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Influence of Various Herbicides on Weed Dynamics and Wheat Yield (*Triticum aestivum* L.)

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Abstract

Weed management is crucial for sustainable crop production, and chemical herbicides are widely utilized for weed control in developed countries. Nevertheless, mounting concerns about the negative environmental impacts of pesticides have spurred efforts to reduce their usage by farmers. Three trials conducted in Iran evaluated the use of the different herbicides, adjuvant and herbicide mixture for weed control in wheat crop. A range of herbicides type, herbicides mixture and adjuvants were evaluated. The following parameters about weeds, including weed density and weed biomass (m^{-2}) were recorded 30 days after spray within 0.5 m^2 quadrats (two quadrats per plot), randomly selected from two different locations from each plot. To obtain the grain yields per plot, researchers harvested the grains from the center six rows of each test site, then converted the measurements to ton/ha and weed count per unit area. The results show that herbicides have a significant effect on weed density and weed dry weight comparison with weed control in three years. The maximum weed efficiency (98%) was recorded for Lintur® 70% WG as the first year, second year the maximum weed efficiency was Everest 2.0® plus Cutivate® adjutant and in the third year the maximum weed efficiency (83%) was recorded for Topik® + Bromicide MA®. In conclusion, results of this experiment showed that Lintur, Everest or Topic + Bromicide can be used for weed control in Iran.

Keywords: Adjuvant, Lintur, Mix herbicide, Weed density, Weed dry weight

1. Introduction

Triticum aestivum, commonly known as wheat, is a major food crop and belongs to the grass family known as Poaceae. The genus *Triticum* includes various species such as *T. aestivum*, *T. durum* and others, and covers the largest agricultural area in the world. Wheat is the second-largest crop in terms of production, producing 771.71 million tons in 2017 (FAO, 2019; Mousavinik et al., 2021; Ahmadi et al., 2022). Due to the growing population, urbanization, the emergence of agro-processors and increased household income, the demand for wheat in Ethiopia is rapidly increasing (Tadesse et al., 2019). Weeds deteriorate the quality of the crops, decreasing their market value and reducing the yield by competing with crop plants for available resources (Kardoni et al., 2019). Weeds potentially increase the risks of disease outbreaks by providing shelter and acting

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as an alternate host for the pest (Marwat et al., 2008). Proper control of weeds is a critical factor in sustaining crop yield. According to the literature, the intensity of weeds and their competition time with crop plants are crucial factors in determining yield loss. High weed intensity and prolonged competition with crops, intensify negative impacts on crop yield (Chaudhary et al., 2008). Weed competition at the early growth stages of crop causes more growth and yield (Garibaldi-Marquez et al., 2022; Lou et al., 2022; Horvath et al., 2023). Altering the emergence time of weeds and their timely control are essential components in shifting weed-crop completion in favor of crop (Akhtar et al., 2000). If the proper weed control methods are not implemented during the critical period of competition, effective weed management and profit will not be attained (Chadha et al., 2021; Yu et al., 2021; Naeem et al., 2022; Naseri et al., 2023).

In means of weed control, different methods are obtained depending on the type of weeds, availability of resources, and purposes of crop production. Among all weed control processes, the most common process with highest efficiency and economical reliability is the chemical method (Marwat et al., 2008). In order to determine required introduction of herbicides in agricultural practices, influences of the chemical components on the cultures are studied. Several authors have indicated reductions in winter cereals yield as a result of phytotoxic effects of various herbicides (Stoyanova et al., 2014; Stoyanova et al., 2015; Delchev, 2016). Reduction in herbicide efficacy is most likely due to weeds developing resistance mechanisms. Therefore, herbicide application should be hindered before the resistance develops. This can be possible through determining efficacy levels of a given herbicide. Application of alternate herbicides may prevent such herbicide resistance developments (Owen et al., 2007).

The effectiveness of weed-killing measures lies in the co-operation of herbicide and soil-atmospheric conditions and the developmental phase of weeds. However, according to Green (2001), Ramsdale and Nalewaja (2001) and Van and Zeeland (2001), application of adjuvants in chemical weed control increases the biological activity of herbicides, hence allowing for decreasing applied dosages, thereby reducing costs of treatments and the negative impacts on the environment. Efficacy rates of any specific adjuvant also depends on active substances, formulation of herbicides, species of controlled weed, and environmental conditions as mentioned above. Researchers conducted this study to evaluate the impact of adjuvants on the effectiveness of combined applications of different herbicides.

