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The effect of cationic and nonionic surfactants on the efficacy of ALS-inhibitor herbicides against *Avena sterilis*

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Abstract

A major challenge is selection of a suitable surfactant for a given herbicide. A series of dose-response experiments were conducted during 2013 at Ferdowsi University of Mashhad, Iran under greenhouse and outdoor conditions to determine whether the efficacy of four acetolactate synthase (ALS)-inhibitor herbicides on *Avena sterilis* could be improved by adding two surfactants at two concentrations. Both surfactants were effective at lowering the surface tension of all herbicide solutions with the nonionic surfactant being more effective than the cationic one. According to effective dose (ED)-values, the ranking of the ALS-inhibitor herbicides to control *A. sterilis* was: sulfosulfuron > mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr > mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl > metsulfuron-methyl + sulfosulfuron. The EDs of all herbicides decreased when applied with surfactants. Cationic surfactant had a greater ability to enhance the efficacy of the tested herbicides than nonionic surfactant.

Key words: dose-response, herbicide efficacy, sulfonylurea herbicides.

Introduction

The genus of *Avena* contains several species often infesting small grain cereal crops all over the world. An economic threshold of 5.23 plants m^{-2} for *Avena* spp. was estimated in wheat populations (Gerkhloo et al., 2007). The *Avena sterilis* spp. *ludoviciana* Durieu. (syn: *A. persica* Steud.) has infested excessively many wheat and barley agro-ecosystems. Yield of wheat (*Triticum aestivum* L.) was reduced up to 18% and 44% at the density of 20 and 61 *A. sterilis* m^{-2}, respectively (Montazeri, 2007; Hesammi, 2011). *A. sterilis* is a serious annual weed reproducing by seeds which belongs to the family *Poaceae* native to Europe and Asia. It can produce 3–5 tillers and has leaf blade twisted counter clockwise. Seeds usually ripen earlier than small grain cereal crops and drop to the ground before time to harvest cultivated crops (Dickinson, Royer, 2014).

During the past two decades, clodinafop-propargyl, diclofop-methyl and fenoxaprop-P-ethyl, all belonging to the acetyl coenzyme A carboxylase (ACCase) inhibitor herbicide group were authorized to control *A. sterilis* in wheat and barley agro-ecosystems (Chhokar et al., 2012). These graminicides were widely used due to their high effectiveness (Zand et al., 2007). During 1995–2005, clodinafop-propargyl, fenoxaprop-P-ethyl and diclofop-methyl were applied in Iran up to 3653, 2379 and 2339 tons, respectively (Deihimfard et al., 2007). Due to a continuous high selection pressure, herbicide resistance to ACCase inhibitors developed in *A. sterilis* populations (Kashani et al., 2007). Accordingly, these observations proved the necessity of replacement of ACCase-inhibiting herbicides with other herbicide modes of action. The sulfonylurea herbicides were assessed (Zand et al., 2010) as good alternatives for this purpose due to their ability to control a broad spectrum of monocot and dicot weeds, combined with their low application rate and good environmental profile (Green, 2007). Therefore, during 2006–2010, four acetolactate synthase (ALS) inhibitors including the herbicides of sulfosulfuron (1), mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr (2), mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl (3) and metsulfuron-methyl + sulfosulfuron (4) were authorized for selective control of *A. sterilis*.

The efficacy of herbicides can be enhanced using surfactants (Knezevic et al., 2009; Loken, Hatterman-Valenti, 2013; Gitsopoulos et al., 2014). Enhancement of herbicidal activity by surfactants may be related to improving the dose transfer process (absorption) of active ingredient on weed leaves (McCullough, Hart, 2009). In this process, surface tension of the droplet is a key factor to be retained and spread on leaves (Stagnari et al., 2007). The surfactants reduce the surface tension of spray solution, leading to both the production of smaller droplets in the atomization process and the promotion of adhesion between spray droplets with leaf surface. Although enhancement of herbicidal activity can allow for reducing herbicide dose (Kudsk, 2008), it is the major cause for herbicide failures/weed escapes and enhanced selection pressure for resistance development (Green, 2007). One of the risks of many ALS-inhibiting herbicides is their long-term soil residual activity, resulting in a long selection pressure towards herbicide resistance (Rao, 2015).

