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Optimizing Sulfosulfuron and Sulfosulfuron Plus Metsulfuron-methyl Activity when Tank-Mixed with Vegetable Oil to Control Wild Barley (*Hordeum spontaneum* Koch.)

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ABSTRACT

Wild barley has invaded wheat fields ever since flamprop-isopropyl was outdated in Iran. Newly developed herbicides such as sulfosulfuron or sulfosulfuron plus metsulfuron-methyl can control it at higher than recommended dosages, but causing significant wheat injury. Hence, two dose-response experiments were conducted to evaluate their efficacy when tank-mixed with thirteen different vegetable oils, at the Ferdowsi University of Mashhad, Iran, during 2013. Moreover, a wheat cultivar (Gaskogen) was also treated with effective dose of 90% (ED_{90}) of both herbicides (21.44 grams active ingredient (g ai) of sulfosulfuron ha^{-1} and 41.95 g ai of sulfosulfuron plus metsulfuron-methyl ha^{-1}) with and without each vegetable oil to check selectivity. Averaged over vegetable oils, the effective dose of 50% (ED_{50}) was decreased 2.6- and 3.0-fold with sulfosulfuron and sulfosulfuron plus metsulfuron-methyl, respectively. Among the evaluated vegetable oils, cottonseed and coconut oil were the best ones to enhance the efficacy of both herbicides. The castor oil had the least effect. A negative correlation was observed between the efficiency of vegetable oils and its unsaturated/saturated fatty acids ratio. No phytotoxic effect on wheat was observed when these herbicides were applied with or without the vegetable oils.

Keywords: Crop selectivity, Herbicide efficacy, Penetrant agent, Vegetable oils, Wild barley.

INTRODUCTION

The genus *Hordeum* contains several weed species such as wild barley (*Hordeum spontaneum* Koch.), mouse barley (*Hordeum murinum* L.), smooth barley (*Hordeum glaucum* Steud.), and volunteer barley (*Hordeum vulgare* L.), infesting both wheat and barley fields all over the world (Hosseini *et al*., 2011). In Iran, wild barley has successfully adapted to a wide range of climatic conditions and is documented as a major weed in 16 provinces (Baghestani *et al*., 2008). It is believed that a weed shift has occurred in communities from *Avena* spp. and *Phalaris* spp. to *Hordeum* spp. because of close morphological and physiological similarities between wild barley and wheat (Sheibani and Ghadiri, 2012). With the exception of flamprop-isopropyl, wild barley is naturally tolerant to the majority of selective herbicides used in wheat (Jamali and Jokar, 2010). Previous research has indicated that wild barley can rapidly metabolize clodinafop-propargyl (Kreuz *et al*., 1991), metsulfuron-methyl (Anderson *et al*., 1989), and mesosulfuron-methyl plus iodosulfuron-methyl sodium (King *et al*., 2003) to non-lethal metabolites. Therefore, selective herbicides to control wild barley are lacking since flamprop-isopropyl was

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outdated, causing a weed shift to wild barley that now threatens wheat production in Iran (Jamali and Jokar, 2010).

Since the herbicides sulfosulfuron (Apyrous®) and sulfosulfuron plus metsulfuron-methyl (Total®) inhibit Aceto Lactate Synthase (ALS) enzyme to biosynthesize the branched-chain amino acids, they provide wild barley suppression, but they are not effective enough for this use in wheat (Baghestani *et al*., 2007, 2008; Zand *et al*., 2007; Jamali and Baghestani, 2011). Therefore, a higher than recommended dosage of both herbicides is required to achieve an appropriate control (Hosseini *et al*., 2011). In Iran, sulfosulfuron or sulfosulfuron plus metsulfuron-methyl at the rates of 27 and 50 g ha^{-1} are recommended in wheat to control other grass weeds. As a result, crop injury is unavoidable due to higher than recommended dosages. Ball and Walenta (1997) observed a height reduction in winter wheat with sulfosulfuron applied post-emergence at 35 g ha^{-1}, but seed yield was not significantly reduced.

