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Research Article

The effect of adjuvants on nicosulfuron efficacy for controlling *Amaranthus retroflexus*, *Chenopodium album*, and *Echinochloa crus-galli*

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Abstract: Three dose-response experiments were conducted separately to study the effect of several adjuvants on nicosulfuron efficacy for controlling *Amaranthus retroflexus* L., *Chenopodium album* L. and *Echinochloa crus-galli* L. The experiments were arranged in a completely randomized block design with a factorial arrangement of the treatments and four replications. The treatments consisted of six doses of nicosulfuron at 0 (control), 5, 10, 20, 40, and 80 g a.i.ha^{-1} of the recommended dose with and without the adjuvants of cotton oil, rocket oil, soybean oil, maize oil, Adigor®, Volck®, HydroMax™ at 0.5% (v/v), Cytogate, Trend® 90, and D-octil® at 0.2 % (V/V). The efficacy of nicosulfuron in control of *A. retroflexus*, *C. album*, and *E. crus-galli* increased significantly when the adjuvants were used. HydroMax™ and Trend® 90 were the best adjuvants, considering enhanced nicosulfuron efficacy for controlling *C. album*, *E. crus-galli*, and *A. retroflexus*. In the presence of HydroMax™ nicosulfuron efficacy was raised by a factor of 4.02, 3.45, and 1.65-fold for controlling *A. retroflexus*, *E. crus-galli*, and *C. album*, respectively. In general, the efficacy of nicosulfuron to control *A. retroflexus* and *E. crus-galli* was higher than *C. album*.

Keyword: dose-response, herbicide, surfactant, vegetable oil

Introduction

Weeds are the most omnipresent class of pests that interfere with crops through competition and allelopathy, and this might result in the direct loss of the quantity and quality of agricultural products. Chemical weed control is an indispensable and efficient method for weed control. In Iran, herbicide usage accounts for 50% of the total pesticide consumption (Nazeri-Gahkani and Mirshekari, 2014).

Indiscriminate use of herbicides to control weeds during the past few decades has resulted in severe ecological and environmental

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problems, such as herbicide resistance and shifts in weed populations (Hammami *et al.*, 2014). Only a very small part (< 0.1%) of herbicides used to control weeds reaches the sites of action (Pimentel, 1995), which not only increases the cost of crop protection but also causes severe environmental pollution. Therefore, optimizing herbicide use in crops is necessary. One of the most important methods to improve the efficacy of herbicides and minimize their impact on off-target organisms is the application of an appropriate dosage of the relevant adjuvant (Nazeri-Gahkani and Mirshekari, 2014). That is usually along with the intensified herbicide penetration into the plant foliage (Izadi *et al.*, 2013; Green and Beestman, 2007).

According to previous reports, it appears that the use of adjuvants is the best solution to improve the efficacy of herbicides and minimize their impact on off-target sites (Izadi and Aliverdi, 2015). Adjuvants could reduce herbicide usage, side effects, and unpredictable costs (Aliverdi *et al.*, 2009; Izadi *et al.*, 2013). Adjuvants are commonly added to the formulations or applied as tank mix herbicide spray solutions to enhance the herbicide performance and improve weed control efficacy (Bunting *et al.*, 2004; Kammler *et al.*, 2010). Some other research has indicated that adjuvants can reduce the leaching of herbicides through the soil profile (Reddy, 1993). Additionally, it has been discovered that adjuvants' properties such as molecular weight, ethylene oxide content, HLB (Hydrophilic–Lipophilic Balance), melting point, and surface tension can affect the enhancement of herbicide phytotoxicity (Mathey *et al.*, 1995).

