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Evaluation the Efficiency of Newly Combined Herbicide Pyroxsulam and Galaxifen-methyl in Winter Wheat (*Triticum aestivum* L.)

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ABSTRACT

Background: Globally, wheat production is essential for food security as it is an essential staple food crop for a huge population. However, there are different biotic and abiotic factors affected the productivity of wheat. One of the essential competitors of wheat crop are weeds. Wheat is infested by both annual and perennial dicotyledonous weeds. The main purpose of this study is to evaluate the efficiency of the new combined herbicide Tarzec WG based on pyroxsulam and galaxifen-methyl + safener cloquintocet-mexyl for protecting winter wheat from the weeds.

Methods: The field experiment was conducted during 2019 and 2020. The experimental treatments consisted of Tarzec two application rates: 19 g/ha and 22 g/ha.Reference standards were applied, Pallas 45 (22 g/ha of pyroxsulam).

Result: Results revealed that the greatest advantage of the combined herbicide Tarzec WG over the single-component agent Pallas 45 OD was attained through the inhibition degree against weeds in both the seasons of experiment. Unfortunately, these compelling advantages of combined agent over the single-component one was not identified with respect to *Cerastiumnemorale*, *Avenafatua* and *Alopecurus myosuroides*. Tarzec WG herbicide was not phytotoxic to the plants of the winter wheat.

Key words: Galaxifen-methyl, *Galium aparine,* Herbicide, *Papaver rhoea,* Pyroxsulam, Winter wheat.

INTRODUCTION

Winter wheat is a valuable cereal that is essential in cooking many foods that make up the diet of modern human. In Russia, one of the most favorable regions for cultivation of this crop in terms of soil and climatic conditions is Krasnodar Krai. Regardless of the farmers' use of improved varieties and good agricultural practices, there is a large discrepancy between farmers' yields and the potential yield of this crop. There are several factors responsible for the decrease in production per unit area in the wheat yield. Among these factors, weed infestation plays a critical role in determining the production of wheat.

Compared to other factors such as population density, crop variety and plant nutrition, losses caused by weeds estimate more loss (27%-38%) (Jaffar *et al*., 2023). According to Chauhan, (2020) globally, it is estimated that, the crop losses due to weeds are projected as 100 billion dollars.

It is impossible to achieve high yields of winter wheat even in regions favorable for its cultivation without taking protective measures against weeds (Fetyukhin and Baranov, 2019). The existing range of herbicides do not fully meet the demands of time. Most agents on the market protect crops from only one of the groups of weeds-cereals or dicotyledons, while the most common type of weed infestation in the fields is mixed (Luneva and Zakota, 2018).

Among the few primary materials capable of meeting such a challenge is pyroxsulam. This herbicide efficiently destroys such grass weeds as downy brome (*Bromus tectorum* L.), wild oat (*Avena fatua* L.) and ryegrass (*Lolium temulentum* L.) (El-Metwally and Gad, 2019). The herbicide is efficient against such dicotyledon weeds as flixweed (*Descurainiasophia* L.), blue mustard (*Chorisporatenella* (Pallas) DC.) and henbit (*Lamium amplexicaule* L.) (Reddy *et al*., 2013). Despite the high efficiency of pyroxsulam, three problems related to its use have been revealed in recent years.

First, some types of weeds were not too sensitive to pyroxsulam. Practice shows that pure pyroxsulam is not sufficient to efficiently control Redroot pigweed (*Amaranthus retroflexus* L) in winter wheat (Zargar *et al*., 2020).

Second, it was found that high rates of pyroxsulam application might have negative impacts on crop plants. Practice shows that application of 15 and 18 g a.i. ha^{-1} pyroxsulam did not cause visual injury above 10% in wheat. However, pyroxsulam may visual injury to wheat when applied at 21, 30, 36 and 42 g a.i. ha^{-1} (Zobiole *et al*., 2018).

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Third, weeds started developing tolerance to the herbicide. Initially, pyroxsulam (ALS-inhibiting herbicides) was used to combat weed plants (such as *Alopecurus* ssp.), that developed tolerance to ACCase-inhibiting herbicides. However, in a while, weeds started developing tolerance to this herbicide as well (Huang *et al*., 2021). Over time, the number of tolerant weed species began to increase and this fact keeps being reported. Tolerant populations of Italian Ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot) were found in North Carolina (Jones *et al*., 2021).

