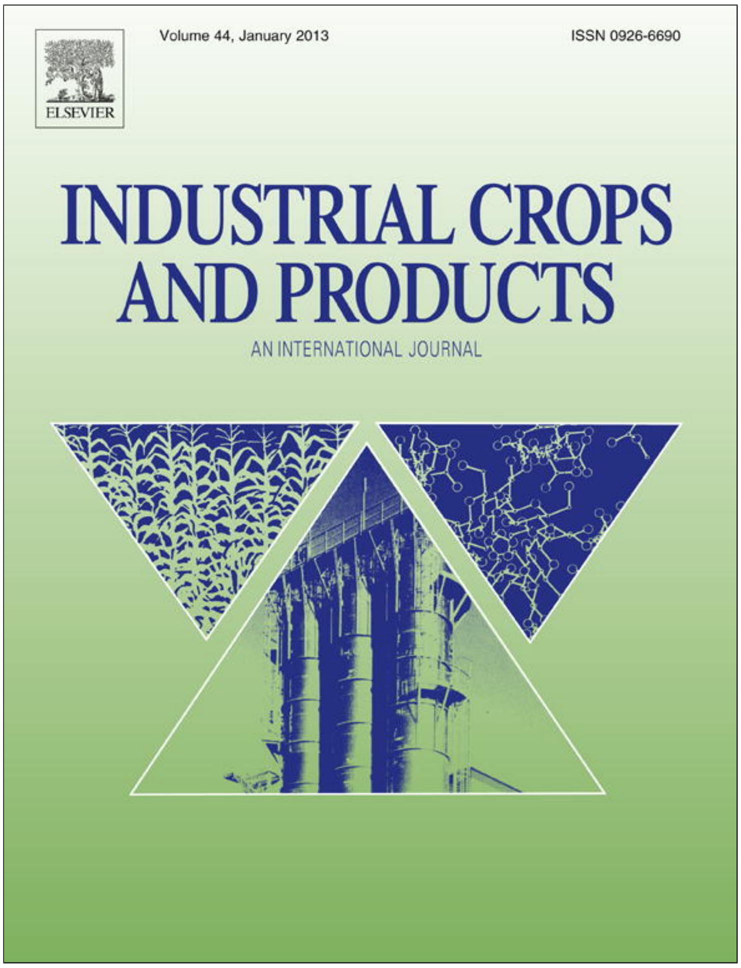
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Behavior of vegetable oils in relation to their influence on herbicides' effectiveness

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ABSTRACT

Three dose–response greenhouse experiments were conducted against wild oat separately and synchronically to compare the influence of nine vegetable oils on the effectiveness of three herbicides including imazamethabenz-methyl at 0, 25, 50, 100, 150, and 200 g a.i. ha^{-1}, sethoxydim at 0, 45, 94, 187, 281, and 375 g a.i. ha^{-1}, and sulfosulfuron at 0, 62, 125, 250, 375, and 500 g a.i. ha^{-1}. When vegetable oils were applied alone, only cottonseed had a phytotoxic effect on wild oat. All vegetable oils improved herbicides' effectiveness significantly. The vegetable oils decreased the ED_{50} 4.03-, 3.06-, and 1.63-fold with imazamethabenz-methyl, sethoxydim, and sulfosulfuron, respectively, when averaged over the nine vegetable oils. In other words, oil receptivity for sethoxydim was lower than for imazamethabenz-methyl and higher than for sulfosulfuron which strongly represents a positive relationship between the oil receptivity and the herbicides' log K_{ow}. With a slight difference, the vegetable oils were ranked based on their performance in enhancing the tested herbicides to rapeseed, soybean, cottonseed, bitter almond, olive, canola, sesame, castor, and sweet almond oils which represents a negative correlation between the vegetable oils' performance with its un-saturates/saturates ratio of fatty acids in a theory.

1. Introduction

During last and recent century, population explosion forced man to produce adequate supplies of food (Hay, 1974) by consuming more energy with chemical and looking for different management strategies. By the introduction of the phenoxy herbicides in 1947, herbicides started tremendous contributors to world of agriculture (Kudsk, 2008) and they contributed a major positive impact on crop yield throughout world (Pacanoski, 2007). Deihimfard et al. (2007) reported that during 1994–2004 in Iran, mean wheat yield in irrigated and rainfed farms has been increased from 3100 and 1000 kg ha^{-1} to 3800 and 1200 kg ha^{-1}, respectively, mainly due to increasing herbicide usage from 2100 to 3700 t $year^{-1}$ during this period. Nonetheless, herbicides have had also a major negative impact on the environment and human health (Rashed-Mohassel et al., 2010). Hamilton et al. (1988) reported that the application of atrazine presents a reduction in mean number of phytoplankton, rotifer and crustacean species. Paganelli et al. (2010) reported that when frog (*Xenopus laevis*) embryo was treated with glyphosate herbicide, a morphological abnormal change was observed in frog.