The leaf epicuticle is the first barrier to diffusing the active ingredient into the leaf tissue of plants (Hess and Foy, 2000). It is believed that vegetable oils could promote the penetration of the active ingredient via solubilizing or disrupting the nature of cuticular waxes (Izadi *et al.*, 2013; Rastgoo *et al.*, 2020). Previous studies have represented that increasing the penetration of vegetable oils' active ingredients via softening or disrupting cuticular waxes is more effective than decreasing the surface tension of spray droplets by surfactants (Izadi and Aliverdi, 2015; Rastgoo *et al.*, 2020), and this allows the herbicides' retention and diffusion on foliage (Rashed-Mohassel *et al.*, 2010). Moreover, adjuvants can delay crystallization (Bunting *et al.*, 2004) and, reduce volatilization (Ramsey *et al.*, 2006), and decrease photo-degradation of herbicides on the leaf surface (Si *et al.*, 2004). It is indicated that vegetable oils have a less phytotoxic impact and are degraded and metabolized faster than mineral oil in the environment (Cabanne *et al.*, 1999). In some experiments, vegetable-based oils were less effective than petroleum-based ones (Zawierucha and Penner, 2001). However, in some other experiments, vegetable-based oils enhanced herbicidal activity as much as petroleum-based ones (Hammami *et al.*, 2011).

Therefore, from the environmental and economic points of view, optimizing the herbicide dosage is essential in reducing its possible side effects. This research aims to determine the best adjuvant for enhancing the biological activity of nicosulfuron on *A. retroflexus* L., *C. album* and *E. crus-galli* L.

Materials and Methods

Plant material and growth

Seeds of *A. retroflexus*, *C. album*, and *E. crus-galli* were collected from the Research Field of Ferdowsi University of Mashhad (Lat. 36° 15' N, Long 59° 28' E; 985 m Altitude) in 2018 and then stored in a refrigerator at 4 ± 1 °C for five months. Seeds were sown in 1 to 1.5 cm depth into 2 L plastic pots filled with sand, peat, and soil (1:1:1; v/v/v). The soil texture was sandy loam (75% sand, 22.62% silt, 2% clay), 0.48% organic matter, and a pH of 7.8. The pots were kept in a greenhouse at 25/16°C (± 0.5 °C) day/night temperature with 60% (± 5%) relative humidity. The soil moisture was maintained at the field capacity level throughout the experimental period by surface water application as required. After the development of the second true leaf, the plants with uniform height were selected and thinned to five plants per pot and 40 ml of a water-soluble N:P:K (20:20:20) fertilizer at the concentration of 3 g fertilizer per liter of tap water was applied to each pot.

Treatments and chemicals

Nicosulfuron at 0 (control), 5, 10, 20, 40, and 80 g a.i. ha^{-1} of the recommended dose (Cruz®, 4% SC, Mahan, Iran) was used separately against *A. retroflexus*, *C. album*, and *E. crus-galli* in three-dose-response experiments. Nicosulfuron was applied without and with the adjuvants: (1) vegetable oils including cotton, (2) soybean, (3) maize, (4) rocket, and (5) Adigor® (a methylated seed oil, 44% methylated rapeseed oil, Plant Co., Iran), (6) Volck® oil (80% a paraffin oil, 18% water, 2% surfactant, Mahan, Iran), (7) HydroMax™ (90% yucca extract, 2% humic acid, 5% surfactant, Arman Sabz, Iran at 0.5% (v/v),(8) Cytogate® (a nonionic emulsifier, 100% alkylarylpolyglycol ether, Taranom Pars, Iran), (9) Trend® 90 (a Isodecyl alcohol ethoxylate, BASF, Germany and (10) D-octil® (sodium sulfosuccinate and small amounts of copper and molybdenum, Arman Sabz, Iran) at 0.2 % (V/V). Emulsifiable oils were prepared by dissolving Cytogate® emulsifier in each vegetable oil (95% vegetable oil + 5% emulsifier). These experiments were carried out as factorial arrangement based on completely randomized design (CRD) with four replications.

The herbicide was applied at four leaf stages 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 200 kPa spray pressure. Four weeks after herbicide spraying, the aboveground shoot of surviving plants in each pot was harvested and weighed to estimate the fresh weight. Then, the plants were oven-dried at 75°C for 48 h and reweighed to measure their dry weight. This experiment was performed twice, and similar results were obtained each time. Therefore, the data from the two runs were pooled and analyzed.

