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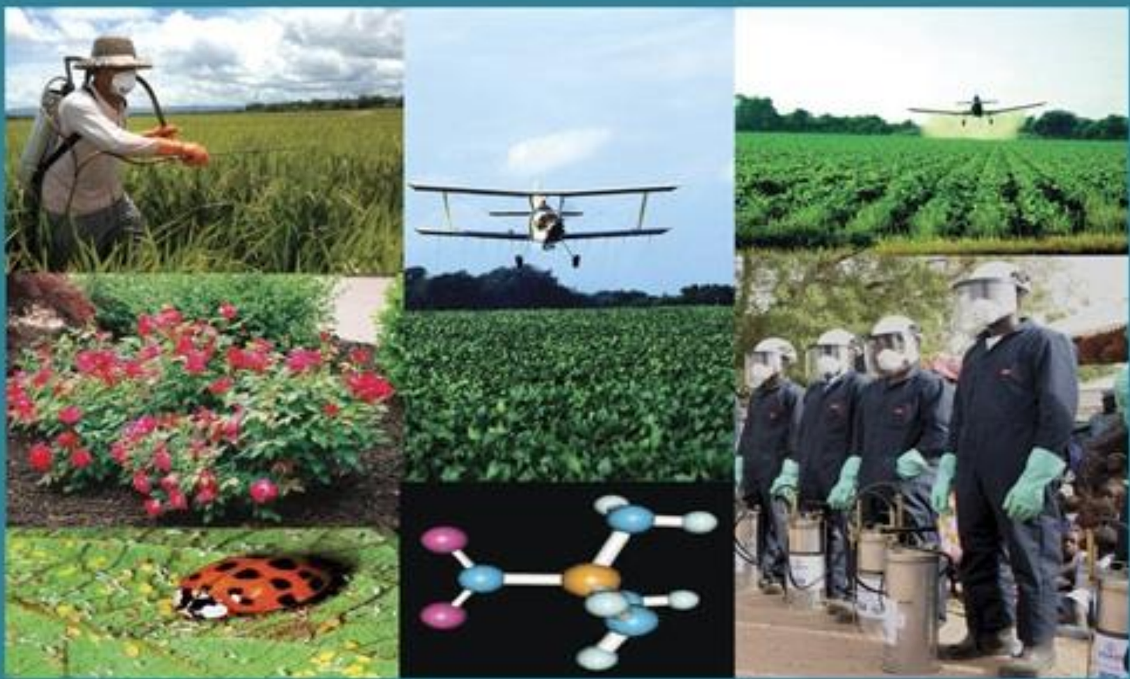

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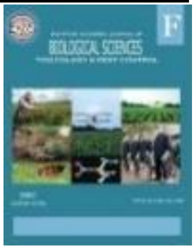

The Potency of Separated and New Premix Formulations of Carfentrazone- Based Herbicide Against Annual Broadleaved Weeds in Wheat

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ABSTRACT

A field study was carried out at the Experimental Farm of Assiut University, Egypt during 2019–2020 and 2020–2021 to evaluate the potency of carfentrazone (CARF) alone and four new premixes of carfentrazone + dicamba (CARF+DICA), carfentrazone + tribenuron (CARF+TRIB), carfentrazone + fenoxaprop (CARF + FENO), and carfentrazone + fenoxaprop + tralkoxydim (CARF + FENO + TRAL), on broadleaved weed and its influence on the productivity of winter wheat. Wheat fields were infested with different annual broad-leaved weeds during the study years and *Rumex dentatus* L., *Chenopodium album* L., and *Beta vulgaris* L. were the dominant weed species. All herbicide treatments performed a high efficacy against broadleaved weeds in wheat fields 30 days after herbicide treatments (DAHT) in both years. All tested herbicides achieved 95.24–96.30% and 84.92–96.65% in controlling broad-leaved weeds and significantly reduced fresh weed biomass by 99.14–99.87% and 98.20–99.68% in the first and second year, respectively, compared with control. CARF+DICA caused severe injury to the flag leaves of wheat and performed alteration in spike and spikelet form that resulted in a significant reduction in grain yield by 47.37 and 16.28%, in the first and second year compared to the control, respectively. CARF+DICA should not be used to control weeds in wheat cultivar 'Sids 14'. Other tested herbicides caused a slightly visible injury on the leaves of wheat in the first days after application but the injury disappeared after 28 DAHT, without any effect on crop yield. All herbicides except CARF+DICA resulted in significantly higher biological yield and grain yield than the control and CARF+DICA. CARF+FENO and CARF+FENO+TRAL resulted in the highest biological yield and grain yield in both years followed by CARF+TRIB (in 2020–2021) and CARF (in 2019–2020) compared to the control. All herbicides except CARF+DICA are considered new promising options for the control of broad-leaved weeds in common wheat in the Upper Egypt region.

