Efficacy and selectivity of post-emergent application of flumioxazin and oxyfluorfen in sunflower

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ABSTRACT

Four efficacy and selectivity small plot field trials were carried out in four sunflower hybrids at two localities in Middle Bohemia during 2008 and 2009 with herbicides containing the active ingredients flumioxazin and fluorochloridone. For *Chenopodium album*, an efficacy of 97% was found after pre-emergent application of fluorochloridone + acetochlor; the efficacy of oxyfluorfen was 88–95%; the efficacy of flumioxazin was below 50% at both tested application rates (30 and 60 g/ha) and application timings (2 sunflower leaves and 4 to 6 sunflower leaves); efficacy of flumioxazin increased to 67% and 69%, when surfactants were added (isodecyl alcohol ethoxylate and heptamethyltrisiloxan). Full control of *Amaranthus retroflexus* was found after all pre-emergent and early post-emergent herbicide treatments; efficacy of late post-emergent herbicide treatments was below 93%. Full control of *Mercurialis annua* was found only after application of oxyfluorfen. *Thlaspi arvense* was fully controlled by fluorochloridone + acetochlor (pre-emergent) and oxyfluorfen (in both application terms). Selectivity of the four tested sunflower hybrids to fluorochloridone + acetochlor, bifenox and flumioxazin was acceptable (phytotoxicity 6 to 27%). Higher phytotoxicity (23–45%) was recorded when surfactants were added to flumioxazin. The highest phytotoxicity (68–81%) was recorded after the application of oxyfluorfen.

Keywords: weeds; sunflower; herbicide efficacy; phytotoxicity; surfactants

Sunflower (*Helianthus annuus*) has a medium tolerance for weeds because of their lower competition ability; however, data from certain authors suggest differently (Durgan et al. 1990, Onofri and Tei 1994, Carranza et al. 1995, Lehoczky et al. 2006). According to Wanjari et al. (2001), the critical weed free period is between the 20^{th} and 49^{th} day after sowing. Weed competition is manifested by a decrease of sunflower biomass and yield loss, which can be up to 81% depending on weed density, time of competition duration, weed spectrum and other factors (Carranza et al. 1995).

There is a relatively high selection of herbicides for weed control in sunflower, but most of them are for pre-emergent treatments only. This is because most herbicides were primarily developed for weed control in economically more important crops (Gressel 2002), and their use in sunflower is often only possible if the sunflower seeds are deeply sown (positional selectivity). Intensive precipitation after application of these herbicides can cause high phytotoxicity, especially in sandy soils. Nevertheless, 95% of the sunflower growing area in the Czech Republic was treated by pre-emergent herbicides (Málek 2010).

In cases in which pre-emergent herbicides were not applied or their efficacy failed, post-emergent herbicide treatment is necessary. However, sunflower is very sensitive to post-emergence herbicides; thus, weed control is not easily achieved using these kinds of herbicides (Pannacci et al. 2007, Andr et al. 2009). Only pendimethalin, prosulfocarb and bifenox were recently registered for post-emergence usage in the Czech Republic. In states with larger sunflower sowing areas, trifluralin, aclonifen, flufenacet, or metolachlor are

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used for post-emergence control of annual weeds. The herbicides cited above are primarily used for early post-emergence control. Only flumioxazin and oxyfluorfen can be used for control of dicotyledonous weeds in later growth stage (Andr et al. 2009). In herbicide tolerant sunflower hybrids (ClearField or Express technology), some acetolactate synthase inhibitors may be used for post-emergent weed control (Baumgartner et al. 1999, Pfenning et al. 2008).

Oxyfluorfen and flumioxazin are inhibitors of protoporphyrinogen oxidase, which is taken up by both the leaves and roots, and have a longer persistence in soil (Alister et al. 2009). When they are applied after the emergence of weeds, the protoplast membranes of sensitive weeds are disrupted during the few hours after application, and the affected tissues turn brown and display necrosis. A high intensity of solar radiation accelerates the efficacy of these herbicides (Dayan and Duke 1997). Annual weeds are only sensitive at early growth stages (maximum of 4 to 8 true leaves). Perennial weeds cannot be completely controlled because their underground system is not affected, and new stems are promptly formed (Jursík et al. 2010). Both of the herbicides mentioned in this section have a low selectivity to sunflower and need to be precisely applied under specific conditions.

