used to control panicoid grasses, in particular 4-hydroxyphenyl pyruvate dioxygenase (HPPD)-inhibiting herbicides and acetolactate synthase (ALS) inhibiting sulfonylureas.

These *Panicum* species are highly competitive and prolific weeds and need to be controlled soon after emergence to prevent yield loss (HOLM *et al.*, 1977). Recently, there have been many complaints about unsatisfactory *Panicum* control. Unfortunately, in sharp contrast to other naturalized panicoid grasses belonging to the genera *Echinochloa*, *Setaria* and *Digitaria*, scientific literature detailing the herbicide sensitivity is lacking for abovementioned naturalized *Panicum* species.

In the present study the following research questions were addressed: *(1)* Do *P. capillare*, *P. dichotomiflorum* and *P. schinzii* show a difference in sensitivity to maize herbicides acting against panicoid grasses, in particular HPPD- and ALS-inhibitors? (2) Do local *P. dichotomiflorum* populations vary in herbicide sensitivity? (3) What is the most optimal leaf stage for *Panicum* control?

Material and Methods

During the summer of 2011, three dose-response pot experiments were conducted in the greenhouse.

In experiment 1, the effectiveness of five foliar-applied HPPD-inhibiting herbicides [topramezone (ARIETTA®), mesotrione (CALLISTO®), tembotrione (LAUDIS®), sulcotrione (MIKADO®), isoxaflutole (Exp. product)] and two ALS-inhibiting herbicides [nicosulfuron (KELVIN®), foramsulfuron (EQUIP®)] for controlling populations of *P. capillare*, *P. dichotomiflorum* and *P. schinzii* was evaluated. Selected *P. capillare* population was 'Herbiseed' (population purchased from the seed company Herbiseed,Twyford, UK). For *P. dichotomiflorum* and *P. schinzii* locally naturalized populations were used, namely 'Bellem' and 'Ursel', respectively.

Although these HPPD-inhibitors are solely applied post-emergence POST in Belgian maize fields, they also have residual soil activity (BULCKE *et al.*, 1996; ROUCHAUD *et al.*, 2000; SCHÖNHAMMER *et al.*, 2006; SCHULTE and KÖCHER, 2009). For this reason, experiment 1 was also designed to investigate the relative contribution from foliar activity to weed control resulting from post applications of

HPPD- and ALS inhibitor herbicides. For this purpose, half of all pots were covered with a herbicide adsorbing film (1 mm) of activated charcoal (Aktivkohle, ROTH, Germany) shortly after sowing. The charcoal-treated pots were used to evaluate foliar activity of the applied herbicides, whereas pots without charcoal were used to evaluate total activity.

Experiment 2 was designed to evaluate the importance of intraspecific variability in herbicide sensitivity. Five geographically distinct *P. dichotomiflorum* populations (e.g. four local populations 'Bellem', 'Adegem', 'Lembeke' and 'Ursel', and one reference population 'Herbiseed') were screened for their sensitivity to four HPPD-inhibitors (mesotrione, tembotrione, sulcotrione and topramezone) and one ALS-inhibitor (nicosulfuron).

In experiment 3, the relation between weed growth stage and herbicide sensitivity was investigated by subjecting *P. capillare*, *P. dichotomiflorum* and *P. schinzii* plants, differing in growth stage, to foliar-applied topramezone and nicosulfuron. The same populations as in experiment 1 were used.

Experimental setup

All dose-response experiments were conducted in greenhouses using plastic pots filled with steamed sandy loam soil containing 2.2% organic matter, 51.6% silt (2-50 µm), 39.9% sand (>50 µm) and 8.6% clay with a pH-KCl of 5.7. The greenhouse was a rain-shelter plastic greenhouse, with sides left open up to 1 m high for natural ventilation. In all experiments, pots were seeded with 25 seeds per pot at 2 mm depth. As soon as seedlings had one fully developed true leaf (BBCH stage 11), they were randomly thinned to five uniform plants per pot. Daytime and night-time mean temperatures were 22.6/15.9°C, 23.0/14.3 °C and 22.9/15.9 °C during experiment 1, 2 and 3, respectively.

