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RESEARCH ARTICLE

Yield of sweet corn varieties and response to sulfonylurea and mix herbicides

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Abstract: Background: Sweet corn is susceptible to weed competition for nutrients, moisture, and light interception. Herbicides labeled for use on sweet corn are limited. Hence, it is necessary to provide information about the POST sulfonylurea herbicides and mixtures and their different degrees of sensitivity in sweet corn varieties.

Objective: The objectives of this experiment were to evaluate the efficacy of sulfonylureas and nicosulfuron+bromoxynil/MCPA and mesotrione/s-metolachlor/terbuthylazine as post herbicide mixtures on broadleaves and grasses weed species, sweet corn grain yield and crop injury.

Methods: Field experiments were conducted in 2017-19 to investigate the efficacy of the acetolactate synthase (ALS)-inhibiting herbicides nicosulfuron at 80 g a.i. (active ingredient) ha^{-1}, nicosulfuron/rimsulfuron (37.5+37.5)% at 131.25 g a.i. ha^{-1}, foramsulfuron at 45 g a.i. ha^{-1}, and mixture of herbicides nicosulfuron at 80 g a.i. ha^{-1}+bromoxynil/MCPA (20+20)% at 600 g a.i. ha^{-1}, mesotrione/s-metolachlor/terbuthylazine (3.75+37.5+12.5)% at 1343.75 g a.i. ha^{-1} on the grain yield of three sweet corn varieties.

Results: The results indicated that nicosulfuron, nicosulfuron+bromoxynil/MCPA and nicosulfuron/rimsulfuron, respectively, controlled ≥ 90% of *Amaranthus retroflexus* L. and *Solanum nigrum* L. at Mashhad. A reduction in biomass nearly ≥ 80% was observed in *A. retroflexus*, *Cyperus rotundus* L., *Heliotropium europaeum* L., *Echinochloa crus-galli* (L.) Beauv., *Abutilon theophrasti* Medik. by these herbicides in Sari, Iran. The applications of nicosulfuron, foramsulfuron and mesotrione/s-metolachlor/terbuthylazine at 80, 45 and 1343.75 g a.i. ha^{-1} respectively, to 'Golden KSC403su', mesotrione/s-metolacholor/terbuthlazine at 1343.75 g a.i. ha^{-1} to 'Merit' and nicosulfuron and mesotrione/s-metolachlor/terbuthylazine at 80 and 1343.75 g a.i. ha^{-1} respectively, to 'Chase' were associated with the maximum sweet corn yield.

Conclusion: The experiment showed that weed control improved grain yield on sweet corn varieties through sulfonylurea herbicide applications.

Keywords: ALS inhibitor; grain yield; herbicide sensitivity; recommended dose; *Zea mays* L

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1. Introduction

Sweet corn is an important vegetable, grown over 2,000 hectares in Iran. The demand for sweet corn consumption in its fresh form or as a processed vegetable has contributed to a significant increase in its cultivation in recent years (Rahmani et al., 2010).

Weed management is a critical problem in sweet corn production because weeds strongly compete with the crop for nutrients, moisture, and light (Wilson et al., 2010). Bollman et al. (2008) reported that sweet corn yield is reduced to 77% when one *Ambrosia trifida* L. plant/m^2 is present. Therefore, to achieve suitable sweet corn production, broad-spectrum weeds should be controlled effectively (Tavella et al., 2014). Currently, chemical control can be very important because of the low efficiency and cost effectiveness of mechanical or other methods of weed control (Khan et al., 2016). Chikoye et al. (2001) suggests hand weeding is more expensive than chemical control.

Sulfonylureas such as nicosulfuron, rimsulfuron, and foramsulfuron are effective group of herbicides for annual and perennial weed control in maize. These herbicides provides a new chance for weed management in maize. Their mode of action occurs through inhibiting acetolactate synthase (ALS), thereby interfering with the production of branched-chain amino acids, leucine, isoleucine, and valine (Zhang et al., 2013; Mariani et al., 2019). The primary symptoms appears on the meristemic growing points. A few days after treatment, chlorosis and the necrosis of the terminal buds are visible, followed by gradual death of the plants in 3-4 weeks. The spectrum of most prevailing and damaging weeds controlled by sulfonylureas in maize includes *Amaranthus* spp., *Chenopodium album* L., *Solanum nigrum* L., *Convolvulus arvensis* L., *Abutilon theophrasti* Medik., *Helianthus annuus* L., *Sorghum halepense* (L.) Pers., *Setaria* and *Panicum* spp., *Cyperus rotundus* L., and *Echinochloa crusgalli* (L.) Beauv. (Baghestani et al., 2007). Baghestani et al. (2007) reported that nicosulfuron, rimsulfuron, and foramsulfuron were very effective on broadleaf and grass weed species control at different provinces of Iran in maize fields. Koeppe et al. (2000) stated that nicosulfuron and rimsulfuron provided satisfactory control of *A. retroflexus* L. and *C. album*. Zand et al. (2009) found that nicosulfuron/rimsulfuron had more effective control on grasses, whereas the greater impact on the broad leaves was caused by mesotrione/s-metolachlor/terbuthylazine.

Herbicides labeled for use on sweet corn are limited and dependent on tolerance of varieties. Therefore, further studies should be performed to identify herbicide options in Iran. Sweet corn varieties have different tolerance to sulfonylureas. In addition, some sweet corn varieties are sensitive to multiple P450-metabolized herbicides, such as mesotrione (Soltani et al., 2007). However, tolerance of sweet corn to herbicides is affected by several factors, i.e., variety, herbicide application dose, and environmental conditions (Williams et al., 2005; Wilson et al., 2010). Soltani et al. (2007) demonstrated that some sweet corn hybrids in Ontario such as 'Calico Belle', 'Delmonte 2038', and 'GH2684' are sensitive to mesotrione, nicosulfuron, primisulfuron, foramsulfuron, isoxaflutole, and bentazon.

