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TESTING THE CROP SELECTIVITY AND WEED CONTROL EFFICACY OF AUTUMN APPLICATION OF BELKAR HERBICIDE AND ITS MIXTURES WITH OTHER HERBICIDES IN WINTER OILSEED RAPE CROPS IN UKRAINE

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The article presents the results of a series of field trials conducted between 2016 and 2020 in various regions of Ukraine. The aim of these trials was to determine crop selectivity and weed control efficacy during autumn application in winter oilseed rape (*Brassica napus* L.) crops using a new complex herbicide, Belkar EC. The active substances of this herbicide are synthetic auxins: halauxifen-methyl (9.6 g/L) and picloram (48 g/L). It is well known that winter oilseed rape is sensitive to halauxifen-methyl. Due to this, halauxifen-methyl can only be used in winter oilseed rape crops in combination with other synthetic auxins — specifically clopyralid, whose safening effect ensures the mixture's selectivity toward the crop. For autumn application, picloram is more suitable than clopyralid for a number of reasons. Therefore, during the development of Belkar EC, clopyralid was replaced by picloram. Because autumn application during the early growth stages of winter oilseed rape requires higher herbicide selectivity compared to spring application, the question of Belkar EC selectivity is particularly relevant. Due to the mixed nature of weed infestation in crops, it may become necessary to combine Belkar EC with other herbicides that are effective against weed species resistant to Belkar EC. Therefore, for the effective use of Belkar EC, it is necessary to verify its selectivity toward winter oilseed rape and its weed control efficacy both when used alone and in mixtures with other herbicides. In the field experiments, spraying of winter oilseed rape crops was carried out during the 2—4 true leaves stage of the crop (BBCH 12—14). The efficacy of dicotyledonous weed control by Belkar EC was compared with the performance of Galera Super SL. It was established that during autumn treatment at the recommended rate of 0.25 L/ha and at a double rate of 0.5 L/ha, the phytotoxic effect of Belkar EC on winter oilseed rape did not exceed that of Galera Super SL. At an application rate of 0.25 L/ha, Belkar EC effectively controlled a wide spectrum of dicotyledonous weed species. The application of Belkar EC in a tank mix with Butisan 400 SC did not affect crop selectivity and allowed for the inclusion of the annual grass weed loose silkey-

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bent (*Apera spica-venti* (L.) Pal. Beauv.) into the control spectrum, while also significantly increasing the control efficacy of the annual dicotyledonous weed scentless chamomile (*Matricaria inodora* L.). The use of Belkar EC in a tank mix with Salsa WG significantly increased the control efficacy of weeds from the *Brassicaceae* family, particularly flixweed (*Descurainia sophia* (L.) Webb.). Application in mixtures with graminicides such as Fusilade Forte EC, Agil EC, Miura EC, and Centurion EC did not affect the selectivity of Belkar EC toward winter oilseed rape or its efficacy in controlling dicotyledonous weed species. Furthermore, the efficacy of grass weed control when applied in a mixture with Belkar EC did not differ from the effect of the graminicides applied alone. The combination of the obtained results indicates that the autumn application of herbicide Belkar EC alone and in mixtures with other herbicides in winter oilseed rape crops is safe for the crop and provides effective protection against weeds during the autumn vegetation period.

Key words: herbicides, herbicide mixtures, selectivity, weed control, halauxifen-methyl, picloram.

In recent years, the sown areas of winter oilseed rape (*Brassica napus* L.) in Ukraine have increased by 19 %, reaching 1.13 million hectares in 2022, while the average countrywide yield increased to 2.87 t/ha [1]. At the same time, with the correct selection and systematic application of plant protection products, the profitability of this crop can reach 100 % [2]. Although winter oilseed rape belongs to the group of crops that are highly competitive against weeds, it cannot withstand weed competition during the early stages of development in the autumn period. Due to global warming, the autumn vegetative period of winter oilseed rape has lengthened, which highlights the urgency of crop protection during this time. Autumn weed infestation can cause the crop's growth point to extend excessively above the soil surface and lead to poorer root system development, which increases the risk of winter-killing and causes subsequent yield losses. Under heavy weed pressure, the loss of oilseed rape biomass can reach 30—50 % [3], and seed yield can decrease by 20—25 % [4].

To control dicotyledonous weed species in cereal crops and other commodities the herbicide halauxifen-methyl has been developed. Based on its chemical structure, it belongs to a new class of compounds with auxin activity known as aryl picolinates [5]. Oilseed rape is inherently sensitive to halauxifen-methyl, however, it was discovered that this active substance can be used in winter oilseed rape crops when combined with other synthetic auxins, specifically clopyralid, due to their safening effect [6]. Trials have shown that when applied in the spring after the resumption of winter oilseed rape vegetation, the herbicide Slash EC, containing the active substances halauxifen-methyl (5 g/L) and clopyralid (120 g/L), at a rate of 1.0 L/ha outperformed the herbicide Galera Super SL (soluble concentrate) (clopyralid, 267 g/L + picloram, 80 g/L + aminopyralid, 17 g/L) applied at 0,3 L/ha in its efficacy against highly harmful dicotyledonous weeds: corn poppy (*Papaver rhoeas* L.), cleavers (*Galium aparine* L.), and field larkspur (*Consolida regalis* S.F. Gray) [7]. However, for autumn application, the herbicide Belkar EC (in which clopyralid was replaced by picloram) was recognized as more promising from an environmental safety

standpoint, particularly for preventing herbicide leaching into groundwater aquifers [8]. Consequently, the question arises whether this substitution leads to a reduction in crop selectivity toward winter oilseed rape.