Pots were irrigated by overhead sprinklers as needed. The experimental design was always a randomized block with three replicates. The experimental unit was one pot of five seedlings. All herbicides were applied with TeeJet 8001EVS flat fan nozzles (TeeJet Technologies, Wheaton, USA) at a spray pressure of 300 kPa and a spray volume of 300 L ha^{-1}. Each herbicide was tested in eight doses and compared to a control as enumerated in Table 1. In experiment 1 and 2, herbicides were applied in the four (BBCH 14) and three (BBCH 13) true leaves stage, respectively. BBCH 14 is the weed growth stage at which POST herbicides are most commonly applied in Flemish maize fields. In experiment 3, topramezone and nicosulfuron were applied at four different weed growth stages: BBCH 11, one true leaf; BBCH 12, two true leaves, BBCH 13, three true leaves; BBCH 14, four true leaves. These weed growth stages were achieved by staggered sowing times.

In all bioassay experiments, foliage fresh biomass was harvested 28 days after treatment (DAT). Foliage fresh weight per pot was obtained by clipping the plants at the soil surface and weighing them.

Statistical analysis

Data obtained from POST bioassays were analysed with the Open Source language and environment R (version R2.11.1; R Development Core Team, 2010) and its dose-response curves extension package drc (RITZ and STREIBIG, 2005) based on KNEZEVIC *et al.* (2007). Foliage fresh weight data were subjected to analysis of variance; dose-response curves, ED_{90} (dose required for 90% biomass reduction) and selectivity indices were determined using procedures by STREIBIG *et al.* (1993) and SEEFELDT *et al.* (1995). Selectivity index (SI, i.e. the ratio between ED_{90} for one curve and ED_{90} for another curve) was used to compare the relative differences of ED_{90} among curves.

Tab. 1 Herbicides and their doses examined in postemergence (POST) dose-response bioassays.

Tab. 1 *Herbizide und deren Aufwandmengen untersucht in Nachauflauf Dosis-Wirkungs-Biotest.*

Herbicide (formulated product)	**Herbicide dose (g ai ha^{-1})**
HPPD-inhibitors (HRAC group F2):	
topramezone[1]	0/1.6/3.2/6.3/12.6/25.2/50.4/100.8/201.6
(Arietta, 336 g ai L^{-1}, SC, BASF Belgium)	
sulcotrione	0/15/30/60/120/240/480/960/1920
(Mikado, 300 g ai L^{-1}, SC, Bayer CropScience)	
tembotrione[2]	0/2.75/5.5/11/22/44/88/176/352
(Laudis, 44 g ai L^{-1}, OD, Bayer CropScience)	
mesotrione	0/2.5/5/10/20/40/80/160/320
(Callisto, 100 g ai L^{-1}, SC, Syngenta Crop protection)	
isoxaflutole[3]	0/3.125/6.25/12.5/25/50/100/200/400
(SP102000016788, 240 g ai L^{-1}, SC, Bayer CropScience)	
ALS-inhibitors (HRAC-group B):	
nicosulfuron	0/0.63/1.25/2.5/5/10/20/40/80
(Kelvin, 40 g ai L^{-1}, SC, DuPont De Nemours)	
foramsulfuron[4]	0/1.875/3.75/7.5/15/30/60/120/240
(Equip, 22.5 g ai L^{-1}, SC, Bayer CropScience)	

[1] 1 L ha^{-1} triglyceride oil (Actirob B, 812 g ai L^{-1}, EC, Novance) was added to the herbicide spray solution to enhance foliar uptake and distribution within the shoot

[2] tembotrione was applied in combination with its safener isoxadifen-ethyl (2:1 ratio) included in the product Laudis. Laudis combines tembotrione and the safener isoxadifen-ethyl with an adjuvant system in an oil dispersion (OD) formulation

[3] isoxaflutole was applied in combination with its safener cyprosulfamide (1:1 ratio) included in the experimental product

[4] foramsulfuron was applied in combination with its safener isoxadifen-ethyl (1:1 ratio) included in the product Equip.