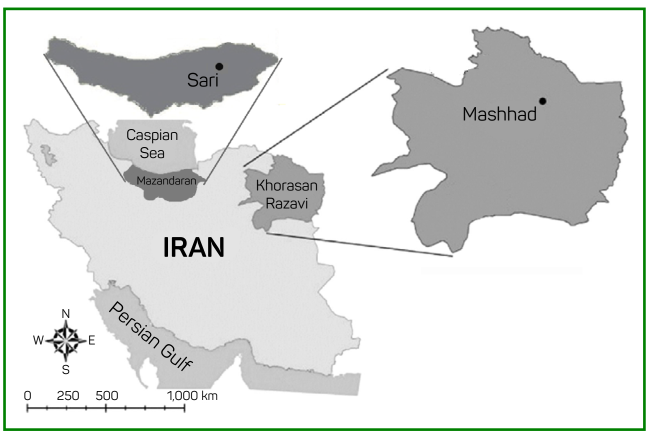

Figure 1 - Map of Iran showing geographical sites of Khorasan Razavi (Mashhad) and Mazandaran (Sari) Provinces

Also, 'Merit' was classified as a hybrid sensitive to RPA 201772, nicosulfuron, foramsulfuron, and mesotrione (O'Sullivan et al., 2001; Pataky et al., 2008). Therefore, variety sensitivity is recognized as a key factor for herbicide registration for sweet corn.

Sweet corn tolerance to sulfonylureas has remained understudied in Iran. Hence, it is necessary to provide information about the POST sulfonylurea herbicides and mixtures and their different levels of sensitivity in sweet corn varieties when applied under the various climatic conditions of Iran. Therefore, this experiment was conducted with the following objectives: (1) to specify the efficacy of sulfonylureas and nicosulfuron+bromoxynil/MCPA and mesotrione/s-metolachlor/terbuthylazine for broadleaved and grassy weed control; (2) to assess herbicide impact to sweet corn grain yield response to them; and (3) to estimate the risk of injury to three varieties of sweet corn from these herbicides.

2. Material and Methods

2.1 Site description and experimental design

Two field experiments were performed at the private farm of Ferdowsi University of Mashhad (lat. 36°15'N; long. 59°28' E; 985 m Altitude) and at research fields of Plant Protection Research Institute of Sari (lat. 36°40' N; long. 53°10' E; 16 m Altitude), to evaluate the efficacy of sulfonylurea nicosulfuron, nicosulfuron/rimsulfuron (37.5+37.5)% and foramsulfuron and post herbicide mixtures nicosulfuron+bromoxynil/MCPA (20+20)% and mesotrione/s-metolachlor/terbuthylazine (3.75+37.5+12.5)% on broadleaved and grass weed control and on three varieties of sweet corn (*Zea mays* L. var. saccharata) 'Golden KSC403su', 'Merit' and 'Chase' grain yield in 2017/2018 and 2018/2019.

The study locations are showed in Figure 1. Table 1 describes climate conditions for air temperature and total

Table 1 - Monthly air temperature and total rainfall at the experimental sites during 2017-2019 at Mashhad and Sari regions, Iran.

Month	Air temperature (°C)						Total rainfall (mm)			
	Mashhad			Sari			Mashhad		Sari	
	2017/18	2018/19	Mean	2017/18	2018/19	Mean	2017/18	2018/19	2017/18	2018/19
October	17.1	16.6	16.9	20	18	19.0	0.51	0.003	134.5	79
November	15.5	14.6	15.1	12.6	10.7	11.7	0.01	0.21	67.2	80.7
December	6.2	5.3	5.7	9.1	8.5	8.8	0.03	0.09	52	46.3
January	7.3	5. 9	6.7	9.4	7.7	8.6	0.04	0.03	73.2	76.7
February	6.8	4.5	5.7	9.4	6.8	8.1	1.1	0.3	135.5	69.4
March	13.3	11.1	12.2	13.2	11.3	12.3	2.8	2.4	74.7	37.7
April	14.7	13.7	14.2	16.3	15.2	15.8	2.2	2.4	70.9	71.9
May	20.4	21	20.7	21.3	21.9	21.6	1.9	0.6	54	2.1
June	26.9	27.3	27.1	25.5	25.3	25.4	1.3	0.09	43.7	2
July	26.1	28.2	27.2	26.3	28.1	27.2	1.4	0.03	107.2	6.2
August	26.3	27.9	27.1	28.5	29.4	29.0	0.2	0.13	2	1

rainfall during the sweet corn-growing season for every year of the experiments. Sweet corn varieties ('Golden KSC403su', 'Merit' and 'Chase'), planting date, and soil properties at both regions are presented in Table 2. The trials were arranged in a two-factor randomized complete block with four replications over the course of two years. Chemical treatments were the different herbicides listed in Table 3, with weed free, weed infested checks in each block as controls.

2.2 Crop sowing and herbicide application

Seedbeds in the experiment sites were prepared in the fall (October of the previous year) through disk and harrow, and with a soil leveler (Hydralic Model ID-LVR-01, Iran) before crop planting. The soil fertility was improved by applying 200 and 150 kg.ha^{-1} of ammonium phosphate and potassium sulphate, respectively, based on soil test results before planting. Moreover, nitrogen was applied as urea at 300 kg.ha^{-1}, with the dose divided into halves, at planting and four to six true sweet corn leaves. Each experimental unit was 6 m long × 3 m wide (four rows), with rows separated 0.75 m apart. Sweet corn seeds were planted 3 to 5 cm deep by foca (e.g. ruler hoes) with 0.18 m between plants in the row. Two or three seeds were scattered by hand into each hole. Sweet corn cultivars (Falatiran Co., Tehran, Iran) were sown in mid-May (Table 2), with a density of 75,000 plants ha^{-1} in both areas. Crops were thinned to one plant per hill at the stage with two to three true leaves. All herbicides were applied post-emergence four weeks after planting with an electric knapsack sprayer (Matabi 121030 Super Agro 20 l sprayer; Agratech Services- Crop®, Spraying Equipment, Rossendale, UK) fitted with 8,002 flat fan nozzles and calibrated to deliver 300 L.ha^{-1} of spray solution at a pressure of 2.5 kPa.

