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APPLICATION EFFICACY OF NEWLY RELEASED PRE-MIXED HERBICIDE IN WINTER WHEAT: JOYSTICK®

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ABSTRACT. In a field experiment, the efficacy of the newly released pre-mixed herbicide, Joystick®, in comparison with other pre-mixed herbicides was evaluated in winter wheat, Iran. The treatments included: weedy check, weed-free check (hand-weeded), Bromicide®MA at 600 g a.i. ha^{-1} + Axial® at 60 g a.i. ha^{-1}, Othello® at 96 g a.i. ha^{-1}, Axial One® at 55, 65, 75, and 85 g a.i. ha^{-1}, Joystick® at 80, 94, and 108 g a.i. ha^{-1}. The latter three treatments mentioned were applied with and without non-ionic surfactant Citogate® at 0.1% v v^{-1}. The results revealed that all treatments significantly decreased the density and dry biomass of each weed species and increased the grain yield and biological yield of wheat. The highest performing treatment was Bromicide®MA + Axial®, followed by Joystick® at 108 g a.i. ha^{-1} plus Citogate®. The application of Joystick® at 108 g a.i. ha^{-1} plus Citogate® decreased the biomass of *Malva neglecta, Lolium rigidum, Hirschfeldia incana, Centaurea pallescens, Veronica persica, and Carthamus oxyacantha* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1%; respectively; with an 88% reduction in total weed dry biomass. Because of Joystick® at 108 g a.i. ha^{-1} plus Citogate® activity against weed species, the grain and biological yields of wheat improved up to 28% as compared to weedy check treatment.

Introduction

Wheat (*Triticum aestivum* L.) is the world's most important food crop belonging to the Poaceae family. In the 2010s, the wheat cultivation area in the world has increased from 215 to 219 million ha, increasing grain production from 640 to 761 million tonnes (FAO, 2020). Like other crops, weeds are considered a limiting factor in the production of wheat. They can reduce the quantity and quality of yield through their competition with wheat for space, light, water, and nutrients (Zimdahl, 2004). In Iran, yield loss of 20–25% has been reported if weeds are not controlled (Zare *et al.*, 2014). Therefore, weed control is very essential to maintain the potential yield in wheat. Currently, chemical weed control is the most important method in wheat because it is generally considered a non-row crop, limiting physical and mechanical weed control methods, leading to the increasing dependence of farmers on herbicides to manage weeds (Melander *et al.*, 2005). Until now, 40 selective herbicides have been labelled for use in wheat. Moreover, there are another 12 herbicides to which wheat is tolerant (Zandstra *et al.*, 2004).

Because of the continuous application of a single mode of action herbicide, weeds can develop resistance. All over the world, 353 out of 509 cases of herbicide-resistant weeds have occurred in wheat. In Iran, 15 out of 16 cases of herbicide-resistant weeds have occurred in wheat (Heap, 2022). Using mixtures of herbicides from a different mode of action is widely accepted to prevent (Lagator *et al.*, 2013) and manage (Comont *et al.*, 2020) herbicide-resistant weed development. When a mixture of herbicides having different modes of action is applied, weeds resistant to one herbicide will be controlled by a partner herbicide existing in the mixture (Abbas *et al.*, 2016). If a resistant weed has a negative cross-resistance, using a herbicide mixture can still control it (Beckie, Reboud, 2009).

In previous studies, the tank-mixed application of herbicides having different modes of action has shown complete control against weeds in wheat (Makvandi *et al.*, 2007; Ebrahim Pour *et al.*, 2012; Idziak *et al.*, 2012; Nazary-Alam *et al.*, 2013; Miklaszewska, Kierzek, 2014; Chan *et al.*, 2018; Pacanoski, Mehmeti, 2018).

Recently, the pre-mixed herbicides of diflufenican + iodosulfuron-methyl-sodium + florasulam were commercially registered with a trading name of Joystick® by Syngenta in 2017. In addition to wheat, this product can also be applied to barley, oats, rye, and triticale to control grasses and broadleaved weeds. According to the label, Joystick® should be applied at 94 g a.i. ha^{-1} (Anonymous, 2017).