Results and Discussion

Experiment 1

Compared to *P. capillare*, *P. schinzii* showed significantly lower sensitivity to the foliar-applied HPPD-inhibitors sulcotrione, topramezone and isoxaflutole (Tab. 2). Compared to *P. dichotomiflorum*, *P. schinzii* was seven- to eight-fold less sensitive to topramezone and mesotrione but two-fold more sensitive to tembotrione. These differential responses may be attributed to differences in foliar uptake. However, differential herbicide metabolism and/or differential sensitivity or activity of the HPPD enzyme cannot be completely ruled out.

Furthermore, doses of sulcotrione and mesotrione required to obtain a 90% reduction in *P. schinzii* biomass, were two to three times higher than their respective maximum field doses in Belgium (Tab. 2). For topramezone the maximum field dose was required. Whereas, *P. dichotomiflorum* had ED_{90} values equal to or less than maximum field doses. The abovementioned unsatisfactory control by some HPPD-inhibiting herbicides partly explains the rapid expansion of *P. schinzii* into Flemish maize fields (VAN LANDUYT *et al.*, 2006). This is particularly true for the widely used sulcotrione, being the first triketone herbicide introduced in 1992 into the Belgian maize market.

All *Panicum* species tested were very sensitive to low doses of the ALS-inhibiting herbicides nicosulfuron and foramsulfuron (relative to their maximum authorized field dose of 60 g a.i. ha^{-1}).

P. capillare showed significantly higher sensitivity to foliar-applied nicosulfuron as compared to *P. schinzii* and *P. dichotomiflorum* which were equally sensitive.

Tab. 2 ED$_{90}$ response (g a.i. ha^{-1}) with standard errors of *P. dichotomiflorum*, *P. capillare* and *P. schinzii* to postemergence HPPD- and ALS-inhibitors applied at the four true leaves stage (Experiment 1).

Tab. 2 *Effektive Dosen ED$_{90}$ (g a.i. ha^{-1}) (mit Standardfehler) für* P. dichotomiflorum, P. capillare *und* P. schinzii *behandelt im 4-Blattstadium mit HPPD- und ALS-Inhibitoren (Experiment 1).*

	P. dichotomiflorum[†] **(g a.i. ha^{-1})**	***P. capillare***[†] **(g a.i. ha^{-1})**	***P. schinzii***[†] **(g a.i. ha^{-1})**	**Max. field dose (g a.i. ha^{-1})**
HPPD-inhibitors:				
sulcotrione		278.3 ± 126.09a	1043.6 ± 217.59b	450
mesotrione	60.9 ± 39.18a	492.0 ± 237.86b	479.8 ± 138.71b	150
topramezone	7.5 ± 4.93a	10.4 ± 2.71a	52.2 ± 10.66b	50
tembotrione	66.0 ± 43.14ab	125.6 ± 34.18a	26.2 ± 1.65b	99
isoxaflutole		231.2 ± 84.68a	2450.5 ± 993.73b	
ALS-inhibitors:				
foramsulfuron		3.4 ± 0.97a	8.5 ± 1.01b	60
nicosulfuron	5.6 ± 3.23a	2.5 ± 0.37b	9.4 ± 0.83a	60

[†] No significant differences (based on computed selectivity indices and corresponding p-values) between figures with the same letter, comparison within herbicide only (Experiment 1)

In our small pot experiments with regular overhead irrigation, considerable soil activity was expected. The relative contribution from soil activity to weed control resulting from post-emergence applications was important for isoxaflutole and to a varying degree also for sulcotrione , mesotrione and tembotrione but not for topramezone and the ALS-inhibitors nicosulfuron and foramsulfuron (Tab. 3). Indeed, significantly higher ED$_{90}$ doses of isoxaflutole were required for plants growing in charcoal-topped pots than for plants growing in charcoal-free pots, irrespective of *Panicum* species. Significant contribution of soil activity was also found for *P. dichotomiflorum* treated with mesotrione, *P. capillare* treated with sulcotrione and tembotrione, and for *P. schinzii* treated with tembotrione.