2.3 Data Collection and Statistical Analysis

Four weeks after herbicide application, the number and dry weight of aboveground weeds parts were harvested within three fixed 0.5 × 0.5 m quadrats in every plot, separated by species, enumerated, oven-dried at 75 °C for 48 h, and then weighed. Then, percent weed density and biomass reductions were measured by dividing the weed density and biomass of a specific treatment by weed density and biomass, respectively, in the weed infested multiplied by 100. Visual crop injury was estimated at 14 days after treatment (DAT) applying a criterion of 0 to 100% with

Table 2 - Sweet corn cultivars and planting date, and soil texture at two locations in 2017-2019.

Location	Varieties	Planting time	Soil properties				pH	EC[1]
					Sandy silt loam			
	Golden KSC403su	May 15, 2018	Sand	Clay	Silt	Organic matter	7.4	1.5 dS m^{-1}
Mashhad	Merit	May 14, 2019	52%	13%	41%	0.91%		
	Chase							
					Silty clay			
	Golden KSC403su	May 22, 2018	Sand	Clay	Silt	Organic matter	6.8	1.2 dS m^{-1}
Sari	Merit	May 21, 2019	48%	15%	36%	2.26%		
	Chase							

[1] Soil electrical conductivity (EC) = is a measure of the amount of salts in soil (salinity of soil). It is an excellent indicator of nutrient availability and loss, soil texture, and available water capacity.

Table 3 - List of post emergence herbicides, active ingredient, their rates, mode of action, and manufacturer in field experiments at Mashhad and Sari regions in 2017/2018 and 2018/2019 to control weeds in sweet corn varieties.

Active ingredient	Application rate	Mode of action	Manufacturer
	g a.i. ha^{-1}		
Nicosulfuron (Cruz®) 4% SC	80	ALS Inhibitor	Biesterfeld, Greece
Nicosulfuron/rimsulfuron (37.5+37.5)% (Ultima) 75% WG	131.25	ALS Inhibitor	Golsam Gorgan Chemicals Corporation, Gorgan, Iran
Foramsulfuron (Equip) 2.25% OD	45	ALS Inhibitor	Bayer Crop Science, Tehran, Iran
Nicosulfuron (Cruz®) 4% SC + bromoxynil/MCPA (20+20)% (Bromicide MA) 40% EC	80+600	ALS Inhibitor+ PSII Inhibitor+ Synthetic auxins	Biesterfeld, Greece+Nufarm, France
Mesotrione/s-metolachlor/terbuthylazine (3.75+37.5+12.5)% (Lumax) 53.75% SE	1343.75	Pigment Inhibitor+ DNA_S Inhibitor+ PSII Inhibitor	Syngenta Crop Protection AG, Post Fach, CH-4002, Basel, Switzerland

0% = no injury and 100% = complete death of the crops. At crop physiological maturity (at the end of the growing season), ten sweet corn plants from two middle rows (a 2 m^2 area) in each plot were clipped at the soil surface, sectioned, placed in paper bags, oven-dried at 75 °C for 72 h, and weighed. Eventually, seeds were separated from the cobs, and total number of seeds from ten sweet corn plants harvested from each plot was used to estimate total sweet corn grain yield on a per hectare basis. Both experiments were repeated and results were combined into one analysis because similar results were recorded for each location. The ANOVA was performed through the PROC GLM procedure in SAS 9.1 statistical software (SAS Institute, 2003) for all data recorded, and treatment means were separated using Fisher's protected least significant difference at $P < 0.05$. For sweet corn injury data at 14 DAT, arcsine square root transformation was applied for the normalization of percent injury data, after which an analysis of variance (ANOVA) and mean separations were performed. The original scale was acquired by comparing the means of percent injury according to the converted scale and then modified back to the primary scale.

Principal component analysis (PCA) technique was used for reducing of data dimensions and better comprehension of the different treatments efficacy on species composition. Biplot diagram related to the variables coefficients of the first and second components was fitted in a two-dimensional biplot.

In the PCA, a biplot species-variety was created by data used as covariables and the varieties as marked variables. On the biplot, vectors and numbered points are shown as species and treatments in three verities, respectively. There is a close correlation between each treatments and species, which are placed in the same sector of the biplot. The longer vectors of the species are indicated that they have higher biomass reductions percent compared with species near the center of the biplot. In this technique, cosine of the angle between vectors was used for illustrating species; if the angle between vectors is ≈ 90°, it considered as zero, angle values larger than 90° indicate negative, while angle values smaller than 90° indicate positive. The drymatter of species biomass reductions percent from each treatment used in three of sweet corn in both locations were subjected to PCA analysis using the R software (R Core Development Team, 2020).

3. Results and Discussion

3.1 Efficacy of herbicides on weed density and biomass

At the Mashhad site, the dominant weeds were *A. retroflexus, Portulaca oleracea* L., *C. arvensis, C. album*, *S. nigrum* and *C. rotundus* during both years (Table 4). The percentages of weed density and biomass reduction were significantly different among herbicide treatments (Table 4).