It is known that the herbicide Slash EC can control certain weed species from the *Brassicaceae* (mustard) family [7]. However, under high weed pressure in winter oilseed rape crops, a combined application of Belkar EC with Salsa WG (water-soluble granules) (ethametsulfuron-methyl, 750 g/kg) may be required, as the latter is effective against specific *Brassicaceae* species, particularly wild mustard (*Sinapis arvensis* L.). Furthermore, the need for a comprehensive application of Belkar EC may be driven by high infestation rates of *Poaceae* (grass) weeds. In this scenario, Butisan 400 SC (suspension concentrate) (metazachlor, 400 g/L) serves as an appropriate tank-mix partner for Belkar EC.

Additionally, because winter cereals are frequently the predecessor crop to winter oilseed rape, these fields are often infested with volunteer cereals alongside other annual and perennial monocotyledonous and dicotyledonous weeds, with volunteer seedlings appearing simultaneously with oilseed rape emergence. To control weeds from the *Poaceae* family, acetyl-CoA carboxylase (ACCase) inhibitor herbicides (graminicides) are widely used. These include derivatives of aryloxyphenoxypropionic acid (AOPP), such as Fusilade Forte 150 EC (fluazifop-P-butyl, 150 g/L), Agil EC (propaquizafop, 100 g/L), and Miura EC (quizalofop-P-ethyl, 125 g/L), as well as the cyclohexanedione derivative Centurion EC (clethodim, 240 g/L).

However, it remains unknown whether the joint application of Belkar EC with graminicides will intensify its phytotoxic effect on the crop or if a reduction in graminicide efficacy will occur. It is well established that the phytotoxic effect of graminicides can be antagonistically reduced when combined with herbicides targeting dicotyledonous weeds, particularly those from the synthetic auxin class [9, 10].

Thus, the aim of this work was to evaluate selectivity and determine weed control efficacy during the autumn application of Belkar EC, both alone and in tank mixtures with other herbicides, in winter oilseed rape crops.

Materials and Methods

Field trials were conducted between 2016 and 2020 in winter oilseed rape crops at three locations representing different soil and climatic zones of Ukraine: 1) Location 1 — Experimental Agricultural Production Unit of the Institute of Plant Physiology and Genetics, National Academy of Sciences of Ukraine, located in Hlevakha village, Fastiv district, Kyiv region, (located at the boundary of the Polissia and Forest-Steppe zones); 2) Location 2 — a commercial agricultural enterprise in Horokhovatka village, Obukhiv district, Kyiv region (Forest-Steppe zone); 3) Location 3 — a commercial agricultural enterprise in Kanizh village, Kirovohrad district, Kirovohrad region (Steppe zone).

Field experiments were established in winter oilseed rape cultivars/hybrids differing by location: Chornyi Veleten at Location 1 (preceding

crop — winter wheat), PR44D06 at Location 2 (preceding crop — spring barley), and Smart at Location 3 (preceding crop — sunflower).

Herbicide applications were carried out using a compressed-air backpack plot sprayer operated at a pressure of 4 atm. The boom width was 3 m and equipped with five nozzles evenly spaced at 50 cm intervals. Applications were made at a forward speed of 5 km/h using a spray volume of 300 L/ha. The area of experimental plots was 15 m^2 (3 m × 5 m), they were arranged in a randomized complete block design with four replications.

The selectivity of Belkar EC and herbicide mixtures to winter oilseed rape was evaluated through assessments of general phytotoxicity (PHYGEN) conducted on 7th, 14th, and 28th days after treatment (DAT) during autumn, and again in the following spring after crop vegetation resumed. Crop response was visually assessed using a scale from 0 to 100 %, where 0 % indicated the absence of visible crop injury and 100 % represented complete destruction of the crop. Evaluations included the occurrence and severity of herbicide-induced symptoms such as growth suppression, chlorosis, necrosis, leaf deformation, abnormalities in leaf venation, formation of lanceolate leaves, and other morphological alterations. The phytotoxicity score reflected the overall extent of injury observed within each experimental plot relative to untreated plants.

Weed assessments were conducted immediately before herbicide application and subsequently on 14th and 28th DAT. Herbicide efficacy was initially estimated by visual assessment based on reductions in weed density and suppression of individual weed species, expressed as a percentage, where 0 % represented no herbicide effect and 100 % indicated complete weed control. Visual assessments were verified by the gravimetric method, and weed control efficacy was calculated according to the following equation:

$$E_i\ (\%) = (M_k - M_i) \times 100/M_k$$

where: E_i (%) — weed control efficacy; M_i — fresh aboveground biomass of a given weed species in the treated plot; M_k — fresh aboveground biomass of the same weed species in the untreated control plot.