Previous research indicated that a nonionic surfactant must be added as a tank-mixture for increasing the efficacy of both herbicides (Hosseini *et al*., 2011; Baghestani *et al*., 2008). It is well established that using activator adjuvant (e.g. penetrant, wetter, sticker, acidifier, and fertilizer agents) is one of the acceptable manners to improve the efficacy of post-emergence herbicides, which may allow herbicide dosage to be reduced (Rashed-Mohassel *et al*., 2011). Activator adjuvants, especially penetrant agents, are used to improve the transfer of active ingredients from surface to interior tissues (Izadi-Darbandi *et al*., 2013). Chemically, penetrant agents are derived from either vegetable or mineral oils. Performance of mineral oils and vegetable oils has often been compared. In some reports, vegetable oils were less effective than mineral oils. This has been reported for propanil (Jordan *et al*., 1997), clethodim (Jordan *et al*., 1996), quinclorac (Zawierucha and Penner, 2001) and clodinafop-propargyl, haloxyfop-p-methyl and difenzoquat-methyl-sulfate (Hammami *et al*., 2014). In contrast, in many reports, vegetable oils were reported to be more effective than mineral oils. This has been noted for sethoxydim (Matysiak and Nalewaja, 1999), diclofop, fluazifop-butyl (Manthey *et al*., 1989), dithiopyr (Keeley *et al*., 1997), phenmedipham (Ruiter *et al*., 1997), isoxaflutole (Young and Hart, 1998), triflusulfuron (Starke *et al*., 1996), tralkoxydim (McMullan *et al*., 1995), clethodim (Jordan *et al*., 1996), nicosulfuron (Strahan *et al*., 2000), aciflurofen (Nalewaja *et al*., 1995), primisulfuron (Nandula *et al*., 1995), rimsulfuron (Tonks and Eberlein, 2001) and atrazine (Robinson and Nelson, 1975). Occasionally, vegetable oils enhance herbicidal activity as much as mineral oils. This has been reported for quizalofop, haloxyfop (Manthey *et al*., 1989), sethoxydim (Mack *et al*., 1995), fenoxaprop-P (McMullan *et al*., 1995). It is generally believed that improved penetration occurs because penetrant agents are able to solubilize or disrupt cuticular waxes (Rashed-Mohassel *et al*., 2011).

Vegetable oils are less phytotoxic, safer, renewable, and degrade quicker than mineral oils. Therefore, the application of vegetable oil seems to be a suitable alternative to conventional synthetic activator adjuvants (Izadi-Darbandi *et al*., 2013). The objective of this study was to seek for a vegetable oil that can significantly enhance the efficacy of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl against wild barley without causing unacceptable injury to wheat.

MATERIALS AND METHODS

Bio-efficacy Studies

Caryopses of wild barley were collected from a heavily infested wheat field in Shiraz area, in Fars Province, Iran, during June to July 2012. Intact caryopses were stored in the dark at room temperature (20±5ºC) until

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use. Bioassays were conducted in greenhouses located on the Ferdowsi University of Mashhad, Mashhad, Iran, during March to May 2013. To improve seed germination, the glumella were removed by hand and the naked seeds were placed in 11 cm diameter Petri dishes on a single layer of filter paper (Whatman No.1; Whatman International, Maidstone, UK). Then, 15 mL of 0.2% KNO_3 solution were added to each Petri dish and incubated for 72 hours at 7±1°C in the dark (Hamidi *et al.*, 2009). As soon as the radicles emerged from the seeds, 10 seedlings were planted at 1cm of depth in 2 L plastic pots filled with an equal proportion of clay, loam soil, and sand (consisting of 19.8% sand, 19.1% clay, 57% silt, 4.1% organic matter, and a pH of 6.7). The pots were irrigated every three days. At one-leaf stage, the seedlings were thinned to five per pot.

Treatments included six concentration levels of 75% emulsifiable concentrate (WG) Apyrous® (0, 2.5, 5, 10, 15, and 20 g sulfosulfuron ha^{-1}) and six concentration levels of 5%+75% WG Total® (0, 5.625, 11.25, 22.5, 33.75, and 45 g sulfosulfuron+metsulfuron-methyl ha^{-1}). Sulfosulfuron was prepared with distilled water, based on 20 g ai ha^{-1} as a stock solution, from which the other treatment solutions were prepared. Likewise, from 45 g ai ha^{-1} of sulfosulfuron plus metsulfuron-methyl as a stock solution, the treatment solutions were prepared with distilled water and then mixed with and without the emulsifiable vegetable oils including: (i) castor (*Ricinus communis* L.), (ii) olive (*Olea europaea* L.), (iii) canola (*Brassica napus* L.), (iv) soybean (*Glycine max* L.), (v) cotton (*Gossypium hirsutum* L.), (vi) sesame (*Sesamum indicum* L.), (vii) linseed (*Linum usitatissimum* L.), (viii) rapeseed (*Brassica napus* L.), (ix) groundnut (*Arachis hypogaea* L.), (x) sunflower (*Helianthus annus* L.), (xi) maize (*Zea mays* L.), (xii) safflower (*Carthamus lanatus* L.), and (xiii) coconut (*Cocos nucifera* L.) at 0.5% (v/v). The vegetable oils were obtained from the Oil Laboratory, Department of Food Industries, Ferdowsi University of Mashhad, Mashhad, Iran. Average composition of the vegetable oils is given in Table 1. The emulsifiable vegetable oils were prepared by dissolving the emulsifier alkylarylpolyglycol ether (Zarnegaran Pars Company, Karaj, Iran) in each vegetable oil (95% crude vegetable oil plus 5% emulsifier). The experiment was arranged in a completely randomized design with a factorial arrangement of treatments and four replications.