The aim of this work was to review the possibility of flumioxazin and oxyfluorfen usage for post-emergence weed control in sunflower. We also analysed their optimal usage, with a focus on biological efficacy and selectivity in relation to application timing, rate of herbicide and usage of surfactants.

MATERIAL AND METHODS

Four identical small plot field trials were carried out in sunflower in two locations (Prague and Čáslav) in the Central Bohemia area of the Czech Republic in 2008 and 2009. The plots were established in randomised blocks with three replications; row spacing was 0.7 m with in-row plant spacing of 0.18 m. The depth of sowing was 0.06 m. Four morphologically different sunflower hybrids (Alexandra, Karamba, Heliaroc and Picasol (only in Čáslav)) were sown for assessment of crop safety. Each hybrid was sown in two rows that were five meters in length. The dominant weed species was *Chenopodium album* (10–80 plant/m^2) in both experimental fields. Other weeds species found in the fields at a lower density (4–12 plant/m^2 for individual species) included the following: *Echinochloa crus-galli*, *Amaranthus retroflexus* (only in Prague), *Mercurialis annua* (only in Prague), and *Thlaspi arvense* (only in Čáslav in 2009). The characteristics of the experimental fields are shown in Table 1.

The applications of the herbicides were carried out at three different times of weed growth. Pre-emergence (PRE) application was carried out shortly after sunflower sowing (conventional standard). Early post-emergence (EPOST) application was carried out when the sunflower had two true leaves and the dicotyledonous weeds had four true leaves. The second post-emergence (POST) application was performed when the sunflower had four to six leaves and the dicotyledonous weeds began to create lateral shoots. A detailed description of the meteorological data and growth stage of weeds at the time of application is shown in Table 2. A description of the experimental herbicide treatments is shown in Table 3. A small-plot sprayer was used to apply the herbicides. The water volume applied was 300 L/ha, the nozzles were Lurmark 015 F 80 (Hypro EU Limited, Cambridge, Great Britain), and the application pressure was 0.3 MPa.

Herbicide efficacy was assessed by estimation method using a percentage scale from 0 to 100% (0% = untreated, 100% = full control) according to the European and Mediterranean Plant Protection Organisation (EPPO) 1/63 (2) guidelines. The first assessment was carried out one week after POST application, and second assessment was carried out between three and four weeks after POST application. The weight of *C. album* aboveground biomass (g/m^2) was assessed in the second half of the growing season when the sunflower was at its milk ripeness stage (BBCH 81). The selectivity to all tested hybrids was assessed according to

Table 1. Experimental field characteristics

	Prague	Čáslav
Altitude (m a.s.l.)	285	265
Soil type	Chernozem	Greyic Phaeozem
Content of clay (%)	45	35
Content of humus (%)	3.5	3.6
Soil pH (KCl)	7.55	6.33
Fertilization N:P:K (kg/ha)	90:36:70	86:37:70
Previous crop 2008	maize	winter wheat
Previous crop 2009	potatoes	winter barley

Table 2. Meteorological data and growth stage of tested weeds in terms of application of herbicides in both locations and for both experimental years

Term of applic.	Date	Weather at application			BBCH of weed
		cloud amount (%)	temperature (°C)	moisture of soil surface	
Čáslav 2008					
PRE	21.4.2008	50	16	dry	00
EPOST	13.5.2008	80	19	dry	CHEAL 12
POST	26.5.2008	85	18	dry	CHEAL 16
Čáslav 2009					
PRE	17.4.2009	100	10	dry	00
EPOST	7.5.2009	90	15	wet	CHEAL14 THLAR 16
POST	21.5.2009	30	20	dry	CHEAL 22 THLAR 31
Prague 2008					
PRE	15.5.2008	80	23	dry	00
EPOST	3.6.2008	100	20	dry	11-13
POST	9.6.2008	90	22	dry	CHEAL 21 AMARE 16 MERAN 21
Prague 2009					
PRE	23.4.2009	80	10	wet	00
EPOST	12.5.2009	60	15	wet	12-14
POST	20.5.2009	50	20	wet	CHEAL 22 AMARE 16 MERAN 51

CHEAL – *Chenopodium album*; THLAR – *Thlaspi arvense*; AMARE – *Amaranthus retroflexus*; MERAN – *Mercurialis annua*; PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

the EPPO 1/135 (2) guideline at the same time as the efficacy was assessed. Phytotoxicity was assessed visually and by measuring the weight of the sunflower seed heads in BBCH 81.