Nicosulfuron and nicosulfuron+bromoxynil/MCPA at 80 and 80 + 600 g a.i. ha^{-1} reduced *A. retroflexus* density and biomass by more than 80% and 90%, respectively (Table 4). Nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1} also reduced *A. retroflexus* biomass by nearly 90%. Mohajeri et al. (2010) reported that the highest control (≥ 80%) of *A. retroflexus* can be achieved by nicosulfuron. Wilson et al. (2010) showed that nicosulfuron and nicosulfuron/rimsulfuron in maize provided > 70% control of volunteer cereals such as hard red winter wheat (*Triticum aestivum* L.) ('Hyland AC Morley'), soft red winter wheat ('Pioneer 25R47'), soft white winter wheat ('Pioneer 25W41'), and autumn rye (*Secale cereale* L.). Mesotrione/s-metolachlor/terbuthylazine at 1343.75 g a.i. ha^{-1} resulted in a biomass reduction of approximately 75% in *A. retroflexus* (Table 4). Hadizade et al. (2011) reported that mesotrion/s-metolacholor/terbuthlazine caused significant control (≥ 80%) on *A. retroflexus*. Wilson et al. (2010) reported that despite the similar mode of action, sulfonylureas' efficacy would be different in control of hard red winter wheat (*Triticum aestivum* L.) ('Hyland AC Morley'), soft red winter wheat ('Pioneer 25R47'), soft white winter wheat ('Pioneer 25W41'), and autumn rye (*Secale cereale* L.) ('FR') cultivar. However, no significant differences were observed between the density and biomass of *P. oleracea,* or *C. arvensis* reduction. The reduction of *P. oleracea* and *C. arvensis* density and biomass ranged from 60 to 65% and 54 to 75% respectively. *C. rotundus* density and biomass were reduced by 70% and 76%, respectively, when sprayed with nicosulfuron/rimsulfuron (Table 4). Hadizade et al. (2011) found that mesotrion/s-metolacholor/terbuthlazine efficacy was greater on *P. oleracea* control (≥ 78%) at 2,150 g a.i. ha^{-1}. Zand et al. (2009) indicated that post-emergence mesotrion/s-metolacholor/terbuthlazine application caused more than 75% control of *P. oleracea*. *C. rotundus* density and biomass diminished by 70% and 76% when sprayed by nicosulfuron/rimsulfuron. Mesotrione/s-metolachlor/terbuthylazine also provided acceptable control of *C. rotundus*, with 50 and 54% reductions, respectively, whereas the maximum *C. rotundus* survival occurred when nicosulfuron+bromoxynil/MCPA was applied (Table 4). Mohajeri et al. (2010) suggested that the highest control of *C. arvensis* was provided by foramsulfuron and nicosulfuron in maize. The greatest reduction in *C. album* biomass was obtained by nicosulfuron and mesotrione/s-metolachlor/terbuthylazine applications of 81 and 96%, respectively (Table 4). All treatments resulted in more than 69% and 96% reductions in density and biomass of *S. nigrum*. The least reduction in biomass (90%) was observed with nicosulfuron+bromoxynil/MCPA. This was significantly different from other treatments (Table 4). Barros et al. (2007) also suggested that apparent discrepancy among the herbicides in controlling weeds could be attributed to weed species. Hadizade et al. (2011) found that 100% control of *C. album* was

Table 4 - Efficacy of different herbicide treatments on percent weed density and biomass reductions at 4 weeks after post herbicide spray (WAPHS) at Mashhad in 2017-2019.

Treatments	Dose	Weed species													
	g a.i.ha^{-1}	*Amaranthus retroflexus*		*Portulaca oleracea*		*Convolvulus arvensis*		*Chenopodium album*		*Solanum nigrum*		*Cyperus rotundus*		Other [2]	
		Density reduction	Biomass reduction	Density reduction	Density reduction	Density reduction	Density reduction	Density reduction	Density reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction
		(%)													
Nicosulfuron	80	84.5b [1]	90.3b	66.3b	64.4b	66.3b	57.0b	82.2b	81.3b	80.1b	95.7b	62.4bc	48.8c	56.0b	66.1c
Nicosulfuron+ Bromoxinyl/ MCPA	80 + 600	82.4b	94.1ab	60.5b	62.2b	67.2b	65.1b	71.9c	76.5bc	73.1bc	90.8c	43.6c	37.1c	62.5b	74.3a
Nicosulfuron/ Rimsulfuron	131.25	60.8c	89.4b	60.7b	56.4b	75.4b	40.0b	82.1b	70.0c	77.5b	95.3b	69.8b	76.4b	60.0b	69.9bc
Foramsulfuron	45	39.6d	51.4d	60.4b	53.5b	73.6b	58.5b	74.1c	78.1bc	77.7b	96.4b	48.6bc	43.2c	54.3b	65.9c
Mesotrion/ S-Metolacholor/ Terbuthlazine	1343.75	39.0d	74.9c	62.2b	65.3b	73.0b	54.1b	72.6c	95.7a	68.8c	94.5b	50.4bc	54.3bc	57.4b	70.2bc
Hand weeding	-	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a
Weed infested	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LSD_{0.05}$ sweet corn variety (V)		4.03	3.31	5.97	7.27	4.46	4.58	4.04	2.12	4.44	0.93	4.74	4.69	6.09	3.78
$LSD_{0.05}$ herbicide type (H)		6.15	5.06	9.12	11.11	6.81	7.00	6.17	3.24	6.78	1.42	7.24	7.17	9.31	5.78
$LSD_{0.05}$ V × H		10.66	8.77	15.79	19.23	11.80	12.12	10.70	5.60	11.74	2.45	12.54	12.42	16.12	10.01

[1] Means within each column followed by same letter are not significantly different at 0.05 probability level according to least significant difference (LSD); [2] Other weeds were found on the experimental location included *Tribulus terrestris* L., *Astragalus gummifer* Labill., *Echinochloa crus-galli* (L.) Beauv. and *Poa annua* L.

achieved by mesotrion/s-metolacholor/terbuthlazine. The former studies also indicated that effective control of broadleaves such as *C. album* and *S. nigrum* could be obtained by nicosulfuron and foramsulfuron (Bruce, Kells, 1997; Lum et al., 2005a). In addition, these results are in agreement with those of Zand et al. (2009) and Hadizade et al. (2011).