The plants were treated at the four-leaf stage (Syedipuor *et al.*, 2009) using moving boom sprayer equipped with an 8002 flat-fan nozzle, delivering 200 L ha^{-1} at 200 kPa. Shoots were harvested by cutting at the soil surface four weeks after spraying, dried for 48 hours at 70°C and dry weight was determined. For statistical analysis, the data were changed to individual plant and were subjected to a non-linear regression analysis using the following logarithmic logistic dose-response model described by Ritz and Streibig (2005):

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

Where, Y is the response (dry weight), C is the lower limit, D is the upper limit, B is the slope of the curve, E denotes the dose required to give a response halfway between the upper and lower limits; and X is the herbicide dose. The dose-response curves were analyzed by open-source statistical software ($R_{2.6.2}$), utilizing the *drc* statistical addition package (Ritz and Streibig, 2005). The values of ED_{10}, ED_{50}, and ED_{90} i.e. herbicide dose needed to give 10, 50, 90% wild barley control, respectively, were detected. Significances among ED values were determined by the standard error. The Relative Potency (RP), which is the horizontal displacement between the two curves, was calculated using the ratio of doses producing the same response (Ritz and Streibig, 2005), as follows:

$$RP = ED_{50a} / ED_{50b}\,; R \leq 1 \leq R \quad (2)$$

Where, ED_{50a} denotes the ED_{50} of the herbicide formulation alone; and ED_{50b} denotes the ED_{50} of the herbicide

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Table 1. Average fatty acids composition and unsaturated to saturated fatty acid ratio of thirteen vegetable oils.[a]

Vegetable oil	Saturated									Unsaturated						Unsat/Sat ratio [b]
	8:0	10:0	12:0	14:0	16:0	18:0	20:0	22:0	24:0	16:1	18:1	20:1	22:1	18:2	18:3	
Canola	-	-	-	-	3.9	1.9	0.6	0.2	0.2	0.2	64.1	1.0	2	18.7	9.2	14.45
Castor	-	-	-	-	4.0	1.0	-	-	-	-	82.0	-	-	4.0	-	17.20
Coconut	7.8	6.7	47.6	18.1	8.8	2.6	0.1	0.1	-	-	6.2	-	-	1.6	-	0.08
Cottonseed	-	-	-	0.8	24.0	2.6	0.3	0.5	0.2	0.8	19.0	-	-	52.5	-	2.57
Linseed	-	-	-	-	6.1	3.2	-	-	-	0.1	16.6	-	-	14.2	59.8	9.75
Maize	-	-	0.1	0.2	13.0	2.5	0.5	0.3	-	0.1	30.5	0.2	-	52.0	0.1	4.99
Olive	-	-	-	-	13.7	2.5	0.2	0.3	-	1.2	71.1	0.5	0.2	9.4	0.3	4.95
Peanut	-	-	-	0.1	12.5	2.5	1.2	2.5	1.3	0.1	37.0	0.7	1.0	41.0	0.3	4.33
Rapeseed	-	-	-	-	3.0	1.0	1.0	-	-	-	16.0	6.0	49.0	14.0	10.0	18.00
Safflower	-	-	-	0.1	6.5	2.9	0.4	0.2	-	0.1	13.8	-	-	75.3	-	8.83
Sesame	-	-	-	0.1	7.9	5.2	0.1	0.1	-	0.1	39.9	0.1	-	45.5	0.5	6.43
Soybean	-	-	-	0.1	14.6	4.0	1.0	0.6	-	0.1	22.0	1.0	-	53.0	7.5	4.12
Sunflower	-	-	-	1.0	5.5	4.7	0.3	0.9	0.2	0.1	19.5	0.1	1.0	68.5	0.1	7.22

[a] Data were obtained from Velasco *et al.* (2004). [b] Abbreviations: Unsat: Unsaturated fatty acids, Sat: Saturated fatty acids.

formulation with each emulsifiable vegetable oil. If R= 1, the addition of emulsifiable vegetable oil would not have any effect on herbicide response. But, if R was higher or lower than 1, the herbicide accompanied by emulsifiable vegetable oil would be more or less potent than the herbicide alone, respectively. Significances among R values were determined by the standard error.