Although the performance of foliar applied herbicides is greatly affected by surfactants, not all surfactants have a synergistic effect with herbicides (Kammler et al., 2010). Rashed-Mohassel et al. (2010) evidenced that various surfactants carry out different functions to various herbicides on different weed species. Besides, each surfactant is not able to increase absorption of all kinds of herbicides. The objectives of the present study were to determine the effect of nonionic and cationic surfactants on the activity of four ALS-inhibiting herbicides and the possibility of reducing the dose in order to achieve the goals mentioned above including identifying a proper indicator to select a suitable surfactant.

Materials and methods

Dose-response study. A pot experiment was repeated twice during 2013 at Ferdowsi University of Mashhad, Iran; once in greenhouse conditions and once in outdoor conditions (the pots were taken out). Seeds of *Avena sterilis* were collected from farm fields of Mashhad Agricultural and Natural Resources Research Center, Iran (36°15″ N, 59°28″ E, 985 m a.s.l.). To break dormancy, seeds were de-hulled and placed in 11 cm diameter Petri dishes on the surface of a single layer of Whatman No. 1 filter paper. Then, 10 ml of 0.2% KNO_3 solution were added to each Petri dish and the seeds were incubated for 48 h at 4–5°C in the dark (Rashed-Mohassel et al., 2011). Seeds were sown in potting trays (3 × 3 × 5 cm) filled with moistened peat. One week after sowing, when the seedlings had one leaf, they were transplanted into 2 L black plastic pots (14 cm diameter top, 9 cm diameter base and 16 cm depth) filled with a mixture of sand, clay loam soil, and peat (1:1:1 v:v:v). The plants were sub-watered as required, thinned from ten to five per pot at the two-leaf stage and fertilized once with 40 ml of a water-soluble N:P:K (20:20:20) fertilizer at a concentration of 3 g L^{-1} drinking water.

Four formulations of herbicides at six concentrations were used against *A. sterilis*. The concentrations of each herbicide tested are indicated in the first column of Tables 1 and 2. These doses consisted of 0, 12.5, 25, 50, 75 and 100 % of the recommended dose, respectively. Each of these doses was applied alone or with the surfactants of nonionic and cationic surfactants at two concentrations. There were four replications of each treatment. The drinking water was used as spray carrier with an acceptable quality level of Na^+ = 113.4 mg L^{-1}, Ca^{+2} = 27.9 mg L^{-1}, Mg^{+2} = 8.3 mg L^{-1}, HCO_3^- = 199.3 mg L^{-1}, SO_4^- = 188.0 mg L^{-1}, electrical conductivity = 1012 µmho cm^{-1} and pH = 7.6. The drinking water used in this study had hardness ~70 mg L^{-1} of $CaCO_3$. According to McDougall (2012), water with this quality can be classified into the class of moderately soft (50–75; hardness expressed as mg L^{-1} of $CaCO_3$). The spray treatments were applied at the four-leaf stage using a calibrated moving boom sprayer Matabi 121030 Super Agro 20 L (Agratech Services, UK), equipped with an 8002 flat fan nozzle tip delivering 200 L ha^{-1} at a pressure of 200 kPa. The spray conditions in the greenhouse were a simulation of the spray conditions in the field. Therefore, here the mentioned nozzle was applied. Four weeks after spraying, aboveground biomass from each pot was collected and weighed after oven-drying at 75°C for 48 h.