For gravimetric assessments, aboveground weed biomass was harvested and weighed. When weed density exceeded three plants on m^2, biomass samples were collected from four quadrats of 1.0 m^2 within each plot. At lower infestations, all plants of the target species within the entire plot were harvested and weighed using electronic scales.

Experimental data were subjected to analysis of variance (ANOVA) using Microsoft Excel software. Treatment means were separated using the Least Significant Difference (LSD) test with Bonferroni correction, and differences were considered statistically significant at $p < 0,05$.

Results and Discussion

In 2016, field experiments were established at Locations 1 and 3 according to the following design: Belkar EC (0.25 L/ha); Belkar EC (0.3 L/ha); Galera Super SL (0.3 L/ha); untreated Control. Crop spraying at Location 1

TABLE 1. Selectivity (%) of herbicides on winter oilseed rape assessed on 14th day after treatment (DAT) in autumn (1: 2016) and in spring after resumption of crop vegetation (2: 2017), and weed control efficacy (%) assessed on 28th DAT in autumn (3: 2016) and in spring after resumption of crop vegetation (4: 2017)

Treatment	Location 1				Location 3			
	PHYGEN (autumn)[1]	PHYGEN (spring)[2]	Control efficacy[3]		Control efficacy[4]			
			Cirsium arvense	*Chenopodium album*	*Cirsium arvense*	*Matricaria inodora*	*Erodium cicutarium*	PHYGEN (autumn)[1]	PHYGEN (spring)[2]	Control efficacy[3]	
										Helianthus annuus	*Chenopodium album*
Belkar EC (0.25 L/ha)	2^{b}	0	68^{a}	34^{ab}	65^{a}	43^{a}	38^{b}	2^{b}	0	35^{a}	90^{b}
Belkar EC (0.3 L/ha)	2^{b}	0	74^{ab}	46^{b}	71^{a}	53^{a}	40^{b}	5^{c}	0	48^{a}	95^{b}
Galera Super SL (0.3 L/ha)	0^{a}	0	79^{b}	25^{a}	95^{b}	93^{b}	20^{a}	0^{a}	0	74^{b}	28^{a}

Note. Means followed by different letters differ significantly ($p < 0.05$); [1, 2] — PHYGEN — general phytotoxicity on winter oilseed rape assessed in autumn on 14th day after treatment (DAT) and in spring after resumption of crop vegetation, respectively; [3] — weed control efficacy on 28th DAT (autumn 2016); [4] — weed control efficacy in spring after resumption of winter oilseed rape vegetation (2017).

was conducted at the 2—3 true leaves stage (BBCH 12—13), and at Location 3 at the 2 true leaves stage (BBCH 12) of the oilseed rape. At Location 1 on 7th day after treatment (DAT), no phytotoxic effects on winter oilseed rape were recorded. On 14th DAT, a minor (less than 2 %) reduction in growth rate was observed in treatments where Belkar EC was applied; however, no formative leaf defects were observed (Table 1). On 28th DAT and following the resumption of spring vegetation the next year, no symptoms of herbicide phytotoxicity on oilseed rape plants were recorded. At Location 3 on 7th and 14th DAT, individual oilseed rape plants exhibited crinkling and curling of leaf margins in the Belkar EC variants. The percentage of plants showing symptoms of phytotoxicity was 2 % and 5 % at application rates of 0.25 L/ha and 0.3 L/ha, respectively. On 28th DAT and after spring regrowth, no signs of herbicide phytotoxic action were observable.

In the trial at Location 1, the application of Belkar EC at a rate of 0.25 L/ha, and particularly at 0.3 L/ha, provided more effective control of common lambsquarters (*Chenopodium album* L.) compared to Galera Super SL (soluble concentrate) (Table 1). Conversely, the perennial dicotyledonous weed creeping thistle (*Cirsium arvense* (L.) Scop.) was better controlled by Galera Super SL both in autumn and in the spring of the following year. It is worth noting that the spring of 2017 was arid, which reduced annual weed pressure. However, even under these conditions, the autumn application of Belkar EC at 0.25 and 0.3 L/ha proved insufficiently effective for the control of scentless chamomile (*Matricaria inodora* L.), whereas Galera Super suppressed this weed with high efficacy. In spring, the level of control achieved by Belkar EC against com-

mon stork's-bill (*Erodium cicutarium* (L.) L'Hér.), though not remarkably high (30—40 %), was still superior to that of Galera Super SL. Thus, under the specific conditions of this field trial, Belkar EC proved more effective for controlling common lambsquarters in autumn, but less effective than Galera Super for controlling creeping thistle and scentless chamomile in spring.