Phytotoxic Studies

The winter wheat (*Triticum aestivum* L. cultivar Gaskogen) seeds were obtained from Khorasan Razavi Agricultural Research Center, Iran. Before using, seeds were disinfected with sodium hypo chloride (5%) for 5 minutes and followed by dipping for 2 hours in water. Wheat plants were raised, treated at the same growth stage and harvested similar to wild barley. This experiment was set up as a completely randomized design with four replications from October to December 2013. Since the acceptance of 10% damage to the crop is used as a selectivity index (Tind *et al.***,** 2009), all doses of both herbicides, which were required to give 90% wild barley control, were chosen as the optimized doses. Therefore, the treatments consisted of a control and the optimized doses of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl with and without each emulsifiable vegetable oil, used in bio-efficacy study. The dry weight data were changed to individual plant and subjected to ANOVA using PROC GLM in SAS software by the least significant difference test at 5% level of probability.

RESULTS AND DISCUSSION

Bio-efficacy Studies

The validity of the above model and the comparisons between the parameters were made using F-test for lack of fit at 5% level of significance. Thereby, no significant lack of fit was detected when model 1 was tested; hence, the model was acceptable and the curves were parallel. The parameters determined by model 1 are given in Table 2. The dose-response curves of wild barley dry weight in response to sulfosulfuron or sulfosulfuron plus metsulfuron-methyl alone or in the presence of the vegetable oils were significantly similar as indicated by the same slope. This signifies that the dose-response curves can be considered to be parallel (Kudsk and Mathiassen, 2007). These data indicated that the vegetable oils were biologically inactive when applied at 0.5% (v/v). Nonetheless, Izadi-Darbandi *et al*. (2013) observed that cottonseed oil had a phytotoxic potential at 0.5% (v/v) on wild oat; however, the opposite result has been demonstrated by Tworkoski (2002) on dandelion.

The estimated ED_{10}, ED_{50}, and ED_{90} parameters by dose-response model based on wild barley dry weight in response to sulfosulfuron were 9.2, 13.4, and 21.4 g ai ha^{-1}, respectively. The corresponding values for sulfosulfuron plus metsulfuron-methyl were 16.9, 26.6, and 41.9 g ai ha^{-1},

Table 2. Estimated ED_{10}, ED_{50}, and ED_{90} of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl with and without the vegetable oils against wild barley.[a]

