WEED COMPETITIVENESS AND HERBICIDAL SENSITIVITY OF GRAFTED TOMATOES (*SOLANUM LYCOPERSICON* MILL.)

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Abstract: Field and greenhouse experiments were conducted in 2007 and 2008 to evaluate weed competitiveness and herbicidal sensitivity of grafted tomatoes. Three weed interference levels were established in the field by imposing different weeding pressures. Results indicated that grafting of tomato seedlings did not increase the ability of plants to suppress weeds over self rooted plants. Grafted tomatoes had more vigorous growth and fruit yield compared to self rooted tomatoes across all weed levels. Weeds were found to have more prominent adverse effects on tomato productivity, but had less adverse effects on plant growth. Greenhouse experiments were conducted to detect herbicidal sensitivity of grafted and self rooted tomatoes towards metribuzin and sethoxydim herbicides. The experiments revealed that grafted tomatoes showed a relatively higher herbicidal sensitivity than self rooted seedlings. Grafted plants probably were less able to metabolize and detoxify high herbicide rates whenever variations in plant height or dry matter accumulations were detected in the experiments. Researchers and producers should be aware of this newly observed sensitivity when designing herbicide application programs for weed management in grafted crops.

Key words: grafted tomatoes, self rooted, weed interference, herbicide sensitivity, metribuzin, sethoxydim

INTRODUCTION

Tomatoes (*Solanum lycopersicon* Mill.), a major vegetable crop worldwide, are usually grown outdoors to be used fresh or processed (Lucier et al., 2000). Grafting is a new technique for the production of fruit-bearing vegetables. Grafting is used to provide protection of soil-borne diseases and nematodes in grafted plants (Marsic and Osvald, 2004) a major problem in tomato production (El-Mougy, 2008). Root-knot nematodes (RKNs, *Meloidogyne* spp.) attack a wide range of crop species. Annually, about 5% of the world crop production is destroyed by *Meloidogyne* species (Karajeh, 2008). In the absence of other control measures, repeated fungicide applications are needed for the protection of plants against diseases of fungal origin (Szpyrka and Sadło, 2009). Grafting also proved to enhance chilling tolerance, extends growth period, and improves fruit quality of tomatoes (Besri, 2005).

Grafting also provides a useful tool for increasing salt stress resistance in plants (Garcia *et al.* 2002). Grafting first began in Japan and Korea in the late 1920s with watermelon (Lee 1994). In this propagation method, tissues of two plants are fused together (Besri 2003). The fruit-producing shoot (scion) of a desirable cultivar, is inserted onto the disease resistant rootstock from of another cultivar (McAvoy 2005). Tomato grafting was introduced in Jordan to accommodate methyl bromide phasing out projects in 2002. A resistant rootstock was used in grafting tomatoes that provided excellent control of many tomato soil-borne pathogens, particularly *Fusarium* spp., *Verticillium* spp., and *Melodogyne* spp. (Besri 2005). Grafting was found to have positive and negative influences on the yield of various tomato cultivars according to the method and rootstock-scion combination used (Marsic and Osvald 2004).

Weeds are undesirable pests. They are also undesirable from an economical point of view. Weeds can cause an 80% crop production loss in some cases if not controlled (Weaver *et al.* 1987). Cultivar weed competitiveness refers to the ability of the crop to maintain high yields despite weed interference. Crop weed suppressive ability refers to the ability of a particular crop to reduce weed growth through competition. Weed competitiveness is a desirable characteristic in crops grown by commercial growers (Zhao *et al.* 2006). Cultivar differences in weed-competitiveness were documented among four tomato cultivars in tomatoes in response to velvetleaf competition (Ngouajio *et al.* 2001).