The problems demonstrated may be resolved by using tank mixtures of herbicides based on primary materials having different action modes (*e.g*., ALS-and ACCase inhibiting) (Petersen, 2018), or through presentation of combined agents. In this respect, special interest arises to agents based on new primary materials such as halauxifen-methyl which is one of the few herbicide molecules discovered in early 21st century (Epp *et al*., 2016).

Halauxifen-methyl is a new auxinic herbicide for broadleaf weed control for a wide range of crops: corn, soybean, grassland, pasture, woody landscape ornamentals (Krenchinski *et al*., 2019; McCauley and Young, 2019; Zimmer *et al*., 2019). Halauxifen-methyl applied alone controlled small and large horseweed (including Glyphosate-Resistant) [*Conyza Canadensis* (L.) Cronq.], common ragweed (*Ambrosia artemisiifolia* L.), henbit (*Lamium amplexicaule* L.), purple deadnettle (*Lamium purpureum* L.), yet it is less efficient against Polygonum (*Polygonum persicaria* L., *P. pensylvanicum* L., *P. hydropiper* L., *P. orientale* L., pigweed (*Amaranthus retroflexus* L.), common chickweed [*Stellaria media* (L.) Vill.] (Askew *et al*., 2021).

On cereals, it is mostly a component for combined agents. For instance, in Europe the first two premix herbicides containing halauxifen-methyl are Zypar (with florasulam) and Pixxaro (with fluroxypyr) (Dzikowski, *et al*., 2016).

The main objective of the research is to study the efficiency of the new Tarzec WG herbicide based on pyroxsulam and halauxifen-methyl on winter wheat plantings and evaluate its safety for crop plants.

MATERIALS AND METHODS

The research was carried out on experimental field of All-Russian Institute of Plant Protection (VIZR) in Krasnodar Krai (45.0 N, 38.8 E) during the vegetation periods of 2018-2019 and 2019-2020. Soft winter wheat (*Triticum aestivum* L.) Kalym strain was cultivated on the experimental ground. The plant is short-growing. Weight of 1,000 grains is 33-44 g. The cultivar is mid-ripening.

The soil is chernozem (black soil), weakly-leached, extra-thick; with heavy-loamy particle-size distribution; with humus content in topsoil of 3.7%; pH=6.9. Seeding rate was 200 kg/ha. Previous crop was winter wheat. Soil treatment: disk harrowing, plowing to a depth of 22-25 cm, pre-seeding cultivation.

Weather conditions in 2019 were characterized by higher air humidity and large amount of precipitation, the latter being about 50% above normal. In the conditions of 2020, the amount of precipitation was 15% above normal. The temperature in both years of research was at the level of long-term annual average values (differences on average did not exceed 1-2°C). All this contributed, on the one hand, to the rapid development of winter wheat plants and, on the other hand, to the development of weeds.

The area of each plot was 25 m^2. The plots were randomly allocated around the experimental field. Each option of the experiment was set to four repetitions. Table 1

Table 1: Details of products, common name and active ingredients.

Product	Company	Formulation	Active substance	Content
Tarzec	Dow agro sciences	WG	pyroxsulam: N-(5,7-dimethoxy [1,2,4] triazolo [1,5-a] pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl)-3-pyridinesulfonamide	25.0%
			halauxifen-methyl: 2-pyridinecarboxylic acid, 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-, methyl ester	6.95%
			safener cloquintocet-mexyl: 1-methylhexyl (5-chloroquinolin-8-yloxy) acetate	35.4%
Pallas 45	Dow agro sciences	OD	pyroxsulam: N-(5,7-dimethoxy [1,2,4] triazolo [1,5-a] pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl)-3-pyridinesulfonamide	4.31%
			safener cloquintocet-mexyl: 1-methylhexyl (5-chloroquinolin-8-yloxy) acetate	9.0%
Verdikt	Bayer cropscience	WG	mesosuifuron-methyl: methyl 2-[(4,6-dimethoxypyrimidin-2-yl) carbamoylsulfamoyl]-4-(methanesulfonamidomethyl)benzoate	3.0%
			iodosulfuron-methyl-sodium: sodium;(5-iodo-2-methoxycarbonylphenyl) sulfonyl-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) carbamoyl] azanide	0.6%
			safener mefenpyr-diethyl: diethyl 1-(2,4-dichlorophenyl)-5-methyl-4H-pyrazole-3,5-dicarboxylate	9.0%
Surfer	Dow agro sciences	SL	2-ethyl hexanol eo-po	72%
Bio-power	Bayer crop science	SL	sodium laureth sulfate	27%

illustrated the details of the agent under study, its reference standards and adjuvants.