In the trial at Location 3, the efficacy of common lambsquarters control by Belkar EC significantly exceeded the performance of Galera Super SL. At the same time, the effect on volunteer sunflower (*Helianthus annuus* L.) was higher in the Galera Super SL treatment (see Table 1). In the spring of 2017, after overwintering, no impact of the autumn herbicide treatment was observed on the composition or density of dicotyledonous weeds, which included field violet (*Viola arvensis* Murr.) (0,5 specimens/m^2 (s/m^2)), shepherd's-purse (*Capsella bursa-pastoris* (L.) Med.) (0,3 s/m^2), common chickweed (*Stellaria media* (L.) Vill.) (0,3 s/m^2), wall speedwell (*Veronica arvensis* L.) (0,1 s/m^2), and flixweed (*Descurainia sophia* (L.) Webb.) (0,1 s/m^2). The low weed pressure was likely due to the dry conditions of autumn 2016 and early spring 2017. Volunteer sunflower and common lambsquarters were absent in all treatments, including the control, as these species perished during the winter freezing period.

The efficacy of herbicides can depend heavily on application timing. To determine the effect of treatment timing on weed control efficacy, a field trial was established in 2018 at Location 2, where the application of Belkar EC at a rate of 0.25 L/ha was carried out at two distinct timings: Timing A — at the BBCH 12 stage (two true leaves) of the crop, coinciding with weed seedling emergence. Timing B — at the BBCH 14 stage (four true leaves) of the crop.

Field inspections revealed no signs of phytotoxic impact from Belkar EC on winter oilseed rape at either application timing. Weed counts demonstrated that the later treatment (Timing B) provided superior control of dicotyledonous weeds from the *Brassicaceae* family — field pennycress (*Thlaspi arvense* L.) and flixweed, *Amaranthaceae* — common lambsquarters, *Ranunculaceae* — field larkspur (*Consolida regalis* S.F. Gray), and *Caryophyllaceae* — white campion (*Melandrium album* (Mill.) Garcke) infesting the crop (Table 2). It should be noted that following the treatment at Timing A, nocturnal frosts down to — 2 °C occurred for two consecutive days, which may have compromised the efficacy of Belkar EC. The autumn application of Belkar EC maintained a high level of control over *Brassicaceae* weeds into the spring, with the later application timing achieving higher suppression rates than the early treatment. A similar pattern was observed for field larkspur and white campion. Common lambsquarters plants that infested the plot in autumn perished during winter.

The results of this trial indicate that delaying the application of Belkar EC from the 2-leaf to the 4-leaf stage of winter oilseed rape does not lead to a loss of weed control efficacy. Furthermore, when determining application windows, weather forecasts must be evaluated to avoid situations when air temperatures drop below freezing immediately following treatment.

To expand the spectrum of weed control, and simultaneously mitigate the risk of herbicide resistance development, studying the efficacy of her-

TABLE 2. Phytotoxicity (%) on winter oilseed rape and weed control efficacy (%) following different application timings of Belkar EC at Location 2: assessments on 28th DAT (2018) and in spring after resumption of crop vegetation (2019)

Treatment	Application timing	PHYGEN (autumn)[1]	PHYGEN (spring)[2]	Control efficacy[3]					Control efficacy[4]			
				Thlaspi arvense	*Descurainia sophia*	*Chenopodium album*	*Consolida regalis*	*Melandrum album*	*Thlaspi arvense*	*Descurainia sophia*	*Consolida regalis*	*Melandrum album*
Belkar EC (0.25 L/ha)	?	0	0	53[a]	55[a]	80[a]	45[a]	30[a]	71[a]	63[a]	53[a]	28[a]
Belkar EC (0.25 L/ha)	B	0	0	85[b]	87[b]	94[b]	65[b]	35[a]	80[a]	75[b]	65[b]	40[b]

Note. Means followed by different letters differ significantly ($p < 0.05$); [1, 2] PHYGEN — general phytotoxicity on winter oilseed rape assessed on 28th DAT (autumn 2018) and in spring after resumption of crop vegetation (2019), respectively; [3, 4] — weed control efficacy assessed on 28th DAT (autumn 2018) and in spring after resumption of crop vegetation (2019), respectively.

bicide mixtures with different sites of action is highly relevant. The selectivity and efficacy of Belkar EC applied alone and in tank mixes with herbicides featuring distinct mechanisms of action were investigated in 2016 within a 9-variant field trial at Location 1 (Table 3). The experiment included the following treatments: Belkar EC (0.25 L/ha); Belkar EC (0.5 L/ha); Belkar EC (0.25 L/ha) + Butisan 400 SC (1.5 L/ha); Belkar EC (0.25 L/ha) + Salsa WG (0.025 kg/ha); Galera Super SL (0.3 L/ha) + Salsa WG (0.025 kg/ha) + Trend (0.2 L/ha); Galera Super SL (0.3 L/ha); Salsa WG (0.025 kg/kg); Butisan 400 SC (1.5 L/ha); untreated Control. Crop spraying was carried out at the 2—3 true leaves stage of winter oilseed rape (BBCH 12—13).