Selective herbicides are used successfully for weed management worldwide (Tei *et al.* 2003). However, crop injuries might happen due to cultivar variations. Crop cultivars were found to exhibit differential tolerance or differential susceptibility to herbicide applications (Porterfeild *et al.* 2002; Bunnel *et al.* 2003). Higher herbicide tolerance to injury is a desirable cultivar characteristic that leads to higher weed control efficiency without causing significant crop-injury or losses (Dear *et al.* 1995;

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Al-Khatib *et al.* 1997). Among the selective herbicides; metribuzin and sethoxydim are commonly used in tomatoes. Metribuzin [4-amino-6-(1,1-dimethelethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] is a selective pre-emergence and post-emergence herbicide that controls many broadleaf weeds in a wide variety of crops including tomato. Sethoxydim ±(2-[1-(ethoxyamino)butyl-5-[2-(ethylthio)-propyl]-3-hydroxy-2-cyclo-hexaen-1-one) is a selective post-emergence herbicide for the control of annual and perennial grasses in many crops, including tomatoes (Senseman 2007).

Since grafting of tomatoes has become common, we decided to investigate weed problems and herbicide sensitivity associated with grafted plants. Research results are not available for the competitive ability of grafted tomatoes, nor for the herbicidal sensitivity of such plants. Our specific objectives were to: a) compare the competitive ability of grafted tomatoes and self rooted tomatoes with local weeds to determine the required level of weed management practices in grafted tomatoes, b) evaluate the differential sensitivity of grafted tomatoes to applications of metribuzin and sethoxydim herbicides, to alert producers of possible herbicidal sensitivity risks upon using grafted tomatoes.

MATERIALS AND METHODS

Field trials

Field trials were conducted during the year 2007 at the Jordan University of Science and Technology (JUST) campus, Irbid, to evaluate weed competitive ability of grafted and self rooted tomatoes. The site is located 20 km east of Irbid (32°34 N; 35°59 E; 520 m altitude). Cold winters and hot summers prevail most years. Generally, rainfall incidents start in late October to early November and end in late March to early April. Maximum rainfall occurs during January and February. The soil at the site is fine loamy, mixed, thermic, calcic palearrgid (Khresat *et al.* 1998).

A split plot design was utilized in a Randomized Complete Block arrangement. Raised beds (0.6 m wide, 0.1 m high) were manually prepared after disking the site twice. Three weed interference levels (high, medium, and low) were randomly assigned to the main plots of 4x12 m. To allow for the establishment of the desired weed-interference levels, mulches were not used. Low weed interference level was accomplished by performing five hand-hoeings at 22, 33, 50, 68, and 85 days after transplanting (DAT). Medium weed interference level was accomplished by a single hand-hoeing practiced 40 DAT. High level of interference (weedy) was achieved by allowing weeds to grow without any removal from the time of tomato transplanting to the termination of the experiment. Grafted and self rooted tomato seedlings were hand transplanted simultaneously to subplots of 4x6 m, assigned randomly. Scions of the tomato cultivar ''Sadeen'' were grafted in the rootstock ''He-Man'' in a commercial nursery, following the "Top-Grafting method'' (McAvoy 2005). Both grafted and self rooted tomatoes were transplanted to the experimental field, 20 days after initiating the grafting process.

Plant distances within rows were 40 cm. Each subplot contained 50 plants. Subplots were irrigated by 5 drip irrigation lines (1.20 m spaced apart). The experiment was replicated 4 times and was performed twice; the first time during the spring of 2007 and the second run during the fall of 2007. Seedlings were transplanted to experimental sites on 17th April and 18th September 2007. All management practices were performed to be in accordance with commercial farming activities. Tomato plants in the experimental field received the necessary amounts of water, fertilizers, and pesticide applications.

Weed species present in the experiments were natural infestations common to the site. The most abundant weeds in spring 2007 were identified according to Abu-Irmaileh (2000), as being *Achillea santolina* L., *Amaranthus* spp. L., *Avena sterilis* L., *Chenopodium album* L., *Diplotaxis erucoides* (L.) DC., *Ecballium eleatrium* (L.) Rick., *Erucaria hispanica* (L.) Druce., *Solanum nigrum* L., and *Sorghum halepense* L. The most abundant weeds observed in fall 2007, were *Amaranthus* spp. L., *Anthemis palaestina* L., *Avena sterilis* L., *Malva sylvestris* L., *Rumex cyprius* L., and *Trigonella arabica* Delile.