In Sari, the experiment site was infested with *A. retroflexus*, *C. arvensis*, *Heliotropium europaeum* L., *A. theophrasti*, *S. halepense*, *C. rotundus*, and *E. crus-galli* in both years (Table 5). The maximum *A. retroflexus* density and biomass reductions (> 84% and 81%, respectively) were achieved when nicosulfuron and nicosulfuron+bromoxynil/MCPA were applied. Control levels of *A. retroflexus* density and biomass by nicosulfuron/rimsulfuron, foramsulfuron, and mesotrione/s-metolachlor/terbuthylazine were between 70 to 77% and 66 to 75%, respectively (Table 5). Similar to *A. retroflexus*, application of nicosulfuron and nicosulfuron+bromoxinyl/MCPA provided > 70% *S. halepense* biomass reduction. Nicosulfuron/rimsulfuron satisfactorily reduced density and biomass of *S. halepense* as well (almost 70%); the poorest control of *S. halepense* was obtained by foramsulfuron and mesotrione/s-metolachlor/terbuthylazine (Table 5). The highest density and biomass reductions in *C. arvensis* were achieved following treatment with foramsulfuron and nicosulfuron+bromoxynil/MCPA, with reductions of 58 to 60% and 64 to 66%, respectively. Some chemical treatments provided control > 50% of *C. arvensis* (Table 5). All applied treatments reduced *C. rotundus* and *H. europaeum* biomass by at least 81%, except for mesotrione/s-metolachlor/terbuthylazine, which provided 76% biomass reduction in *C. rotundus*. The reductions of *E. crus-galli* density and biomass were 88 to 90% with mesotrione/s-metolachlor/terbuthylazine. Satisfactory control (77% to 86%) of *E. crus-galli* was accomplished with nicosulfuron+bromoxynil/MCPA and nicosulfuron/rimsulfuron treatments (Table 5). Nicosulfuron and foramsulfuron led to > 70% control of *E. crus-galli* (Table 5). Previous performed research showed that nicosulfuron/rimsulfuron had a suitable efficiency on *C. rotundus* and *E. crus-galli* (Zand et al., 2009; Pourazar, Zand, 2010), which was in consistent with our results. Zand et al. (2009) stated that mesotrion/s-metolacholor/terbuthlazine offer a good efficacy for *E. crus-galli* control. The highest density and biomass reductions were recorded with nicosulfuron+bromoxynil/MCPA applications to *A. theophrasti*. Good control of *A. theophrasti* was also achieved with nicosulfuron and nicosulfuron/rimsulfuron, which resulted in > 70% biomass and density reduction. The reductions of *A. theophrasti* density and biomass were 43% to 45% and 53% with mesotrione/s-metolachlor/terbuthylazine and foramsulfuron, respectively (Table 5). Zhang et al. (2013) observed that nicosulfuron offered effective control of broadleaved and grass weeds such as *A. theophrasti* and *E. crus-galli*.

3.2 Injury of herbicides on sweet corn

The results indicated that almost all herbicides had a phytotoxic effect on sweet corn varieties (Table 6). Injury symptoms included foliar chlorosis and necrosis, scorched lower leaves, and plant stunting, especially in highly sensitive varieties ('Merit').

At two weeks after post herbicide application (WAPHA), 'Golden KSC403su' had 12.7% injury due to nicosulfuron+bromoxynil/MCPA. Mesotrione/s-metolachlor/terbuthylazine in Mashhad resulted in minimal injury to 'Golden KSC403su' (5.1%). Nicosulfuron, nicosulfuron/rimsulfuron, and foramsulfuron had moderate Injury ranging from 8.7 to 10.2%. Foramsulfuron caused 89.2% injury in 'Merit' at 14 WAPHA (Table 6). Nicosulfuron/rimsulfuron, nicosulfuron, and nicosulfuron+bromoxynil/MCPA also caused nearly 80% injury at 14 WAPHA in Mashhad. However, no significant 'Merit' injury with mesotrione/s-metolachlor/terbuthylazine was detected. The highest 'Chase' injury was approximately 8% due to nicosulfuron/rimsulfuron. All other treatments caused little injury to 'Chase' (Table 6). A similar trend was observed for sweet corn variety injury at 14 WAPHA in Sari. In general, 'Merit' was sensitive to foramsulfuron, nicosulfuron/rimsulfuron, nicosulfuron, and nicosulfuron+bromoxynil/MCPA applications, and all of these chemical treatments caused ≥ 60% injury. Our results showed that there were various levels of injury among sweet corn varieties at two WAPHA. Among the three varieties tested, 'Merit' presented high sensitivity to sulfonylurea in 2017 and 2018 at both locations. 'Merit' was killed at two WAPHA by the time of evaluation or soon thereafter. Monks et al. (1992) described that 'Merit' was sensitive to primisulfuron and nicosulfuron, but that other cultivars such as 'Landmark' were relatively resistant. O'Sullivan and Bouw (1998) reported that nicosulfuron-rimsulfuron at 25 or 50 $g.ha^{-1}$ caused significant injury to 'Merit'.

The high sensitivity of 'Merit' to sulfonylureas such as nicosulfuron, foramsulfuron, primisulfuron, and rimsulfuron has been previously reported by various researchers (Robinson et al., 1993; Williams et al., 2005). The extensive injury of sweet corn varieties was due to drought conditions in Mashhad compared with Sari. Reduced soil moisture and high temperatures in Mashhad in 2017 and 2018 resulted in the diminished metabolism of herbicides, thus converting them to more injurious forms and increasing injury to sweet corn (Monks et al., 1992).

Injury < 11% was obtained for all treatments in varieties 'Golden KSC403su' and 'Chase'. Overall, there were similar results for 'Golden KSC403su' and 'Chase' at both locations. Although there were slight (almost less than 12%) and minimal (less than 7%) injuries for 'Golden KSC403su' and 'Chase', respectively, none of the injuries persisted until the end of the season, and the treated sweet corn recovered from initial crop injury. O'Sullivan et al. (1998) and Lum et al. (2005b) reported that nicosulfuron application for maize resulted in a transient crop injury and did not reduce yield.

Table 5 - Efficacy of different herbicide treatments on percent weed density and biomass reductions at 4 weeks after post herbicide spray (WAPHS) at Sari in 2017-2019.