Herbicide	Vegetable oil	*B*	ED_{10} (g ai ha^{-1})	ED_{50} (g ai ha^{-1})	ED_{90} (g ai ha^{-1})
Sulfosulfuron	None	3.61 (1.50)	9.24 (0.76)	13.40 (0.77)	21.44 (2.57)
	Canola	2.63 (0.65)	2.16 (0.39)	4.99 (0.51)	13.48 (3.09)
	Castor	3.46 (1.07)	4.99 (0.94)	9.42 (0.76)	18.77 (4.14)
	Coconut	1.82 (0.47)	1.08 (0.30)	3.62 (0.48)	12.09 (2.76)
	Cottonseed	2.29 (0.60)	0.98 (0.28)	2.68 (0.24)	7.28 (2.10)
	Linseed	3.41 (0.78)	3.76 (0.55)	7.16 (0.59)	13.64 (2.58)
	Maize	2.58 (0.58)	2.54 (0.46)	5.92 (0.58)	13.84 (3.41)
	Olive	2.72 (0.63)	2.61 (0.46)	5.84 (0.53)	13.10 (3.05)
	Peanut	2.23 (0.54)	2.17 (0.48)	5.83 (0.69)	15.61 (1.77)
	Rapeseed	2.76 (0.48)	1.50 (0.32)	4.38 (0.53)	12.73 (4.14)
	Safflower	2.58 (0.60)	3.47 (0.64)	8.13 (0.94)	14.04 (1.05)
	Sesame	2.27 (0.51)	2.13 (0.38)	5.60 (0.72)	13.71 (3.57)
	Soybean	2.21 (0.52)	1.38 (0.30)	3.72 (0.39)	10.01 (2.92)
	Sunflower	2.35 (1.04)	2.98 (0.51)	8.69 (1.76)	21.33 (3.17)
Sulfosulfuron plus metsulfuron-methyl	None	3.34 (1.32)	16.92 (1.59)	26.64 (1.89)	41.95 (5.48)
	Canola	2.16 (0.39)	6.92 (0.99)	19.09 (3.20)	34.65 (4.01)
	Castor	3.56 (0.91)	10.81 (1.70)	20.03 (1.42)	39.80 (5.90)
	Coconut	2.46 (0.44)	3.43 (0.56)	8.38 (0.66)	20.44 (3.89)
	Cottonseed	2.30 (0.49)	3.79 (0.71)	9.85 (0.99)	25.62 (6.77)
	Linseed	3.43 (0.68)	8.58 (1.12)	16.27 (1.20)	30.84 (2.02)
	Maize	2.27 (0.47)	4.80 (0.80)	12.63 (1.51)	33.15 (5.58)
	Olive	2.80 (0.61)	5.96 (1.00)	13.05 (1.07)	28.55 (4.01)
	Peanut	2.23 (0.49)	4.89 (1.01)	13.13 (1.44)	35.21 (3.10)
	Rapeseed	2.58 (0.53)	4.67 (0.73)	10.93 (0.99)	25.57 (5.98)
	Safflower	2.59 (0.54)	5.70 (0.96)	13.33 (1.21)	31.13 (6.11)
	Sesame	2.42 (0.49)	5.69 (0.92)	14.09 (1.49)	34.91 (4.86)
	Soybean	2.78 (0.57)	5.23 (0.78)	11.53 (0.96)	25.42 (5.36)
	Sunflower	2.58 (0.55)	7.81 (1.35)	18.29 (1.96)	40.86 (6.55)

The vegetable oils were added at 0.5% (v/v); *B* is the slope of curve fitted using model 1; ED_{10}, ED_{50}, and ED_{90} are the required rate of herbicide to give 10, 50, and 95% control, respectively, and standard errors are given in parentheses.

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respectively. As judged by the parameters given in Table 2, all vegetable oils decreased the ED_{10} and ED_{50} values significantly ($P \leq 0.05$), indicating an increase in the performance of both herbicides. A similar trend for the ED_{90} values was also observed. However, there was no significant difference ($P \leq 0.05$) between the ED_{90} values of each herbicide when they were applied alone or in presence of castor and sunflower oils.

The estimated relative potencies of the herbicides' efficacy in the presence of the vegetable oils, against wild barley, are given in the first column of Table 3. In other columns, the vegetable oils were compared. Data showed that the values of the relative potency were significantly higher than 1.00 when the herbicides were applied in combination with vegetable oils, indicating an increase in the efficacy of herbicides when the vegetable oils were added to their spray solution (Table 3). In case of sulfosulfuron, the highest relative potency was obtained with cottonseed oil and then coconut oil. There was no significant difference between these two vegetable oils in enhancing the efficacy of sulfosulfuron (see the fourth column 4 in Table 3). The efficacy of 1.00 g sulfosulfuron per hectare in the presence of cottonseed oil or coconut oil was equivalent to the efficacy of 4.99 or 3.69 g sulfosulfuron ha^{-1} when it was applied alone, respectively. With the exception of castor and sunflower oils, all vegetable oils improved the efficacy of sulfosulfuron significantly ($P \leq 0.001$). Therefore, according to the relative potency values, the ranking of the vegetable oils for enhancing the efficacy of sulfosulfuron to control wild barley was: Cottonseed (4.99)≥ coconut (3.69)≥ soybean (3.60)> rapeseed (3.05)≥ canola (2.68)≥ sesame (2.38)≥ olive (2.29)= Peanut (2.29)≥ maize (2.26)≥ linseed (1.87)> safflower (1.64)≥ sunflower (1.46)≥ castor (1.42) (Table 3).