Statistical analysis

The response of fresh and dry weight (U) of the weeds to herbicide dose (z) was analyzed by a three-parameter log-logistic model described by Nielsen *et al.* (2004).

$$U = \frac{D}{1+exp\,\{b\,(log(z)-log(ED_{50}))\}} \qquad [1]$$

Where U denotes the fresh or dry weight at the dose of herbicide preparation (Z); D is the upper limit; ED_{50} denotes the required dose of herbicide to give 50% *A. retroflexus*, *C. album*, and *E. crus-galli* control, which can be replaced with ED_{10} and ED_{90}; and b is the slope of the curve (Equation 1). The dose-response curves were analyzed by open-source R software (ver. 4.1.1), utilizing the drc package (Ritz and Streibig, 2005). Based on the analysis of residuals, in some cases, homogeneity of variance was not met, and a transformation both sides technique (Box-Cox data transformation) was applied (Ritz et al., 2015). 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) (Equation 2).

$$RP = \frac{ED_{50f}}{ED_{\,50f+v}} \qquad [2]$$

ED_{50f} denotes the ED_{50} of herbicide alone, and ED_{50f+v} shows the ED_{50} of herbicide with each adjuvant (Equation 2). If R = 1, the addition of adjuvant would not have any effect on herbicide response. But, if R were higher or lower than 1, the herbicide accompanied by adjuvant would be more or less potent than the herbicide alone, respectively. Significant differences among $ED_{(10,\ 50,\ or\ 90)}$ and RP values were analyzed using the drc package (Keshtkar *et al.*, 2021). Also, the response of the dry weight of plants to adjuvants alone was statistically analyzed using analysis of variance (ANOVA), and the mean comparisons were done by fischer's protected least significant Difference (LSD) test ($p \leq 0.05$) in SAS version 9.1.

Results

Phytotoxicity of adjuvant

When adjuvants were applied alone, only Hydromax had a negative effect on *E. crus-galli* and significantly decreased its fresh and dry weight (Figure 1).

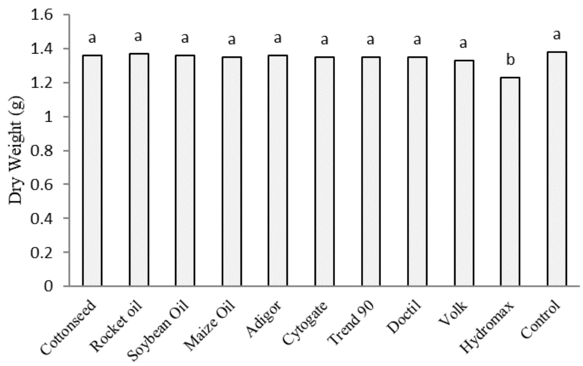

Figure 1 The response of *E. crus-galli* dry weight to different adjuvants alone. Means with the same letter are not significantly different at p ≤ 0.05 based on LSD Test.

Bio-Efficacy Studies

Accordingly, nicosulfuron alone required dose to reduce 50 percent of *A. retroflexus*, *E. crus-galli*, and *C. album*' dry weight (ED_{50}) was 3.68, 8.21, and 18.65 g a.i. ha^{-1}, and for fresh weight was; 5.76, 12.39, and 28.53 g a.i. ha^{-1}, respectively (Tables 1, 2 and 3). Results indicate that *C. album*' tolerance to nicosulfuron herbicide is higher than *A. retroflexus* and *E. crus-galli*. However the performance of nicosulfuron increased significantly when applied with adjuvants. (Tables 1-3).

According to the parameters estimated by the log-logistic model, the highest efficacy (i.e., lowest ED_{10}, ED_{50}, and ED_{90}) in each weed species was obtained when nicosulfuron was applied with HydroMax™, Trend® 90, and D-octil® adjuvants, respectively. The ED_{10}, ED_{50} and ED_{90} values for nicosulfuron plus HydroMax™ in *A. retroflexus* dry weight were 0.09, 0.92 and 9.50 g a.i. ha^{-1}; in *E. crus-galli* were 0.3, 2.38 and 18.79 g a.i. ha^{-1}, and in *C. album* were 2.23, 11.31 and 53.87 g a.i. ha^{-1}, respectively, which showed statistically significant differences with nicosulfuron alone. The fresh weight data also showed similar results (Tables 1, 2 and 3).