Treatments	Dose	Weed species															
	g a.i.ha^{-1}	*Amaranthus retroflexus*		*Convolvulus arvensis*		*Heliotropium europaeum*		*Abutilon theophrasti*		*Sorghum halepense*		*Cyperus rotundus*		*Echinochloa crus-galli*		Other [2]	
		Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction	Density reduction	Biomass reduction
		(%)															
Nicosulfuron	80	84.9b [1]	81.8b	43.7bc	55.2b	84.7b	91.4b	73.4c	79.0b	72.7b	71.8b	81.1cd	81.5c	77.7c	78.9bc	47.9b	62.1c
Nicosulfuron+ Bromoxinyl/ MCPA	80+600	83.9bc	80.8b	58.2b	65.8b	80.8bc	80.7c	89.5b	91.8a	59.8bc	70.4b	90.1b	89.6b	82.7bc	86.5b	53.7b	69.7b
Nicosulfuron/ Rimsulfuron	131.25	77.2bcd	75.0cd	52.6bc	51.1b	81.2bc	81.3c	73.1c	78.3b	69.5bcd	66.7bc	84.5bc	88.0b	77.6c	86.3b	51.7b	65.8bc
Foramsulfuron	45	76.3cd	74.2cd	59.8b	64.1b	76.2cd	81.4c	53.1d	53.2c	47.2cd	45.3cd	83.9c	88.8b	71.8d	73.5c	45.7b	61.5c
Mesotrion/ S-Metolacholor/ Terbuthlazine	1343.75	69.6d	66.2c	37.5c	50.1b	72.1d	81.5c	43.4e	44.9c	45.9d	44.2d	77.7d	75.9c	87.5b	90.2ab	48.4b	65.8bc
Hand weeding	-	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a
Weed infested	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LSD_{0.05}$ sweet corn variety (V)		3.68	3.49	12.28	9.16	5.95	5.39	6.15	6.79	8.84	9.19	3.77	4.00	3.93	4.04	7.53	4.16
$LSD_{0.05}$ herbicide type (H)		5.63	5.33	18.75	14.00	9.09	8.23	9.39	10.38	13.51	14.04	5.76	6.11	6.00	6.17	11.51	6.36
$LSD_{0.05}$ V × H		9.74	9.24	32.48	24.22	15.75	14.25	16.26	17.97	23.39	24.31	9.98	10.57	10.39	10.69	10.61	11.01

[1] Means within each column followed by same letter are not significantly different at 0.05 probability level according to least significant difference (LSD); [2] Other weeds were found on the experimental location included *Xanthium strumarium* L., *Cynodon dactylon* (L.) Pers., *Setaria viridis* (L.) Beauv. and *Poa annua* L.

3.3 Sweet corn yield

All herbicide treatments resulted in increased grain yield in sweet corn varieties, except for 'Merit' in both locations.

In Mashhad, foramsulfuron at 45 g a.i. ha^{-1} provided the maximum yield of 'Golden KSC403su' (490 $kg.ha^{-1}$), whereas the lowest yield (257.4 $kg.ha^{-1}$) was obtained when 'Golden KSC403su' was sprayed with nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1} (Table 7). 'Merit' yield was reduced completely by applying nicosulfuron, nicosulfuron+ bromoxynil/MCPA, nicosulfuron/rimsulfuron, and foramsulfuron at both locations due to high crop injury caused by these herbicides. Mesotrione/s-metolachlor/terbuthylazine applied to 'Merit' and 'Chase' resulted in a higher yield compared with hand weeding (Table 7). The probable injury due to hand weeding in the sweet corn crop seems to have contributed to reduced grain yield compared with mesotrione/s-metolachlor/terbuthylazine. This result is consistent with the findings of Baghestani et al. (2007) and Zand et al. (2009), who reported that the maize grain yield was lower with hand weeding compared with selective and some dual-purpose herbicides. Chikoye et al. (2009) suggested that maize yield was enhanced by 12 to 22%

Table 6 - Effect of different herbicide treatments on three varieties of sweet corn injury at two weeks after post herbicide spray (WAPHS) in 2017-2019.

Treatments	Dose	Mashhad			Sari		
	(g a.i. ha^{-1})	Golden KSC403su	Merit	Chase	Golden KSC403su	Merit	Chase
		(%)					
Nicosulfuron	80	8.7cdef [(1)]	80b	3.9ghi	7de	59.3b	2.8fg
Nicosulfuron+Bromoxinyl/MCPA	80+600	12.7c	79.3b	5.6efgh	11c	58.3b	4ef
Nicosulfuron/Rimsulfuron	131.25	9.7cde	81b	7.7defg	7.8cde	61b	4.6def
Foramsulfuron	45	10.2cd	89.2a	5.8efgh	8.3cd	68.3a	4.3ef
Mesotrion/S-Metolacholor/Terbuthla-zine	1343.75	5.1fgh	0i	3.4hi	4ef	0g	2fg
Hand weeding		0i	0i	0i	0g	0g	0g
Weed infested		0i	0i	0i	0g	0g	0g
$LSD_{0.05}$ sweet corn variety (V)			2.20			2.55	
$LSD_{0.05}$ herbicide type (H)			3.37			3.89	
$LSD_{0.05}$ V × H			5.83			6.74	

[(1)] Means within each column followed by same letter are not significantly different at 0.05 probability level according to least significant difference (LSD).

Table 7 - Effect of different herbicide treatments on sweet corn varieties yield at two weeks after post herbicide spray (WAPHS) in 2017-2019.