The use of spray-tank adjuvants, which improve the efficacy of foliar-applied crop protection products, including post-emergence herbicides, is well known, and there are a significant number of adjuvants available for that purpose in the market (Foster et al., 2006; Krogh et al., 2003). Properties of adjuvants increase herbicide activity through mechanisms such as droplet adhesion, retention, spreading, deposit formation, uptake, and translocation. These adjuvant properties can be chemical, physical, or biological (Skiba et al., 2017; Todorova et al., 2021; Bhardwaj et al., 2022; Zhao et al., 2022). Adjuvants strongly influence pesticide delivery, uptake, redistribution, persistence, and, thus, the final biological performance (Zhao et al., 2022; Ingvordsen et al., 2022; Xu et al., 2023).

Many studies also emphasis the significance of selecting appropriate activator adjuvants to the spray liquid to reduce the effect of factors hindering retention of spraying droplets on the surface of weeds and absorption and transport of active herbicide substances to the place of action (da Silva Santos et al., 2021; Duan et al., 2022; Kolanjiyil et al., 2022; Liu et al., 2022; Zwertvaegher et al., 2022). Growing concerns about food safety and the environmental impact of herbicide use highlight the need for efficient and responsible deployment. The effectiveness of herbicides is influenced by various factors, and researchers have documented that the addition of adjuvants to the spray composition can reduce the surface tension and contact angle of droplets, leading to enhanced weed control levels.

In light of reports highlighting how different herbicides affect wheat yield and weed control, researchers conducted an experiment to evaluate the efficacy of commonly used herbicides in Iran over the course of three years.

2. Materials and Methods

Field experiments were conducted for three winter wheat growing seasons in 2016–2017, 2017–2018, and 2018–2019. In 2017-2018 influence of three adjuvants on the efficacy of different herbicides was studied under field conditions. All experiments were randomized block designs with individual plots of 24 m^2 containing 30 crop rows, and treatments were replicated four times. In Table 1 below, a list of soil characteristics, wheat cultivar variants, sowing rate, planting dates, harvesting dates, and herbicide application dates is provided. The seedbed was prepared by one ploughing with a disc harrow followed by two ploughing with cultivators, and each ploughing was followed by planking. At all year, wheat (*Triticum aestivum* L. Var. Chamran) was seeded at 4-5 cm depth in moist soil in rows spaced at 10 cm on flatbeds at the seed rate of 25 kg ha^{-1}.

The applications of the herbicides were carried out when the wheat was at the tillering stage, and the weeds had four true leaves. All herbicide treatments were applied with a knapsack hand-sprayer in 200 - 300 liters water/ha at 2.5 bars.

Each plot of treatment was manually harvested at physiological maturity of wheat crop (12.5% moisture content). The following parameters regarding weeds, including weed density and biomass (m^2) were recorded 30 days after spray application in 0.5 m^2 quadrats (two quadrats per plot), randomly selected from two different locations from each plot. To obtain the grain yields for each test site, the researchers harvested the six center rows of each plot, then the data was converted to ton/ha and weed count per unit area. After counting number of weeds per unit area, they were harvested from the ground surface. As for dry weight measurement, weeds were oven-dried for 24 hours at 70°C.

The data collected in this experiment was analyzed using Stat Graphics Plus software. A one-way analysis of variance (ANOVA) was conducted, and Duncan's test was employed to identify significant differences between the treatments at a significance level of 0.05. The untreated control treatment was excluded from the weed control data but was included in the analysis of wheat grain yields.