The estimated relative potencies of nicosulfuron in the presence of all adjuvants were more than 1 (Fig. 1). These values were statistically significant and confirmed the role of adjuvant in increasing the efficacy of nicosulfuron. In all studied weeds, the highest relative potency of nicosulfuron was achieved in the presence of HydroMax™ adjuvant (Figure 2). So, the application HydroMax™ plus nicosulfuron increased the nicosulfuron efficacy in reducing the dry weight of *A. retroflexus*, *E. crus-galli*, and *C. album* by 4.02, 3.45, and 1.65 folds, respectively (Fig. 2).

Table 1 Estimated ED_{10}, ED_{50} and ED_{90} of nicosulfuron (recommended dose 80 g a.i. ha^{-1}) with and without the adjuvant against *Amaranthus retroflexus*.

Treatments	Dry Weigh			Fresh weigh		
	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE
Nico. + Cottonseed	0.16 (0.12) ^{b}	1.65 (0.69) ^{b}	17.14 (3.31) ^{b}	0.37 (0.21) ^{b}	2.65 (0.86) ^{b}	19.09 (3.67) ^{b}
Nico. + rocket	0.15 (0.12) ^{b}	1.70 (0.72) ^{b}	19.09 (4.16) ^{b}	0.21 (0.15) ^{b}	2.02 (0.81) ^{b}	19.98 (4.32) ^{b}
Nico. + Soyabean	0.11 (0.09) ^{b}	1.40 (0.66) ^{b}	18.04 (5.02) ^{b}	0.19 0.15) ^{b}	2.02 (0.86) ^{b}	21.91 (5.07) ^{b}
Nico. + Maize	0.15 (0.12) ^{b}	1.84 (0.78) ^{b}	22.14 (5.02) ^{b}	0.15 (0.13) ^{b}	1.87 (0.83) ^{b}	23.12 (5.53) ^{b}
Nico. + Adigor	0.09 (0.08) ^{b}	1.50 (0.61) ^{b}	15.59 (3.62) ^{c}	0.21 (0.16) ^{b}	1.94 (0.79) ^{b}	17.60 (3.82) ^{b}
Nico. + Cytogate	0.09 (0.08) ^{b}	1.15 (0.59) ^{b}	14.95 (3.50) ^{c}	0.15 (0.13) ^{b}	1.62 (0.74) ^{b}	17.07 (3.95) ^{b}
Nico. + Trend 90	0.09 (0.08) ^{b}	1.09 (0.56) ^{b}	13.09 (3.00) ^{c}	0.13 (0.12) ^{b}	1.45 (0.72) ^{b}	16.13 (3.90) ^{c}
Nico. + Doctil	0.10 (0.09) ^{b}	1.22 (0.60) ^{b}	14.50 (3.29) ^{c}	020 (0.15) ^{b}	1.83 (0.76) ^{b}	16.41 (3.58) ^{c}
Nico. + Volk	0.12 (0.10) ^{b}	1.45 (0.67) ^{b}	17.73 (4.05) ^{c}	0.24 (0.16) ^{b}	2.09 (0.79) ^{b}	18.35 (3.81) ^{b}
Nico. + Hydromax	0.09 (0.08) ^{b}	0.92 (0.48) ^{b}	9.50 (2.19) ^{d}	0.13 (0.11) ^{b}	1.23 (0.60) ^{b}	11.72 (2.27) ^{c}
Nico. (Control)	0.46 (0.14) ^{a}	3.68 (0.36) ^{a}	29.41 (5.79) ^{a}	1.11 (0.13) ^{a}	5.76 (0.33) ^{a}	29.97 (4.87) ^{a}

Nico = nicosulfuron, SE = Standard Error, Values with the same letters in each column are not significantly different at 5% probability level.

Table 2 Estimated ED_{10}, ED_{50} and ED_{90} of nicosulfuron (recommended dose 80 g a.i. ha^{-1}) with and without the adjuvant against *Echinochloa crus-galli.*