Increasing the effectiveness of the post-emergence herbicides by adjuvants is a tool for reducing the herbicide usage which allows to decreasing the risk of their side effects and cost (Aliverdi et al., 2009). From previous reports, it appears that the use of adjuvants seems a best solution to achieve this goal (Zabkiewicz, 2000). Using adjuvants to enhance herbicidal activity is not new which may date back as far as the 1700s as glucose and molasses were applied to improve the sticking properties of inorganic herbicides (Green and Beestman, 2007).

In spite of these advantages, some synthetic adjuvants have been shown a side effect on wildlife, similar to agrochemicals (Rashed-Mohassel et al., 2009). Previous reports indicated that polyoxyethylene alkyether-containing adjuvants induce significant hypotension human acute oral poisoning and bradycardia (Chan et al., 2007). Polyethoxylated tallowamine adjuvants were very toxic in fairy shrimp (*Thamnocephalus platyurus*) with LC_{50} of 2.01 mg L^{-1} (Brausch and Smith, 2007) and for midge larvae (*Chironomus plumosus*) with LC_{50} of 13 mg L^{-1} (Buhl and Faerber, 1989). However, the so-called vegetable oil based are both very pleasant for herbicide applicators and environmentally safe. They are not phytotoxic and likely degraded and metabolized quickly in the environment (Cabanne et al., 1999). They are renewable resources and provide a new opportunity to replace fossil fuels (Penner, 2000).

The first barrier for diffusing the active ingredient into the leaf tissue is plant cuticle (Hess and Foy, 2000). Vegetable oils are

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Table 1
Fatty acid composition of vegetable oils.

Source	Saturates		Mono-unsaturates		Poly-unsaturates		Unsat./Sat. ratio
	16:0	18:0	16:1	18:1	18:2	18:3	
Rapeseed	11	2	–	55	15	13	5.78
Soybean	10	6	0.4	24	26	7	3.7
Cottonseed	18	3	0.6	29	50	1	4.2
Bitter almond	8	2	0.5	59	25	0.1	8.4
Olive	7	3	1.2	63	15	1	7.2
Canola	6	2	0.3	55	22	10	14.2
Sesame	6	6	0.2	41	34	–	6.3
Castor	5	2	–	82	7	–	12.7
Sweet almond	3	1	1	71	21	4	21.5

The fatty acid composition values indicated for vegetable oils were obtained from Soler et al. (1988), Hazen (2000), Were et al. (2006), Shibahara et al. (2008), Rafalowski et al. (2008) and Kim et al. (2010). Percentages may not add to 100% due to rounding and other constituents not listed.

believed to promote the penetration of the active ingredient via the solubilizing or disrupting the nature of cuticular waxes. Previous studies have shown that increase in the penetration of active ingredient by the vegetable oils via softening or disrupting of the cuticular waxes is more effective factor than decreasing the surface tension of spray droplets by surfactants (Sharma and Singh, 2000; Rashed-Mohassel et al., 2011). Moreover, vegetable oils have been shown to delay crystallization (Bunting et al., 2004) and to reduce the volatilization (Ramsey et al., 2006) and photo-degradation (Si et al., 2004) of the herbicides on the leaf surface. The objective of this research is to determine the best vegetable oil on biological activity of imazamethabenz-methyl, sulfosulfuron, and sethoxydim herbicides against wild oat (*Avena ludoviciana* L.).

2. Materials and methods

2.1. Plant growth

The seeds of wild oat were collected from plants in the fields of the Mashhad Agricultural and Natural Resources Research Center, in Mashhad, Iran and preserved in a refrigerator (at 4 ± 1 °C). To increase seed germination before the start of experiment, the seeds were dehulled and placed in Petri dishes on top 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 for breaking dormancy, then the seeds were incubated for 48 h at 4–5 °C in the dark (Rashed-Mohassel et al., 2011). Then the seeds were sown in potting trays (3 cm × 3 cm × 5 cm) filled with moistened peat. One week after sowing, at one leaf seedlings stages, they were transplanted to 2 L plastic pots filled with a mixture of sand, clay loam soil, and peat (1:1:1; v/v/v). The pots were sub-irrigated every three days. The seedlings were thinned to five per pot at the two leaf stage and 40 mL of a water supplied with N:P:K (20:20:20) fertilizer, at a concentration of 3 g of fertilizer per liter of tap water, were added to each pot.