In the case of sulfosulfuron plus metsulfuron-methyl, a similar trend was observed, except that the highest relative potency was obtained with coconut oil followed by cottonseed oil. No significant difference was observed between these two vegetable oils in enhancing the efficacy of sulfosulfuron plus metsulfuron-methyl (see the fourth column in Table 3). The efficacy of 1.00 g sulfosulfuron plus metsulfuron-methyl per hectare in the presence of coconut oil or cottonseed oil was equivalent to the efficacy of, respectively, 3.17 or 2.70 g sulfosulfuron plus metsulfuron-methyl ha^{-1} applied alone. With the exception of canola, castor, and sunflower oils, all vegetable oils improved the efficacy of sulfosulfuron plus metsulfuron-methyl significantly ($P \leq 0.001$). Therefore, according to the relative potency values, the ranking of the vegetable oils for enhancing the efficacy of sulfosulfuron plus metsulfuron-methyl to control wild barley was: Coconut (3.17)≥ cottonseed (2.70)≥ rapeseed (2.43)≥ soybean (2.31)≥ maize (2.11)≥ olive (2.04)≥ peanut (2.02)≥ safflower (1.99)≥ sesame (1.89)≥ linseed (1.63)≥ sunflower (1.39)= Canola (1.39)≥ castor (1.33) (Table 3). Previous studies have also shown that the vegetable oils enhanced the efficacy of some herbicides (Muller *et al*., 2002; Zawierucha and Penner, 2001; Gauvrit *et al*., 2007; Rashed-Mohassel *et al*., 2010; Ruiter *et al*., 1997). This may be attributed to several factors. Firstly, vegetable oils can decrease the surface tension of spray solution (Sharma and Singh, 2000; Shu *et al*., 2008; Rashed-Mohassel *et al*., 2011), which is an effective factor to atomize spray droplets (Ejim *et al*., 2007), allowing it to remain on the foliage (Tu *et al*., 1986). Secondly, vegetable oils can soften or disrupt the cuticular wax. It is another effective factor to make the cuticular wax penetrable to the active ingredient (Rashed-Mohassel *et al*., 2011). Previous studies have asserted that the second factor is more effective than the first factor in improving the performance of herbicide (Sharma and Singh, 2000; Rashed-Mohassel *et al*., 2011). The difference in the performance between the tested vegetable oils could be attributed to their different chemical properties such as fatty acids composition (Table 1). A negative relationship between the relative potency

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Table 3. The estimated relative potencies (R= $ED_{50}a$/ $ED_{50}b$) of different vegetable oils.[a]

	$ED_{50}a$													
$ED_{50}b$	None	Canola	Castor	Coconut	Cottonseed	Linseed	Maize	Olive	Peanut	Rapeseed	Safflower	Sesame	Soybean	Sunflower
Sulfosulfuron														
None	1.00													
Canola	2.68 ***	1.00												
Castor	1.42 NS	0.52 ***	1.00											
Coconut	3.69 ***	1.37 NS	2.59 ***	1.00										
Cottonseed	4.99 ***	1.86 ***	3.51 ***	1.35 NS	1.00									
Linseed	1.87 ***	0.69 **	1.31 *	0.50 ***	0.37 ***	1.00								
Maize	2.26 ***	0.84 NS	1.58 **	0.61 ***	0.45 ***	1.20 NS	1.00							
Olive	2.29 ***	0.85 NS	1.61 **	0.62 **	0.45 ***	1.22 NS	1.01 NS	1.00						
Peanut	2.29 ***	0.85 NS	1.62 **	0.62 ***	0.46 **	1.22 NS	1.01 NS	1.00 NS	1.00					
Rapeseed	3.05 ***	1.13 NS	2.14 **	0.82 NS	0.61 **	1.63 **	1.35 NS	1.33 NS	1.33 NS	1.00				
Safflower	1.64 ***	0.61 ***	1.15 NS	0.44 ***	0.33 **	0.88 NS	0.72 *	0.71 **	0.71 *	0.53 ***	1.00			
Sesame	2.38 ***	0.88 NS	1.67 **	0.64 **	0.47 **	1.27 ***	1.05 NS	1.04 NS	1.03 NS	0.78 NS	1.44 NS	1.00		
Soybean	3.60 ***	1.34 NS	2.53 ***	0.97 NS	0.72 **	1.92 ***	1.59 *	1.57 **	1.56 *	1.17 NS	2.18 **	1.50 *	1.00	
Sunflower	1.46 NS	0.57 **	1.08 NS	0.41 ***	0.30 **	0.82 NS	0.68 *	0.67 *	0.67 *	0.50 ***	0.93 NS	0.64 *	0.42 **	1.00
Sulfosulfuron plus metsulfuron-methyl														
None	1.00													
Canola	1.39 NS	1.00												
Castor	1.33 NS	0.95 NS	1.00											
Coconut	3.17 ***	2.27 **	2.39 ***	1.00										
Cottonseed	2.70 ***	1.93 *	2.03 ***	0.85 NS	1.00									
Linseed	1.63 ***	1.17 NS	1.23 NS	0.51 ***	0.60 ***	1.00								
Maize	2.11 ***	1.51 NS	1.58 **	0.66 **	0.78 NS	1.29 NS	1.00							
Olive	2.04 ***	1.46 NS	1.54 **	0.64 **	0.75 NS	1.24 NS	0.97 NS	1.00						
Peanut	2.02 ***	1.45 NS	1.52 **	0.63 **	0.75 NS	1.23 NS	0.96 NS	0.99 NS	1.00					
Rapeseed	2.43 ***	1.74 *	1.83 ***	0.76 *	0.90 NS	1.48 **	1.15 NS	1.19 NS	1.20 NS	1.00				
Safflower	1.99 ***	1.43 NS	1.50 **	0.62 **	0.73 NS	1.22 NS	0.94 NS	0.97 NS	0.98 NS	0.82 NS	1.00			
Sesame	1.89 ***	1.35 NS	1.42 *	0.59 **	0.69 **	1.15 NS	0.89 NS	0.92 NS	0.93 NS	0.77 *	0.94 NS	1.00		
Soybean	2.31 ***	1.65 *	1.73 ***	0.73 **	0.85 **	1.41 **	1.09 NS	1.13 NS	1.13 NS	0.94 NS	1.15 NS	1.22 NS	1.00	
Sunflower	1.39 NS	1.04 NS	1.09 NS	0.45 **	0.53 **	0.88 NS	0.69 **	0.71 **	0.71 *	0.59 *	0.72 **	0.77 *	0.63 **	1.00