Based on ED$_{90}$ response levels, sensitivity to HPPD-inhibitors and nicosulfuron varied enormously among naturalized *Panicum dichotomiflorum* populations (Tab. 4). Populations 'Adegem' and 'Herbiseed' were significantly less sensitive to mesotrione than population 'Ursel'. Population 'Bellem' was significantly more sensitive to sulcotrione than 'Adegem'. Compared to other *P. dichotomiflorum* populations tested, population 'Bellem' required a two- to three-fold higher dose of tembotrione to achieve 90% reduction in biomass. Contrary to mesotrione, sulcotrione and tembotrione, no significant intraspecific differences in ED$_{90}$ response were found for topramezone and nicosulfuron. This high degree of intraspecific variability in herbicide sensitivity is rather surprising for a species that only recently (end of the 1980`s) became a naturalized species in Flemish maize fields. Most likely, new populations with different genetic background are continuously introduced in Flemish maize fields, thus increasing genetic variability among populations.

Tab. 3 ED_{90} response (g a.i. ha^{-1}) with standard errors of *P. dichotomiflorum*, *P. capillare* and P. *schinzii* to post-emergence HPPD- and ALS-inhibitors. Herbicides were applied at the four leaves stage of plants growing in charcoal-topped pots(+charcoal) and in charcoal-free pots (-charcoal) (Experiment 1).

Tab. 3 *Effektive Dosen ED_{90} (g a.i. ha^{-1}) (mit Standardfehler) für* P. dichotomiflorum, P. capillare *und* P. schinzii *behandelt im 4-Blattstadium mit HPPD- und ALS-Inhibitoren. Behandelte Pflanzen sind gewachsen in Töpfen mit (+charcoal) oder ohne (-charcoal) Deckschicht aus Aktivkohle (Experiment 1).*

Herbicide	***P. dichotomiflorum*†**		***P. capillare*†**		***P. schinzii*†**	
	-charcoal	**+charcoal**	**-charcoal**	**+charcoal**	**-charcoal**	**+charcoal**
HPPD-inhibitors:						
isoxaflutole	-	-	231±70.7a	1256±660.2b	1043±356.9a	94996±175705.7b
mesotrione	49±17.1a	155±44.8b	382±188.9a	407±101.3a	459±156.9a	478±155.7a
sulcotrione	-	-	278±115.4a	1434±449.6b	884±236.0a	448±85.7a
tembotrione	67±20.0a	46±3.3a	139±30.5a	247±39.3b	26±2.8a	40±4.5b
topramezone	34±6.7a	27±5.0a	8±1.2a	8±1.2a	6±2.2a	9±2.0a
ALS-inhibitors:						
foramsulfuron	-	-	4±1.5a	5±1.1a	8±1.4a	10±1.3a
nicosulfuron	7±2.8a	10±1.5a	2±0.4a	3±0.2a	14±3.6a	18±4.3a

† No significant differences (based on computed selectivity indices and corresponding p-values) between figures with the same letter, comparison within herbicide/species combination only (Experiment 1)

Experiment 2

Tab. 4 ED_{90} responses (g a.i. ha^{-1}) with standard errors of geographically distinct *P. dichotomiflorum* populations to foliar-applied HPPD-inhibitors (mesotrione, sulcotrione, tembotrione and topramezone) and nicosulfuron (Experiment 2).

Tab. 4 *Effektive Dosen ED_{90} (g a.i. ha^{-1}), mit Standardfehler, für geografisch getrennte* P. dichotomiflorum *Populationen behandelt mit HPPD-Inhibitoren (Mesotrione, Sulcotrione, Tembotrione und Topramezone) und Nicosulfuron aufgebracht auf das Blattwerk (Experiment 2).*

Herbicide	***P. dichotomiflorum* population†**				
	Adegem	**Bellem**	**Herbiseed**	**Lembeke**	**Ursel**
mesotrione	68.9 ± 13.1a	57.3 ± 10.44ab	79.0 ± 18.23a	55.8 ± 9.54ab	36.8 ± 9.03b
sulcotrione	186.4 ± 31.83a	105.7 ± 15.74b	177.6 ± 43.20ab	133.1 ± 23.92ab	-
tembotrione	101.4 ± 24.88a	38.6 ± 7.29b	75.1 ± 19.10a	105.9 ± 28.23a	57.7 ± 21.53ab
topramezone	10.0 ± 1.24a	10.0 ± 2.19a	3.6 ± 2.97a	9.2 ± 2.76a	11.3 ± 3.26a
nicosulfuron	7.6 ± 1.50a	5.2 ± 1.26a	6.6 ± 1.35a	9.2 ± 2.75a	-