The objectives of this research were 1) optimizing the dose of Joystick® by a non-ionic surfactant and 2) comparing its efficacy in comparison with other pre-mixed herbicides (Bromicide®MA, Othello®, and Axial One®).

Materials and Methods

A field experiment was conducted in Darab, Fars Province, Iran (28°45'N and 54°33'E, 1150 m above sea level) having long-term average precipitation of 160 mm yr^{-1}. The soil was a loam clay with 0.68% organic carbon, 7.9 pH, 0.68 dS m^{-1} electrical conductivity, 248 mg kg^{-1} K_2O, and 23 mg kg^{-1} P_2O_5.

The seedbed was fertilized with potassium sulfate at 100 kg ha^{-1} and triple superphosphate at 80 kg ha^{-1}, disc-plugged, and then levelled. The seeds of wheat (*T. aestivum* cv. Mehregan) were planted with a plant density of 400 plants $m^{2\,-1}$ on 28th November 2020. Each plot had a size of 8 × 1.3 m. Each plot consisted of eight rows with a 15 cm row spacing. The plots were one meter apart and watered using a drip irrigation system.

The experimental layout was a randomized complete block design comprising 13 treatments: weedy check, weed-free check (hand-weeded), Bromicide®MA at 600 g a.i. ha^{-1} + Axial® at 60 g a.i. ha^{-1}, Othello® at 96 g a.i. ha^{-1}, Axial One® at 55, 65, 75, and 85 g a.i. ha^{-1}, Joystick® at 80, 94, and 108 g a.i. ha^{-1}. The latter three treatments mentioned were applied with and without non-ionic surfactant Citogate® at 0.1% v v^{-1}. There were four replicates for each treatment. The active substance(s) of herbicide formulations used in this experiment is shown in Table 1. Each plot was divided into two subplots. One subplot was sprayed with the treatments and the other subplot was unsprayed to consider a weedy check treatment for comparison purposes. Herbicide treatments were applied at the stage of tillers formed (Zadoks' scale = 25) using a pressure backpack sprayer. It was equipped with a flat-fan 8002 nozzle and delivered 350 l ha^{-1} at 200 kPa.

Thirty days after spraying, the density of weeds was counted. Weed dry biomass was obtained after oven-drying at 70°C for 48 h. Weed control efficiency (WCE) representing the degree of reduction in the density or dry biomass of weeds due to herbicide treatment was determined using Equation 1.

$$\mathrm{WCE}\ (\%) = \frac{(\mathrm{A} - \mathrm{B})}{\mathrm{A}} \times 100, \qquad (1)$$

where, A and B are the density or dry biomass of weeds in the unsprayed and sprayed subplots, respectively (Ghosh *et al.*, 2016).

At the stage of wheat grain ripening (Zadoks' scale = 87), height, no. spikes $m^{2\,-1}$, no. grains $spike^{-1}$ and 1000 grain-weight were measured. At the stage of wheat grain ripening (Zadoks' scale = 92), the grain yield and biological yield of wheat were measured. The changes in each trait of wheat (Y_i), as mentioned above, were determined using Equation 2

$$\mathrm{Y}_i\ (\%) = \frac{Y_s}{Y_u} \times 100, \qquad (2)$$

where Y_s and Y_u are the amount of each trait in the sprayed and unsprayed subplots (weedy check treatment), respectively (Ghosh *et al.*, 2016).