INTRODUCTION

Wheat (*Triticum aestivum* L.) ranks as the first important and leading cereal crop in Egypt, as it occupies more than 47% of the cultivated lands during winter (Abdelmageed *et al.*, 2019). Nevertheless, a great gap (approximately 50%) between annual wheat production

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in Egypt and the current human consumption, which is compensated through importation, is still (Abdelmageed *et al.,* 2019). In 2020, Egypt is the world's biggest importer of wheat as it imported about 12.89 million tons ($3.2 billion) of wheat (Abdalla *et al.,* 2023). Weeds are among the most serious wheat pests and the main obstacles in the production of wheat grain worldwide, including in Egypt (Singh *et al.,* 2011; Mohamed, 2017). Generally, a wide range of broad-leaf and grassy weeds infest wheat fields and their interference with wheat can cause a reduction in the quality and quantity of the crop grain yield (Singh *et al.,* 1995, Zand *et al.,* 2007; Reddy *et al.,* 2013; Mohamed, 2017).

Grain yield losses caused by annual and perennial weeds in wheat cropping regions worldwide vary depending on different factors such as the weed species and their density (Singh *et al.,* 2011). It could be 25-30% (Yadav and Malik, 2005), 13-38% (Conley and Bradley, 2005), and 48-86% (Tessema *et al.,* 1996). The only efficacious and economic strategy to minimize the incidence of crop yield reduction is to prevent and control weeds, by applying herbicides compared to manual weeding (Zand *et al.,* 2007; Mohamed *et al.,* 2016). Several post-emergence herbicides have been registered in the world to control a wide variety of weeds in wheat such as fenoxaprop-p-ethyl, pinoxaden, and tralkoxydim as grass herbicides, bromoxynil, dicamba, and tribenuron-methyl as broadleaved herbicides, and mesosulfuron plus idosulfuron as dual-purpose herbicides (Zand *et al.,* 2007; Reddy *et al.,* 2013; APC, 2019). Herbicides can be applied in weed control programs alone, and either as a tank mixture or as a ready mixture (Singh *et al.,* 2011).

Carfentrazone-ethyl (CARF) is a contact post-emergence herbicide that farmers are used as a selective one to control broadleaf and sedge weeds in some cereals, including wheat (Punia *et al.,* 2006; Singh *et al.,* 2011). Carfentrazone-ethyl is a disrupter of cell membranes in weeds by inhibiting the activity of the protoporphyrinogen oxidase (PPO) enzyme resulting in the cell death of weeds (Shaner, 2014). However, CARF can cause little phototoxic effects on the leaves of wheat and barley after treatment, but treated plants of both crops recover within 15–21 days without any reduction in grain yield (Howatt, 2005). Wheat crop injury by CARF can be lowered by its mixing with herbicides or by adding a safener material, thus CARF herbicide can be mixed with various herbicides such as dicamba, fenoxaprop-p-ethyl, tribenuron-methyl, metsulfuron, and clodinafop either as a tank mixture or as a ready mixture for controlling weed flora in wheat (Howatt, 2005; Singh *et al.,* 2011; Delchev and Georgiev, 2015). Fenoxaprop-p-ethyl and tralkoxydim are acetyl co-A carboxylase (ACCase) inhibitors used as post-emergence grassy herbicides in wheat and barley (APC, 2019).

Dicamba and tribenuron-methyl are post-emergence broad-leaf herbicides in wheat and barley; dicamab is a mimic auxin plant herbicide but tribenuron-methyl is an acetolactate synthase inhibitor (Chhokar *et al.,* 2007a; Shaner, 2014). A tank mixture of carfentrazone with tribenuron elicited effective control against broad-leaved weeds, but not with 2,4-D herbicide against some target weeds (Singh *et al.,* 2008). Tank mixed of carfentrazone with tralkoxydim caused a slight injury to wheat leaves but it has not occurred when carfentazone tank mixed with fenoxaprop-P-ethyl and clodinafop-propargyl or sulfonylurea herbicides (Howatt, 2005; Singh *et al.*, 2011). Application of carfentrazone+metsulfuron premix with 0.2% non-ionic surfactant (NIS) at 25 g/ha in wheat showed 5-15% wheat injury, reduced the population and dry weight of broad-leaved weeds by ≥ 97% and ≥ 98%, respectively and increased grain yield by 31% over the control (Singh et al. 2011). Mohamed (2017) found that dicamba caused injury to the spike form of common wheat 'Sids 12' but did not decrease the wheat yield. Recently, some new pre-mix products of carfentrazone-based are under registration in Egypt for use in common wheat including carfentrazone-ethyl + fenoxaprop-p-ethyl (CARF + FENO), carfentrazone-ethyl + fenoxaprop-p-ethyl + tralkoxydim (CARF+FENO+ TRAL), carfentrazone-ethyl + dicamba (CARF+DICA), carfentrazone-ethyl + tribenuron-methyl (CARF+TRIB). However, the effect of new carfentrazone-based herbicides on broad-leaf weeds in common wheat in Upper Egypt is not studied yet.