Adjuvants have been used as their adding to herbicides, their efficacy is significantly increased (Sobiech*et al*., 2020). It is known that nonionic surfactant (isodecyl alcohol ethoxylate) is not the best adjuvant of pyroxsulam, therefore, we used Surfer (2-ethyl hexanol eo-po) (Hamouda*et al*., 2021).

Treatment was carried out on vegetating winter-wheat plants (BBCH 30-32) using manual low-volume sprayer in accordance with the experimental design given in (Table 2). The flow rate of the process fluid was calculated based on 200 l/ha.Tarzec was applied at two application rates: 19 g/ha and 22 g/ha. An herbicide based on pure pyroxsulam-Pallas 45 (22 g/ha of pyroxsulam) was used as one of reference standards.

In the untreated control, the exact number of weeds was counted prior to the experiment and during each evaluation of the efficiency. Efficiency was recorded visually 14, 28 and 56 days after treatment.

The yield of winter weed was gathered with Hege 125 harvester. The data obtained in the experiments were subjected to statistical processing by analysis of variance (ANOVA) method at a probability level of 95%.

RESULTS AND DISCUSSION

Dicotyledonous and grass weeds

Before the treatment in 2019, weeds from two groups-dicotyledonous and grass weeds-were found on the experimental ground. The first group included the following species: catchweed bedstraw (*Galium aparine* L.; BBCH 25; 17 specimen/m^2), corn poppy (*Papaver rhoeas* L.; BBCH 25; 12 specimen/m^2), wood cerastium (*Cerastium nemorale* M. Bieb.; BBCH 51; 9 specimen/m^2). The second group included: common wild oat (*Avena fatua* L.; BBCH 25; 18 specimen/m^2) and black foxtail (*Alopecurus myosuroides* Huds; BBCH 27; 37 specimen/m^2). In 2020, before the treatment, the species composition of weeds was similar, but their total number was less by 17% (77 specimen/m^2). Table 3 shows the weed density in control plot during the period of experiment.

Table 2: Details of treatments and application rates.

Treatments	Application rates
Tarzec WG + Surfer SL	0.075 Kg ha^{-1} + 1.0 L ha^{-1}
Tarzec WG + Surfer SL	0.09 Kg ha^{-1} + 1.0 L ha^{-1}
Pallas 45 OD (standard 1)	0.5 L ha^{-1}
Verdikt WG + Biopower SL (standard 2)	0.3 Kg ha^{-1}+ 0.5 L ha^{-1}
Nontreated check	-

Efficiency of herbicides

A significant excess of the efficiency of the combined agent over the single-component one was noted by the effect on two types of weeds: *Galium aparine* and, specifically, on *Papaver rhoeas*.

Common poppy (*Papaver rhoeas*)

Pure pyroxsulam's effect on *Papaver rhoeas* was the least: in the first year of research, the number of plants of this species decreased by 5.5-24.0% and in the second year, the reference standard Pallas 45 OD had no effect on them at all.

As is shown in Table (4) the use of Tarzec WG herbicide against *Papaver rhoeas* was significantly more efficient: in the first year of research. The efficiency of both application rates exceeded that of both reference standards (91.8-100%); in the second year, the efficiency of 0.075 kg ha^{-1} of Tarzec herbicide was equal to that of the reference standard and the efficiency of 0.09 kg ha^{-1} was the highest in the experiment (89.3-95.5%).

Cleavers (*Galium aparine*)

The use of Tarzec in both application rates in 2019 made it possible to destroy all plants of *Galium aparine* (100%) in 28 and 56 days after treatment (Table 4). The efficiency of reference standard Pallas 45 OD was credibly lower than this level. Reference standard Verdict WG was the least efficient in the experience (72.8-81.5%).

In 2020, the efficiency of 0.075 kg ha^{-1} of Tarzec herbicide exceeded that of the Pallas reference standard in 28 and 56 days after application and the efficiency of 0.09 kg ha^{-1} of the agent under study exceeded that of all other herbicide options during the entire observation period (Table 4).