Table 1. The active substance(s) of commercial products used in the study

Trade name	Formulation	Active ingrident(s)	Labeled rate	Manufacturer
Axial®	5% EC	Pinoxaden (50 g l^{-1})	60 g a.i. ha^{-1}	Syngenta
Axial One®	5% EC	Pinoxaden (45 g l^{-1}) + Florasulam (5 g l^{-1}) Cloquintocet-mexyl (11.25 g l^{-1}) (safener)	85 g a.i. ha^{-1}	Syngenta
Bromicide®MA	40% EC	Bromoxynil (200 g l^{-1}) + MCPA (200 g l^{-1})	600 g a.i. ha^{-1}	Nofam
Joystick®	47% WG	Diflufenican (400 g kg^{-1}) + Iodosulfuron-methyl-sodium (50 g kg^{-1}) + Florasulam (20 g kg^{-1}) + Cloquintocet-mexyl (100 g kg^{-1}) (safener)	108 g a.i. ha^{-1}	Syngenta
Othello®	6% OD	Diflufenican (50 g l^{-1}) + Iodosulfuron-methyl-sodium (7.5 g l^{-1}) + Mesosulfuron-methyl (2.5 g l^{-1}) + Mefenpyr-diethyl (22.5 g l^{-1}) (safener)	96 g a.i. ha^{-1}	Bayer Crop Science
Citogate®	100%	Alkylaryl polyglycol ether (surfactant)	0.1% v v^{-1}	Zarnegaran

After checking data normality, the data were subjected to analysis of variance using SAS 9.2 software. The means were separated using the Fishers' Least Significant Difference (LSD) test at the 5% level of significance.

Results and Discussion

The relative density and dry biomass of each weed species observed at the experimental site are shown in Table 2. The highest and lowest density was observed on *V. persica* (47.9%) and *H. incana* (6.9%), respectively. While, the highest and lowest weight was observed on *C. pallescens* (22.8%) and *L. rigidum* (10.4%), respectively. The analysis variance of the results of WCE showed the effect of herbicide treatments on the density and dry weight of each weed species (df = 11; P ≤0.01). The best WCE on the density and biomass of each weed species was observed by tank-mixed herbicide Bromicide®MA + Axial®, followed by pre-mixed herbicide Joystick® at 108 g a.i. ha^{-1} along with tank-mixing surfactant Citogate® (Tables 3 and 4). The application of Joystick® at 108 g a.i. ha^{-1} plus Citogate® decreased the biomass of *M. neglecta, L. rigidum, H. incana, C. pallescens, V. persica, and C. oxyacantha* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1; respectively; with an 88% reduction in total weed dry biomass. Overall, Joystick® was less effective against *L. rigidum* than other weed species. The application of pre-mixed herbicides Othello® at 96 g a.i. ha^{-1}, Axial One® at 75 g a.i. ha^{-1}, and Joystick® at 94 g a.i. ha^{-1} was done based on the label. Among the latter three pre-mixed herbicides mentioned, the WCE on total weed density and dry biomass can be ranked as follows: Othello® > Joystick® > Axial One®. Based on the results of weed density, the WCE of Joystick® in the controlling of *C. pallescens, V. persica, C. Oxyacanthus* was higher than Axial One®. Based on the weed dry biomass results, the WCE of Joystick® improved control of *L. rigidum, C. pallescens, V. persica, C. Oxyacanthus* compared to Axial One®.

Table 2. The relative density and weight of weed species observed at the experimental site

Name	Plant family	Weight, %	Density, %
Carthamus oxyacantha L.	Asteraceae	20.6	13.4
Centaurea pallescens Delile.	Asteraceae	22.8	11.3
Hirschfeldia incana (L.) Lagr. Foss.	Brassicaceae	14.9	6.9
Lolium rigidum L.	Poaceae	10.4	11.6
Malva neglecta Wallr.	Malvaceae	18.6	8.6
Veronica persica Poir.	Plantaginaceae	12.4	47.9

Table 3. The weed control efficiency (%) of treatments on the density of weed species