2.2. Treatments and chemicals

Imazamethabenz-methyl at 0, 25, 50, 100, 150, and 200 g a.i. ha^{-1} (Assert, 25% EC, Nufarm, USA), sulfosulfuron at 0, 62, 125, 250, 375, and 500 g a.i. ha^{-1} (Apirus, 75% WG, Monsanto, USA), and sethoxydim at 0, 45, 94, 187, 281, and 375 g a.i. ha^{-1} (Nabo-S, 12.5% EC, Basf, Germany) were used separately against wild oat in three experiments. Each of these herbicides was applied alone and along with the emulsifiable vegetable oils including: (i) castor (*Ricinus communis*), (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) bitter almond (*Prunus amygdalus* Batsch.), (viii) sweet almond (*Prunus nana* L.), and (ix) rape seed (*B. napus* L.) at 0.5% (v/v). The vegetable oils' fatty acids composition is summarized in Table 1. Emulsifiable oils were prepared by dissolving the emulsifier Cittowet® (a non-ionic emulsifier, 100% alkylarylpolyglycol ether) in each vegetable oil (95% vegetable oil + 5% emulsifier). For each herbicide, the experiment was arranged in a completely randomized design with a factorial arrangement of treatments and four replications. The spray was done at the four leaf stage by using an overhead trolley sprayer (Matabi 121030 Super Agro 20 L sprayer; Agratech Services-Crop Spraying Equipment, Rossendale, UK), equipped with an 8002 flat fan nozzle tip delivering 200 L ha^{-1} at 2 bar spray pressure. Four weeks after spraying, the biomass of experimental units was harvested fresh weight and also dry

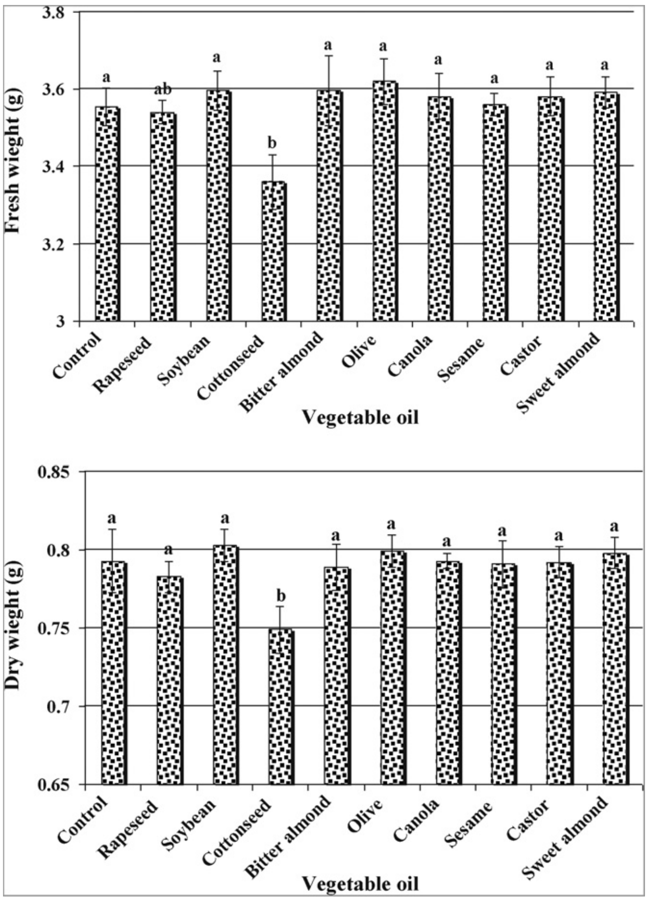

Fig. 1. The response of intact wild oat (*Avena ludoviciana* L.) plant to vegetable oils alone, applied at 5% (v/v). Means in a column followed by same letter are not significantly different at $p < 0.05$ based on Duncan's Multiple Range Test.

weight was determined after the fresh samples were oven-dried at 75 °C for 48 h.