Treatments	Dry Weigh			Fresh weigh		
	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE
Nico. + Cottonseed	0.43 (0.13) ^{c}	3.64 (0.50) ^{b}	31.03 (3.81) ^{c}	0.56 (0.23) ^{c}	4.28 (1.01) ^{b}	32.66 (4.96) ^{b}
Nico. + rocket	0.45 (0.14) ^{c}	3.80(0.52) ^{b}	31.97 (4.00) ^{c}	0.58 (0.25) ^{c}	4.60 (1.10) ^{b}	36.15 (5.66) ^{b}
Nico. + Soyabean	0.46 (0.14) ^{c}	3.79 (0.52) ^{b}	31.05 (3.86) ^{c}	061(0.25) ^{c}	4.65 (1.07) ^{b}	35.45 (5.40) ^{b}
Nico. + Maize	0.76 (0.18) ^{b}	5.31 (0.60) ^{b}	37.08 (4.28) ^{b}	0.68 (0.27) ^{c}	5.26 (1.16) ^{b}	40.62 (6.34) ^{b}
Nico. + Adigor	0.49 (0.14) ^{c}	3.84 (0.48) ^{b}	29.82 (3.41) ^{c}	0.67 (0.28) ^{c}	4.88 (1.15) ^{b}	35.46 (5.53) ^{b}
Nico. + Cytogate	0.50 (0.14) ^{c}	4.03 (0.52) ^{b}	32.75 (3.81) ^{c}	0.65 (0.25) ^{c}	4.78 (1.18) ^{b}	35.46 (5.65) ^{b}
Nico. + Trend 90	0.40 (0.12) ^{c}	2.95 (0.39) ^{c}	21.60 (2.17) ^{d}	0.52 (0.23) ^{c}	4.12 (1.02) ^{b}	32.46 (5.19) ^{b}
Nico. + Doctil	0.42 (0.12) ^{c}	3.40 (0.46) ^{bc}	27.75 (3.15) ^{c}	0.64 (0.2 7) ^{c}	4.77 (1.15) ^{b}	35.81 (5.70) ^{b}
Nico. + Volk	0.57 (0.16) ^{c}	4.37 (0.54) ^{b}	33.32 (3.97) ^{c}	0.75 (0.30) ^{b}	5.21 (1.18) ^{b}	36.03 (5.37) ^{b}
Nico. + Hydromax	0.30(0.11) ^{d}	2.38 (0.41) ^{d}	18.79 (2.08) ^{d}	0.53 (0.23) ^{c}	3.86 (0.96) ^{b}	28.18 (4.39) ^{c}
Nico. (Control)	0.93(0.22) ^{a}	8.21 (0.89) ^{a}	72.76 (9.91) ^{a}	2.25 (0.99) ^{a}	12.39 (2.88) ^{a}	68.18 (9.84) ^{a}

Nico = nicosulfuron, SE = Standard Error, Values with the same letters in each column are not significantly different at 5% probability level.

Table 3 Estimated ED_{10}, ED_{50} and ED_{90} of nicosulfuron (recommended dose 80 g a.i. ha^{-1}) with and without the adjuvant against *Chenopodium album.*

Treatments	Dry Weigh			Fresh weigh		
	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE	ED_{10} ± SE	ED_{50} ± SE	ED_{90} ± SE
Nico. + Cottonseed	3.20 (0.58) ^{ab}	15.03 (1.26) ^{b}	79.77 (11.07) ^{c}	2.98 (1.34) ^{b}	20.60 (4.11) ^{b}	142.56 (34.53) ^{c}
Nico. + rocket	3.06 (0.62) ^{b}	15.15 (1.36) ^{b}	102.89 (15.96) ^{b}	2.83 (1.31) ^{b}	20.13 (4.10) ^{b}	143.20 (35.06) ^{c}
Nico. + Soyabean	2.91 (0.59) ^{b}	15.56 (1.29) ^{b}	83.13 (11.77) ^{c}	2.55 (1.23) ^{b}	19.85 (4.19) ^{b}	154.43 (40.61) ^{c}
Nico. + Maize	2.90 (0.63) ^{b}	15.09 (1.22) ^{b}	79.04 (10.78) ^{c}	2.65 (1.23) ^{b}	21.68 (4.41) ^{b}	177.37 (49.67) ^{b}
Nico. + Adigor	2.83 (0.57) ^{b}	15.04 (1.20) ^{b}	68.37 (8.69) ^{d}	2.50 (1.20) ^{b}	17.60 (3.80) ^{b}	124.30 (29.40) ^{d}
Nico. + Cytogate	2.37 (0.44) ^{bc}	14.54 (1.17) ^{b}	68.25 (8.83) ^{d}	2.27 (1.13) ^{b}	16.86 (3.75) ^{b}	125.02 (30.45) ^{d}
Nico. + Trend 90	3.31 (0.64) ^{a}	13.36 (1.00) ^{b}	55.79 (7.15) ^{e}	2.42 (1.18) ^{b}	16.21 (3.61) ^{b}	108.73 (23.97) ^{e}
Nico. + Doctil	2.88 (0.57) ^{b}	15.18 (1.19) ^{b}	65.17 (8.30) ^{d}	2.53 (1.21) ^{b}	17.43 (3.81) ^{b}	120.32 (27.99) ^{d}
Nico. + Volk	3.10 (0.60) ^{ab}	15.93 (1.33) ^{b}	82.98 (11.60) ^{c}	2.92 (1.36) ^{b}	19.70 (4.06) ^{b}	132.86 (31.67) ^{d}
Nico. + Hydromax	2.23 (0.49) ^{c}	11.31 (0.86c	53.87 (6.99) ^{e}	1.85 (0.91) ^{c}	13.63 (3.17) ^{c}	100.59 (22.66) ^{e}
Nico. (Control)	3.53 (0.66) ^{a}	18.65 (1.61) ^{a}	120.04 (18.17) ^{a}	4.48 (1.40) ^{a}	28.53 (5.09) ^{a}	181.77 (45.91) ^{a}