The experimental data were evaluated using the software package Statgraphics Plus. A one-way analysis of variance was used. The contrasts between treatments were verified by the *LSD* test (α = 0.05).

Table 3. Treatment list

Herbicide/surfactant	Rate a.i. per hectare (g)	Trade name of herbicide/surfactant	Application term	BBCH of sunflower
Untreated control	–	–	–	–
flurochloridone	500	racer 25 EC	PRE	00
Acetochlor	1.152	trophy	PRE	
Flumioxazin	30	pledge 50 WP	EPOST	12
Oxyfluorfen	240	galigan 240 EC	EPOST	12
Flumioxazin	30	pledge 50 WP	POST	14–16
Flumioxazin	30	pledge 50 WP	POST	14–16
Heptamethyltrisiloxan	84	silwet L-77	POST	
Flumioxazin	30	pledge 50 WP	POST	14–16
Isodecyl alcohol ethoxylate	90	trend 90	POST	
Flumioxazin	0.12	pledge 50 WP	POST	14–16
Oxyfluorfen	1.00	galigan 240 EC	POST	14–16
Bifenox	1.50	modown	POST	14–16

PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

Table 4. Efficacy of tested herbicides on *Chenopodium album*

	Efficacy (%)		Weight of *C. album* biomass (g/m^2)
	1st assessment	2nd assessment	
Untreated check	–	–	561.7^{cd}
Racer + trophy (PRE)	98^{e}	97^{e}	37.5^{a}
Pledge 1N (EPOST)	56^{c}	44^{c}	477.5^{bcd}
Galigan (EPOST)	96^{e}	95^{e}	280.0^{abcd}
Pledge 1N (POST)	26^{a}	3^{a}	713.3^{d}
Pledge 1N + Silwet (POST)	77^{d}	69^{d}	342.5^{abcd}
Pledge 1N + Trend (POST)	72^{d}	67^{d}	250.8^{abc}
Pledge 2N (POST)	40^{b}	18^{b}	664.2^{d}
Galigan (POST)	92^{e}	88^{e}	145.8^{ab}
Modown (POST)	50^{c}	26^{b}	583.8^{cd}
$LSD_{(0.05)}$	8	12	338.0
F-Ratio	77.51	68.88	2.60
P-Value	0.0000	0.0000	0.0094

PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence; 1st – assessment one week after POST application; 2nd – assessment 3 to 4 weeks after POST application, and dry weight of *C. album* aboveground biomass, measured at BBCH 81 of sunflower

RESULTS AND DISCUSSION

Efficacy of herbicides. The efficacy of all herbicide treatments on *Chenopodium album* decreased during the vegetation season (Table 4). The highest efficacy (97%) was shown using the PRE tank-mix (TM) combination of fluorochloridone + acetochlor. The efficacy of oxyfluorfen was also high, especially with the EPOST application (95%). Schumacher and Hatterman-Valenti (2007) found a higher efficacy of oxyfluorfen at early growth stage of *C. album* using a reduced rate of herbicide, compared with later treatments at a full rate of herbicide. The efficacy of fluorochloridone + acetochlor (PRE) and