[a] ED_{10}, ED_{50}, and ED_{90} are the required rate of herbicide to give 10, 50, and 95% control, respectively. *R* is relative potency. If $R > 1$, the treatment A is more effective than treatment B, and if $R < 1$, the reverse is correct. * Statistical significance ($P \leq 0.05$); ** Highly statistical significant ($P \leq 0.01$); *** Very highly statistical significant $P \leq 0.001$, NS: Not statistical Significant.

values of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl in the presence of each vegetable oil with the unsaturated/saturated fatty acids ratio was obtained by a simple linear regression model with a coefficient of determination (R^2) of 0.35 or 0.52, respectively (Figure 1). In fact, the higher unsaturated/saturated fatty acids ratio of a vegetable oil, the lower is the adjuvancy properties. This finding was in agreement with the results of Izadi-Darbandi *et al*. (2013). Shu *et al*. (2008) stated that the number of unsaturated bands and the length of fatty acid hydrocarbon chain affect the surface tension. The surface tension was increased by increasing of unsaturated bonds at a similar hydrocarbon chain. Therefore, the higher the unsaturated/saturated fatty acids ratio of a vegetable oil, the higher is its surface tension. As mentioned above, a decrease in surface tension of spray solution affects atomization and retention of the droplets by plant foliage.

Furthermore, the vegetable oils decreased the ED_{50} about 2- and 3-fold with sulfosulfuron and sulfosulfuron plus metsulfuron-methyl, respectively, when averaged over the thirteen vegetable oils (Table 2). Therefore, oil receptivity for sulfosulfuron was higher than for sulfosulfuron plus metsulfuron-methyl. The reason for these different responses may be attributed to their different chemical properties, such as "Log-K_{ow}" (n-octanol-water partition coefficient), as described elaborately by Izadi-Darbandi *et al*. (2013).

Phytotoxic Studies

No significant phytotoxic effect was observed by applying the optimized doses of both herbicides with and without the vegetable oils on shoot dry weight of wheat. Because the means could not be separated, data are not shown. Therefore, these vegetable oils at 0.5% concentration (v/v) could enhance the ability of both herbicides to kill wild barley without damaging wheat.