† No significant differences (based on computed selectivity indices and corresponding p-values) between figures with the same letter, comparison within herbicide only (Experiment 2)

Experiment 3

The ED_{90} response (expressed relative to ED_{90} dose for *P capillare* plants treated at the one leaf stage) of *P. capillare, P. dichotomiflorum* and *P. schinzii* to foliar-applied topramezone (Fig. 1) and nicosulfuron (Fig. 2) was largely dependent on growth stage. Sensitivity of *P. dichotomiflorum* and *P. schinzii* to topramezone (Fig. 1) decreased exponentially with increasing number of true leaves at time of herbicide application, whereas for *P. capillare* a linear decrease was found. The latter can be explained by a lower penetration, since herbicide penetration is hampered as plants age owing to the development of a thicker cuticle or altered cuticle composition (ALDRICH and KREMER, 1997). Topramezone sensitivity dropped drastically beyond the two true leaves stage for *P. schinzii* and the three true leaves stage for *P. dichotomiflorum*. Plants were two- to eleven-fold less sensitive to topramezone when treated at the four true leaves stage than at the one leaf and two true leaves stage, irrespective of *Panicum* species. When *P. schinzii* seedlings are further developed than the three leaves stage, poor control by topramezone in the field is expected even when applied at their maximum authorized field doses.

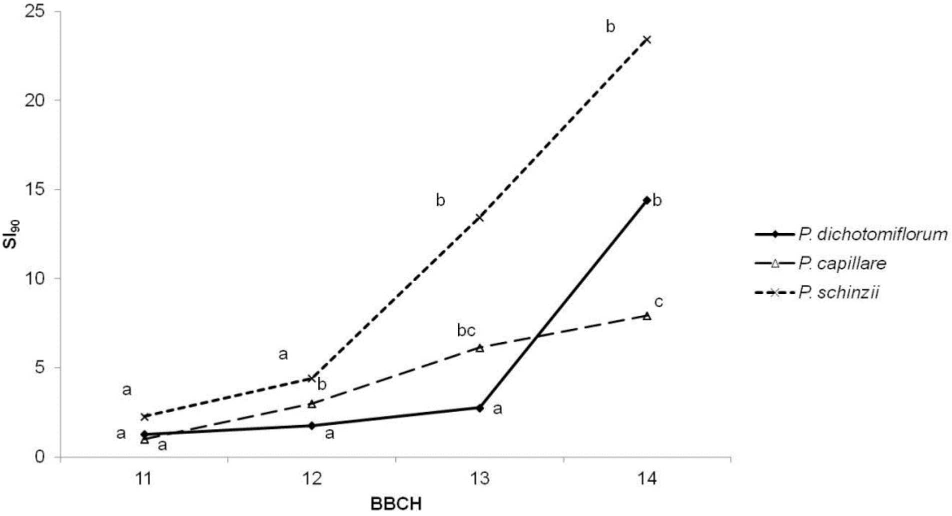

Fig. 1 Influence of growth stage on the performance of topramezone for *P. capillare*, *P. dichotomiflorum* and *P. schinzii*. The performance is expressed as a SI_{90} index, i.e. ED_{90} dose relative to ED_{90} response for first leaf stage plants of *P. capillare* (i.e. 2.6 g a.i. ha^{-1} topramezone). No significant differences (based on computed selectivity indices and corresponding p-values) between data points with the same letter, comparison within species only (Experiment 3).

Abb. 1 *Einfluss des Blattstadiums zur Wirksamkeit von Topramezone gegen* P. capillare, P. dichotomiflorum *und* P. schinzii. *Die Wirksamkeit wurde ausgedrückt als Verhältnis (SI90 Index) von der ED_{90}-Dosis zu der ED_{90}-Dosis für* P. capillare *behandelt im 1-Blattstadium (i.e. 2.6 g a.i. ha^{-1} Topramezone). Keine signifikanten Unterschiede (für berechnete SI90 Indizes und entsprechende p-Werte) zwischen Datenpunkten mit dem gleichen Buchstaben, Vergleich nur innerhalb der Arten (Experiment 3).*

Nicosulfuron sensitivity of *P. schinzii* and *P. capillare* linearly decreased with increasing number of true leaves (Fig. 2). Contrary to *P. capillare* and *P schinzii, P. dichotomiflorum* showed highest sensitivity at the two true leaves stage. However, beyond the two leaves stage, sensitivity was lowered again. *P. capillare* plants were significantly less sensitive to nicosulfuron when treated at the four leaves stage than at all other leaf stages. Four leaves stage plants of *P. schinzii* were four-fold less sensitive than plants at the one leaf stage. For P. dichotomiflorum sensitivity was four-fold lower at the four true leaves stage than at the two true leaves stage.