The weed control efficiency (WCE) was calculated by using the formula suggested by previous research (Auskalnis and Kadzys, 2006).

$$WCE = \frac{NWC - NWT}{NWC} * 100$$

where:

NWC = Number of weeds/m^{-2} from Control plots (Without weeded)

NW T = Number of weeds/m^{-2} in plots Treated with herbicides

WCE = Weed Control Efficiency

Table 1 Soil characteristics

Soil type	Soil pH	Organic matter (%)	Wheat cultivar	Seed rate (kg ha^{-1})
Silt loam	7.57	0.2	Chamran	25

Table 2 Planting, harvesting and spraying date in 2016–2019

	2016–2017	2017–2018	2018–2019
Planting date	14/7	16/8	9/7/92
Spraying date	23/12	27/12	22/12
Harvesting date	25/3	21/3	27/3/

Table 3 Herbicide treatments in experiment 2016-2019

The First year			The Second year			The Third year	
Trade Name	**Common Name (Formulation)**	**Application rate**	**Trade Name**	**Common Name (Formulation)**	**Application rate**	**Common Name (Formulation)**	**Application rate**
Othello OD® 0.6%	Diflufenican 5% + Mesosulfuron Methyl 0.75% + Iodosulfuron Methyl sodium 0.25% + Mefenpyr- Diethyl 2.25%	1.6 lit/ha	Othello OD® 0.6% plus Codside® adjutant	Diflufenican 5% + Mesosulfuron Methyl 0.75% + Iodosulfuron Methyl sodium 0.25% + Mefenpyr- Diethyl 2.25%	1.6 lit/ha + 750 ml/ha adjutant	Axial 45® (Pinoxaden) 4.5% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	1.5 + 1.5 L/ha
Atlantis® 1.2% OD	Mesosulfuron Methyl 10 g/lit + Idosulfuron Methyl 2 g/lit + Mefenpyr- Diethyl 30 g/lit	1.5 lit/ha	Othello OD® 0.6% plus Cutivate® adjutant	-	1.6 lit/ha + 300 ml/ha adjutant	Axial 45® (Pinoxaden) 4.5% EC + Granstar® 75% DF (Tribenoron Methyl)	1.5 L/ha + 20 g/ha
Lintur® 70% WG	Triasulfuron 659 g + Dicamba 41g/lit	180 gr/ha	Othello OD® 0.6% plus Trend 90® adjutant	-	1.6 lit/ha + 600 ml/ha adjutant	Topik® (Clodinafop Propargyl) 8% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	0.8 + 1.5 L/ha
Duplosan Super® 60% SL	MCPA 160 g + Dichloprop-P 310 g + Mecoprop-P 130 g	2.5 lit/ha	Everest 2.0® plus Trend 90® adjutant	Flucarbazone Sodium SC 35%	70 ml/ha + 300 ml/ha adjutant	Topik® (Clodinafop Propargyl) 8% EC + Granstar® 75% DF (Tribenoron Methyl)	0.8 L/ha + 20 g/ha
Granstar® 75% DF	Tribenuron Methyl 750 g/kg	20 gr/ha	Everest 2.0® plus Cutivate® adjutant	-	70 ml/ha + 600 ml/ha adjutant	Topik® (Clodinafop Propargyl) 8% EC + U46 Combi Fluid® 55% SL (2,4-D + MCPA)	1 + 1.5 L/ha
Chevalier® 6% WG	Mesosulfuron Methyl 15 gr + 30 g Iodosulfuron Methyl + Mefenpyr- Diethyl 90 g/kg	400 ml/ha	Everest 2.0® plus Codeside® adjutant	-	70 ml/ha + 750 ml/ha adjutant	Hand weeded	0
Bromicide MA® EC 40%	Bromoxynil 200 g/lit + MCPA 200 g/lit	1.5 lit/ha	Hand weeded	-	0	Without weeded	0
Dialen Super® 46.4% SL	120 g/lit Dicamba + 344 g/lit 2,4 D	1 lit/ha	Without weeded	-	0		
U46 Combi Fluid® SL 55%	350 g/lit 2,4-D + 300 g/lit MCPA	1.5 lit/ha	Citowett® 100%	$(C_{12}H_{17}(OC_2H_4)_nOH)$ 100% of alciloarylopoliglicol ether	2.5 lit/1000 lit BASF company		
Hand weeded	-	0	Trend 90®	Isodecyl alcohol ethoxylate 900 g/lit	250-300 ml/ ha Covera company		
Without weeded	-	0	Codeside®	-	2.5 lit/1000 lit Zarafshan company		

3. Results and Discussion

The following Weed types were recorded at the experimental field: *Convolvulus arvensis* L., *Hordeum spontaneum* C. Koch, *Raphanus raphanistrum*, *Avena ludoviciana* Durieu, *Galium aparine*, *Conringia orientalis* L., *Anchusa* sp. and *Lamium amplexicaule*.