CONCLUSIONS

Recently, a shift has occurred from non-environmentally friendly mineral oil-based adjuvants to environmentally friendly vegetable oil-based adjuvants (Zollinger, 2000). Vegetable oils are less phytotoxic, safer, more renewable, and quickly degradable compared to mineral oils. Since a

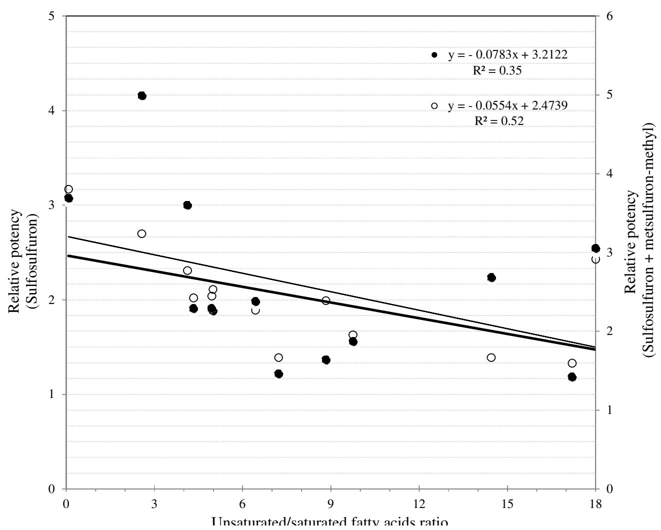

Figure 1. Relationship between relative potencies values obtained from sulfosulfuron (○), sulfosulfuron plus metsulfuron-methyl (●) in presence of vegetable oils and unsaturated/saturated fatty acids ratio of vegetable oils.

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higher than recommended dosage of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl is required to control wild barley appropriately, it is necessary to look for a vegetable oil that can help reduce their dosage. Besides, since crop selectivity is a function of application rate (Zimdahl, 2007), a vegetable oil can improve not only herbicide efficacy but also crop selectivity. From the present study, it could be concluded that, among the evaluated vegetable oils, cottonseed and coconut oils showed strong adjuvancy properties for both sulfosulfuron and sulfosulfuron plus metsulfuron-methyl against wild barley. The castor oil had the least effect.

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بهینه‌سازی فعالیت سولفوسولفورون و سولفوسولفورون+متسولفورون‌متیل با استفاده از روغن‌های گیاهی در کنترل جو دره (*Hordeum spontaneum* **Koch.**)

ا. ایزدی‌دربندی، و ا. علی‌وردی

چکیده

از زمانی که کاربرد فلم‌پروپ‌متیل‌ایزوپروپیل منسوخ شد، علف‌هرز جو دره به اکثر مزارع گندم کشورمان تهاجم پیدا کرده است. علف‌کش‌های جدیداً توسعه یافته، یعنی سولفوسولفوورن و سولفوسولفوورن+مت‌سولوفورون‌متیل، در مقادیر بالاتر از مقدار توصیه‌شده قادر به کنترل این علف‌هرز هستند که این باعث خسارت به گندم می‌شود. از این‌رو، دو آزمایش واکنش به مقدار به منظور بهینه-سازی مقدار مصرف این دو علف‌کش در کنترل علف‌هرز جو دره با استفاده از ۱۳ روغن گیاهی در دانشگاه فردوسی مشهد در سال ۱۳۹۲ به اجرا درآمد. تیمارها شامل ۶ غلظت از هر علف‌کش با و بدون

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هر یک از روغن‌های گیاهی بودند. علاوه براین، غلظتی از علف‌کش‌ها که موجب فراهمی کنترل ۹۰ درصدی جو دره (۲۱/۴۴ گرم ماده موثره از سولفوسولفوورن و ۴۱/۹۵ گرم ماده موثره از سولفوسولفوورن+مت‌سولوفورون‌متیل) با و بدون روغن‌های گیاهی شده بودند، نیز بر روی رقم گاسکوژن گندم بکار برده شدند تا انتخابی بودن آنها مورد سنجش قرار گیرد. در حالتی که متوسط عملکرد روغن‌های گیاهی در نظر گرفته شود، در مجموع، آنها توانستند غلظتی از سولفوسولفوورن و سولفوسولفوورن+مت‌سولوفورون‌متیل که موجب فراهمی کنترل ۵۰ درصدی جو دره شوند را به ترتیب ۲/۶ و ۳/۰ برابر کاهش دهند. بین روغن‌های مورد ارزیابی، روغن‌های پنبه و نارگیل دارای بهترین عملکرد در بهبود کارایی هر دو علف‌کش‌ها داشتند. در حالی که، روغن کرچک بدترین بود. یک ارتباط منفی بین عملکرد روغن‌های گیاهی و نسبت اسیدهای چرب غیراشباع به اشباع مشاهد شد. کاربرد علف‌کش‌ها با و بدون روغن‌های گیاهی هیچ‌گونه اثر گیاه‌سوزی بر روی گندم نداشت.

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