Data measurements were recorded and samples were collected from the three middle rows to avoid the border effect. The following parameters were recorded: a) tomato height (average of 4 plants/subplot) at 16 day after treatment (DAT); b) number of lateral branches (average of 4 plants/subplot) at 33 DAT; c) number of fruits on the first and second cluster/plant (average of 4 plants/subplot) at 50 DAT; d) cumulative total fruit yield (average for 10 plants/subplot); e) above ground weed biomass (g/m^2/subplot) only at the end of the first season; f) tomato aboveground biomass (g/m^2/subplot) only at the end of the first season.

Because of significant season X treatment interactions, data for each season were analyzed separately. Data were subjected to the analysis of variance (ANOVA) using SAS program (SAS 1989). Means were separated according to Fisher's least significant difference (LSD) test at $p = 0.05$.

Greenhouse Experiments

Greenhouse trials were conducted at JUST campus during the fall of the year 2007 and winter of 2008, to evaluate the differential sensitivity of grafted tomatoes to metribuzin and sethoxydim herbicide mixtures (Monaco *et al.* 2002). The recommended rates on the herbicides label were 70 g active substance (a.s.)/ha and 150 g a.s./ha for metribuzin and sethoxydim, respectively. Thus, a 1X for the mixture at a 15 : 7 mixing ratio was considered to be 220 g a.s./ha. Preliminary tests performed using a hand sprayer that delivered 200 l/ha, allowed us to consider mixture rates of 8X (1760 g a.s./ha) and above, to be lethal to self rooted tomatoes.

Single seedlings of grafted tomato (cultivar Amani, and rootstock He-man) or self rooted tomatoes (cultivar Amani), were transplanted into two liter plastic pots containing a mixture of peat moss, perlite, and soil at a volume ratio of 1 : 1 : 1. A gradient of 12-mixture concentrations of 0, 55, 110, 220, 330, 440, 550, 660, 880, 1 760, 3 520, and 7 040 g a.s./ha, representing 0.25, 0.5, 1, 1.5, 2, 2.5, 3, 4, 8, 16, and 32 fold of the recommended label rates, were applied using a hand sprayer. These doses were applied to grafted and self rooted tomatoes simultaneously 7 days after transplanting.

Plant heights (base to uppermost part) for seedlings not showing terminal injury symptoms were recorded daily until 6 days after application (DAA). Dry weights for shoots of tomato seedling were determined either after complete death (treatments receiving 8, 16 and 32 X) or 6 DAA for all other concentrations, after cutting at soil surface. At 6 DAA, plant recovery was noticed without any further development of injury symptoms. Shoots were air-dried in the oven at 70°C for 48 h.

Treatments were arranged in a completely randomized design (CRD) with five replications. ANOVA (SAS 1989) performed on combined data revealed significant season and treatment-by-season effects, thus, data were analyzed for each season separately. Data sets were subjected to multiple linear regression analysis using PROC REG (SAS 1989). Herbicide concentrations and tomato seedling type (grafted; self rooted) were assigned as independent variables. T-tests generated by SAS outputs were used to determine the significance of the independent variables on the measured dependent variables.

RESULTS AND DISCUSSION

Field experiments

Interaction effects between weed infestation levels and tomato seedling types were not detected in both seasons for all measured variables. Thus, grafting of tomato seedlings had no apparent effect on plants competitive ability with weeds under our experimental circumstances.

In the spring experiment, weed interference levels and tomato seedling types had no significant effects on tomato height (Table 1). The lack of adverse competitive effects from weed-interference levels on plant height indicates that weeds did not impose suppression effects on the vegetative growth of tomatoes in either of the growing seasons. This conclusion is similar to observations recorded by Ngouajio *et al.* (2001). In the fall experiment, self rooted plants were taller than grafted tomatoes (Table 1), but we cannot draw conclusions about better light competitive ability for self rooted seedlings. It is known that grafted tomatoes are slower in growth early in the season, which might explain the differences in height after 16 days of having been planted. An after grafting recovery period is needed for these seedlings to re-grow vigorously (Khah *et al.* 2006).

Grafted tomatoes had more branching in spring 2007 (Table 1). Marsic' and Osvald (2004) and Khah *et al.* (2006) found grafted tomatoes to have more branching compared to self-rooted tomatoe plants in greenhouse and open-field conditions. Branching capacity is less expected to be affected by weed competition, since this capacity is determined early on during vegetative growth (Montanyá and Ponce 2006). Environmental conditions were more adequate for grafted plants to express a greater branching capacity, compared to conditions prevailing during fall 2007. However, such conditions allowed the presence of more competitive weeds during fall compared to spring, as low- and moderate-weed interference levels had more fruits in the second cluster compared to weedy plots (Table 2).