2.3. Statistical analyses

The response of fresh and dry matter (U) to herbicides dose (z) was assumed by a log-logistic model that was described by Nielsen et al. (2004):

$$U_{ij} = C_i + \frac{D - C_i}{1 + \exp[b_i(\log(z_{ij}) - \log(ED_{50i}))]} \tag{1}$$

where U_{ij} denotes the fresh or dry matter at the jth dose of the ith herbicide preparation; D and C_i denote the upper and lower limit of the fresh or dry weight at zero and at infinite doses; ED_{50i} denotes the required dose of herbicide, i, to give 50% wild oat control; and b_i is proportional to the slope of the curve around the ED_{50i}. The ED_{50} parameter can be replaced by any ED level (e.g. the ED_{95}). The ED_{95} denotes the required dose of herbicide, i, to give 95% wild oat control. The logistic response-dose model was fitted to the experimental data by the Slide Write software (Advanced Graphics Software, Carlsbad, CA, USA). Theoretically, whether the response curves are parallel or not, horizontal displacement between curves described by relative potency:

$$R = \frac{ED_{50f}}{ED_{50f+v}} \tag{2}$$

where ED_{50f} denotes the ED_{50} of herbicide formulation alone; and ED_{50f+v} denotes the ED_{50} of herbicide formulation along 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 herbicide alone, respectively.

3. Results

When emulsified vegetable oils alone were sprayed against wild oat, only cottonseed oil had the phytotoxic potential and decreased fresh weight and dry weight of wild oat significantly as compared to the control and other emulsified vegetable oils (Fig. 1). The ED_{50} and ED_{90} determined parameters estimated by dose–response model based on wild oat dry weight for imazamethabenz-methyl, sethoxydim, or sulfosulfuron were 163.15, 128.83, and 6.80 g a.i. ha^{-1} and 312.23, 251.29, and 13.37 g a.i. ha^{-1}, respectively. Wild oat fresh matter data showed similar trend. So that, the ED_{50} and ED_{95} parameters for wild oat treated with imazamethabenz-methyl, sethoxydim, or sulfosulfuron were 156.77, 123.45, and 6.61 g a.i. ha^{-1} and 361.05, 288.42, and 15.48 g a.i. ha^{-1}, respectively (Table 2). As judged by the ED_{50} and ED_{95} values given in Table 2, all of the emulsifiable vegetable oils improved significantly the effectiveness of all herbicides compared to herbicide alone. Among emulsifiable vegetable oils, the lowest effect observed in sweet almond. However, according to wild oat dry weight, in experiments 1, 2, and 3, the performance of 1 g a.i. ha^{-1} imazamethabenz-methyl, sethoxydim, or sulfosulfuron plus emulsifiable sweet almond oil was equivalent to the performance of 1.46, 1.24, and 1.20 g a.i. ha^{-1} from the mentioned herbicides alone, respectively (Fig. 2). Based on ED_{50} values, the best of all was rapeseed oil for imazamethabenz-methyl, soybean oil for sethoxydim, and cottonseed oil for sulfosulfuron; however, no difference was observed between these three vegetable oils.

Table 2
Estimated ED_{50} and ED_{95} doses of imazamethabenz-methyl or sulfosulfuron or sethoxydim alone and in the presence of vegetable oils in the control of fresh and dry weight of wild oat.