3.1 Weeds density after herbicidal application in 2016-2017, 2017-2018 and 2018-2019

A description of the experimental herbicide treatments in different years are shown in Table 3. The data about weed control at 30 DAS are presented in Table 4. Data analysis showed that different herbicides significantly affected weed control efficiency and all treatments reduced the density and dry weight of weeds well.

Table 4 Analysis of variance for treatment effects on weed density and total dry weight of weeds compare with without weeding in experiment 2016-2019

Year	Source of variation	df	Mean of Squares	
			Weed density reduction (%) of control without weeding	Weed dry weight reduction (%) of control without weeding
2016-2017	Block	3	292.478^{ns}	476.905^{ns}
	Treatment	9	2052.532**	1643.374**
	Error	27	615.767	378.936
	Coefficient of variation (%)	-	32.17	24.011
2017-2018	Block	3	159.482^{ns}	48.027^{ns}
	Treatment	6	273.722^{ns}	180.427*
	Error	18	209.639	56.063
	Coefficient of variation (%)	-	15.908	8.000
2018-2019	Block	3	260.380^{ns}	594.226^{ns}
	Treatment	5	1594.691**	1630.244**
	Error	15	213.634	294.260
	Coefficient of variation (%)	-	20.667	24.281

^{ns}, * and ** represent non-significant and significant at 5 and 1% probability level, respectively

Based on the data collected during the experiments between 2016-2017, the weed density efficiency of Lintur® 70% WG was found to be the highest at 98%. Meanwhile, the minimum value of 29% was recorded for Chevalier® 6% WG during the same period. The results of the second year showed that all herbicide treatments significantly reduced weed density. In the third year as herbicides treatment significantly affected weed density. The maximum weed density efficiency in 2018-2019 (83 %) was recorded for Topik® 8% EC + Bromicide MA® 40% EC while the minimum value (47%) was recorded for Topik® 8% EC + U46 Combi Fluid® 55% SL.

The outcome of the studies showed that Isoproturon, Agritop and 2, 4-D performed similarly with respect to their impacts on weed control (Bibi et al., 2008). In accordance with previous researches, (Singh et al., 2019; Yonas et al., 2023) the results indicate that herbicides significantly affected the weed population per unit area

Table 5 Mean comparison of treatment effects on Weed density reduction (%) of control without weeding in experiment 2016-2019

2016-2017		2017-2018		2018-2019	
Treatment	Weed density (%)	Treatment	Weed density (%)	Treatment	Weed density (%)
Othello 0.6% OD®	95.37 ab	Othello OD® 0.6% plus Codside® adjutant	98.81 a	Axial 45® (Pinoxaden) 4.5% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	55.35 c
Atlantis® 1.2% OD	75.20 ab	Othello OD® 0.6% plus Cutivate® adjutant	90.78 a	Axial 45® (Pinoxaden) 4.5% EC + Granstar® 75% DF (Tribenoron Methyl)	58.58 bc
Lintur® 70% WG	98.15 a	Othello OD® 0.6% plus Trend 90® adjutant	98.68 a	Topik® (Clodinafop Propargyl) 8% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	83.69 a
Duplosan Super® 60% SL	86.22 ab	Everest 2.0® plus Trend 90® adjutant	86.05 a	Topik® (Clodinafop Propargyl) 8% EC + Granstar® 75% DF (Tribenoron Methyl)	78.79 ab
Granstar® 75% DF	60.17 abc	Everest 2.0® plus Cutivate® adjutant	81.54 a	Topik® (Clodinafop Propargyl) 8% EC + U46 Combi Fluid® 55% SL (2,4-D + MCPA)	47.93 c
Chevalier® 6% WG	29.17 c	Everest 2.0® plus Codeside® adjutant	81.23 a	Hand weeded	100 a
Bromicide MA® 40% EC	55.00 bc	Hand weeded	100 a	Without weeded	-
Dialen Super® 46.4% SL	85.17 ab	Without weeded	-	-	-
U46 Combi Fluid® 55% SL	86.72 ab	-	-	-	-
Hand weeded	100 a	-	-	-	-
Without weeded	-	-	-	-	-