Treatments	Dose	Mashhad			Sari		
	(g a.i. ha^{-1})	Golden KSC403su	Merit	Chase	Golden KSC403su	Merit	Chase
		(kg ha^{-1})					
Nicosulfuron	80	364.1bcdef [(1)]	0h	404.4bcd	660.9fg	0k	847.1b
Nicosulfuron+Bromoxinyl/ MCPA	80+600	281.6defg	0h	380.4bcdef	623.3gh	0k	781.5c
Nicosulfuron/Rimsulfuron	131.25	257.4gh	0h	348.6cdefg	635.6fg	0k	685ef
Foramsulfuron	45	490ab	0h	345.6cdefg	795.5c	0k	723de
Mesotrion/S-Metolacholor/Terbuthlazine	1343.75	345.6cdefgh	400.9bcde	566.5a	775.2c	771.1cd	976.9a
Hand weeding		269.6efg	269.3efg	440.7abc	770.4cd	774.6c	979.2a
Weed infested		275.8defg	219.9g	428bc	457.4i	345j	574h
$LSD_{0.05}$ sweet corn variety (V)			50.39			19.35	
$LSD_{0.05}$ herbicide type (H)			76.97			29.56	
$LSD_{0.05}$ V × H			133.32			51.20	

[(1)] Means within each column followed by same letter are not significantly different at 0.05 probability level according to least significant difference (LSD).

with Lumax (a mixture of mesotrione, s-metolachlor and atrazine) due to the effective control of weeds.

All applied herbicides resulted in greater sweet corn yield for all three varieties compared with the infested check (i.e. a satisfactory season-long weed control was achieved by these herbicides). Weed interference causes severe competition with the crop and, finally, a reduction in grain yield. Previous studies indicated that a significant reduction in maize yield occurred when weeds interfered with crops, particularly during early stages (Lum et al., 2005b; Chikoye et al., 2009). Therefore, effectiveness of the herbicide for suppressing weeds and reducing the period of competition between crops and weeds is responsible for the increase of sweet corn grain yield. Generally, satisfactory sweet corn yield was also attained when crops were treated with nicosulfuron and foramsulfuron compared with the infested check (Table 7). Baghestani et al. (2007) demonstrated that nicosulfuron and foramsulfuron at high rates resulted in the maximum grain yield of maize due to reducing weed density and biomass. Mohajeri et al. (2010) and Lum et al. (2005a; 2005b) indicated that the highest grain yield was provided by nicosulfuron in maize. A satisfactory grain yield was achieved with nicosulfuron, nicosulfuron+ bromoxynil/ MCPA, and nicosulfuron/rimsulfuron for 'Chase'.

In general, almost twice the grain yield of sweet corn varieties was obtained at the Sari location compared with Mashhad (Table 7). Foramsulfuron and mesotrione/s-metolachlor/terbuthylazine increased 'Golden KSC403su' yield considerably more than hand weeding (795.5 and 775.2 kg.ha^{-1}, respectively, compared with 770.4 kg.ha^{-1}) (Table 7). Other treatments did not reduce 'Golden KSC403su' yield, despite early season chlorosis. 'Merit' was also severely injured by all herbicides except mesotrione/s-metolachlor/terbuthylazine in Sari. Similarly, a higher yield was attained for all herbicides used on 'Chase' compared to the two other varieties in Sari. The higher sweet corn yields in Sari were affected by both climatic conditions and on soil properties compared to Mashhad. Sari field with its desirable clay, organic matter, and rainfall caused improved crop yield by lengthening the growing season and through faster rate of acquiring resources.

3.4 Weed composition

Biplots of PC_1 and PC_2 of the different herbicide treatments on percent weed biomass reductions in Mashhad and Sari are shown in Figures 2 and 3. Results are presented that two components; i.e. PC_1 and PC_2 are interpreted 88.3% (PC_1 = 80.7% and PC_2 = 7.6%) and 94.6% (PC_1 = 89.6% and PC_2 = 5%) of variation in species composition of the various

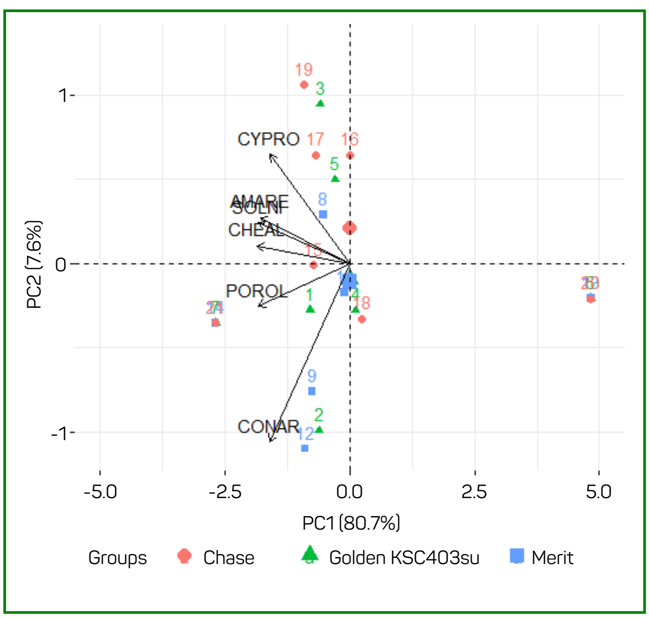

Figure 2 - Biplot of the main component scores (PC) for treatments and species drymatter (→) in three sweet corn varieties at Mashhad. Treatments are indicated with numbers: 1,8,15 = NICO80; 2,9,16 = NICO80+BROM/ MCPA600; 3,10,17 = NICO/RIM131.25; 4,11,18 = FORAM45; 5,12,19 = MES/ S-METH/TERB1343.75; 6,13,20 = Untreated; 7,14,21 = Hand weeding in Golden KSC403su (▲), Merit (■) and Chase (●), respectively. Codes are used for illustrating of weed species: AMARE, *Amaranthus retroflexus* L.; POROL, *Portulaca oleracea* L.; CONAR, *Convolvulus arvensis* L.; CYPRO, *Cyperus rotundus* L.; CHEAL, *Chenopodium album* L.; SOLNI, *Solanum nigrum* L.