	Experimental treatments	Fresh weight		Dry weight	
		ED_{50} (g a.i. ha^{-1}) ± SD	ED_{95} (g a.i. ha^{-1}) ± SD	ED_{50} (g a.i. ha^{-1}) ± SD	ED_{95} (g a.i. ha^{-1}) ± SD
1	Imazamethabenz alone	163.15 ± 2.10	312.23 ± 2.28	156.77 ± 2.46	361.05 ± 2.93
	Imazamethabenz + sweet almond	127.76 ± 1.75	184.67 ± 1.64	107.18 ± 3.00	267.91 ± 3.62
	Imazamethabenz + castor	101.94 ± 2.59	206.56 ± 2.76	96.19 ± 2.69	243.96 ± 2.34
	Imazamethabenz + sesame	91.54 ± 2.87	165.97 ± 2.23	65.30 ± 2.10	185.62 ± 2.45
	Imazamethabenz + canola	70.46 ± 2.32	121.51 ± 2.09	44.88 ± 2.06	192.56 ± 2.32
	Imazamethabenz + olive	53.81 ± 2.61	95.77 ± 2.88	37.55 ± 2.56	142.38 ± 2.67
	Imazamethabenz + bitter almond	45.63 ± 1.02	116.39 ± 1.11	36.88 ± 2.50	140.38 ± 1.98
	Imazamethabenz + cottonseed	30.06 ± 1.76	68.57 ± 1.54	32.42 ± 1.14	79.00 ± 1.39
	Imazamethabenz + soybean	29.51 ± 1.62	78.80 ± 1.82	25.87 ± 1.09	75.00 ± 1.02
	Imazamethabenz + rapeseed	22.95 ± 1.36	48.86 ± 1.12	19.60 ± 1.82	51.63 ± 1.65
2	Sethoxydim alone	128.83 ± 2.40	251.29 ± 2.11	123.45 ± 2.45	288.42 ± 2.91
	Sethoxydim + sweet almond	101.24 ± 2.11	166.23 ± 2.21	99.43 ± 2.01	160.11 ± 2.33
	Sethoxydim + castor	100.21 ± 1.35	165.33 ± 1.78	97.33 ± 2.45	160.34 ± 2.09
	Sethoxydim + sesame	88.02 ± 1.43	142.67 ± 1.55	81.74 ± 1.78	139.13 ± 1.01
	Sethoxydim + canola	68.65 ± 1.67	140.81 ± 1.61	77.95 ± 1.11	141.19 ± 1.36
	Sethoxydim + olive	56.34 ± 1.56	129.51 ± 1.40	51.55 ± 1.29	116.81 ± 1.20
	Sethoxydim + bitter almond	42.77 ± 1.70	103.99 ± 1.87	35.89 ± 1.22	105.34 ± 1.28
	Sethoxydim + cottonseed	30.61 ± 0.43	88.91 ± 0.99	28.11 ± 2.83	90.77 ± 2.71
	Sethoxydim + soybean	29.11 ± 0.98	89.65 ± 0.71	21.01 ± 2.91	86.00 ± 2.82
	Sethoxydim + rapeseed	31.01 ± 1.88	89.02 ± 1.67	21.12 ± 1.62	82.09 ± 1.60
3	Sulfosulfuron alone	6.80 ± 0.29	13.37 ± 0.24	6.61 ± 0.32	15.48 ± 0.38
	Sulfosulfuron + sweet almond	5.57 ± 0.21	11.45 ± 0.05	5.49 ± 0.24	12.05 ± 0.42
	Sulfosulfuron + castor	5.38 ± 0.13	10.91 ± 0.05	5.32 ± 0.09	11.22 ± 0.12
	Sulfosulfuron + sesame	5.35 ± 0.22	10.94 ± 0.11	5.28 ± 0.04	10.71 ± 0.03
	Sulfosulfuron + canola	4.90 ± 0.09	10.21 ± 0.02	4.87 ± 0.21	10.03 ± 0.23
	Sulfosulfuron + olive	4.49 ± 0.03	9.74 ± 0.61	4.45 ± 0.15	9.97 ± 0.12
	Sulfosulfuron + bitter almond	4.13 ± 0.02	9.01 ± 0.01	4.09 ± 0.18	8.89 ± 0.08
	Sulfosulfuron + cottonseed	3.04 ± 0.07	8.33 ± 0.08	3.01 ± 0.09	8.41 ± 0.13
	Sulfosulfuron + soybean	3.23 ± 0.13	8.19 ± 0.09	3.02 ± 0.13	8.08 ± 0.11
	Sulfosulfuron + rapeseed	3.22 ± 0.19	8.21 ± 0.12	3.08 ± 0.09	8.12 ± 0.09

Imazamethabenz-methyl is shortened to imazamethabenz. The vegetable oils were added at 0.5% (v/v) that 5% of the vegetable oils were non-ionic alkyl aryl polyglycol ether emulsifier.