Dry weight data were subjected to a non-linear regression analysis using the following logarithmic logistic dose-response model described by Kudsk and Mathiassen (2007):

$$Y = C + \{D - C / 1 + \exp\,[B(\log X - \log ED)]\} \quad (1),$$

where *Y* is the response (e.g., dry weight), *C* – the lower limit, *D* – the upper limit, *B* – the slope of the curve, *X* – the herbicide dose and effective dose (ED) – the required dose of herbicide to give a reduction of 50% (ED_{50}) or 90% (ED_{90}) between the upper and lower limits. The upper limit (D) corresponds to the response of the untreated control. All data were checked for normality through tests of the Shapiro-Wilk statistic. The non-linear regression analysis of dose-response curves were determined utilizing the R software and were performed separately for each herbicide.

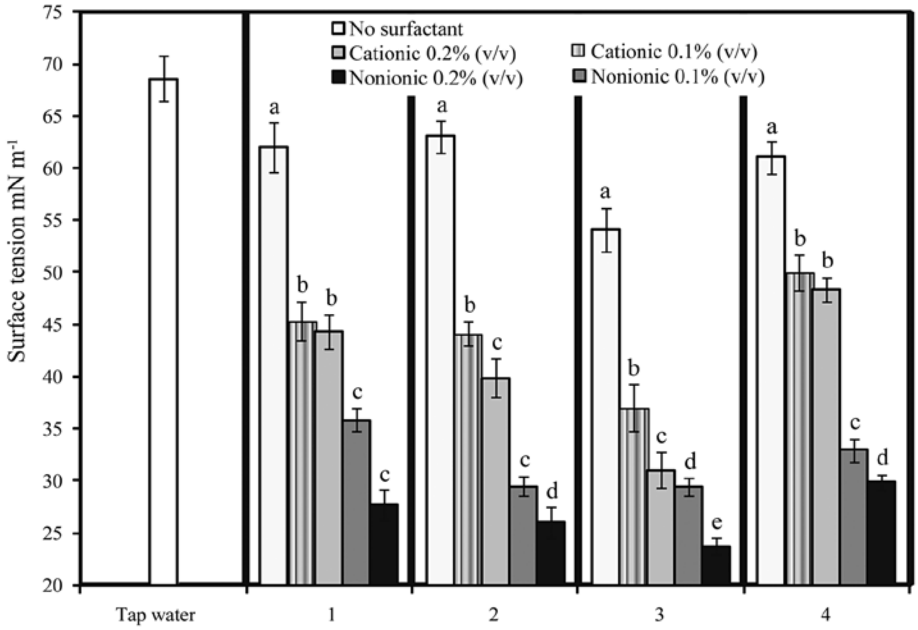
Static surface tension study. A capillary rise technique was used to measure the static surface tension of aqueous solutions (Vanhanen et al., 2008), using the following equation:

$$\gamma = 0.5\rho g r(h + (r/3)) \quad (2),$$

where γ is the surface tension (Nm^{-1}) which was converted to mNm^{-1} for analysis, ρ is the density of liquid (kg m^{-3}), *g* – the acceleration due to gravity which is 9.8 ms^{-2}, *r* – the inner radius of the glass capillary tube (m) which was 0.5 mm, and *h* – the capillary rise (m). The static surface tension of aqueous solution of cationic and nonionic surfactant alone was measured as reported by Aliverdi et al. (2009). The herbicides Nos. 1, 2, 3 and 4 (Tables 1 and 2) were prepared at concentrations corresponding to the maximum doses applied (a.i. 20, 24, 30 and 45 g) in 200 L drinking water ha^{-1}, respectively. Frigate® (ISK Biosciences Corp., England) as a cationic surfactant (81.2% polyoxyethylene tallow amines), and Citogate® (ZarNegaranPars, Iran) as a non-ionic surfactant – 100% alkylarylpolyglycol ether were applied. For each herbicide, a trial was conducted as a completely randomized design with three replications for each treatment. The treatments included each herbicide at concentrations corresponding to the maximum doses (as controls) with and without each of the nonionic and cationic surfactants at 0.1% and 0.2% (v/v). Each solution was prepared twice and three measurements were conducted on each solution. The results were combined into one analysis as similar results were detected in both trials. Data (except those of drinking water) were subjected to an *ANOVA* and treatment means were separated using Tukey's test at the 0.05 probability level.