In each column, means with the same letter have no significant difference

3.2. Analysis of Weed Dry Weight following Herbicidal Applications during 2016-2019

A comprehensive analysis conducted over a period of three years (2016-2019) revealed that various herbicides had a significant impact on Weed dry weight efficiency in the studied fields (Table 4). The results of dry weight have shown that in the two years 2017 to 2018 experiments, all herbicide treatments reduced the dry weight of weeds equally and significantly, except Everest 2.0® plus Codeside® adjutant (82%). But in the third year The maximum Weed dry weight efficiency (86 %) was recorded for Topik® 8% EC + Bromicide MA® 40% EC, while the minimum value (51%) was recorded for Axial 45® 4.5% EC + Bromicide MA® 40% EC.

Table 3 presents an overview of the different herbicide treatments employed in the experimental fields of wheat during the years of 2016, 2017, and 2019. Among these treatments, the combination of isoproturon and carfentrazone consistently showed the most effective results in terms of reducing the weed population density and biomass levels and improving the number of spikes, TGW, and overall grain yields. The combination of deep tillage and herbicide application (isoproturon and carfentrazone) was also shown to be the most suitable option for optimal weed management in wheat crop at higher altitudes (Lu et al., 2015).

Table 6 Mean comparison of treatment effects on Weed dry weight reduction (%) of control without weeding in experiment 2016-2019

2016-2017		**2017-2018**		**2018-2019**	
Treatment	**Weed dry weight (%)**	**Treatment**	**Weed dry weight (%)**	**Treatment**	**Weed dry weight (%)**
Othello 0.6% OD®	73.56 [a]	Othello OD® 0.6% plus Codside® adjutant	94 [a]	Axial 45® (Pinoxaden) 4.5% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	51.38 [b]
Atlantis® 1.2% OD	76.91 [a]	Othello OD® 0.6% plus Cutivate® adjutant	96.933 [a]	Axial 45® (Pinoxaden) 4.5% EC + Granstar® 75% DF (Tribenoron Methyl)	57.61 [b]
Lintur® 70% WG	99.58 [a]	Othello OD® 0.6% plus Trend 90® adjutant	96.998 [a]	Topik® (Clodinafop Propargyl) 8% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	86.76 [a]
Duplosan Super® 60% SL	93.75 [a]	Everest 2.0® plus Trend 90® adjutant	91.020 [ab]	Topik® (Clodinafop Propargyl) 8% EC + Granstar® 75% DF (Tribenoron Methyl)	76.08 [ab]
Granstar® 75% DF	32.72 [b]	Everest 2.0® plus Cutivate® adjutant	87.690 [ab]	Topik® (Clodinafop Propargyl) 8% EC + U46 Combi Fluid® 55% SL (2,4-D + MCPA)	52.05 [b]
Chevalier® 6% WG	68.87 [a]	Everest 2.0® plus Codeside® adjutant	82.443 [b]	Hand weeded	100 [a]
Bromicide MA® 40% EC	90.10 [a]	Hand weeded	100 [a]	Without weeded	-
Dialen Super® 46.4% SL	80.22 [a]	Without weeded	-	-	-
U46 Combi Fluid® 55% SL	94.99 [a]	-	-	-	-
Hand weeded	100 [a]	-	-	-	-
Without weeded	-	-	-	-	-

In each column, means with the same letter have no significant difference

3.3. Grain yield of wheat after herbicidal application 2016-2019

The effect of different herbicide treatments on grain yield is highlighted in Table 7, which demonstrates that all herbicides for weed management had a significant impact on this outcome.