Nico = Nicosulfuron, SE = Standard Error, Values with the same letters in each column are not significantly different at 5% probability level.

Therefore, the performance of 1 g a.i. ha^{-1} nicosulfuron in the presence of Hydromax in reducing dry weight of *A. retroflexus*, *E. crus-galli,* and *C. album* has equaled the performance of 4.02, 3.45, and 1.65 g a.i. ha^{-1} nicosulfuron alone, respectively, that had statistically significant differences (Fig. 2). Thus, applying nicosulfuron with adjuvants could lead to better control of *A. retroflexus*, *E. crus-galli*, than *C. album.*

Based on the relative potency values, there were no statistical differences between adjuvants ($p \leq 0.05$) to enhance the efficacy of nicosulfuron for decreasing the dry weight of *A. retroflexus.* However, HydroMax™, Trend®90, Cytogate, and Adigor® had the highest efficacy for controlling *A. retroflexus.* Similar results were obtained in *E. crus-galli* and *C. album.* However HydroMax™ and Trend®90 were the most effective adjuvants in the performance of nicosulfuron (Figure 2). Accordingly, among the evaluated adjuvants, HydroMax™ and Trend®90 had the highest effect on nicosulfuron efficacy in all three weeds (Fig. 2).

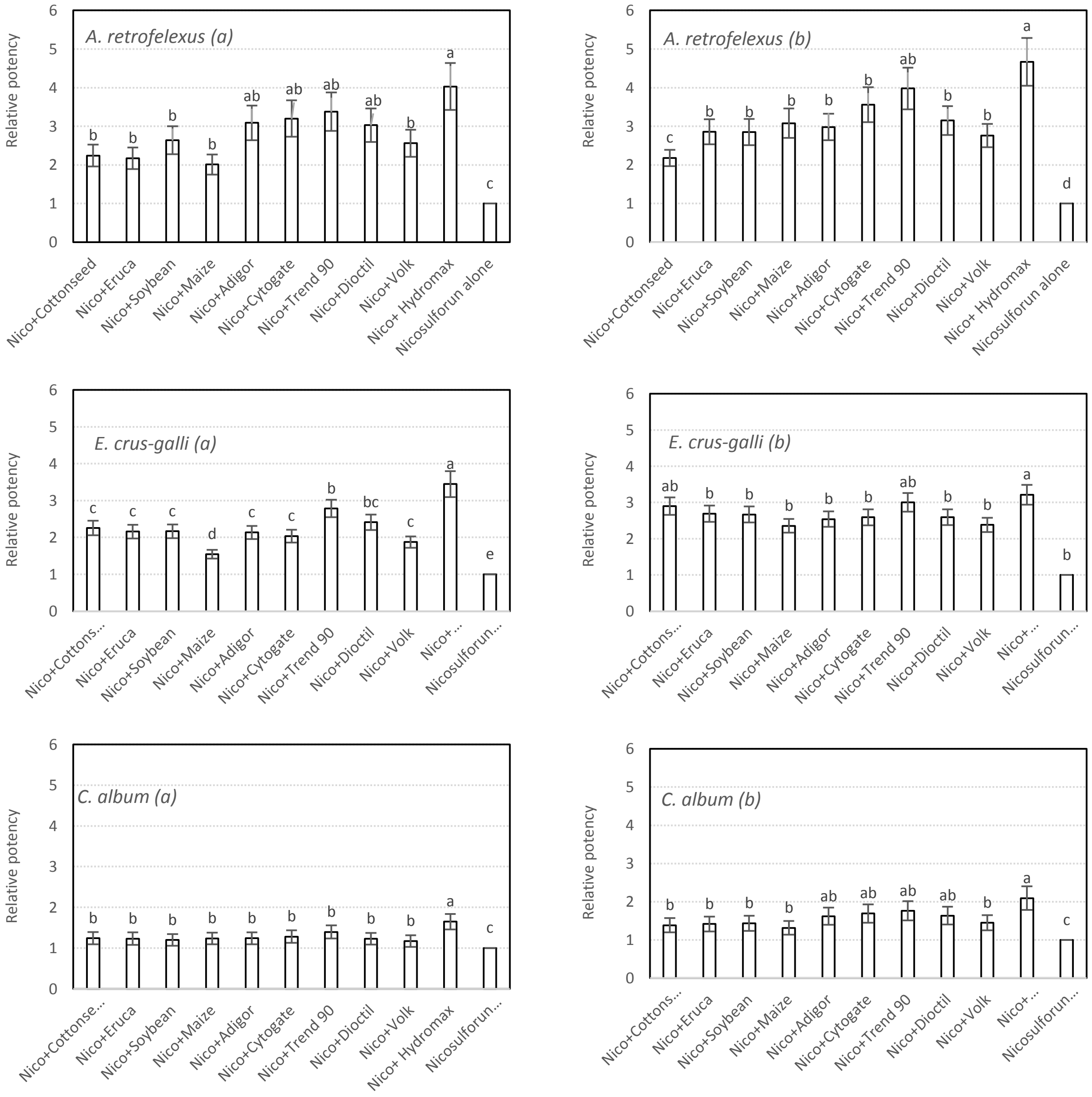

Figure 2 Relative potency values of nicosulfuron plus adjuvant on *A. retroflexus*, *C. album*, and *E. crus-galli* dry weight (a) and fresh weight (b). Values with the same letters are not significantly different at 5% probability level. Nico = Nicosulfuron. Error bars represent the standard error (SE).

Discussion