Treatment	Rate	*M. neglecta*	*L. rigidum*	*H. incana*	*C. pallescens*	*V. persica*	*C. oxyacanthus*	Total
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	100.0^{a}	80.4^{a}	100.0^{a}	92.3^{a}	92.1^{a}	100.0^{a}	92.86^{a}
Othello®	96 g a.i. ha^{-1}	82.3^{cd}	65.3^{bc}	85.2^{bc}	81.6^{ab}	73.5$^{b–d}$	65.1$^{e–g}$	73.2^{de}
Axial One®	55 g a.i. ha^{-1}	50.0^{h}	40.8^{e}	65.6^{f}	43.7^{f}	41.1^{f}	50.6^{h}	46.3^{j}
Axial One®	65 g a.i. ha^{-1}	60.2^{gh}	45.6^{de}	70.4^{ef}	55.3^{ef}	55.2^{ef}	54.9^{gh}	54.9^{i}
Axial One®	75 g a.i. ha^{-1}	68.0^{fg}	50.4^{de}	75.3^{de}	57.0^{ef}	57.5^{de}	55.4^{gh}	57.8^{hi}
Axial One®	85 g a.i. ha^{-1}	80.4$^{c–e}$	63.7^{bc}	85.3^{bc}	61.4^{de}	60.5^{de}	75.2$^{c–e}$	64.5$^{f–h}$
Joystick®	80 g a.i. ha^{-1}	65.5^{fg}	50.4^{de}	75.5^{de}	58.8$^{d–f}$	58.7^{de}	60.1$^{f–h}$	59.5$^{h–j}$
Joystick®	94 g a.i. ha^{-1}	75.0$^{d–f}$	55.9^{cd}	80.3^{cd}	63.5$^{c–e}$	63.7^{de}	70.2$^{d–f}$	66.3$^{e–g}$
Joystick®	108 g a.i. ha^{-1}	85.2$^{b–d}$	65.8^{bc}	90.0^{b}	73.4$^{b–d}$	81.8$^{a–c}$	84.4^{bc}	79.8^{cd}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	70.0$^{e–g}$	55.6^{dc}	80.3^{cd}	68.7$^{b–e}$	68.7$^{c–e}$	80.4$^{b–d}$	70.5^{ef}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	90.0$^{a–c}$	70.5^{ab}	100.0^{a}	77.5$^{a–c}$	84.0$^{a–c}$	90.6^{ab}	83.6^{bc}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	95.0^{ab}	75.0^{ab}	100.0^{a}	88.8^{a}	88.9^{ab}	95.0^{a}	88.5^{ab}
$LSD_{0.05}$		12.4	13.0	9.0	15.2	15.9	10.3	8.1

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Table 4. The weed control efficiency (%) of treatments on the dry biomass of weed species

Treatment	Dose	*M. neglecta*	*L. rigidum*	*H. incana*	*C. pallescens*	*V. persica*	*C. oxyacanthus*	Total
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	100.0^{a}	83.0^{a}	100.0^{a}	95.1^{a}	95.0^{a}	100^{a}	95.8^{a}
Othello®	96 g a.i. ha^{-1}	88.2^{cd}	67.1^{bc}	85.1^{bc}	85.0^{bc}	75.1$^{b–e}$	76.0$^{d–f}$	80.9^{cd}
Axial One®	55 g a.i. ha^{-1}	55.1^{i}	43.2^{e}	65.1^{f}	49.0^{h}	46.0^{g}	60.1^{h}	54.1^{i}
Axial One®	65 g a.i. ha^{-1}	66.1^{h}	48.0^{e}	70.1^{ef}	58.01^{gh}	55.0^{fg}	65.0^{gh}	61.7^{hi}
Axial One®	75 g a.i. ha^{-1}	70.0^{gh}	53.1^{de}	75.1^{de}	60.1^{g}	59.0$^{e–g}$	68.0$^{f–h}$	65.2^{gh}
Axial One®	85 g a.i. ha^{-1}	85.1^{de}	64.1^{bc}	85.1^{bc}	67.0$^{e–g}$	63.2$^{e–g}$	80.0$^{c–e}$	72.0$^{e–g}$
Joystick®	80 g a.i. ha^{-1}	69.1^{h}	52.1^{de}	75.0^{de}	65.0^{fg}	61.0$^{e–g}$	72.0$^{e–g}$	67.3$^{f–h}$
Joystick®	94 g a.i. ha^{-1}	80.0^{ef}	58.2^{cd}	80.0^{cd}	70.4^{ef}	66.1$^{d–f}$	78.0$^{d–e}$	74.0$^{e–f}$
Joystick®	108 g a.i. ha^{-1}	90.7$^{b–d}$	78.0^{a}	90.0^{b}	80.1^{cd}	82.0$^{a–d}$	90.1$^{a–c}$	85.4^{bc}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	76.4^{fg}	59.0^{dc}	80.0^{cd}	75.0^{de}	71.1$^{c–f}$	86.0$^{b–d}$	76.5^{de}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	94.2$^{a–c}$	74.1^{ab}	100.0^{a}	87.0$^{a–c}$	86.1$^{a–c}$	95.0^{ab}	90.6^{ab}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	96.2^{ab}	78.1^{a}	100.0^{a}	91.0^{ab}	91.0^{ab}	96.1^{ab}	92.4^{ab}
$LSD_{0.05}$		6.7	10.0	9.3	9.1	18.2	10.1	8.3