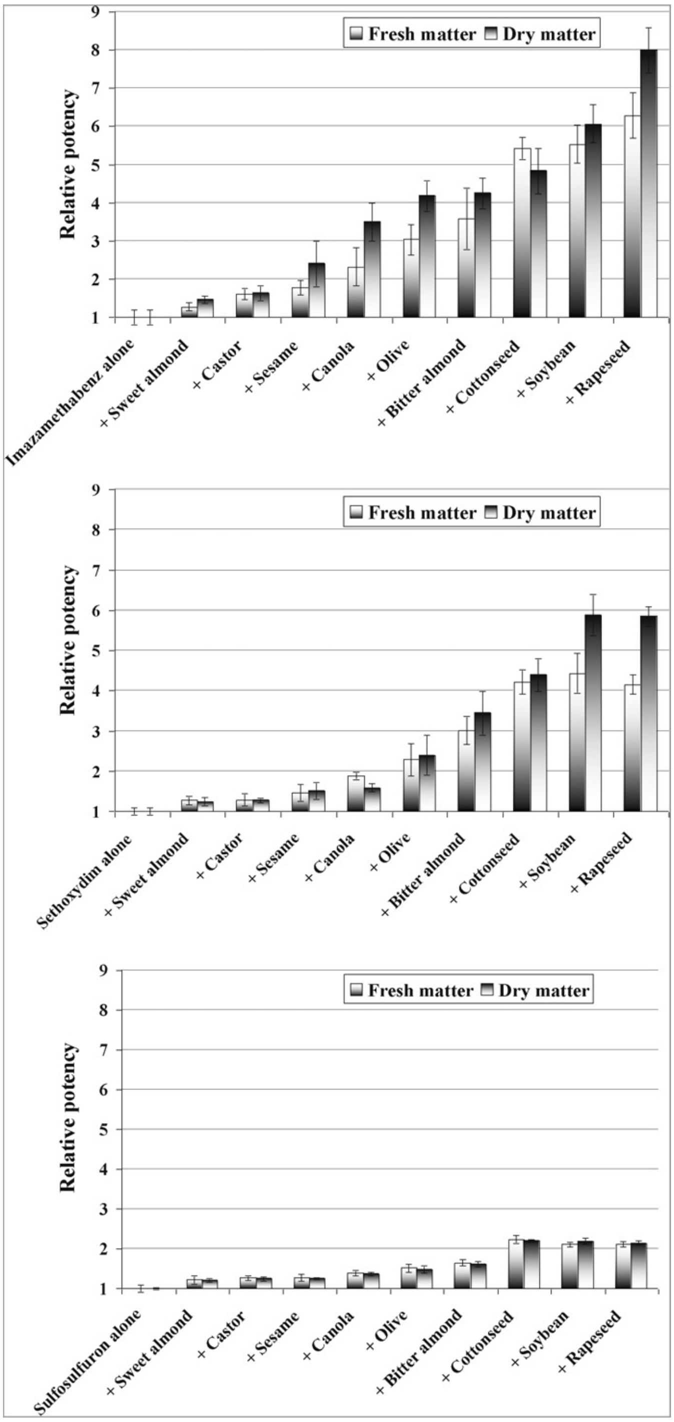

Fig. 2. Relative potencies values of imazamethabenz-methyl (top), sethoxydim (meddle), or sulfosulfuron (bottom) plus vegetable oils.

According to wild oat fresh weight or dry weight, in experiment 1, the performance of 1 g a.i. ha^{-1} imazamethabenz-methyl plus rapeseed oil was equivalent to the performance of 6.29 and 7.99 g a.i. ha^{-1} imazamethabenz-methyl alone, respectively (Fig. 2); in experiment 2, the performance of 1 g a.i. ha^{-1} sethoxydim plus soybean oil was equivalent to the performance of 4.15, and 5.84 g a.i. ha^{-1} sethoxydim alone, respectively; and in experiment 3, the performance of 1 g a.i. ha^{-1} sulfosulfuron plus cottonseed oil was equivalent to the performance of 2.11, and 2.15 g a.i. ha^{-1} sulfosulfuron alone, respectively. Therefore, in all experiments, by a slight difference, the vegetable oils performance in enhancing the tested herbicides efficacy is being ranked according the following the order based on ED_{95}-values, rapeseed > soybean > cottonseed > bitter almond > olive > canola > sesame > castor > sweet almond. For instance, in experiment 1, the performance of imazamethabenz-methyl plus the mentioned emulsifiable vegetable oils to control dry matter was 1.46, 1.63, 2.40, 3.49, 4.17, 4.25, 4.84, 6.06, and 7.99 times higher than that of imazamethabenz-methyl alone, respectively (Fig. 2).

With respect to the fresh weight or dry weight, the vegetable oils were decreased the ED_{50} 3.43-fold and 4.03-fold with imazamethabenz-methyl, 2.66-fold and 3.06-fold with sethoxydim, and 1.64-fold and 1.63-fold with sulfosulfuron when averaged over the nine emulsifiable vegetable oils (Fig. 2). Therefore, oil receptivity for sethoxydim was lower than for imazamethabenz-methyl and higher than for sulfosulfuron.

4. Discussion

A preferred emulsifier which may be suited to disperse vegetable oils into spray solution is alkyl aryl polyglycol ether ($C_8H_{16}C_6H_4(C_2H_4O)_{10}H$) (Delabie et al., 1985) with HLB (hydrophilic–lipophilic balance value) of equal ∼14 according to Griffin (1954) formula. This emulsifier is capable of lowering the surface tension of spray solution (Aliverdi et al., 2009) because of having ethylene oxide (C_2H_4O) in its molecule structure (Myers, 2006). Whereas, Green (2002) stated that surfactant activity was reduced with increasing alkyl chain and decreasing number of ethylene oxide units. Our previous study indicated that adding this emulsifier alone at 0.025 (v/v) (5% of the vegetable oil) to some acetyl coenzyme A carboxylase inhibitors cannot improve their effectiveness (Rashed-Mohassel et al., 2010). Therefore, we may conclude that it had merely worked as dispersive agent.