The results showed that *C. album* tolerance to nicosulfuron is higher than to *A. retroflexus* and *E. crus-galli*. Previous studies have also demonstrated that nicosulfuron herbicide can control *A. retroflexus* species and *E. crus-galli* (Baghestani *et al.*, 2013). However, it has also been documented that *C. album* is more tolerant than *A. retroflexus* in response to glyphosate (Azad et al., 2014) and 2, 4-D + MCPA (Izadi-Drabandi *et al.*, 2011) herbicides. The main underlying idea is that the difference between the morphological and physiological properties of the weeds (Bullman *et al.*, 2008), from the viewpoint of cuticle structure and chemical composition of leaf cuticle wax, is the effectiveness of herbicide droplet retention and penetration in the cuticle (Izadi-Drabandi *et al.*, 2011). Perhaps more tolerance of *C. album* to nicosulfuron is associated with the high amounts of calcium and its cuticle (Izadi-Drabandi *et al.*, 2011).

All adjuvants, specially HydroMax™ and Trend® 90 increased nicosulfuron efficacy for controlling A. *retroflexus, C. album,* and *E. crus-galli*. The improvement of the nicosulfuron by HydroMax™ and Trend®90 adjuvants may be associated with a theory that states the solubilizing, softening or disordering nature of cuticular waxes by adjuvants (Hazen 2000). Also, it is known that the adjuvants are likely to improve the spreading and permeability of the herbicides active ingredients (Johnson *et al.*, 2002; Stock and Briggs 2000). It seems that the HydroMax™ and Trend®90 led to more cuticular penetration and stomata infiltration, allowing better nicosulfuron absorption and translocation and increasing the it·s efficacy for controlling the studied weeds.