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

The results showed that the reduced doses of Axial One® (55 and 65 g a.i. ha^{-1}) had significantly lower WCE on the density and biomass of each weed species. While the WCE was not affected by a reduction in the dose of Joystick® from 94 to 80 g a.i. ha^{-1} (Tables 3 and 4). On the other hand, the increased dose of Joystick® (108 g a.i. ha^{-1}) improved significantly the WCE on the density and biomass of each weed species. However, the WCE was not affected by an increase in the dose of Axial One® from 75 to 85 g a.i. ha^{-1}.

Previously, it was reported that the tank mixing of Othello® and Atlantis® (a pre-mixed herbicide: mesosulfuron-methyl + iodosulfuron-methyl sodium) can completely control *Polygonum aviculare* L. in wheat (Ebadati *et al.*, 2019). In other studies, the tank mixing of Atlantis® + Bromicide®MA had shown excellent control efficacy against *Convolvulus arvensis* L. in wheat (Zalghi, Saeedipor, 2017). Veisi *et al.* (2018) reported that the tank mixing of Bromoxynil + MCPA could control *Carduus pycnocephalus* L., *Carthamus oxyacantha* M.B., *Galium tricornutum* Dandy, and *Sinapis arvensis* L. up to 100%.

The results showed that the addition of Citogate® to the spray solution could effectively improve the WCE of Joystick®. The treatment of Joystick® at 230 g ha^{-1} plus surfactant Citogate® could provide a favourable WCE; significantly similar to the treatment of Bromicide®MA + Axial®. This treatment reduced the density of *M. neglecta*, *L. rigidum*, *H. incana*, *C. pallescens*, *V. persica*, and *C. oxyacanthus* up to 95.0, 75.0, 100, 88.8, 89.9, and 95.0; respectively; with an 88.5% reduction in total weed density. Moreover, it reduced the dry biomass of *M. neglecta*, *L. rigidum*, *H. incana*, *C. pallescens*, *V. persica*, and *C. oxyacanthus* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1; respectively; with a 92.4% reduction in total weed dry biomass (Tables 3 and 4). It is established that the surface tension of spray solutions can be decreased by adding Citogate® (Aliverdi *et al.*, 2009), decreasing the contact angle of droplets with the surface of the leaf, increasing the deposition of the droplets on the surface of the leaf, increasing herbicide absorption and translocation, subsequently improving herbicide efficacy (da Silva Santos *et al.*, 2021).