Whole-wild oat response to vegetable oils alone is shown in Fig. 1. Except cottonseed oil, no other vegetable oil caused wild oat leaf injury significantly at 0.5% (v/v) concentration. This finding was in contradictory with the results of Tworkoski (2002) who reported that cottonseed oil (0.5%, v/v) were no phytotoxic on leaves of dandelion. The phytotoxic potential of twenty-five different oils on the electrolyte leakage of dandelion leaves in a laboratory experiment was investigated by Tworkoski (2002) who stated that the vegetable oil altered membrane permeability and resulted in a electrolyte leakage; moreover, without any effect on DNA, RNA, or protein synthesis (Ismaiel and Pierson, 1990).

When any vegetable oils were added to each herbicide (Fig. 2), the relative potency values were considerably increased, resulting an increase in the performance of them. The reason for this may attributed to several factors. Hence, decrease in the surface tension of spray solution by the vegetable oil (Sharma and Singh, 2000; Shu et al., 2008; Rashed-Mohassel et al., 2011) is an effective factor to atomize spray droplets (Ejim et al., 2007) and allowing to retain it on foliage (Tu et al., 1986), an increase in the penetration of a.i. via softening or disrupting of the cuticular waxes is a more effective factor in improving herbicides' effectiveness (Rashed-Mohassel et al., 2011). Other studies have shown that the vegetable oils lead to better control with 2,4-D, phenmedipham (Muller et al., 2002), quinclorac (Zawierucha and Penner, 2001), glyphosate (Gauvrit et al., 2007), diclofop-methyl, cycloxydim, clodinafop-propargyl (Rashed-Mohassel et al., 2010), metoxuron, sethoxydim, and quizalofop (Ruiter et al., 1997).

Using Eq. (2), the relative potency values of the tested herbicides in the presence of each vegetable oil were calculated and compared. Rapeseed, soybean, and cottonseed oils had the best performance to improve herbicides' effectiveness against wild oat compared with other vegetable oils, particularly with emulsifiable

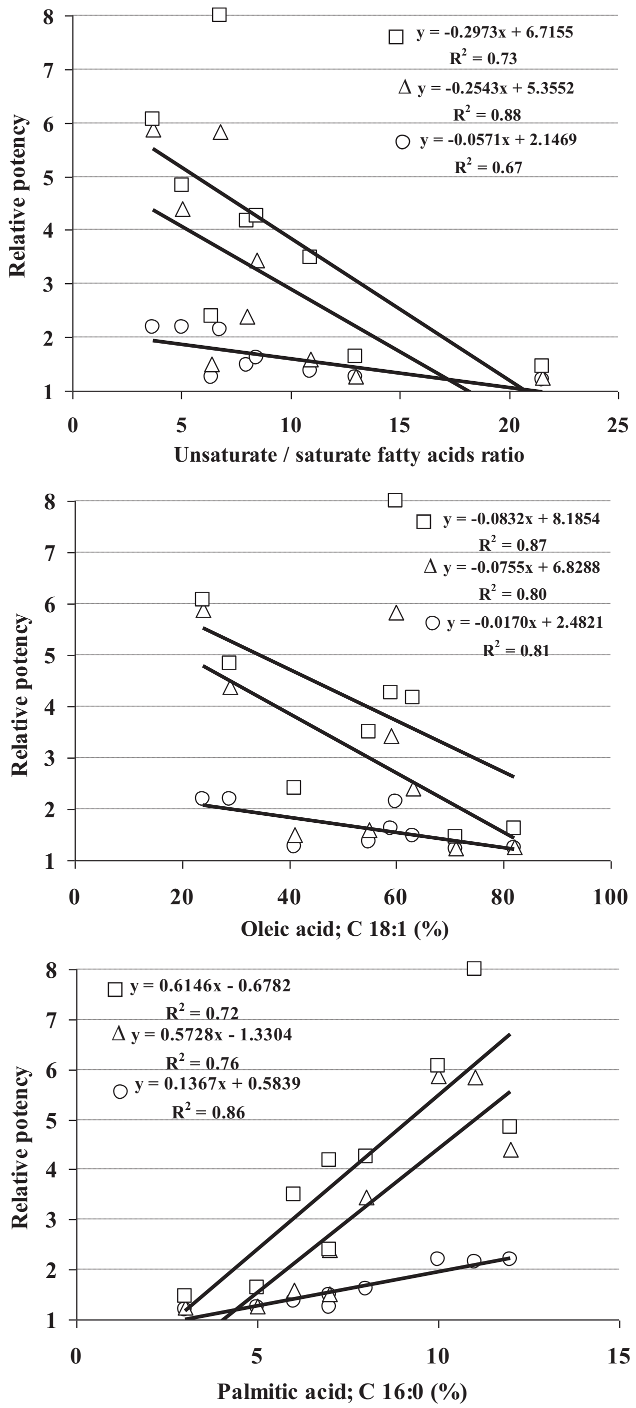

Fig. 3. Relationship between relative potencies values obtained from imazamethabenz-methyl (□), sethoxydim (△), or sulfosulfuron (○) plus vegetable oils and un-saturate/saturate fatty acids ratio of vegetable oils (top), oleic acid (%) of vegetable oils (middle), and palmitic acid (%) of vegetable oils (bottom). Relative potency values belong to data of dry weight.