Therefore, this study was performed to evaluate the efficacy of some new carfentrazone-based herbicides including carfentrazone-ethyl, carfentrazone-ethyl + fenoxaprop-p-ethyl, carfentrazone-ethyl + fenoxaprop-p-ethyl + tralkoxydim, carfentrazone-ethyl + tribenuron-methyl, and carfentrazone-ethyl + dicamba for controlling annual broadleaved weeds in common wheat in Upper Egypt.

MATERIALS AND METHODS

Field experiments were carried out in 2019–2020 and 2020–2021 at the Experimental Farm of Assiut University, Egypt. The field soil is clay in both years. Common wheat seeds of ‘Sids 14’ cultivar were sown manually on 24 and 3 December 2019–2020 and 2020–2021, respectively. All field experiments were performed in a randomized complete block design, RCBD, with three replications for each treatment. Each experimental plot size was 3.5 m long and 3 m wide in both seasons. Fertilizers and irrigation were applied following the local recommendations and standard agricultural practices. The herbicide treatment details are presented in Table (1) including their trade names, application rates, and manufacturer information.

Table 1. Product name, herbicide active ingredient(s), and application rate in 2019–2020 and 2020–2021.

Common name	Trade name	Application rate	Manufacturer
Carfentrazone	Value 40% WG	35.70 g ha^{-1}	Starchem Industrial Chemicals -Egypt
Carfentrazone + dicamba	Up-Turbo 42% WP	714.30 g ha^{-1}	Starchem Industrial Chemicals -Egypt
Carfentrazone + fenoxaprop	Future-Extra 9.5% EC	1190.50 ml ha^{-1}	Starchem Industrial Chemicals -Egypt
Carfentrazone + fenoxaprop + tralkoxydim	Finish 21.5% EC	952.40 ml ha^{-1}	Starchem Industrial Chemicals -Egypt
Carfentrazone + tribenuron*	Justine 28% WP	83.30 g ha^{-1}	Starchem Industrial Chemicals -Egypt

* Carfentrazone + tribenuron used in 2020-2021.

The treatments consisted of carfentrazone-ethyl (CARF, Value 40% WG) at 35.70 g ha^{-1}, four new premixes herbicides of carfentrazone-ethyl + fenoxaprop-P-ethyl (CARF+FENO, Future-Extra 9.5% EC) at 1190.50 ml ha^{-1}, carfentrazone-ethyl + fenoxaprop-P-ethyl + tralkoxydim (CARF + FENO + TRAL, Finish 21.5% EC) at 952.40 ml ha^{-1}, carfentrazone-ethyl + dicamba (CARF + DICA, Up-Turbo 42% WP) at 714.30 g ha^{-1}, carfentrazone-ethyl + tribenuron-methyl (CARF + TRIB, Justine 28% WP) at 83.30 g ha^{-1}, and the control (Table 1). All treatments were tested in both years (except CARF + TRIB [Justine 28% WP] tested only in 2020–2021). All herbicides were awarded by Weed Research Central Laboratory in Egypt. Herbicides were applied as a post-emergence at the stage of 4-5 wheat leaves with an electric knapsack sprayer fitted with flat-fan nozzles (Granada, model KF-20C-18) and calibrated to deliver 476.19 L ha^{-1} of spray solution.

The number of broad-leaved weed species and their fresh weed biomass was assessed 30 days post-treatment of herbicides (DPT) from 1 m^{-2} section for each plot in the experiment in both years. To assess the biological yield and the grain yield of wheat; plants growing in each plot in the experiment were harvested manually, weight, and expressed as ton ha^{-1}.

Statistical Analysis:

The density and fresh biomass of broad-leaved weed species and their rates in control plots of wheat were calculated. The efficiency of all herbicides against target broad-leaved weeds compared to the control was also assessed through the enumeration of the percentages of weed density and fresh biomass reduction according to Amare *et al.* (2016). After that, data in each year were transferred using (X+0.5) square root transformation. Each one was subjected to ANOVA and statistically analyzed using CoStat–software (2004). The comparisons between means of treatments were made by Fisher's Protected LSD at a 5% level of probability (Steel and Torrie, 1980).

RESULTS

Annual broad-leaved weeds in the wheat experimental field were *Beta vulgaris* L., *Chenopodium album* L., *Rumex dentatus* L., *Ammi majus* L., and *Coronopus niloticus* (Del) Spreng, and *Snochus oleraceus* L during the study years of 2019–2020 and 2020–2021 (Tables 2 and 3). The most dominant annual broad-leaved species were *R. dentatus* and *C. album* (in both years) and *B. vulgaris* (in 2020–2021). In contrast, *S. oleraceus* (in 2019–2020) and *A. majus* and *C. niloticus* (in 2020–2021) occurred in fewer numbers. Overall, broad-leaved weed population density and fresh biomass in the wheat experimental field were higher in the first year compared to the second year (Tables 2 and 3). Maximum population and fresh biomass of broad-leaved weeds were presented in the control plots in both years.