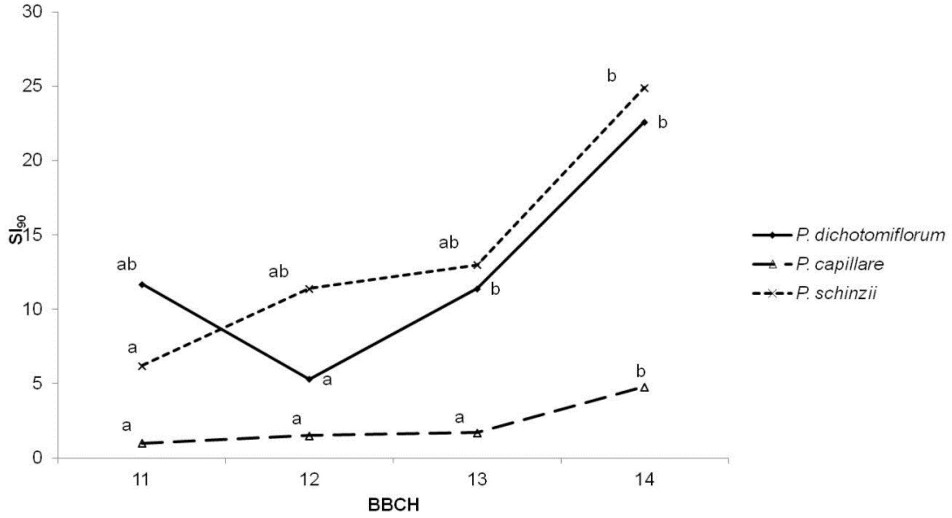

Fig. 2 Influence of growth stage on the performance of nicosulfuron for *P. capillare*, *P. dichotomiflorum* and *P. schinzii*. The performance is expressed as a SI_{90} index, i.e. ED_{90} dose relative to ED_{90} response for first leaf stage plants of *P. capillare* (i.e. 1.0 g a.i. ha^{-1} nicosulfuron). No significant differences (based on computed selectivity indices and corresponding p-values) between data points with the same letter, comparison within species only (Experiment 3).

Abb. 2 *Einfluss des Blattstadiums zur Wirksamkeit von Nicosulfuron gegen* P. capillare, P. dichotomiflorum *und* P. schinzii. *Die Wirksamkeit wurde ausgedrückt als Verhältnis (SI90 Index) von der ED_{90}-Dosis zu der ED_{90}-Dosis für* P. capillare *behandelt im 1-Blattstadium (i.e. 1.0 g a.i. ha^{-1} Nicosulfuron). Keine signifikanten Unterschiede (für berechnete SI90 Indizes und entsprechende p-Werte) zwischen Datenpunkten mit dem gleichen Buchstaben, Vergleich nur innerhalb der Arten (Experiment 3).*

Conclusions

Where mixed populations of *P. capillare*, *P. dichotomiflorum* and *P. schinzii* are present in a field, difficulties may arise in the successful chemical control of *Panicum* grasses due to interspecific differences in herbicide sensitivity in particular for HPPD-inhibiting herbicides. Hence, correct identification of *Panicum* species before treatment is a prerequisite to avoid insufficient *Panicum* control. In addition, successful control of P. *capillare*, *P. dichotomiflorum* and *P. schinzii* largely depended on growth stage at the time of herbicide application. Sensitivity of *Panicum* seedlings to topramezone and nicosulfuron linearly or exponentially increased with increasing number of true leaves at the time of herbicide application. Poor control by topramezone and nicosulfuron in the field can be expected in circumstances where *P. dichotomiflorum* and *P. schinzii* seedlings in particular are developed beyond the three true leaves stage.

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