Cerastium nemorale

With respect to *Cerastium nemorale*, the efficiency of pure pyroxsulam (93.8-100%) in the first year of research was equal to that of the combined agent in both application rates. All of these options credibly exceeded the performance of reference standard Verdikt WG.

In the second year, with records on days 14 and 28, the efficiency of 0.075 kg ha^{-1} of Tarzec herbicide exceed

Table 3: The weed density in control plot.

Years of experiment	Dates accounting after treatment	Weed density (Number of weeds/m^2)				
		Galiuma parine	*Papaver rhoeas*	*Cerastium nemorale*	*Avena fatua*	*Alopecurus myosuroides*
2019	14	15.3	11.3	8.0	16.3	35.0
	28	14.8	10.5	7.8	15.8	33.5
	56	14.5	10.3	7.8	15.0	32.3
2020	14	13.4	9.7	8.1	11.3	31.2
	28	12.9	9.5	7.9	10.8	30.6
	56	12.3	9.4	7.8	10.3	29.7

Table 4: Efficiency of herbicides against weed species, % to nontreated check (2019, 2020).

Treatments	*Galium aparine*			*Papaver rhoeas*			*Cerastium nemorale*			*Avena fatua*			*Alopecurus myosuroides*		
	14 DAT*	28 DAT	56 DAT	14 DAT	28 DAT	56 DAT	14 DAT	28 DAT	56 DAT	14 DAT	28 DAT	56 DAT	14 DAT	28 DAT	56 DAT
							2019								
1. Tarzec WG + Surfer SL - 0.075 Kg ha^{-1} + 1.0 L ha^{-1}	91.3	100	100	91.8	100	100	92.5	100	100	87.5	95.5	93.3	85.5	93.5	92.5
2. Tarzec WG + Surfer SL - 0.09 Kg ha^{-1} + 1.0 L ha^{-1}	93.5	100	100	94.0	100	100	95.0	100	100	90.5	97.5	96.5	88.5	96.5	95.5
3. Pallas 45 OD - 0.5 L ha^{-1}	82.0	90.3	87.3	24.0	19.0	5.5	93.8	100	100	92.3	97.3	96.3	90.3	96.3	94.0
4. Verdikt WG + Biopower SL - 0.3 $Kgha^{-1}$+ 0.5 L ha^{-1}	72.8	81.5	76.8	87.8	96.0	93.0	87.5	96.5	94.3	80.5	87.5	85.0	78.3	85.5	83.5
LSD 0.05	3.3	1.6	1.9	3.3	2.7	2.1	2.5	1.0	1.3	1.9	1.9	2.1	2.3	1.9	1.8
							2020								
1. Tarzec WG + Surfer SL - 0.075 Kg ha^{-1} + 1.0 L ha^{-1}	84.3	94.3	92.0	85.5	94.5	93.0	86.5	95.5	93.5	82.5	93.5	91.5	81.3	92.3	90.3
2. Tarzec WG + Surfer SL - 0.09 Kg ha^{-1} + 1.0 L ha^{-1}	88.3	97.3	96.3	89.3	96.5	95.5	90.3	97.5	96.5	85.5	96.5	95.5	84.5	95.5	94.5
3. Pallas 45 OD - 0.5 L ha^{-1}	82.5	92.3	90.3	0	0	0	84.5	93.5	92.0	80.5	93.0	89.5	79.3	90.3	88.3
4. Verdikt WG + Biopower SL - 0.3 $Kgha^{-1}$+ 0.5 L ha^{-1}	83.5	93.0	91.0	84.5	93.5	91.5	85.5	94.5	92.5	81.5	92.5	90.5	79.5	90.5	88.5
LSD 0.05	1.8	1.4	2.1	1.6	1.7	2.0	1.9	2.0	2.4	2.0	3.6	2.0	1.8	1.8	1.8