oils of sesame, castor, and sweet almond. A reason for these differences can be attributed to their different chemical properties such as fatty acids composition (Table 1). The relationships between the relative potency values of the tested herbicides in the presence of each vegetable oil with three chemical properties of vegetable oils such as un-saturate/saturate fatty acids ratio, oleic acid (C 18:1) content and palmitic acid (C 16:0) content were obtained by a simple linear regression model (Fig. 3), unveiling a relationship exists between them. The R^2 values given in Fig. 3, showed a negative relationship between the relative potency values of imazamethabenz-methyl, sethoxydim, and sulfosulfuron in the presence of each vegetable oil and un-saturate/saturate fatty acids ratio with a coefficients of determination (R^2) of 0.73, 0.88, and 0.67, respectively. In other words, the more un-saturate/saturate fatty acids ratio, the less vegetable oil's performance (Fig. 3). This relationship with content of oleic acid and palmitic acid of vegetable oils was negative and positive, respectively, with coefficients of determination (R^2) of 0.87, 0.80, and 0.81 for the former and with coefficients of determination (R^2) of 0.72, 0.76, and 0.86 for the latter, respectively (Fig. 3). It means, the more oleic acid or the more palmitic acid content, the less vegetable oil's performance occurred. No correlation between the relative potency values of the tested herbicides in the presence of each vegetable oil with content of stearic acid (C 18:0), palmitoleic acid (C 16:1), linoleic acid (C 18:2), and linolenic acid (C 18:3) of each vegetable oil was observed.

In spite of a rapid plant injury occurred with short fatty acid hydrocarbon chain such as pelargonic acid (C 9:0) (Pline et al., 1999), which is used in organic systems of agriculture, Freitas et al. (2011) and Shu et al. (2008) reported that the length of the number of unsaturated bands and he fatty acid hydrocarbon chain affect the surface tension. They resulted that with elongation of hydrocarbon chain of a fatty acid, gives a higher surface tension. Likewise, at a similar hydrocarbon chain, with increasing of unsaturated bonds, the surface tension was increased. Therefore, with increasing of palmitic acid (C 16:0) content of a vegetable oil, the surface tension of spray solution may decreases compared with oleic acid (C 18:1) (Ejim et al., 2007). As mentioned above, a decrease in surface tension of spray solution compatibility affects atomization and produces smaller droplets (Ejim et al., 2007) and, lower level of energy exists in smaller droplets, improves the retention of droplets by the leaf surface (Rashed-Mohassel et al., 2009). With greater interception and retention of droplets, the efficacy of an herbicide would be improved accordingly.

On the whole, the result obtained in this study indicates that on the average these emulsifiable vegetable oils could increase the efficiency of sethoxydim higher than sulfosulfuron and lower than imazamethabenz-methyl (Fig. 2). The reason for these different responses may be attributed to their different chemical properties such as $\log K_{ow}$ (n-octanol–water partition coefficient). $\log K_{ow}$ is for *p*-isomer and *m*-isomer of imazamethabenz-methyl equal 1.54 and 1.82, respectively. It is for sethoxydim and sulfosulfuron equal 1.56, and −0.77 (pH 7), respectively. It can be seen from this comparison that the performance of lipophilic herbicides (imazamethabenz-methyl and sethoxydim) with emulsifiable vegetable oils were increased more than of hydrophilic herbicide (sulfosulfuron). This finding was in contraction with the results of Ruiter et al. (1997).

5. Conclusions

Based on our results, the application of vegetable oil seems to be a suitable alternative to conventional synthetic activator adjuvants. The fatty acid compositions of vegetable oils are clearly effective in their performance. Our findings indicate that a correlation exists between quantity of oleic and palmitic acid of vegetable oil and its performance to improve the herbicide effectiveness. More systematic research is required to elucidate that how the process of spraying solutions on the leaf surface is related to herbicide performance by elongating of hydrocarbon chain or increasing of unsaturated bonds of a fatty acid.

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