Efficacy of Herbicide Treatments on Broad-Leaved Weed Density and Biomass:

All post-emergence herbicide treatments including CARF, CARF+DICA, CARF+FENO, CARF+FENO+TRAL (in both years) and CARF+TRIB (in 2020–2021) provided a high efficiency to control annual broad-leaved weeds in the wheat field and all herbicides resulted in a significant high reduction on total broad-leaved weed density and fresh weed biomass compared to the control 30 days after herbicide treatments (DAHT) (Tables 2 and 3). In 2019-2020, CARF, CARF+DICA, CARF+FENO, and CARF+FENO+TRAL reduced the total broad-leaved weed density by 95.24–96.30% and fresh weed biomass by 99.14–99.87% compared to the control (Tables 2 and 3). In 2020–2021, the same trend with slight change was noted (Table 2 and 3), where the application of CARF, CARF+DICA, CARF+FENO, CARF+FENO+TRAL, and CARF+TRIB reduced the density of total broad-leaved weeds by 84.92–96.65% and fresh weed biomass by 98.23–99.68%, versus the control (Tables 2 and 3).

The effect of the post-emergence herbicides on individual annual broad-leaved weed species presented in the wheat experimental field in both years 30 DAHT was shown in Tables (2 and 3). All tested herbicide treatments exhibited variable effects on broad-leaved weed species. CARF, CARF+FENO, and CARF+TRIB (only in 2020–2021) completely controlled *B. vulgaris* population (100%) in both years. However, CARF+DICA and CARF+FENO+TRAL reduced the density of *B. vulgaris* by at least 85% and 90% and its fresh biomass by at least 97% and 98% in 2019–2020 and 2020–2021, respectively compared with the control (Tables 2 and 3). All tested herbicides completely controlled *R. dentatus* population (100%) in both years (except for CARF+TRIB in 2020–2021) and *A. majus* population only in 2020–2021 (Table 2-5). In 2019–2020, all tested herbicides reduced *C. pumilum* density by 80.65% to 100% and the weed fresh biomass by 98.49% to 100% (Table 2). In 2020–2021, CARF+DICA and CARF+FENO completely controlled *C. niloticus* population (100%), but CARF, CARF+FENO+TRAL and CARF+TRIB provided the least reduction in *C. niloticus* population (ranging from 53.86% to 69.24%) and *C. niloticus* fresh biomass (ranged from 76.58% to 80.04%) (Table 3). Controlling *C. album* population with CARF, CARF+DICA, CARF+FENO, and CARF+FENO+TRAL was above 90% in 2019–2020, but the control of *C. album* dropped to 51.28%, 56.41%, and 76.92% with CARF, CARF+TRIB, and CARF+FENO+TRAL in 2020–2021, respectively.

Table 2. Effect of herbicide treatments on density and fresh weight biomass and percentage of reduction (% of control) of annual broad-leaved weeds in wheat fields after 30 days of treatments during 2019–2020.

Weed species	Treatments								
	Control	CARF		CARF + DICA		CARF + FENO		CARF + FENO + TRAL	
	Weed density[a] (m^{-2})	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)
Beta vulgaris L.	13.33±4.81a	0.00±0.00b	100a	2.00±2.00b	85a	0.00±0.00 b	100a	2.00±2.00b	85a
Rumex dentatus L.	49.33±12.13a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a
Chenopodium album L.	34.67±15.33a	0.00±0.00b	100a	3.33±1.76b	90.39a	2.00±2.00b	94.23a	0.00±0.00b	100a
Snochus oleraceus L.	8.00±2.31a	0.67±0.67b	91.67a	0.67±0.67b	91.67a	0.67±0.67b	91.67a	0.67±0.67b	91.67a
Cichorium pumilum Jacq.	20.67±5.21a	4.00±2.00b	80.65a	0.00±0.00b	100.0a	2.00±2.00b	90.32a	2.00±1.15b	90.32a
Total broadleaf	126.00±10.58a	4.67±1.76b	96.30a	6.00±2.31b	95.24a	4.67±1.33b	96.30a	4.67±0.67b	96.30a
Weed species	Weed FW[b] (g m^{-2})	Weed FW (g m^{-2})	Control (%)	Weed FW (g m^{-2})	Control (%)	Weed FW (g m^{-2})	Control (%)	Weed FW (g m^{-2})	Control (%)
Beta vulgaris L.	219.58±101.96a	0.00±0.00b	100a	2.12±2.12b	99.03a	0.00±0.00b	100a	5.73±5.73b	97.39a
Rumex dentatus L.	1693.26±662.67a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a
Chenopodium album L.	434.31±245.31a	0.00±0.00b	100a	3.55±2.78b	99.18a	6.51±6.51b	98.50a	0.00±0.00b	100a
Snochus oleraceus L.	104.49±53.25a	4.35±4.35b	95.84a	0.51±0.51b	99.52a	5.28±5.28b	94.95a	5.06±5.06b	95.16a
Cichorium pumilum Jacq.	2323.33±127.22a	35.19±19.09b	98.49a	0.00±0.00b	100.0a	4.40±4.40b	99.81a	30.18±28.21b	98.70a
Total broadleaf	4774.97±935.75a	39.54±15.87b	99.17a	6.17±2.35b	99.87a	16.19±1.84b	99.66a	40.97±22.80b	99.14a