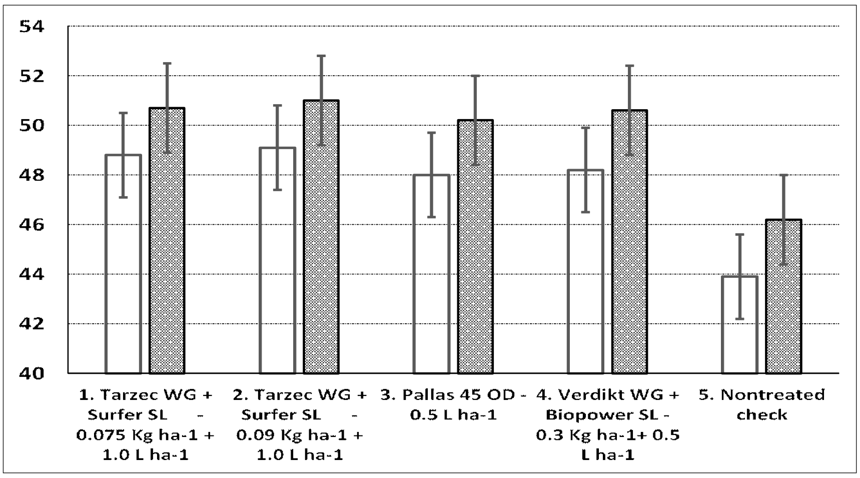

Fig 1: Winter wheat yield after herbicides treatments (2019, 2020). The vertical bars represent LSD 0.05.

that of Pallas 45 OD reference standard and the efficiency of 0.09 kg ha^{-1} of Tarzec herbicide was the highest in the experiment during all observations (90.3-96.5%).

It is known that Corn poppy (*Papaver rhoeas* L.) having developed herbicide resistance to acetolactate synthase inhibitors, especially in Mediterranean countries and Great Britain (Stankiewicz-Kosyl *et al*., 2020). Therefore, obvious is the benefit of herbicides mixtures with halauxifen-methyl for the control of *Papaver* resistant to ALS herbicides (Group 2) as well as 2, 4-D (Sleugh *et al*., 2021). Concerning grass weeds, the use of combined agent in the first year of research had no significant advantage: pure-pyroxsulam efficiency against *Avenafatua* and *Alopecurus myosuroides* was at the level of the maximum combined-agent application rate. A lesser herbicide application rate was less efficient. Altogether, it corresponds with the available. Furthermore, Morderer *et al*., (2018) noticed that Mixing halauxifen-methyl with pyroxsulam and florasulam increases the effectiveness for controlling perennial dicotyledonous in wheat crops. Data that Halauxifen-methyl combination with pyroxsulam succeeded to control both broad and grassy weed without antagonistic effect between them (Morderer *et al*., 2018).

In the second year of the study, the combined agent had an advantage over the single-component one in both application rates. Identification of chromosomes in *Triticum aestivum* possessing genes that confer tolerance to halauxifen-methyl is currently under study (Obenland and Riechers, 2020) and the herbicides based on this primary material are produced with the safener cloquintocet-mexyl. Safeners associated to ALS inhibitors reduce the sensitivity grass weeds to their associated herbicides (Duhoux*et al*., 2017). Therefore, it is possible that the advantage of combined agent was caused by the lesser amount of safener cloquintocet-mexyl (0.02655 kg and 0.03186 kg per ha of Tarzec WG VS 0.045 kg/ha of Pallas 45 OD).

The use of Tarzec WG herbicide, as well as reference standards Pallas 45 OD and Verdikt WG had not negative effect on winter wheat Kalym strain plants. Spots, necroses or other symptoms of phytotoxicity were not found on herbicide-treated plots during the whole experimental period. The winter wheat plants, whether herbicide-treated or untreated-control, were developing simultaneously.

In the untreated control, the yield of winter wheat Kalym strain was 43.9 dt/ha (in 2019) and 46.2 dt/ha (in 2020). In all herbicide options, a significant increase in crop yield was noted: by 9.3-11.8% in 2019; by 8.7-10.4% in 2020 (Fig 1). Despite the stronger inhibition of some weed species in comparison with the reference standard in the options where herbicide Tarzec WG herbicide was applied, the yield of winter wheat in all herbicide options was at the same level.

CONCLUSION

In general, it can be concluded that the application of the candidate herbicides are considered very Important effective treatments to control harmful weeds. These compelling advantages of combined agent over the single-component one was not identified with respect to *Cerastium nemorale, Avena fatua* and *Alopecurus myosuroides*. Being used, Tarzec WG herbicide was not phytotoxic to the plants of winter wheat Kalym strain. When the agent was applied additionally to the untreated control, from 4.5 dt/ha to 5.2 dt/ha of winter wheat grain was obtained.

Conflict of interest: None.

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