The results of analysis variance for the data showed the effect of herbicide treatments on the height, no. spikes $m^{2\,-1}$, no. grains $spike^{-1}$, 1000 grain-weight, grain yield and biological yield of wheat (df = 12; P ≤0.01). The height of wheat was significantly decreased with increasing the dose of Joystick® and Axial One®. As compared to weed-free check treatment, increasing the dose of Axial One® from 55 to 85 g a.i. ha^{-1} decreased the height of wheat up to 6%. While increasing the dose of Joystick® from 80 to 108 g a.i. ha^{-1} decreased it up to 4%. Moreover, adding Citogate® to Joystick® spray solution decreased the height of wheat up to 7%. The latter treatment had no significant difference with Othello® (Table 5). The number of spikes $m^{2\,-1}$, the number of grains $spike^{-1}$, and 1000 grain-weight of wheat were increased with increasing dose of Joystick® and Axial One®. Adding Citogate® to Joystick® spray solution increased the number of spikes $m^{2\,-1}$, the number of grains $spike^{-1}$, and 1000 grain-weight of wheat up to 10, 23, and 27% as compared to weed-free check treatment, respectively (Table 5). In general, the changes of 1000 grain-weight were less than the number of spikes $m^{2\,-1}$ and the number of grains $spike^{-1}$. The number of spikes $m^{2\,-1}$ and the number of grains $spike^{-1}$ of wheat were dependent on the WCE of herbicides. Already, it is established that the greater the WCE of herbicides, the more the number of spikes $m^{2\,-1}$ and grains $spike^{-1}$ of wheat (Mahmood *et al.*, 2013; Mamnoie, Karaminejad, 2020). The grain and biological yields of wheat were improved by increasing the dose of Joystick® and Axial One®. Moreover, adding Citogate® to Joystick® spray solution significantly improved the grain and biological yields of wheat. The treatment of Joystick® at 108 g a.i. ha^{-1} plus Citogate® showed the greatest overall control after the weed-free check treatment (Table 6). Because of the WCE by Joystick® at 108 g a.i. ha^{-1} plus Citogate®, the grain and biological yields of wheat improved up to 28% as compared to the weedy check treatment. The improvement in the grain and biological yields of wheat have already been reported by Manea *et al.* (2016) using pinoxaden + florasulam, Makvandi *et al.* (2007) using tribenuron-methyl + diclofop-methyl, Ebadati *et al.* (2019) using mesosulfuron-methyl + iodosulfuron-methyl-sodium, and Mohammaddoust *et al.* (2011) using 2,4-D + MCPA.

Table 5. The effect of treatments on some wheat traits and the changes (%) in each trait in comparison with weedy check treatment

Treatment	Dose	Height		No. spikes $m^{2\,-1}$		No. grains $spike^{-1}$		1000 grain weight	
		cm	%	no.	%	no.	%	g	%
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	$90.2^{a–d}$	100^{a}	446^{ab}	28.5^{a}	$32.0^{a–c}$	21.9^{ab}	$42.2^{a–c}$	10.5^{ab}
Othello®	96 g a.i. ha^{-1}	87.6^{d}	94.9^{b}	$427^{a–e}$	$25.2^{a–c}$	$32.0^{a–c}$	21.9^{ab}	$41.5^{a–d}$	10.2^{ab}
Axial One®	55 g a.i. ha^{-1}	94.4^{ab}	100.0^{a}	401^{e}	14.1^{e}	26.0^{g}	11.8^{f}	39.5^{d}	5.3^{c}
Axial One®	65 g a.i. ha^{-1}	$93.1^{a–c}$	100.0^{a}	405^{de}	15.2^{de}	27.0^{fg}	12.4^{ef}	39.8^{cd}	5.8^{c}
Axial One®	75 g a.i. ha^{-1}	88.7^{cd}	96.5^{ab}	$409^{c–d}$	16.4^{de}	$28.0^{e–g}$	13.1^{ef}	40.1^{cd}	7.6^{bc}
Axial One®	85 g a.i. ha^{-1}	87.6^{d}	94.9^{b}	$418^{b–e}$	$20.5^{b–e}$	$30.0^{c–e}$	17.6^{cd}	$40.9^{a–d}$	9.2^{ab}
Joystick®	80 g a.i. ha^{-1}	$93.4^{a–c}$	100.0^{a}	$413^{c–e}$	$18.2^{c–e}$	$29.0^{d–f}$	15.5^{de}	40.0^{cd}	9.7^{ab}
Joystick®	94 g a.i. ha^{-1}	$89.0^{b–d}$	97.4^{ab}	$421^{b–e}$	$22.8^{a–d}$	$30.0^{c–e}$	$18.8^{b–d}$	$40.5^{b–d}$	$8.4^{a–c}$
Joystick®	108 g a.i. ha^{-1}	88.8^{cd}	96.4^{ab}	$429^{a–e}$	$25.8^{a–c}$	$31.0^{b–d}$	19.2^{bc}	$41.4^{a–d}$	9.9^{ab}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	$91.3^{a–d}$	100.0^{a}	$425^{a–e}$	$21.9^{a–e}$	$31.0^{b–d}$	21.5^{ab}	$41.2^{a–d}$	9.7^{ab}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	$89.6^{b–d}$	100.0^{a}	$433^{a–d}$	26.7^{ab}	33.0^{ab}	22.2^{ab}	42.7^{ab}	10.7^{ab}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	87.5^{d}	93.9^{b}	$438^{a–c}$	27.6^{ab}	34.0^{a}	23.6^{a}	42.9^{a}	10.8^{a}
Hand–weeded	–	95.0^{a}	100.0^{a}	455^{a}	29.2^{a}	34.5^{a}	24.3^{a}	43.0^{a}	11.0^{a}
$LSD_{0.05}$		5.3	4.7	31.0	7.9	2.9	3.6	2.3	3.1