a) Weed density and b) weed fresh weight (FW) data were subjected to square-root transformation $\sqrt{(x+0.5)}$ before analysis and original values of weed emergence are shown in parenthesis. * Means within each row (separated for each weed) with the same letters indicate no significant different according to LSD test ($p < 0.05$). CARF = carfentrazone, CARF+DICA = carfentrazone + dicamba, CARF+FENO = carfentrazone + fenoxaprop, CARF+FENO+TRAL = carfentrazone + fenoxaprop + tralkoxydim.

Table 3. Effect of herbicide treatments on density and fresh weight biomass and percentage of reduction (% of control) of annual broad-leaved weeds in wheat fields after 30 days of treatments during 2020–2021.

Weed species	Treatments										
	Control	CARF		CARF + DICA		CARF + FENO		CARF + FENO + TRAL		CARF +TRIB	
	Weed density[a] (m^{-2})	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)	Weed density (m^{-2})	Control (%)
Ammi majus L.	13.33±4.81a	0.00±0.00b	100a	2.00±2.00b	85a	0.00±0.00 b	100a	2.00±2.00b	85a	0.00±0.00b	100a
Beta vulgaris L.	49.33±12.13a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a
Chenopodium album L.	34.67±15.33a	0.00±0.00b	100a	3.33±1.76b	90.39a	2.00±2.00b	94.23a	0.00±0.00b	100a	11.33±4.67b	56.41ab
Coronopus niloticus Spreng	8.00±2.31a	0.67±0.67b	91.67a	0.67±0.67b	91.67a	0.67±0.67b	91.67a	0.67±0.67b	91.67a	6.00±3.46a	56.40a
Rumex dentatus L.	20.67±5.21a	4.00±2.00b	80.65a	0.00±0.00b	100.0a	2.00±2.00b	90.32a	2.00±1.15b	90.32a	0.67±0.67b	98.15a
Total broadleaved	126.00±10.58a	4.67±1.76b	96.30a	6.00±2.31b	95.24a	4.67±1.33b	96.30a	4.67±0.67b	96.30a	18.00±7.02b	84.92b
Weed species	Fresh weight[b] (g m^{-2})	Fresh weight (g m^{-2})	Control (%)	Fresh weight (g m^{-2})	Control (%)	Fresh weight (g m^{-2})	Control (%)	Fresh weight (g m^{-2})	Control (%)	Fresh weight (g m^{-2})	Control (%)
Ammi majus L.	219.58±101.96a	0.00±0.00b	100a	2.12±2.12b	99.03a	0.00±0.00b	100a	5.73±5.73b	97.39a	0.00±0.00b	100a
Beta vulgaris L.	1693.26±662.67a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a	0.00±0.00b	100a
Chenopodium album L.	434.31±245.31a	0.00±0.00b	100a	3.55±2.78b	99.18a	6.51±6.51b	98.50a	0.00±0.00b	100a	14.41±4.19ab	78.99a
Coronopus niloticus Spreng	104.49±53.25a	4.35±4.35b	95.84a	0.51±0.51b	99.52a	5.28±5.28b	94.95a	5.06±5.06b	95.16a	3.57±1.94a	76.58a
Rumex dentatus L.	2323.33±127.22a	35.19±19.09b	98.49a	0.00±0.00b	100.0a	4.40±4.40b	99.81a	30.18±28.21b	98.70a	5.05±5.05b	96.15a
Total broadleaved	4774.97±935.75a	39.54±15.87b	99.17a	6.17±2.35b	99.87a	16.19±1.84b	99.66a	40.97±22.80b	99.14a	23.03±5.80b	98.40a

a) Weed density and b) weed fresh weight (FW) data were subjected to square-root transformation $\sqrt{(x+0.5)}$ before analysis and original values of weed emergence are shown in parenthesis. * Means within each row (separated for each weed) with the same letters indicate no significant different according to LSD test ($p < 0.05$). CARF = carfentrazone, CARF+DICA = carfentrazone + dicamba, CARF+FENO = carfentrazone + fenoxaprop, CARF+FENO+TRAL = carfentrazone + fenoxaprop + tralkoxydim, CARF+TRIB = carfentrazone + tribenuron.