On 14th DAT, a minor reduction in oilseed rape plant height (by 1—3 %) was observed. This effect was most pronounced in the treatment using a double rate of Belkar EC at 0.5 L/ha (2 %) and in the Galera Super SL treatment at 0.3 L/ha (3 %). No formative defects of the oilseed rape leaves were recorded. In spring, after vegetative regrowth, through the flowering period, and up to pod formation, no negative herbicide impacts were observed. During the pod development stage, isolated plants across all treatments exhibited morphological changes in the upper part of the stem; however, no statistically significant differences in the number of deformed plants were found between the treatments.

These data confirm that Belkar EC does not yield to Galera Super SL in terms of selectivity toward winter oilseed rape. Under the conditions of this specific experiment, the autumn application of Belkar EC alone at the 0.25 L/ha rate demonstrated limited efficacy. In autumn, the control of common lambsquarters and, to some extent, creeping thistle improved when the application rate of Belkar EC was doubled. Salsa

TABLE 3. Phytotoxicity (%) of Belkar EC alone and in mixtures with Butizan 400 SC and Salsa WG on winter oilseed rape, and weed control efficacy (%) at Location 1: assessments on 14th DAT (1), 28th DAT (3), and in spring after resumption of crop vegetation (2, 4) during 2016–2017

Treatment	PHYGEN (autumn)[1]	PHYGEN (spring)[2]	Control efficacy[3]		Control efficacy[4]			
			Cirsium arvense	*Chenopodium album*	*Cirsium arvense*	*Matricaria inodora*	*Erodium cicutarium*	*Apera spica-venti*
Belkar EC (0.25 L/ha)	1[a]	0	69[b]	35[b]	60[b]	48[b]	35[c]	0[a]
Belkar EC (0.5 L/ha)	2[ab]	0	73[b]	48[c]	90[c]	53[b]	55[e]	0[a]
Belkar EC (0.25 L /ha) + Butisan 400 SC (1.5 L/ha)	1[a]	0	64[b]	35[b]	65[b]	98[c]	48[d]	99[b]
Belkar EC (0.25 L /ha) + Salsa WG (0.025 kg/ha)	1[a]	0	70[b]	33[b]	70[b]	53[b]	48[d]	0[a]
Galera Super SL (0.3 L/ha) + Salsa WG (0.025 kg/ha) + ? rend 90 (0.2 L/ha)	3[b]	0	83[c]	0[a]	93[c]	97[c]	8[b]	0[a]
Galera Super SL (0.3 L/ha)	3[b]	0	76[bc]	0[a]	95[c]	90[c]	8[b]	0[a]
Salsa WG (0.025 kg/ha)	1[a]	0	16[a]	0[a]	5[a]	0[a]	0[a]	0[a]
Butisan 400 SC (1.5 L/ha)	1[a]	0	8[a]	0[a]	0[a]	98	13[b]	99[b]

Note. Means followed by different letters differ significantly ($p < 0.05$); [1, 2] PHYGEN — general phytotoxicity on winter oilseed rape assessed on 14th DAT (autumn 2016) and in spring after resumption of crop vegetation (2017), respectively; [3, 4] — weed control efficacy assessed on 28th DAT (autumn 2016) and in spring after resumption of crop vegetation (2017), respectively.

WG and Butisan 400 SC applied alone exerted weak control over these specific weeds. Consequently, adding these components to Belkar EC did not significantly alter the control levels for common lambsquarters and creeping thistle. In spring, enhanced action against dicotyledonous weeds — creeping thistle, common stork's-bill, and partially scentless chamomile — was achieved with the double rate of Belkar EC. The application of Belkar EC in a mixture with Butisan 400 SC delivered an increase in control efficacy against scentless chamomile and the grass weed loose silkybent (*Apera spica-venti* (L.) Pal. Beauv.). However, none of the treatments demonstrated suppression of volunteer wheat, which constituted one of the primary threats to the winter oilseed rape crop.

To verify the findings regarding the efficacy of combining Belkar EC with Salsa WG

TABLE 4. Phytotoxicity (%) of Belkar EC alone and in mixture with Salsa WG on winter oilseed rape, and weed control efficacy (%) at Location 2: assessments on 14th DAT (1), 28th DAT (3), and in spring after resumption of crop vegetation (2, 4) during 2019—2020

Treatment	PHYGEN (autumn)[1]	PHYGEN (autumn)[2]	Control efficacy[3]			Control efficacy[4]		
			Thlaspi arvense	*Capsella bursa-pastoris*	*Descurainia Sophia*	*Capsella bursa-pastoris*	*Descurainia Sophia*
Belkar EC (0.25 L/ha)	1,3 [c]	0	71 [b]	70 [b]	60 [a]	75 [b]	69 [a]
Belkar EC (0.25 L/ha) + Salsa WG (0.025 kg/ha)	0,3 [ab]	0	74 [b]	74 [b]	80 [c]	75 [b]	88 [b]
Belkar EC (0.25 L/ha) + Salsa WG (0.025 kg/ha) + Trend 90 (0.2 L/ha)	0,5 [b]	0	73 [b]	74 [b]	79 [c]	75 [b]	89 [b]
Salsa WG (0.025 kg/ha)	0 [a]	0	48 [a]	23 [a]	70 [b]	40 [a]	86 [b]