Table 7 Analysis of variance for treatment effects on grain yield of wheat in experiment 2016-2019

Year	Source of variation	df	Means of Squares
2016-2017	Block	3	0.22153^{ns}
	Treatment	10	1.04876**
	Error	30	0.18989
	Coefficient of variation (%)	-	9.469
2017-2018	Block	3	0.043942^{ns}
	Treatment	7	4.3535**
	Error	21	0.14920
	Coefficient of variation (%)	-	6.183
2018-2019	Block	3	2.134*
	Treatment	6	2.586**
	Error	18	0.630
	Coefficient of variation (%)	-	17.118

^{ns}, * and ** represent non-significant and significant at 5 and 1% probability level, respectively

In the first year, Total dry weight results indicated that the maximum grain yields of 5.6 t/ha was observed in Othello OD® 0.6% treated plots followed by Lintur® 70% WG (5.2 t/ha). The minimum grain yields of 3.9 t/ha was observed without weeded plots.

The excellent performance of Lintur® 70% WG and other herbicide applications may be attributed to their effective control of weeds, which mitigated the competition for nutrients and subsequently led to an increased flow of nutrients towards the grain and consequently, higher yields. During the second year, as the herbicide treatment significantly affected grain yield wheat, the maximum grain yields of 5.1 t/ha was observed in manually weeded plots and Everest 2.0® + Cultivate®. The minimum grain yields of 3.2 t/ha was observed in plots with no weeding procedures, and Everest 2.0® plus Codeside® adjutant.

In the third year, maximum grain yields of 5.1 t/ha was observed in Topik® 8% EC + Bromicide MA® 40% EC treated plots followed by Topik® 8% EC + Granstar® 75% DF. The minimum grain yields of 3.2 t/ha was observed in plots without weeding procedures. These results are consistent with previous research (Singh et al., 2019; Yonas et al., 2023). According to the reports, herbicidal treatments significantly increased the wheat grain yield.

In a field study conducted by Azab et al. (2020), it was observed that the use of isoproturon at 1000 g/ha 32 days after sowing was ineffective in controlling little seed canary grass (Phalaris minor) and led to a significant reduction in wheat grain yield by 65% in comparison to the weed-free control. According to Singh et al. (2019), the dry weight of S biotype was observed to decrease upon application of 0.25 kg/ha of isoproturon. There have been reports indicating that the toxicity of isoproturon to wheat and the R biotype increased when P-450 inhibitors were added to herbicide solution. Marwat (2003) documented that an infestation of isoproturon-resistant weed population resulted in a reduction in wheat grain yield by more than 65% with the recommended rate of isoproturon (1000 g ha^{-1}) application. Similarly, an experiment 25 on isoproturon treated maize evidently presented decreases in fresh and dry weight of shoots and roots, as well as lower chlorophyll and carotenoid contents of 10 day old maize seedlings during the following 20 days.

The results of the study indicated that the various herbicidal treatments had a significant impact on the grain yield of the wheat crop. The highest yield (3656 kg/ha) was observed in the plots treated with Topik and Affinity herbicides, followed by manually weeded plots at 3188 kg/ha. These findings indicate that appropriate herbicide application can enhance the grain yield of the wheat crop by effectively controlling weed growthThe results of the study demonstrate that the minimum grain yield, which was recorded to be 1375 kg/ha, was observed in the plots where weeds were left untreated. On the other hand, the yields achieved under the herbicidal treatments using Isoproturon, 2,4-D, and Agritop were found to be statistically comparable to one another. Regarding seed rates, the maximum grain yield (2796.87) was recorded in 140 kg ha^{-1} seed rate, closely followed by (2765.62) in 160 kg ha^{-1} seed rates; while the minimum grain yield (2421.87) was recorded in 120 kg ha^{-1}. The experiment showed that herbicide treatments resulted in increased yields due to efficient weed control, which allows the crop to fully utilize available resources (Bibi et al., 2008). These results are consistent with the reports of Asad et al. (2017), Zahan et al. (2021), and Mekonnen (2022). However, Farzanh et al (2016) stated that The study found that using clodinafop propargyl at 0.08 L a.i. ha^{-1} resulted in better control of grass weeds, and the addition of a codacide adjuvant to this herbicide enhanced its efficacy. The study revealed that the application of tribenuron methyl (12.75 g a.i. ha^{-1}) combined with codacide resulted in substantial reductions in broad-leaved weed density and dry matter. The reductions achieved were comparable to those observed in weed-free controls. Furthermore, this treatment led to a 22% increase in biological wheat yield, 40% increase in grain yield, and 13% increase in the number of fertile spikes compared to the infested control. The study found that the application of tribenuron methyl at a rate of 10.5 g a.i ha^{-1} yielded the lowest crop output, with a harvest index of 34.04% and 36.50 fertile spikes.