Results

Static surface tension. The drinking water surface tension was recorded 68.61 mN m^{-1}. All formulations of herbicides significantly decreased surface tension of drinking water (Fig. 1). The surface tension of drinking water was reduced up to 9.58, 8.11, 21.23 and 11.03 % by adding the herbicides Nos. 1, 2, 3 and 4, respectively. Both surfactants were effective at lowering the surface tension of all spray solutions; however, nonionic surfactant was more effective than cationic surfactant (Fig. 1). In the case of herbicides Nos. 1 and 4, the surface tension spray solution was significantly decreased with increasing concentration of nonionic surfactant; but, it was insignificantly decreased with increasing concentration of cationic one. In the case of herbicides Nos. 2 and 3, the static surface tension of other spray solution was significantly decreased with increasing concentration of both surfactants.



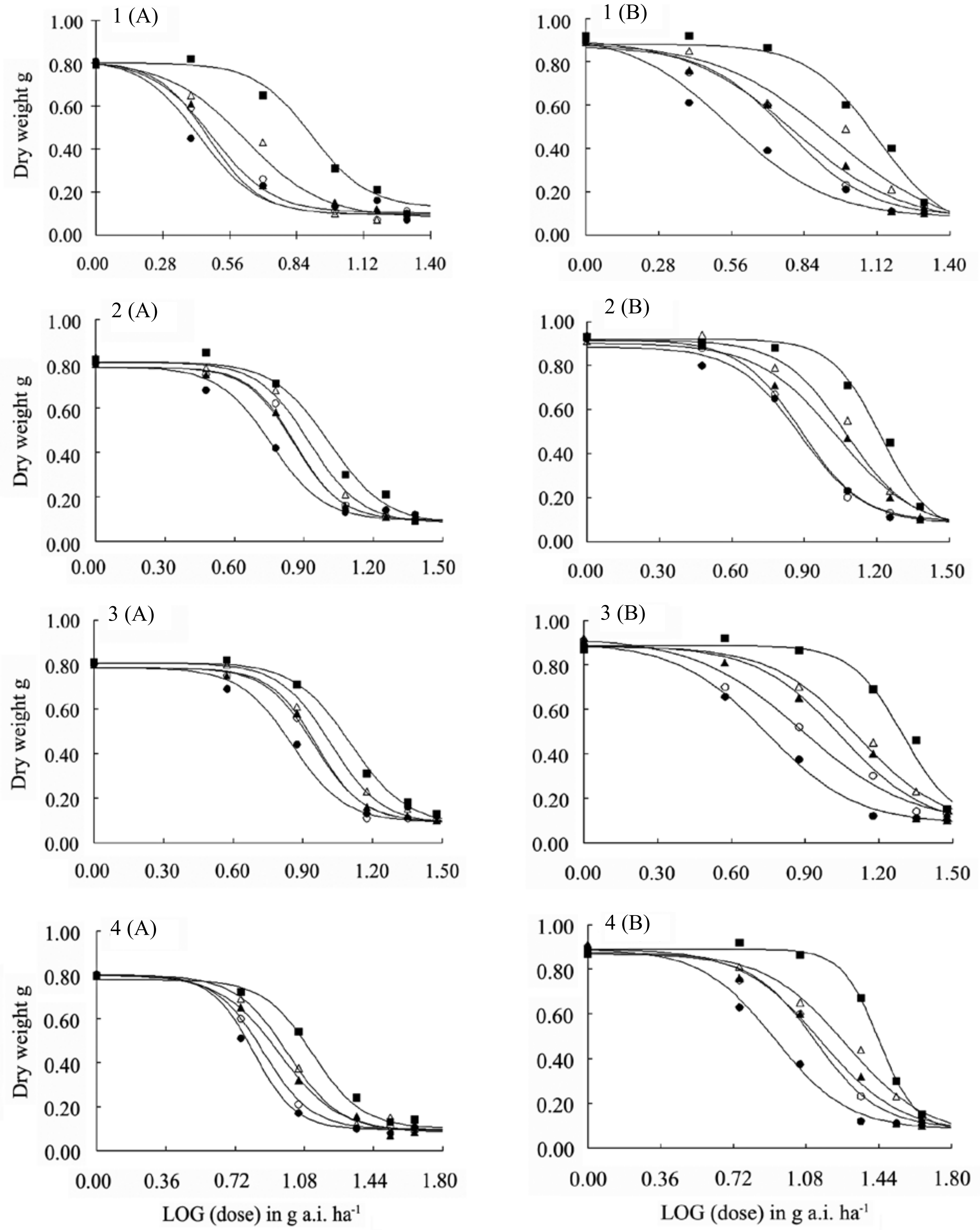
Notes. The vertical lines on the bars show the standard errors. Within each herbicide trial, the surface tension of solutions classes differ ($P \leq 0.05$) when followed by a unique letter according to *ANOVA*-Tukey test. 1 – sulfosulfuron, 2 – mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr, 3 – mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl, 4 – metsulfuron-methyl + sulfosulfuron.