Note. Means followed by different letters differ significantly ($p < 0.05$); [1, 2] PHYGEN — general phytotoxicity on winter oilseed rape assessed on 14th DAT (autumn 2019) and in spring after resumption of crop vegetation (2020), respectively; [3, 4] — weed control efficacy assessed on 28th DAT (autumn 2019) and in spring after resumption of crop vegetation (2020), respectively.

and to evaluate the necessity of using an adjuvant with this mixture, a trial was established in 2019 at Location 2 according to the following design: Belkar EC (0.25 L/ha); Belkar EC (0.25 L/ha) + Salsa WG (0.025 kg/ha); Belkar EC (0.25 L/ha) + Salsa WG (0.025 kg/ha) + adjuvant Trend 90 (0.2 L/ha); Salsa WG (0.025 kg/ha); untreated Control (Table 4). Field assessments conducted on 7th and 14th DAT revealed minor morphological leaf damage in isolated winter oilseed rape plants in the Belkar EC treatments. The proportion of affected plants in the stand alone Belkar EC treatment was 1.3 %, whereas in the tank mix with Salsa WG, it ranged between 0.3 % and 0.5 %. In the spring of the following year, symptoms of Belkar EC phytotoxicity on winter oilseed rape plants were absent. The control efficacy of Belkar EC against weeds of the *Brassicaceae* family stood at 60—71 %. Salsa WG alone very weakly suppressed shepherd's-purse and field pennycress but was more effective in controlling flixweed. The addition of Salsa WG to Belkar EC had practically no impact on the control efficacy of field pennycress and shepherd's-purse, but it significantly enhanced the control of flixweed both in autumn and spring. The inclusion of the Trend 90 adjuvant in the Belkar EC + Salsa WG mixture did not significantly alter weed control efficacy.

Since cereal crops frequently precede winter oilseed rape, managing volunteer cereal infestations is highly critical. To evaluate the possibility of simultaneously controlling dicotyledonous weeds and volunteer cereals using mixtures of Belkar EC with graminicides, and to test for potential interactions, a field trial was set up in 2018 at

TABLE 5. Phytotoxicity (%) of Belkar EC alone and in mixtures with Fusilade Forte 150 EC and Agil EC on winter oilseed rape, and control efficacy (%) of dicotyledonous weeds and volunteer spring barley at Location 2, assessments on 14th DAT (1), 28th DAT (3), and in spring after resumption of crop vegetation (2, 4) during 2018–2019

Treatment	PHYGEN (autumn)[1]	PHYGEN (spring)[2]	Control efficacy[3]					Control efficacy[4]		
			Hordeum vulgare	*Thlaspi arvense*	*Descurainia sophia*	*Chenopodium album*	*Capsella bursa-passtoris*	*Thlaspi arvense*	*Descurainia sophia*	*Capsella bursa-passtoris*
Belkar EC (0.25 L/ha)	1[b]	0	0[a]	53[b]	58[b]	79[b]	48[b]	75[b]	74[b]	53[b]
Belkar EC (0.25 L/ha) + Fuzilad Forte 150 EC (1.0 L/ha)	1[b]	0	95[b]	80[c]	81[c]	93[c]	50[b]	74[b]	74[b]	50[b]
Belkar EC (0.25 L/ha) + Agil EC (0.9 L/ha)	1[b]	0	98[b]	78[c]	84[c]	94[c]	55[b]	79[b]	80[b]	60[b]
Fuzilad Forte 150 EC (1.0 L/ha)	0[a]	0	98[b]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
Agil EC (0.9 L/ha)	0[a]	0	98[b]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]

Note. Means followed by different letters differ significantly ($p < 0.05$); [1, 2] PHYGEN — general phytotoxicity on winter oilseed rape assessed on 14th DAT (autumn 2018) and in spring after resumption of crop vegetation (2019), respectively; [3, 4] — control efficacy of dicotyledonous weeds and volunteer spring barley assessed on 28th DAT (autumn 2018) and in spring after resumption of crop vegetation (2019), respectively.

Location 2 with the following design: Belkar EC (0.25 L/ha); Belkar EC (0.25 L/ha) + Fusilade Forte 150 EC (1.0 L/ha); Belkar EC (0.25 L/ha) + Agil EC (0.9 L/ha); Fusilade Forte 150 EC (1.0 L/ha); Agil EC (0.9 L/ha); untreated Control (Table 5). Herbicide treatments were applied at the two true leaves stage (BBCH 12) of the winter oilseed rape.