Table 8 Mean comparison of treatment effects on grain yield (t/ha) in experiment 2016-2019

2016-2017		2017-2018		2018-2019	
Treatment	**Grain yield (t/ha)**	**Treatment**	**Grain yield (t/ha)**	**Treatment**	**Grain yield (t/ha)**
Othello 0.6% OD®	5.23 a	Othello OD® 0.6% plus Codside® adjutant	6.16 cd	Axial 45® (Pinoxaden) 4.5% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	4.25 bc
Atlantis® 1.2% OD	4.39 c	Othello OD® 0.6% plus Cutivate® adjutant	6.07 d	Axial 45® (Pinoxaden) 4.5% EC + Granstar® 75% DF (Tribenoron Methyl)	4.38 bc
Lintur® 70% WG	5.68 a	Othello OD® 0.6% plus Trend 90® adjutant	6.11 d	Topik® (Clodinafop Propargyl) 8% EC + Bromicide MA® 40% EC (Bromoxynil+MCPA)	5.18 ab
Duplosan Super® 60% SL	4.54 bc	Everest 2.0® plus Trend 90® adjutant	6.73 bc	Topik® (Clodinafop Propargyl) 8% EC + Granstar® 75% DF (Tribenoron Methyl)	5.14 ab
Granstar® 75% DF	4.23 c	Everest 2.0® plus Cutivate® adjutant	7.16 b	Topik® (Clodinafop Propargyl) 8% EC + U46 Combi Fluid® 55% SL (2,4-D + MCPA)	4.58 b

Chevalier® 6% WG	4.35^{c}	Everest 2.0® plus Codeside® adjutant	5.66^{d}	Hand weeded	5.69^{a}
Bromicide MA® 40% EC	4.49^{bc}	Hand weeded	7.78^{a}	Without weeded	3.22^{c}
Dialen Super® 46.4% SL	4.27^{c}	Without weeded	4.29^{e}	-	-
U46 Combi Fluid® 55% SL	4.31^{c}	-	-	-	-
Hand weeded	5.14^{ab}	-	-	-	-
Without weeded	3.99^{c}	-	-	-	-

In each column, means with the same letter have no significant difference

4. Conclusion

Providing nourishment for the growing population requires a decent increase in total wheat production, which must preferably be obtained with the least amount of chemical applications (including herbicides and fertilizers). The use of chemical compounds has negative impacts on the environment and human health, resulting in herbicide-resistant weeds and toxicity towards non-target crops, which pose significant challenges in large-scale production of cultivated crops. The use of herbicides can harm the environment and health. Therefore, research is necessary to develop more environmentally-friendly methods for weed management, such as the use of plant hormones for selective weed control that helps reduce herbicide resistance.

Herbicide safeners, as another favorable alternative, should be taken into consideration. These chemical compounds are formulated to be used alongside herbicides, with the aim of enhancing their safety by minimizing the harmful effects on crop plants. These safeners improve the selectivity between crops and weeds, reducing the impact of herbicides on the intended targets by interacting with receptor proteins. Furthermore, herbicide safeners facilitate crop tolerance to herbicides by regulating the expression of genes involved in herbicide metabolism, thus minimizing the negative impacts of herbicides on both target and non-target species.

In a specific study conducted in western France, the relationship among weeds, herbicides, and winter wheat yields was examined using data collected from 150 winter wheat fields. Surprisingly, no significant correlation was found between crop yields and the use of herbicides. Instead, it was discovered that herbicides were more effective in controlling rare plant species rather than the more abundant weed species. These findings indicate that by reducing herbicide usage by up to 50%, it is possible to maintain crop production—a finding supported by previous studies—while simultaneously promoting weed biodiversity. This reduction in herbicide usage can contribute to both ensuring food security and conserving biodiversity, providing a potential solution within the realm of intensive agriculture.

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