Similar results were reported by Mamnoie *et al.* (2017) in field conditions. They reported that the application of HydroMax™ - nicosulfuron in the corn field increased *Portulaca oleracea* L. *Solanum nigrum* L. and *Amaranthus retroflexus* L. control by 84, 79 and 100%, respectively (Mamnoie *et al.*, 2017). Other studies have demonstrated that adjuvant application with herbicides increased the efficacy of sulfosulfuron imazamethabenz-methyl, sethoxydim *(*Izadi *et al.*, 2013), sulfosulfuron (Izadi and Aliverdi, 2015), diclofop-methyl, cycloxydim, clodinafop-propargyl (Rashed-Mohassel et al., 2010), and haloxyfop-R-methyl (Rastgoo *et al.*, 2020), Sharma and Singh (2000) also believed that an increase in the permeability of the herbicide through disordering the cuticular waxes is more important on weed control than reducing the surface tension of herbicide. Therefore, these results emphasize the dependency of herbicide performance on the adjuvants properties and plant species. Selecting the proper adjuvant is a key factor in efficacious weed management via reducing herbicide rate, which is this research's main priority.

Conclusions

The results showed that *C. album* tolerance to nicosulfuron is higher than *A. retroflexus* and *E. crus-galli*. The efficacy of nicosulfuron was enhanced using the adjuvants on the mentioned three species. Hydromax™ and Trend® 90 were more effective than other adjuvants on nicosulfuron for controlling *A. retroflexus*, *C. album*, and *E. crus-galli*, while the maize oil had the least effect. In general, the benefit of the adjuvants by improving nicosulfuron efficiency to control *A. retroflexus*, *C. album*, and *E. crus-galli* was more significant than nicosulfuron alone, and their effect on nicosulfuron on *A. retroflexus* and E. *crus-galli* was more than on *C. album.*

Acknowledgments

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تأثیر مواد افزودنی بر کارایی نیکوسولفورون در کنترل تاج‌خروس ریشه قرمز *Amaranthus retroflexus*، سلمه تره *Chenopodium album* و سوروف *Echinochloa crus-galli*

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چکیده: به‌منظور بررسی کارایی نیکوسولفورون در کنترل علف‌های‌هرز تاج‌خروس ریشه‌قرمز، سلمه تره و سوروف با استفاده از مواد افزودنی، سه آزمایش به‌صورت فاکتوریل در قالب طرح پایه بلوک‌های کامل تصادفی با چهار تکرار در گلخانه تحقیقاتی دانشکده کشاورزی دانشگاه فردوسی مشهد انجام شد. تیمارهای آزمایش شامل مقادیر کاربرد نیکوسولفورون در شش سطح صفر (شاهد)، ۵، ۱۰، ۲۰، ۴۰، ۸۰ گرم ماده مؤثره در هکتار و کاربرد مواد افزودنی شامل روغن‌های پنبه‌دانه، منداب، سویا، ذرت، آدیگور، ولک و هیدرومکس، سیتوگیت، ترند۹۰ و دی‌اُکتیل به‌همراه شاهد (بدون کاربرد مواد افزودنی) بودند. نتایج نشان داد که کارایی نیکوسولفورون در کنترل تاج خروس ریشه قرمز، سلمه تره و سوروف با کاربرد مواد افزودنی به‌طور معنی‌داری افزایش یافت. دو ماده افزودنی هیدرومکس و ترند ۹۰ بیش‌ترین تأثیر در افزایش کارایی نیکوسولفورون در کنترل علف‌های هرز تاج خروس ریشه قرمز، سلمه تره و سوروف داشتند. به‌طوری‌که کارایی نیکوسولفورون در حضور ماده افزودنی هیدورومکس در کنترل تاج خروس ریشه قرمز، سوروف و سلمه تره به‌ترتیب ۴/۰۲، ۳/۴۵ و ۱/۶۵ برابر کاربرد نیکوسولفورون بدون ماده افزودنی بود. درمجموع، کارایی کاربرد نیکوسولفورون با مواد افزودنی در کنترل تاج خروس ریشه قرمز و سوروف بیش‌تر از سلمه تره بود.

واژگان کلیدی: دز پاسخ، روغن گیاهی، علف‌کش، مویان