The addition of graminicides did not affect the selectivity of Belkar EC. In all treatments containing Belkar EC, a small number of plants (below 1 %) exhibited minor leaf crinkling on 14th DAT. No further manifestations of herbicide phytotoxicity were noted. Volunteer spring barley was controlled with high efficacy both when graminicides were applied alone and when mixed with Belkar EC. The autumn control efficacy of dicotyledonous weeds by Belkar EC increased slightly with the addition of graminicides, while in spring it did not differ from the stand alone Belkar EC treatment, suggesting an acceleration of Belkar EC action when co-applied with graminicides. These findings support the viability of tank-mixing Belkar EC with the graminicides Fusilade Forte 150 EC and Agil EC during autumn applications for the simultaneous control of dicotyledonous and grass weeds, including volunteer cereals.

To validate this conclusion, a follow-up trial was arranged in 2019 at Location 2 using the following setup: Belkar EC (0.25 L/ha); Bel-

TABLE 6. Phytotoxicity (%) of Belkar EC alone and in mixtures with Agil EC, Miura EC, and Centurion EC on winter oilseed rape, and control efficacy (%) of dicotyledonous weeds and volunteer spring barley at Location 2: assessments on 7th DAT (1), 14th DAT (2), 28th DAT (4), and in spring after resumption of crop vegetation (3, 5) during 2019—2020

Treatment	PHYGEN (autumn)[1]	PHYGEN (autumn)[2]	PHYGEN (spring)[3]	Control efficacy[4]					Control efficacy[5]		
				Hordeum vulgare	*Chenopodium album*	*Thlaspi arvense*	*Capsella bursa-pastoris*	*Descurainia sophia*	*Thlaspi arvense*	*Capsella bursa-pastoris*	*Descurainia sophia*
Belkar EC (0.25 L/ha)	0,3[a]	0	0	0[a]	71[a]	75[a]	73[a]	71[a]	53[a]	74[a]	63[a]
Belkar EC (0.25 L/ha) + Agil EC (0.7 L/ha)	0,5[a]	0	0	83[b]	73[a]	75[a]	73[a]	74[a]	55[a]	73[a]	63[a]
Belkar EC (0.25 L/ha) + Miura EC (0.5 L/ha)	0,4[a]	0	0	80[b]	71[a]	75[a]	74[a]	73[a]	55[a]	73[a]	63[a]
Belkar EC (0.25 L/ha) + Centurion EC (0.4 L/ha) + Amigo (0.4 L/ha)	0,3[a]	0	0	83[b]	74[a]	75[a]	76[a]	75[a]	60[a]	75[a]	66[a]

Note. Means followed by different letters differ significantly ($p < 0.05$); [1–3] PHYGEN — general phytotoxicity on winter oilseed rape assessed on 7th DAT (1; 2019), 14th DAT (2; 2019), and in spring after resumption of crop vegetation (3; 2020); [4, 5] — control efficacy of dicotyledonous weeds and volunteer spring barley assessed on 28th DAT (4; 2019) and in spring after resumption of crop vegetation (5; 2020).

kar EC (0.25 L/ha) + Agil EC (0.7 L/ha); Belkar EC (0.25 L/ha) + Miura EC (0.5 L/ha); Belkar EC (0.25 L/ha) + Centurion EC (0.4 L/ha) + adjuvant Amigo (0.4 L/ha); untreated Control (Table 6). Treatment was performed at the 2-leaf stage of the oilseed rape (BBCH 12). Field inspection on 7th DAT revealed minor leaf margin curling in individual winter oilseed rape plants (0.3—0.5 %) within the Belkar EC treatments. This effect was short-lived, and on 14th DAT, plants in the Belkar EC treatments were indistinguishable from the controls. Arid conditions in the autumn of 2019 led to an overall reduction in herbicide performance. Volunteer spring barley was controlled with nearly identical efficacy (80—83 %) across all tank mixtures of Belkar EC with the various graminicides. The control efficacy for dicotyledonous weeds remained virtually identical whether Belkar EC was applied alone or in combination with graminicides.

Conclusions

Summarizing the results of the conducted trials, the following conclusions can be drawn:

1. When applied in autumn at either the 2-leaf or 4-leaf stage, the herbicide Belkar EC is selective toward winter oilseed rape. The negative impacts of

Belkar EC at the 0.25 L/ha rate are minor and transient, showing no significant difference from the effects observed with Galera Super SL at 0.3 L/ha.

2. The autumn application of Belkar EC in winter oilseed rape crops provides effective control over a wide spectrum of dicotyledonous weed species.

3. The autumn use of Belkar EC in a tank mixture with Butisan 400 SC does not increase the probability of negative effects on winter oilseed rape. This combination enhances the control efficacy of certain dicotyledonous weeds, such as scentless chamomile, and ensures effective control of annual weeds from the *Poaceae* family, specifically loose silky-bent.

4. The autumn application of Belkar EC in a tank mixture with Salsa WG does not compromise herbicide selectivity toward winter oilseed rape and substantially increases the control efficacy of specific dicotyledonous weeds from the *Brassicaceae* family, particularly flixweed.