Wheat Visual Injury:

All post-emergence herbicide treatments resulted in minimal (less than 1%) visible injury in the leaves of wheat plants in the first week after treatment, but no injury symptoms were noted on wheat plants in the control plots. The injury symptoms appeared as chlorosis speckles on the wheat's blade. However, these injury symptoms in wheat leaves were not affected by leave emergence and these symptoms reduced gradually with time and disappeared completely after 30 DAHT. This mentioned injury did not adversely affect wheat grain yields. Unfortunately, CARF+DICA provoked additional injury symptoms in wheat plants at boot and head growth stages such as rolled or twisted flag leaf in treated plants that due to abnormal emergence in the head and induced clear distortion in spike and spikelet form and consequently, the herbicide caused a significant reduction in wheat grain yield (Fig. 1**).**

Fig.1: Adverse effect of carfentrazone + dicamba herbicide on spike shape of wheat cultivar 'Sids 14'. A= control, B to H= carfentrazone + dicamba.

Wheat Crops:

Concerning the effect of herbicide treatments on wheat yield parameters such as the biological yield, grain yield, and grain harvest index; the data is presented in Table 4 and Figure 1. The yield of winter wheat differed significantly among the herbicide treatments. All herbicide treatments except CARF+DICA provided a significant increment in the mentioned wheat yield parameters compared to the control in both years. Indeed, the aforenamed wheat yield parameters varied between years, where higher yield parameters were obtained in the second year than those in the first year. In 2019-2020, the application of CARF+FENO+TRAL and CARF+FENO followed by CARF resulted in the highest biological yield (14.79, 14.73 and 13.68 t ha^{-1}), grain yield (6.88, 6.15, and 5.38 t ha^{-1}) and grain harvest index (46.52, 41.64, and 39.42 t ha^{-1}) without significant differences among them (Table 4). Thus, the treatments of CARF+FENO+TRAL, CARF+FENO and CARF increased the biological yield by 25.90, 25.36, and 16.45%, grain yield by 141.40, 115.79, and 88.7% and grain harvest index by 87.89, 68.16, and 59.19% compared with the control, respectively (Table 4).

In 2020-2021, similar trends were also recorded with a minor change where CARF+FENO and CARF+FENO+TRAL followed by CARF+TRIB provided the greatest biological yield (19.62, 18.92, and 16.63 t ha^{-1}), grain yield (8.43, 8.13, and 7.56 t ha^{-1}), and grain harvest index (43.22, 43.21 and 45.46 t ha^{-1}) with similar statistics, respectively (Table

4). Also, these former herbicides caused increments in the biological yield by 32.65, 27.93, and 27.07%, grain yield by 63.34, 57.50, and 46.43% and grain harvest index by 23.55, 23.52, and 29.96%, respectively versus the control (Table 4).

Table 4. Biological yield (ton ha^{-1}), grain yield (ton ha^{-1}), and harvest index (%) of wheat as affected by carfentazone -based herbicide treatments in 2019–2020 and 2020–2021.

Treatments	Biological yield (ton ha^{-1})	Control (%)	Grain yield (ton ha^{-1})	Control (%)	Harvest Index (%)	Control (%)
2019–2020						
CARF	13.68±0.57a	16.45±4.87a	5.38±0.37a	88.92±12.83a	39.42±2.57a	59.19±10.37a
CARF + DICA	8.48±0.49c	-27.86±4.21c	1.50±0.23b	-47.54±7.91b	17.45±1.65b	-29.53±6.66b
CARF + FENO	14.73±0.44a	25.36±3.78a	6.15±0.52a	115.87±18.08a	41.64±2.18a	68.16±8.81a
CARF + FENO + TRAL	14.79±0.83a	25.90±7.02a	6.88±0.61a	141.27±21.44a	46.52±3.57a	87.89±14.42a
Control	11.75±0.52b	–	2.85±0.72b	–	24.76±6.72b	–
LSD (0.05)	1.85	15.73	1.63	57.14	11.95	48.29
2020–2021						
CARF	18.79±1.17ab	27.07±7.88ab	6.98±0.47b	35.35±9.06b	37.16±0.53abc	6.54±1.53abc
CARF+DICA	13.46±0.34d	-8.99±2.27d	4.32±0.06c	-16.33±1.11c	32.08±1.03c	-7.88±2.95c
CARF + FENO	19.62±0.77a	32.65±5.21a	8.43±0.83a	63.34±16.17a	42.96±5.14ab	23.94±14.70ab
CARF + FENO + TRAL	18.92±0.77a	27.93±5.22a	8.13±0.27ab	57.50±5.23ab	42.95±3.20ab	23.91±9.17ab
CARF + TRIB	16.63±0.32bc	12.47±2.15bc	7.56±0.20ab	46.43±3.78ab	45.42±1.57a	30.37±4.49a
Control	14.79±0.61cd	–	5.16±0.30c	–	34.87±2.44bc	–
LSD (0.05)	2.23	15.04	1.33	25.76	8.57	24.50

* Means within each column with the same letters indicate no significant different according to LSD test ($p < 0.05$). CARF = carfentrazone, CARF+DICA = carfentrazone + dicamba, CARF+FENO = carfentrazone + fenoxaprop, CARF+FENO+TRAL = carfentrazone + fenoxaprop + tralkoxydim, CARF+TRIB = carfentrazone + tribenuron. Harvest Index (%) = (grain yield /biological yield)*100.