Figure 1. Effect of cationic and nonionic surfactants on surface tension of acetolactate synthase (ALS)-inhibitor herbicides

Dose-response experiments. The dose response curves for herbicides Nos. 1, 2, 3 and 4 in greenhouse experiment indicated an ED_{50} of 8.94, 11.24, 12.81 and 13.13 g ha^{-1} a.i., respectively. In outdoor experiment, ED_{50} parameter values were higher –13.11, 17.31, 20.39 and 27.86 g ha^{-1} a.i., respectively (Tables 1 and 2). These findings suggest two points; firstly, in equivalent doses herbicide No. 4 was less effective than the other herbicides. The ranking of the performance on *A. sterilis* of the applied herbicides was 1 > 2 > 3 > 4. This result was also confirmed by the ED_{90} parameters. In outdoor experiment, the estimated ED_{90} value for herbicide No. 3 was higher than the maximum applied dose.

Dose-response curves showed that both surfactants enhanced the activity of all tested herbicides (Fig. 2). Because the dose-response curves of original herbicide formulations were shifted to the left by adding of the surfactants. This consequence depends on the concentration of surfactants. When the surfactants were added to the tested herbicides, the values of ED_{50} and ED_{90} parameters decreased (Tables 1 and 2). Apart from the above mentioned result, increased effectiveness of the tested herbicides depended upon the concentration of both cationic and nonionic surfactants.

In the case of nonionic surfactant, the ED_{50} values of four herbicides decreased with increasing surfactant concentration both in greenhouse and outdoor pot experiments. Although in the case of cationic surfactant behaviour, some differences between the results of greenhouse and outdoor experiments were observed, there are no justifying explanations for such differences. In greenhouse experiments, there was a significant difference between the applied concentrations



1 – sulfosulfuron, 2 – mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr, 3 – mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl, or 4 – metsulfuron-methyl + sulfosulfuron alone (■) and in mixture with cationic surfactant at concentrations of 0.1% (○) or 0.2% (●) or nonionic surfactant at concentrations of 0.1% (Δ) or 0.2% (▲) on the shoot dry weight of *Avena sterilis*; experiments in greenhouse (A) and outdoor conditions (B); LOG – logarithm

Figure 2. Dose-response curves of cationic and nonionic surfactants of acetolactate synthase (ALS)-inhibitor herbicides

of cationic surfactant in enhancing the effectiveness of herbicides Nos. 2 and 3 against *A. sterilis*. In contrast, such influence on herbicide No. 1 was not observed (Table 1). In outdoor experiments, the efficacy of herbicide No. 2 was not improved by increasing the concentration of cationic surfactant (Table 2). Generally, increasing the concentration of nonionic surfactant had more effect on the efficacy of the tested herbicide formulations than increasing the concentration of cationic surfactant (Tables 1 and 2).