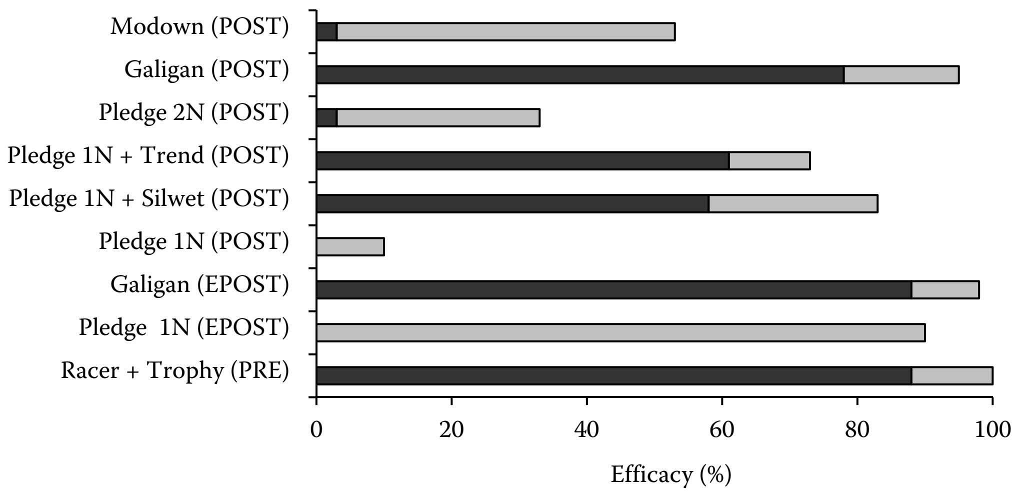

Figure 1. Range of efficacy of tested herbicide treatments on *Chenopodium album* across years and locations (data from assessment 3 to 4 weeks after POST application; the darker part of the column represents the lowest recorded efficacy, and the light part of the column represents the highest recorded efficacy); PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

oxyfluorfen (EPOST and POST) on *C. album* was significantly ($LSD_{\alpha\ 0.05}$) higher than other tested herbicide treatments. The efficacy of flumioxazin was very low (below 50%) at both tested application rates and application terms, but at the EPOST application, differences between experimental locations and years were 0–90% (Figure 1). The highest efficacy of flumioxazin (67, resp. 69%) was recorded when flumioxazin was applied with surfactants that increased adhesion, disturbed wax structure on the surface of *C. album* leaves and increased the uptake of herbicide (Forster et al. 2004). The efficacy of POST application of bifenox was very low (26%).

The lowest weight of *C. album* aboveground biomass (37.5 g/m^2) was recorded after PRE application of flurochloridone + acetochlor (Table 4), which was almost 15 times less than on untreated controls (561.7 g/m^2). For postemergence herbicide treatments, the POST application of oxyfluorfen and flumioxazin + isodecyl alcohol ethoxylate showed the lowest weight of *C. album* aboveground biomass (145.8, resp. 250.8 g/m^2). On the contrary, the highest weight of *C. album* aboveground biomass was measured after the solo POST application of flumioxazin at both tested rates (713.3, resp. 664.2 g/m^2), which was higher than on the untreated controls. This finding was probably caused by the free area available for the growth of *C. album* after the controlled of other weeds.

The full control of *Amaranthus retroflexus* was found at all PRE and EPOST herbicide treatments (Table 5). The efficacy of POST herbicide treatments was significantly ($LSD_{\alpha\ 0.05}$) lower (below 93%). The lowest efficacy (below 90%) was recorded after POST application of solo flumioxazin and when it was combined with isodecyl alcohol ethoxylate.

The full control of *Mercurialis annua* was reached only after the application of oxyfluorfen under both tested application terms (Table 5). Very good efficacy (96 and 97%) was found after EPOST application of flumioxazin and PRE application of fluorochloridone + acetochlor, respectively. The efficacies of other herbicide treatments were significantly ($LSD_{\alpha\ 0.05}$) lower (76 to 87%).

Full control of *Thlaspi arvense* was reached with the TM of fluorochloridone + acetochlor (PRE) and oxyfluorfen (under both application terms). The efficacy of other herbicide treatments was significantly ($LSD_{\alpha\ 0.05}$) lower. The lowest herbicide efficacy (27%) on *T. arvense* was observed after POST application of bifenox. Flumioxazin showed the highest efficacy (85%), but only if it was used with heptamethyltrisiloxan (Table 5).