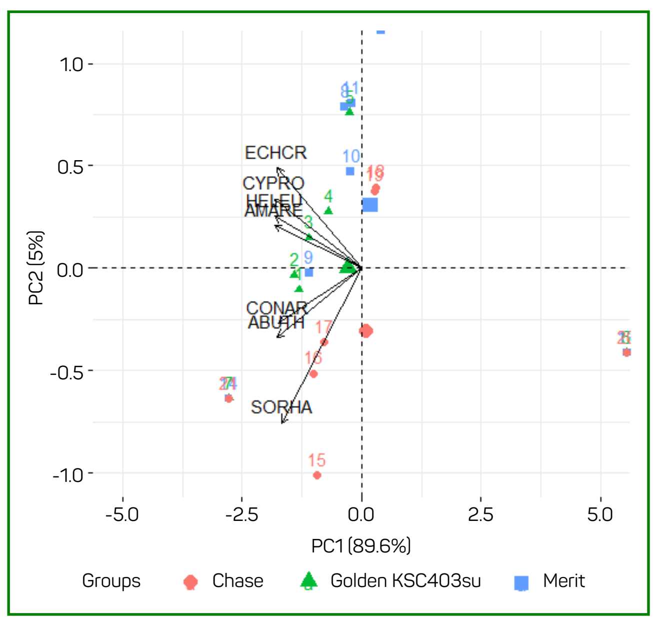

Figure 3 - Biplot of the main component scores (PC) for treatments and species drymatter (→) in three sweet corn varieties at Sari. Treatments are indicated with numbers: 1,8,15 = NICO80; 2,9,16 = NICO80+BROM/MCPA600; 3,10,17 = NICO/RIM131.25; 4,11,18 = FORAM45; 5,12,19 = MES/S-METH/TERB1343.75; 6,13,20 = Untreated; 7,14,21 = Hand weeding in Golden KSC403su (▲), Merit (■) and Chase (●), respectively. Codes are used for illustrating of weed species: AMARE, *Amaranthus retroflexus* L.; SORHA, *Sorghum halepense* (L.) Pers.; CONAR, *Convolvulus arvensis* L.; CYPRO, *Cyperus rotundus* L.; HELEU, *Heliotropium europaeum* L.; ECHCR, *Echinochloa crusgalli* (L.) Beauv.; ABUTH, *Abutilon theophrasti* Medik

treatments (variables variance total) in Mashhad and Sari, respectively (Figure 2 and 3). In Mashhad, the biplot diagram showed that *C. rotundus*, *A. retroflexus, S. nigrum* and *C. album* are presented a strong positive association with each other (angle < 90°) (Figure 2). These weeds were often correlated with nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1} and mesotrione/s-metolachlor/terbuthylazine at 1343.75 g a.i. ha^{-1} in 'Golden KSC403su' and 'Chase' and also with nicosulfuron at 80 g a.i. ha^{-1} in 'Merit'. Also, a positive association (angle < 90°) (Figure 2), was observed by *P. oleracea*, *C. arvensis* and *C. album*. These two species were mostly associated with rates of 80 and 80 + 600 g a.i. ha^{-1} nicosulfuron and nicosulfuron +bromoxynil/MCPA, respectively, in 'Golden KSC403su'; 80 + 600 g a.i. ha^{-1} nicosulfuron+bromoxynil/MCPA and 1343.75 g a.i. ha^{-1} mesotrione/s-metolachlor/terbuthylazine in 'Merit', and also with the weeded control in all three varieties. According to the results presented in Table 7, it suggested that grain yield was increased by these treatments. While, in 'Merit', the grain yield increase was not achieved by nicosulfuron, nicosulfuron+bromoxinyl/MCPA, nicosulfuron/rimsulfuron and foramsulfuron due to the high injury created on it. In Sari, in 'Golden KSC403su', treatments that received nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1}, foramsulfuron at 45 g a.i./ha and mesotrione/s-metolachlor/terbuthylazine at 1343.75 g a.i. ha^{-1} and in 'Merit', nicosulfuron at 80 g a.i. ha^{-1}, nicosulfuron/rimsulfuron at 131.25 g a.i ha^{-1} and foramsulfuron at 45 g a.i. ha^{-1} were *E. crus-galli*, *C. rotundus, H. europaeum*, and *A. retroflexus*. These species had a positive association together (angle < 90°) (Figure 3). A similar composition in species, including *C. arvensis, A. theophrasti* and *S. halepense* was observed by treatments with nicosulfuron at 80 g a.i. ha^{-1} and nicosulfuron+bromoxynil/MCPA at 80+600 g a.i. ha^{-1} in 'Golden KSC403su', nicosulfuron at 80 g a.i. ha^{-1} and nicosulfuron+bromoxynil/MCPA at 80+600 g a.i. ha^{-1} and nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1}, in 'Chase' and also with the weeded control in all three varieties. There was a high positive correlation between the three weeds (angle < 90°) (Figure 3). Similar to Mashhad, all treatments used in biplot are related to increase grain yield except in 'Merit' (Table 7).

4. Conclusions

According to the results obtained from experiments, it was concluded that 'Merit' was a highly sensitive variety to sulfonylureas, whereas 'Golden KSC403su' and 'Chase' were tolerant to sulfonylureas. However, mesotrione/s-metolachlor/terbuthylazine at 1343.75 g a.i. ha^{-1} had no negative effect on sweet corn varieties; hence, application of this treatment resulted in the effective control of weeds, especially broadleaved weeds, and increased the grain yield across all varieties of sweet corn. Significant control of broadleaved and grass weeds was obtained by nicosulfuron at 80 g a.i. ha^{-1}, nicosulfuron+bromoxynil/MCPA at 80+600 g a.i. ha^{-1}, nicosulfuron/rimsulfuron at 131.25 g a.i. ha^{-1}, and foramsulfuron at 45 g a.i. ha^{-1}. Therefore, due to the restricted use of herbicides in sweet corn varieties, the herbicides used in this experiment is not created serious injury in sweet corn varieties (except in 'Merit') at the recommended rate while effectively controlling weeds. Hence, utilization of these herbicides could be a favorable option in contemporary weed control programs for local or regional sweet corn growers.

Author's contributions

The authors contributed equally to this work.

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