CARF also increased the biological yield, grain yield and grain harvest index by 18.79, 6.98, and 37.15 t ha^{-1} with 12.47%, 35.35, and 6.20 % increase over that in the control, respectively in 2020-2021 (Table 4). In contrast, the lower wheat yield parameters (biological yield, grain yield, and grain harvest index) were from the control (11.75, 2.85, and 24.76 t ha^{-1} in 2019-2020; 14.79, 5.16, and 34.98 t ha^{-1} in 2020-2021), but the lowest yield parameters were from CARF+DICA (8.48, 1.50, and 17.45 t ha^{-1} in 2019-2020; 13.46, 4.32, and 32.12 t ha^{-1} in 2020-2021), without significant differences between them in both years (Table 4). CARF+DICA caused great injury to flag leaf of wheat plants, spike and spikelet form and consequently, reduced the biological yield by 27.83 and 8.99%, grain yield by 47.37 and 16.28% and grain harvest index by 29.52 and 8.18%, during 2019-2020 and 2020-2021, respectively compared to the control (Table 4).

DISCUSSION

Weeds are the most widespread and noxious pests in wheat production regions worldwide that provoked a significant loss in wheat grain yield through their severe competition with wheat plants for the main growth resources including water, soil nutrition, space, and sunlight (El-Kholy *et al.*, 2013; Mohamed, 2017). The wheat experimental fields in both years were infested with different annual broad-leaved weeds and *Beta vulgaris* L., *Chenopodium album* L., *Rumex dentatus* L. and *Cichorium pumilum* Jacq were more dominant weed species. The highest broad-leaved weed populations and fresh biomass were presented in the control plots in both years. In previous studies *C. album*, *B. vulgaris*, *R. dentatus*, and *Melilotus indica* (L.) All., and *Malva parviflora* L. were among the dominant and the most competitive annual broadleaf weeds and were found in wheat cultivations worldwide including Egypt (Singh *et al.*, 2011; Mohamed, 2017; Safina and Absy, 2017).

The maximum population or biomass of dicotyledon weeds was also found in the weedy control in winter wheat (Khalil *et al.,* 2013; Mohamed, 2017; Safina and Absy, 2017).

Farmers control annual and perennial weeds in common wheat mainly by application of many post-emergence herbicides, alone or in combinations. In this study, all post-emergence herbicides including CARF, CARF+DICA, CARF+FENO, CARF+FENO+TRAL, and CARF+TRIB treatments provided excellent efficacy on total broadleaf weeds grown in wheat in both years. The tested post-emergence herbicides significantly decreased the total broadleaf weed density and fresh biomass by 95.24 to 96.30% and 99.14 to 99.87% in 2019-2020 and by 84.92 to 96.65% and 98.20 to 99.68%, in 2020-2021, respectively and with similar statistics among the herbicides. Carfentrazone plus tribenuron achieved high efficiency against winter broad-leaved weeds in common wheat and reduced weed density by 82% and fresh weed biomass by 94% (Safina and Absy, 2017). Carfentrazone reduced the population and the dry biomass of total broadleaved weeds by 77.30% and 89.85%, respectively after 120 DAHT (Singh *et al.,* 2011).

The efficacy of carfentrazone on some broad-leaf weeds is unsatisfactory when treated alone, but a combination with herbicides such as metsulfuron and tribenuron would be ideal for an improved spectrum of target weed control (Singh *et al.,* 2008). In the present study, CARF alone or in combination with other herbicides as premix formulations achieved varied potency against individual annual broadleaf weeds in a wheat field in both years and this variable herbicidal potency may be ascribed to the variable susceptibility of these broadleaf species to the tested herbicides, their active ingredient(s) and their formulations. This suggestion is consistent with the previous studies of Singh et al. (2008); El-kholy et al. (2013); Mohamed (2017). Carfentrazone-ethyl at 20 g ha^{-1} exhibited lower efficiency on *C. album*, but it exposed more efficiency on *C. arvensis* and *R. dentatus* (Singh et al. 2008). Also, Punia et al. (2006) stated that carfentrazone-ethyl was very effective against *R. dentatus, M. parviflora,* and *C. arvensis,* but it was less effective against *M. indica* and *C. album* compared to other post-emergence broadleaf herbicides. Carfentrazone exhibited poor efficacy against *Medicago denticulate, Euphorbia geniculata* and *Cichorium intybus* (Yadav and Dixit, 2014).