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Table 6. The effect of treatments on the grain and biological yields of wheat and their changes (%) in comparison with weedy check treatment

Treatment	Dose	Grain yield		Biological yield	
		t ha^{-1}	%	t ha^{-1}	%
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	5.61^{a-d}	26.1^{ab}	15.3^{a}	26.0^{a-c}
Othello®	96 g a.i. ha^{-1}	5.4^{a-e}	25.1^{a-c}	14.6^{a}	25.1^{a-c}
Axial One®	55 g a.i. ha^{-1}	4.0^{f}	8.1^{e}	10.8^{d}	8.0^{g}
Axial One®	65 g a.i. ha^{-1}	4.1^{f}	10.0^{de}	11.3^{cd}	10.1^{g}
Axial One®	75 g a.i. ha^{-1}	4.2^{f}	13.0^{c-e}	11.4^{cd}	13.0^{fg}
Axial One®	85 g a.i. ha^{-1}	4.6^{d-f}	19.0^{a-e}	12.3^{cd}	19.0^{de}
Joystick®	80 g a.i. ha^{-1}	4.3^{ef}	16.1^{b-e}	12.1^{cd}	16.1^{ef}
Joystick®	94 g a.i. ha^{-1}	4.8^{c-f}	22.1^{a-d}	12.8^{b-d}	22.0^{cd}
Joystick®	108 g a.i. ha^{-1}	5.0^{b-f}	24.0^{a-c}	13.1^{bc}	24.0^{b-d}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	5.3^{a-e}	25.0^{a-c}	14.5^{ab}	25.1^{a-c}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	5.7^{a-c}	27.1^{ab}	15.5^{a}	27.1^{a-c}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	5.9^{ab}	28.0^{ab}	15.6^{a}	28.0^{ab}
Hand–weeded	–	6.1^{a}	30.0^{a}	15.9^{a}	29.8^{a}
$LSD_{0.05}$		1.1	12.7	2.1	5.7

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Conclusion

Based on the current results, it is not possible to recommend a reduced dose of Axial One® to control the weeds in wheat. Tank-mixing Bromicide®MA + Axial® can be effectively applied in wheat giving excellent control of broadleaf and grass weeds. Because of the weed control efficacy of Bromicide®MA + Axial®, the grain yields of wheat could be improved. The focus of this study was on the efficacy of the newly released pre-mixed herbicides, Joystick®. Joystick® applied at the labelled dose (108 g a.i. ha^{-1}) could control the density of weed species by 55–80% and the dry biomass of weed species by 60–80%. At the labelled rate, it did not provide improved control compared with the efficacy of the existing pre-mixed herbicide, Othello®. Increasing the dose of Joystick® (up to 108 g a.i. ha^{-1}) along with adding the nonionic surfactant, Citogate® improve weed control and should be a potential herbicide for use in wheat. When these two recommendations were applied, the density and dry biomass of weed species could be reduced by 75–100%.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

EM – analysis and interpretation of data
MRK – acquisition of data
AA – writing, revision, and approve the final manuscript
MMM – acquisition of data

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