In spring 2007, the total yield from 10 harvests indicated that low weed interference plots produced 48% more

Table 1. Effect of weed-interference levels and tomato rooting types on plant height and branching capacity for field experiments in spring and fall, 2007

	Spring 2007		Fall 2007	
	height [cm]	branches [branches/plant]	height [cm]	branches [branches/plant]
Weed interference:				
Low	14.9	6.8	20.5	7.6
Moderate	14.2	5.9	22.3	7.1
High	14.0	5.7	21.8	6.6
LSD values	ns	ns	ns	ns
Rooting type:				
Grafted	14.5	6.5	19.7	7.3
Self	14.3	5.8	23.4	6.9
LSD values	ns	0.6	1.4	ns

ns – not significantly different according to ANOVA at p ≤ 0.05

Table 2. Effect of weed-interference levels and tomato rooting types on number of fruits for the first and second cluster for field experiments in spring and fall 2007

	Spring 2007		Fall 2007	
	fruits – 1st cluster	fruits – 2nd cluster	fruits – 1st cluster	fruits – 2nd cluster
Weed-interference:				
Low	1.7	2.1	2.8	4.6
Moderate	3.3	1.7	2.9	4.1
High	1.6	1.8	2.7	3.6
LSD values	ns	ns	ns	0.5
Rooting type:				
Grafted	3.0	1.9	2.8	4.2
Self	1.5	1.8	2.6	3.8
LSD values	ns	ns	ns	ns

ns – not significantly different according to ANOVA at p ≤ 0.05

tomatoes compared to weedy plots. Data from two harvests in fall 2007, indicated that low and moderate weed interference plots produced more tomato fruit quantities than amounts harvested from weedy plots. That experiment was terminated earlier than scheduled due to an early frost incident (Table 3). Our results are in agreement with previous studies that indicated yield reductions in tomato cropping systems due to weed competition (Ngouajio *et al.* 2001). The results emphasize the significance of practicing weed management practices when raising the tomato. Grafted tomatoes produced more yield than self-rooted plants only in the spring trial (Table 3). Previous higher yields were reported for grafted tomatoes compared to self-rooted plants (Khah *et al.* 2006; Qaryouti *et al.* 2007). Lee (1994) attributed the yield increase of grafted plants to rootstock vigor and to higher uptake of water and nutrients. On the other hand, more fruits were harvested from low weed density plots compared to weedy plots (Table 3). These findings are in agreement with Milton *et al.* (1992) who reported lower yields as black nightshade density increased. More fruits were harvested in spring 2007 from grafted tomatoes. In fall, grafted plants did not express this prolific fruit production due to a shorter growing season (Table 3).

Weed biomass was much higher in weedy plots than the weed biomass in moderate and low weed plots in spring 2007. A single weed removal practice conducted in moderate weed interference levels suppressed weeds to a degree comparable to frequent hand-hoeing of plots (Table 4). This can be attributed to the timing of that single weeding that is associated with the time where tomato canopies close gaps between and within rows, a condition that intensifies shading and adversely affects weed growth (Monaco *et al.* 1981). Grafting, on the other hand, did not affect weed growth, thus, the more vigorous grafted tomatoes did not have any advantage in suppressing weed emergence or growth. Weed-interference levels had no effect on tomato aboveground biomass in spring 2007 (Table 4). Thus, weeds growing naturally did not have any competitive edge over the vegetative growth of tomatoes, but as indicated previously, reduced fruit yields. More negative impacts on above ground biomass of tomato plants were reported previously (Ngouajio *et al.* 2001; Kazinczi *et al.* 2007), which could be attributed to higher weed densities in those experiments. Grafted tomatoes, on the other hand, had a higher dry weight than self rooted tomatoes (Table 4), reflecting a more vigorous growth habit (Marsic' and Osvald 2004; Khah *et al.* 2006).