All herbicides exhibited slight phytotoxic injury symptoms on wheat leaves in the first week after treatment which was observed as chlorosis scattered spots in wheat blades but the injury decreased rapidly and disappeared after 30 DAHT and this slight injury did not affect final grain yield. No crop damage was noted in the control. Similarly, some speckles on the leaves of wheat were observed after the application of carfentrazone-ethyl and they disappeared after three weeks without any yield loss (Howatt, 2005; Singh *et al.,* 2008; Singh *et al.,* 2011). Application of carfentrazone alone or tank mixed with clodinafop or fenoxaprop caused lower injury to wheat than when carfentrazone was tank mixed with tralkoxydim (Singh *et al.,* 2008). CARF, CARF+FENO, CARF+FENO+TRAL, and CARF+TRIB treatments resulted in significantly higher biological yield and grain yield than the control and CARF+DICA. These increments in grain yield are possible because of the high effectiveness of these herbicides on weeds and lower weed competition with wheat plants. Among applied herbicide treatments CARF+FENO and CARF+FENO+TRAL produced high grain yields in both years and followed by CARF+TRIB (in 2020-2021) and CARF (in 2019-2020) compared to the control and CARF+DICA.

In the same manner, Safina and Absy (2017) found that the grain yield of wheat was increased by the application of carfentrazone plus tribenuron by 37.1%. Carfentrazone alone at 20 g ha^{-1} and premix of carfentrazone plus metsulfuron at 25 g ha^{-1} plus 0.2% non-ionic surfactant also increased the wheat biological yield by 31% and 37.9% and grain yield by 31.6% and 45.4%, respectively (Singh *et al.,* 2011). In contrast, CARF+DICA produced additional great injury symptoms on wheat plants at boot and heading stages such as clear wrapping up and distortion in the flag leaf and disfigurement in spike and spikelet form which caused a significant reduction in grain yield by 47.37 and 16.28%, and biological yield by 38.56 and 8.99%, compared to the control in the first and second year, respectively. The adverse effects of CARF+DICA on wheat cultivar Sids 14 might be due to the phytotoxic effects of dicamba. This is in agreement with Mohamed (2017), who found that application of Banvel 4S® (dicamba) herbicide on wheat cultivar Sids 12 caused visible injury in flag leaf and variable deformity in spike and spikelet and reduced grain yield than other tested herbicides but was not than the control. Application of dicamba alone or in combination with 2,4-D or MCPA+mercoprop on wheat and barley also caused phytotoxic injury symptoms on spike and spikelet of both crops (Friesen *et al.,* 1964; Schroeder and Banks, 1989).

It has been found that wheat varieties differ in their response to herbicides including dicamba (Sikkema *et al.,* 2007; Rinella *et al.,* 2001). In the USA, Coker 916 and Stacy wheat cultivars, which were treated with dicamba at 0.14 kg/ha at the full tiller stage showed a reduction in their grain yields by 3.07% and 12.92%, compared to their respective control but the same treatment increased the grain yield of the cultivar Coker 983 by 3.77% than the control (Schroeder and Banks, 1989). The herbicide dicamba+MCPA+mercoprop resulted in great injury to some soft winter wheat varieties (i.e., the soft red wheat and the soft white wheat) and decreased their grain yield but the hard red wheat variety was not affected by the herbicide and also their grain yield (Sikkema *et al.,* 2007). In this study, the winter wheat cultivar 'Sids 14' seems to be more susceptible to CARF+DICA as it reduced the grain yield of this wheat cultivar than the control without significant differences between them. Indeed, the winter wheat cultivar 'Sids 14' is more susceptible to dicamba herbicide than the winter wheat cultivars Gemeza-11 and Sids 12 (Mohamed, 2017; Safina and Absy, 2017). The adverse effects of dicamba on wheat and barley might be caused by the disruptive effects of dicamba on mitosis in plants of both crops (Friesen *et al.,* 1964).

In the control plots, increasing broad-leaf weed density, especially in the first years resulted in a significant reduction in wheat productivity as these weeds interfere with major growth elements in wheat plants and thereby decrease wheat growth and yield components mainly the grain yield. Similar results were reported by El-Metwally et al. (1999), Mohamed (2017), Safina and Absy (2017), who confirmed that competition between broad-leaf weeds and wheat could reduce crop growth and result in decreased yield.

Conclusion

In conclusion, carfentrazone alone or in combination with fenoxaprop, fenoxaprop plus tralkoxydim, dicamba, and tribenuron (as premix formulation) treatments were highly effective against common serious broad-leaved weeds in winter wheat fields in the study periods. Premixes of carfentrazone + fenoxaprop, and carfentrazone + fenoxaprop + tralkoxydim caused the highest improvement in the wheat grain yield followed by carfentrazone + tribenuron then carfentrazone alone compared to the control. Premix of carfentrazone + dicamba should not be sprayed for controlling broad-leaf weeds in the wheat cultivar 'Sids 14' under Assiut condition as it elicited severe injury to the flag leaves of wheat plants and performed alteration in spike and spikelet form that resulted in a significant reduction in grain yield. More field studies are needed to investigate the response of other common and durum wheat cultivars to carfentrazone + dicamba premix in Egypt.

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