5. The autumn application of Belkar EC in tank mixtures with ACCase-inhibitor graminicides — whether aryloxyphenoxypropionic acid derivatives (Fusilade Forte 150 EC, Agil EC, Miura EC) or cyclohexanedione derivatives (Centurion EC) — does not impair the selectivity of Belkar EC toward winter oilseed rape, maintains or even accelerates the development of its phytotoxic action against dicotyledonous weeds, and successfully eliminates volunteer cereal infestations.

Overall, the experimental data demonstrate that the autumn application of Belkar EC, both alone and in combination with other herbicides, is safe for winter oilseed rape crops, delivers effective protection against a broad spectrum of weed species, and represents a promising component for integration into advanced winter oilseed rape crop protection systems.

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ВИПРОБУВАННЯ В УКРАЇНІ СЕЛЕКТИВНОСТІ ЩОДО КУЛЬТУРИ ТА ЕФЕКТИВНОСТІ КОНТРОЛЮВАННЯ БУР'ЯНІВ ЗА ОСІННЬОГО ЗАСТОСУВАННЯ В ПОСІВАХ ОЗИМОГО РІПАКУ ГЕРБІЦИДУ БЕЛКАР ТА ЙОГО СУМІШЕЙ З ІНШИМИ ГЕРБІЦИДАМИ

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У статті представлено результати серії польових випробувань, що проводилися впродовж 2016—2020 рр. у різних регіонах України, метою яких було визначення селективності щодо культури та ефективності контролювання бур'янів при застосуванні в осінній період у посівах озимого ріпаку нового комплексного гербіциду белкар, к.е., діючими речовинами якого є синтетичні ауксини галауксифенметил (9,6 г/л) та піклорам (48 г/л). Відомо, що озимий ріпак є чутливим до галауксифенметилу. З огляду на це в посівах озимого ріпаку галауксифенметил може застосовуватися тільки сумісно з іншими синтетичними ауксинами, зокрема з клопіралідом, антидотна дія якого забезпечує селективність даної суміші щодо культури. В умовах осіннього внесення з ряду міркувань піклорам є придатнішим, ніж клопіралід, тому при створенні гербіциду белкар, к.е клопіралід було замінено на піклорам. Оскільки застосування восени на ранніх фазах розвитку озимого ріпаку потребує більшої селективності гербіцидів порівняно із застосуванням навесні, особливо актуальним є питання щодо селективності гербіциду белкар, к.е. В зв'язку зі змішаним характером забур'янення посівів, може виникати необхідність комплексування гербіциду белкар, к.е. з іншими гербіцидами, ефективними щодо видів бур'янів, стійких до гербіциду белкар, к.е. Тому для ефективного використання гербіциду белкар, к.е. необхідно перевірити селективність щодо озимого ріпаку та ефективність контролювання бур'янів як при застосуванні гербіциду белкар, к.е. окремо, так і у сумішах з іншими гербіцидами. У польових дослідах обприскування посіву озимого ріпаку проводили у фази 2—4 справжніх листків у культури (ВВСН 12—14). Ефективність контролювання дводольних бур'янів гербіцидом белкар, к.е. порівнювали з дією гербіциду галера супер, розчинний концентрат (р.к.). Встановлено, що за обробки восени у рекомендованій

нормі 0,25 л/га та у подвійній нормі 0,5 л/га фітотоксичний вплив гербіциду белкар, к.е. на озимий ріпак не перевищував дію гербіциду галера супер, р.к. За норми внесення 0,25 л/га гербіцид белкар, к.е. ефективно контролював широкий спектр видів дводольних бур'янів. Застосування гербіциду белкар, к.е. у суміші з гербіцидом бутизан 400, к.с., не впливало на селективність щодо культури і давало змогу включити у спектр контрольованих видів однорічний злаковий бур'ян метлюг звичайний (*Apera spica-venti* (L.) Pal. Beauv.), а також значно підвищувало ефективність контролювання однорічного дводольного бур'яну ромашки непахучої (*Matricaria inodora* L.). Застосування гербіциду белкар, к.е. у баковій суміші з гербіцидом сальса, в.г. значно підвищувало ефективність контролювання бур'янів з родини капустяних, зокрема кучерявцю Софії (*Descurainiaa sophia* (L.) Webb.). Застосування у сумішах з гербіцидами з класу граміцидів фюзилад форте, к.е., агіл, к.е., міура, к.е. та центуріон, к.е. не впливало на селективність гербіциду белкар, к.е. щодо озимого ріпаку та ефективність контролювання ним дводольних видів бур'янів. Ефективність контролювання злакових бур'янів за застосування у суміші з гербіцидом белкар, к.е. не відрізнялася від дії граміцидів, застосованих окремо. Сукупність отриманих результатів свідчить, що застосування восени в посівах озимого ріпаку гербіциду белкар, к.е окремо та у сумішах з іншими гербіцидами є безпечним для культури і забезпечує ефективний захист посівів від бур'янів в осінній період.

Ключові слова: гербіциди, суміші гербіцидів, селективність, контролювання бур'янів, галауксифенметил, піклорам.

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