Table 3.   Effect of weed-interference levels and tomato rooting types on tomato yield and fruit numbers in spring and fall 2007

	Spring 2007		Fall 2007	
	yield [kg/ha]	fruits [per 10 plants]	yield [kg/ha]	fruits [per 10 plants]
Weed-interference:				
Low	27 840	317.8	9 050	61.3
Moderate	25 870	284.1	7 989	54.9
High	18 730	211.8	4 633	39.4
LSD values	7 810	84.0	2 040	10.8
Rooting type:				
Grafted	28 900	314.2	7 969	54.5
Self	19 370	228.3	6 480	49.2
LSD values	3 890	36.8	ns	ns

Data converted from a ten-plant yield production to kg/ha; ns – not significantly different according to ANOVA at p ≤ 0.05

Table 4.   Effect of weed-interference levels and tomato rooting types on total weed fresh weight from 1 m² per subplot and dry weight of two tomato plants in spring, 2007

	Weed biomass [kg/m²]	Tomato dry biomass [kg/2 plants]
Weed-interference:		
Low	0.311	0.239
Moderate	0.840	0.183
High	2.080	0.163
LSD values	0.780	ns
Rooting type:		
Grafted	1.110	0.228
Self	1.050	0.162
LSD values	ns	0.064

ns – not significantly different according to ANOVA at p ≤ 0.05

Greenhouse experiments

Plant heights were recorded hours before applying herbicide combinations to detect differences in height between grafted and self-rooted tomato seedlings. ANOVA results (data not presented) indicated the absence of rooting effect on initial heights of seedlings. Thus, any effects detected then after are experiment related effects.

In the fall experiment, plant height measurements recorded in the first to the fifth day after metribuzin and sethoxydim application (DAA) indicated significant herbicide dose and rooting type effects. Higher concentrations caused reductions in seedling heights. Grafted tomatoes were shorter at all recorded dates than self-rooted seedlings (Table 5). In the winter experiment, rooting type effects were not observed at 1, 2, and 3 DAA, but elevated herbicide concentrations caused plant height reductions at those dates. Plant height measurements recorded 4 and 5 DAA indicated significant concentration and rooting type effects, with grafted plants being shorter than self-rooted seedlings (Table 5). Height reductions in response to increased herbicidal concentrations are in agreement with Fortino and Splittstoesser (1974) who found that increasing metribuzin rates from 0 to 1.12 kg/ha caused injury to 15 cm tomato seedlings measured 6 days after application. Our experiments revealed that grafted tomatoes had a relatively higher herbicidal sensitivity compared to self-rooted seedlings. Previous results about the response of grafted plants to herbicide injury were not found within the available literature. Possible reasons for grafting sensitivity might include differences in detoxification rates, or could be related to stresses associated with the grafting process. Differential tolerance of tomato cultivars to metribuzin was associated with detoxification rates through metabolism within tomato leaves (Stephenson *et al.* 1976). Sethoxydim, on the other hand, was not expected to cause injury to tomato (Glaze 1988).

In fall 2007, different concentrations of metribuzin and sethoxydim had significant effects on dry weight of above ground tomato plants. Rooting type had no effect on the dry weight of tomato seedlings (Table 6). However, rooting type and herbicidal concentrations affected seedling dry weight in winter 2008. Self-rooted plants had higher values (Table 6). These findings partially indicate that grafted tomatoes exhibit more sensitively than self-rooted seedlings towards herbicide applications under cooler environments. These findings partially indicate that grafted tomatoes exhibit more sensitively than self-rooted seedlings towards herbicide applications under cooler environments. The senitivity of grafted tomatoes can be attributed to slower growth rates, slower recovery after grafting, and less herbicide detoxification.