Table 1. Effect of surfactants and their concentrations on effective doses ED_{50} and ED_{90} of four herbicides on *Avena sterilis* in greenhouse conditions

No.	Herbicide (formulation name) concentrations tested	Surfactant	Concentration % v/v	ED_{50} g ha^{-1} a.i.	ED_{90} g ha^{-1} a.i.	*R*
1.	Sulfosulfuron (Apyrous® WG 75%) 0, 2.5, 5, 10, 15 and 20 g h^{-1} a.i.	none	–	8.94 (0.71)	13.81 (0.38)	1.00
		nonionic	0.1	4.60 (0.52)	8.66 (0.41)	1.94 (0.18)
			0.2	3.17 (0.44)	6.52 (0.33)	2.81 (0.08)
		cationic	0.1	2.98 (0.43)	5.09 (0.19)	3.00 (0.22)
			0.2	2.74 (0.55)	4.99 (0.12)	3.25 (0.41)
2.	Mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr (Chevalier® WG 3% + 3%) 0, 3, 6, 12, 18 and 24 g h^{-1} a.i.	none	–	11.24 (0.82)	18.31 (0.11)	1.00
		nonionic	0.1	8.32 (0.45)	13.94 (0.09)	1.35 (0.21)
			0.2	7.17 (0.44)	11.75 (0.14)	1.56 (0.20)
		cationic	0.1	7.09 (0.37)	11.76 (0.08)	1.58 (0.25)
			0.2	5.63 (0.51)	9.85 (0.23)	1.99 (0.11)
3.	Mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl (Atlantis® OD 1% + 0.2%) 0, 3.75, 7.5, 15, 22.5 and 30 g h^{-1} a.i.	none	–	12.81 (1.01)	22.88 (0.18)	1.00
		nonionic	0.1	10.41 (0.55)	17.42 (0.22)	1.23 (0.06)
			0.2	9.06 (0.32)	14.69 (0.31)	1.41 (0.08)
		cationic	0.1	8.75 (0.35)	14.71 (0.23)	1.46 (0.29)
			0.2	5.04 (0.48)	12.32 (0.12)	2.54 (0.15)
4.	Metsulfuron-methyl + sulfosulfuron (Total® WG 5% + 75%) 0, 5.625, 11.25, 22.5, 33.75 and 45 g h^{-1} a.i.	none	–	13.13 (0.91)	25.56 (0.41)	1.00
		nonionic	0.1	9.71 (0.54)	18.57 (0.13)	1.35 (0.09)
			0.2	7.01 (0.26)	19.96 (0.23)	1.87 (0.11)
		cationic	0.1	6.34 (0.72)	13.67 (0.12)	2.07 (0.23)
			0.2	5.57 (0.56)	11.65 (0.11)	2.35 (0.05)

Notes. Data are expressed as the means. Standard errors are in parentheses. *R* is the relative potency at ED_{50}, indicates the ratio of the doses of herbicide without surfactant (*R* = 1.00) and with surfactant giving the same effect, *R* = ED_{50} without surfactant / ED_{50} with surfactant, showing horizontal displacement between curves.

Table 2. Effect of surfactants and their concentrations on effective doses ED_{50} and ED_{90} of four herbicides on *Avena sterilis* in outdoor conditions