Table 5. Efficacy of tested herbicides on *Amaranthus retroflexus*, *Mercurialis annua* and *Thlaspi arvense* at the 2nd assessment (3 to 4 weeks after POST application)

	Efficacy (%)		
	A. retroflexus	*M. annua*	*T. arvense*
Racer + trophy (PRE)	100^c	97^b	100^e
Pledge 1N (EPOST)	100^c	96^b	80^d
Galigan (EPOST)	100^c	100^b	100^e
Pledge 1N (POST)	89^{ab}	77^a	50^b
Pledge 1N + Silwet (POST)	93^b	86^a	85^d
Pledge 1N + Trend (POST)	85^a	76^a	72^c
Pledge 2N (POST)	93^b	87^a	72^c
Galigan (POST)	93^b	100^b	100^e
Modown (POST)	93^b	83^a	27^a
$LSD_{(0.05)}$	7	10	8
F-Ratio	4.99	7.40	9.89
P-Value	0.0002	0.0000	0.0000

PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

Table 6. Phytotoxicity of tested herbicides to sunflower hybrids, assessed one week after POST application

	Phytotoxicity (%)			
	Pikasol	Alexandra	Karamba	Heliaroc
Racer + trophy (PRE)	12^a	10^a	7^a	6^a
Pledge 1N (EPOST)	29^{cd}	28^b	21^b	24^b
Galigan (EPOST)	68^e	73^d	68^d	68^d
Pledge 1N (POST)	18^{abc}	21^b	16^b	23^b
Pledge 1N + Silwet (POST)	34^d	40^c	35^c	45^c
Pledge 1N + Trend (POST)	28^{bcd}	25^b	23^b	25^b
Pledge 2N (POST)	17^{ab}	23^b	21^b	24^b
Galigan (POST)	81^f	79^d	73^d	77^e
Modown (POST)	22^{abc}	26^b	23^b	27^b
$LSD_{(0.05)}$	11	9	8	8
F-Ratio	38.59	51.48	60.62	62.94
P-Value	0.0000	0.0000	0.0000	0.0000

PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

Table 7. Weight of sunflower seed heads at BBCH 81 of sunflower compared with untreated controls (100%)

	Relative weight of sunflower seed heads (%)			
	Pikasol	Alexandra	Karamba	Heliaroc
Untreated control	100^{ab}	100^{bc}	100^{bc}	100^{ab}
Racer + trophy (PRE)	127^{de}	124^{d}	131^{e}	135^{d}
Pledge 1N (EPOST)	114^{bcde}	96^{b}	112^{cd}	117^{bcd}
Galigan (EPOST)	95^{a}	74^{a}	87^{a}	91^{a}
Pledge 1N (POST)	120^{de}	101^{bc}	113^{d}	113^{bc}
Pledge 1N + Silwet (POST)	102^{abc}	116^{cd}	108^{cd}	115^{bc}
Pledge 1N + Trend (POST)	128^{e}	115^{cd}	117^{d}	118^{cd}
Pledge 2N (POST)	115^{cde}	107^{bc}	109^{cd}	101^{abc}
Galigan (POST)	103^{abc}	94^{b}	88^{ab}	87^{a}
Modown (POST)	112^{bcd}	107^{bc}	105^{bc}	101^{abc}
$LSD_{(0.05)}$	15	17	13	18
F-Ratio	4.84	5.60	9.17	5.03
P-Value	0.0001	0.0000	0.0000	0.0000

PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

Selectivity of herbicides to sunflower hybrids. The PRE TM of fluorochloridone + acetochlor showed good selectivity to all tested sunflower hybrids (Table 6). The symptoms of phytotoxicity (6–12%) observed were bleaching of the leaves and growth retardation. Similar results were recorded by Jursík at al. (2009) when they compared the selectivity and efficacy of PRE herbicide in sunflower. The highest weight of sunflower seed heads was recorded for this treatment (Table 7). The weight of the seed heads was significantly ($LSD_{\alpha\ 0.05}$) higher (by 24 to 35%) compared with untreated controls (the largest difference was recorded for the Heliaroc hybrid).

One week after POST application of bifenox, the phytotoxicity ranged between 22% (Picasol) and 27% (Heliaroc). The phytotoxicity decreased to 9% over the next 2 to 3 weeks (Figure 2). Symptoms of phytotoxicity were necroses on affected leaves. The weight of sunflower seed heads was insignifi-