Table 5. Regression parameters[1] for the predicted effects of different concentrations of metribuzin and sethoxydim on heights of grafted and self-rooted tomato seedlings derived from observations recorded in greenhouse experiments conducted in fall 2007 and winter 2008

	a	B	C	R^2
Fall 2007				
1 DAA[2]	14.01274	−0.000177	0.575	0.181
2 DAA	15.11407	−0.000660	1.125	0.637
3 DAA	19.38472	−0.004030	1.380	0.646
4 DAA	22.2478	−0.006631	0.128	0.520
5 DAA	24.06297	−0.008532	1.056	0.593
Winter 2008				
1 DAA	15.09227	−0.000386	0	0.298
2 DAA	15.89212	−0.000675	0	0.501
3 DAA	17.42941	−0.001320	0	0.181
4 DAA	18.15556	−0.004041	1.122	0.389
5 DAA	18.95819	−0.005061	0.833	0.426

[1] regression equation was: y (cm) $= a+b*x1+c*x2$, where: $x1$ – combined herbicide concentration; $x2$ – 1 for self-rooted; 0 for grafted; R^2 – coefficient of determination

[2] days after application

Table 6. Regression parameters[1] for the predicted effects of different concentrations of metribuzin and sethoxydim on dry biomass of grafted and self rooted tomato seedlings derived from observations recorded in greenhouse experiments conducted in fall 2007 and winter 2008

	a	B	C	R^2
Fall 2007	570.8446	−0.0401	0	0.2419
Winter 2008	443.80999	−0.0172	104.33333	0.1668

[1] regression equation was: y (cm) $= a+b*x1+c*x2$, where: $x1$ – combined herbicide concentration; $x2$ – 1 for self-rooted; 0 for grafted; R^2 – coefficient of determination

CONCLUSIONS

In this research we tested the weed competitive ability of grafted tomatoes in comparison with self-rooted tomatoes. We also evaluated the differential sensitivity of grafted tomatoes to metribuzin and sethoxydim to alert producers of possible future risks. We found that grafting of tomato seedlings had no apparent advantage or disadvantage in weed competitiveness over self-rooted tomatoes. Weeds did not impose suppression effects on the vegetative growth of tomatoes in either of the growing seasons. Nevertheless, tomato yield was significantly lower in weedy plots compared to weed free plot. Higher yields were harvested from grafted tomatoes, probably due to their more vigorous root system. The presumably more vigorous grafted tomato plants did not cause any extra suppression on weed growth. Greenhouse experiments revealed a relatively higher sensitivity of grafted tomatoes to metribuzin and sethoxydim applications, compared to self-rooted ones. Grafted plants probably were under greater stress to metabolize and detoxify the high rates of herbicides whenever variations in plant height or dry matter accumulations were detected. This is an important fact that should be considered when herbicide management programs are designed to control weeds in grafted tomatoes, and probably in other grafted crops.

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POLISH SUMMARY

KONKURENCJA CHWASTÓW I WRAŻLIWOŚCI NA HERBICYDY SZCZEPIONYCH POMIDORÓW (*SOLANUM LYCOPERSICON* MILL.)

W latach 2007 i 2008 przeprowadzono polowe i szklarniowe doświadczenia w celu oceny konkurencyjności i wrażliwości na herbicydy szczepionych pomidorów. Ustalono trzy poziomy interferencji w polu poprzez stworzenie różnych presji infekcyjnych. Uzyskane wyniki wykazały, że szczepienie siewek pomidora nie powodowało wzrostu zdolności roślin do ograniczania chwastów w stosunku do samoukorzenionych roślin. Zaszczepione pomidory wykazywały silniejszy wzrost i większy plon owoców w porównaniu do samoukorzenionych roślin przy wzięciu pod uwagę różnych poziomów zachwaszczenia. Ustalono, że chwasty wykazywały wyraźniejszy szkodliwy wpływ na produktywność pomidora, lecz mniej szkodliwy wpływ na wzrost roślin. Doświadczenia szklarniowe przeprowadzono w celu określenia wrażliwości na herbicydy metribuzin i sethoxydim szczepionych i samoukorzenionych pomidorów. Jednocześnie wykazano, że szczepione pomidory miały względnie wyższą wrażliwość na herbicydy niż samoukorzenione siewki. Zaszczepione rośliny były, prawdopodobnie, mniej zdolne do metabolizowania i zapobieżenia toksyczności wysokich dawek herbicydów, tam gdzie wykryto zróżnicowanie zmienności w wysokości roślin lub akumulacji suchej masy. Badacze i producenci powinni brać pod uwagę nowo zaobserwowaną wrażliwość, gdy tworzą programy ochrony pomidora szczepionego przed chwastami.