No.	Herbicide (formulation name) concentrations tested	Surfactant	Concentration % v/v	ED_{50} g ha^{-1} a.i.	ED_{90} g ha^{-1} a.i.	*R*
1.	Sulfosulfuron (Apyrous® WG 75%) 0, 2.5, 5, 10, 15 and 20 g h^{-1} a.i.	none	–	13.11 (0.82)	21.16 (0.51)	1.00
		nonionic	0.1	7.81 (0.73)	17.68 (0.46)	1.67 (0.14)
			0.2	5.90 (0.55)	13.99 (0.43)	2.22 (0.27)
		cationic	0.1	5.66 (0.16)	11.89 (0.49)	2.31 (0.04)
			0.2	3.65 (0.55)	8.69 (0.35)	3.59 (0.22)
2.	Mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr (Chevalier® WG 3% + 3%) 0, 3, 6, 12, 18 and 24 g h^{-1} a.i.	none	–	17.30 (1.02)	24.01 (0.37)	1.00
		nonionic	0.1	12.35 (0.56)	20.69 (0.11)	1.40 (0.23)
			0.2	10.07 (0.88)	20.70 (0.10)	1.71 (0.07)
		cationic	0.1	7.61 (0.41)	14.12 (0.26)	2.27 (0.10)
			0.2	7.34 (0.55)	17.68 (0.08)	2.36 (0.18)
3.	Mesosulfuron-methyl + iodosulfuron-methyl-sodium with safener mefenpyr-diethyl (Atlantis® OD 1% + 0.2%) 0, 3.75, 7.5, 15, 22.5 and 30 g h^{-1} a.i.	none	–	20.39 (0.30)	>30	1.00
		nonionic	0.1	12.17 (0.77)	27.13 (0.22)	1.67 (0.23)
			0.2	10.46 (0.48)	22.55 (0.17)	1.94 (0.12)
		cationic	0.1	7.58 (0.51)	20.38 (0.13)	2.68 (0.14)
			0.2	5.51 (0.23)	12.93 (0.21)	3.70 (0.19)
4.	Metsulfuron-methyl + sulfosulfuron (Total® WG 5% + 75%) 0, 5.625, 11.25, 22.5, 33.75 and 45 g h^{-1} a.i.	none	–	27.86 (0.90)	43.57 (0.42)	1.00
		nonionic	0.1	17.48 (0.23)	40.17 (0.33)	1.59 (0.17)
			0.2	13.27 (0.95)	31.39 (0.35)	2.09 (0.15)
		cationic	0.1	12.72 (0.66)	26.77 (0.29)	2.18 (0.18)
			0.2	8.27 (0.87)	19.31 (0.11)	3.36 (0.26)

Notes. Data are expressed as the means. Standard errors are in parentheses. *R* is the relative potency at ED_{50}, indicates the ratio of the doses of herbicide without surfactant (*R* = 1.00) and with surfactant giving the same effect, *R* = ED_{50} without surfactant / ED_{50} with surfactant, showing horizontal displacement between curves.

Compared with nonionic surfactant, cationic surfactant had a greater ability to enhance the activity of all four herbicides tested both in greenhouse and outdoor experiments (Tables 1 and 2). With the exception of herbicides Nos. 2 and 3 in outdoor experiments, cationic surfactant at concentration of 0.1% (v/v) and nonionic surfactant at concentration of 0.2% (v/v) often had similar effect to improve the effectiveness of other herbicides both in greenhouse and outdoor experiments.

Discussion

Difference among the surface tension of herbicides may be related to the difference in their formulations. Aliverdi et al. (2009) observed that emulsifiable concentration formulation of clodinafop-propargyl reduced the surface tension of distilled water more than dry flowable formulation of tribenuron-methy. The performance difference in lowering static surface tension by those two surfactants can be ascribed to their physicochemical properties. The tested nonionic $[C_8H_{16}C_6H_4(C_2H_4O)_{10}H]$ and cationic $[R\text{-}N(C_2H_4O)_7H(C_2H_4O)_8H]$ surfactants have 10 and 15 ethylene oxide units in their chemical structure, respectively. When the non-ionic (Citogate) and cationic (Frigate) surfactants at both concentrations were added, the lowest and the highest values of surface tension to each herbicide solutions were obtained, respectively (Fig. 1). It is well established by experimental evidence that surfactants containing lower ethylene oxide units were more effective than surfactants containing higher ethylene oxide units in decreasing the static surface tension of spray solutions (Shah et al., 2015). When an additional unit of ethylene oxide is affixed to surfactant structure, it decreases the packing density of hydrophobic groups at interface of water-surfactant, resulting in a reduction in surfactant performance to decrease static surface tension (Myers, 2006).