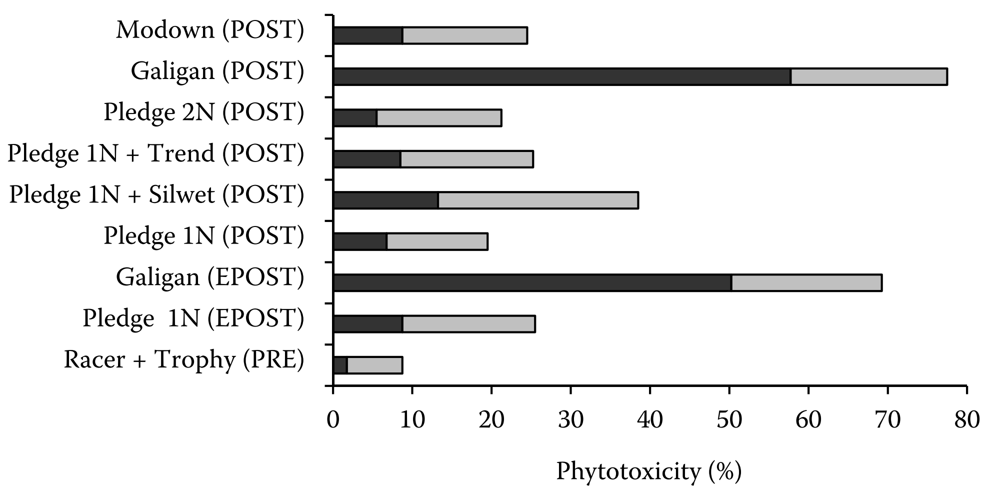

Figure 2. Disappearing phytotoxicity during the growing season (means from all hybrids, both locations and experimental years); the light part of the column shows phytotoxicity one week after POST application and the darker part of the column shows the phytotoxicity 2–3 weeks later; PRE – pre-emergence; EPOST – early post-emergence; POST – post-emergence

cantly ($LSD_{\alpha\ 0.05}$) higher compared with untreated controls for all tested hybrids (Table 7).

The highest phytotoxicity (68 to 81%) was recorded after the application of oxyfluorfen (Table 6). Symptoms of phytotoxicity were strong necroses and growth retardation, but the growing point was not affected. A lower phytotoxicity level was found after the EPOST application of oxyfluorfen, compared with the POST application, which was likely caused by the shorter period between application and assessment at the POST application. Differences in phytotoxicity between tested hybrids of sunflower were insignificant ($LSD_{\alpha\ 0.05}$). Although phytotoxicity decreased during the growing season (Figure 2), the weight of sunflower seed heads was lower compared with untreated controls (by 5 to 26%), except for the Picasol hybrid, whose seed head weight increased by 3% (Table 7). However, the selectivity of oxyfluorfen was also low for the PRE application (Pannacci et al. 2007).

One week after the POST application of flumioxazin (for both tested application rates), the phytotoxicity ranged between 17 and 24% (Table 6), and during the next 2 to 3 weeks, the phytotoxicity decreased below 10%. The TM of flumioxazin with tested surfactants caused higher phytotoxicity, between 34% (Pikasol) and 45% (Heliaroc) using the surfactant heptamethyltrisiloxan and between 23% (Karamba) and 28% (Picasol) using the surfactant isodecyl alcohol ethoxylate. Differences in phytotoxicity between the tested surfactants were significant ($LSD_{\alpha\ 0.05}$) for the Heliaroc, Karamba and Alexandra hybrids at one week after application and for the Heliaroc hybrid 2 to 3 weeks after application (phytotoxicity 8, resp. 18%). Torma et al. (2007) also observed increases in phytotoxicity when flumioxazin was used in combination with surfactants. After the EPOST application of flumioxazin, an insignificantly ($LSD_{\alpha\ 0.05}$) higher phytotoxicity, between 21% (Karamba) and 29% (Picasol), was recorded one week after application, which subsequently decreased to 5 to 12%. The phytotoxicity symptom of flumioxazin was necroses of the leaves. Slower regeneration was recorded after application of flumioxazin with the surfactant heptamethyltrisiloxan by the Karamba and Pikasol hybrids. The largest seed head weight was recorded when flumioxazin was applied with the surfactant isodecyl alcohol ethoxylate – causing an increase of 15 to 28% compared with untreated controls. Conversely, the seed head weight of the Picasol hybrid was higher than that on plots PRE treated by fluorochloridone + acetochlor (but only by 1%). For the flumioxazin treatments, the lowest seed head weight was recorded after EPOST application by the Alexandra hybrid, where the seed head weight was lower than for the untreated controls.

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