The data obtained in these experiments indicated that the improvement in efficacy of all herbicides does not depend on the potential of surfactants to reduce surface tension. Citogate (non-ionic surfactant) decreased the surface tension more than Frigate did (cationic surfactant), but Frigate improved the efficacy of herbicides more than Citogate did (Fig. 1 and both Tables). For this reason, the surface tension-lowering ability of surfactant cannot be a proper indicator to select the best surfactant. Therefore, other characteristics of surfactant such as hydrophilic-lipophilic balance (HLB) and the characteristics of herbicides such as the logarithm of octanol/water partition coefficient (log K_{ow}) should be considered to select the best surfactant for a specific herbicide. The HLB can be estimated by observing surfactant dispersion scale in water with no dispersion = 1 to complete dispersion = 20 (Rashed-Mohassel et al., 2011). In a static surface tension study, when the nonionic surfactant was added to drinking water, an opaque solution was formed (HLB ~ 8). When the cationic surfactant was added to drinking water, a clear solution was formed (HLB > 13).

On the other hand, the log K_{ow} of the tested herbicides ranges from 0.7 for iodosulfuron-methyl-sodium to −1.74 for mesosulfuron-methyl. Previous research (Rashed-Mohassel et al., 2010) showed that surfactants containing higher ethylene oxide units often work best with herbicides with high water solubility (log $K_{ow} < 1$) and surfactants containing lower ethylene oxide units often work best with herbicides with low water solubility (log $K_{ow} > 1$). Therefore, the results of the present research along with previous researches supported the hypothesis that effectiveness of a lipophilic herbicide is improved by adding a surfactant with lower ethylene oxide content, whereas effectiveness of a hydrophilic herbicide is enhanced by adding a surfactant with higher ethylene oxide content (Shah et al., 2015).

Conclusion

We concluded that the surface tension-lowering ability of surfactant is not always a proper indicator to select a better one, but could be an effective factor. The results confirm the idea that the hydrophilic-lipophilic balance (HLB) value can help to select the type of surfactant that is appropriate for a given herbicide. Thus, high-HLB surfactant will be more suitable for water-soluble herbicides than low-HLB surfactant. As judged by the data obtained, the tested cationic surfactant with a high-HLB value was more effective to enhance the activity of four herbicides tested with a logarithm of octanol/water partition coefficient log $K_{ow} < 1$, although the tested nonionic surfactant with a low-HLB value was more effective at lowering the surface tension of all spray solutions. Therefore, our recommendation for choosing the best surfactant for a given application is to use the HLB system.

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Katijioninių ir nejoninių paviršiaus aktyviųjų medžiagų poveikis ALS inhibitorių herbicidų efektyvumui nuo *Avena sterilis*

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Santrauka

Kiekvienam herbicidui sunku parinkti tinkamą paviršiaus aktyviąją medžiagą. Siekiant nustatyti, ar būtų galima pagerinti keturių acetolaktato sintazės (ALS) inhibitorių herbicidų efektyvumą nuo Avena sterilis naudojant dvi paviršiaus aktyviąsias medžiagas ir dvi jų normas, 2013 m. Irano Ferdowsi Mashhad universitete šiltnamio ir lauko sąlygomis buvo atlikti keli eksperimentai. Abi paviršiaus aktyviosios medžiagos buvo efektyvios mažinant visų herbicidų tirpalų paviršiaus įtemptį, tačiau nejoninė paviršiaus aktyvioji medžiaga buvo efektyvesnė nei katijoninė. Pagal efektyviosios dozės vertes ALS inhibitorių herbicidai, naudoti nuo A. sterilis, išsidėstė taip: sulfosulfuronas > metilmezosulfuronas + metiljodosulfuronas ir natris su apsaugine medžiaga mefenpiru > metilmezosulfuronas + metiljodosulfuronas ir natris su apsaugine medžiaga mefenpirdietilu > metilmetsulfuronas + sulfosulfuronas. Visų herbicidų efektyviosios dozės vertės sumažėjo pridėjus paviršiaus aktyviųjų medžiagų. Tirtų herbicidų efektyvumą labiau didino katijoninės paviršiaus medžiagos nei nejoninės.

Reikšminiai žodžiai: dozės poveikis, herbicidų efektyvumas, sulfonilurėjos grupės herbicidai.

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