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The effect of seed treatments on wireworm (Elateridae) performance, damages and yield traits of sunflower (*Helianthus annuus* L.)

Uticaj različitih tretmana semena na oštećenja od žičara (Elateridae) i parametre prinosa suncokreta (*Helianthus annuus* L.)

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ABSTRACT

Sunflower seed treatments are inevitable measure that ensures protection from soil-dwelling insects and pathogens at the first stages of plant development. Due to the ban of neonicotinoid based insecticides for the sunflower seed treatments, new registered preparations are put to test. The aim of this work was to assess the efficacy of currently registered insecticides against the wireworms (observed in field emergence and percent of damaged plants) and their effect on yield traits (yield, oil content and 1,000-seed weight) of the sunflower hybrids (Sumo 2 OR, Oliva and Novak) in comparison to previously used neonicotinoids. Seeds were treated with different pesticidal combinations: metalaxyl-m, metalaxyl-m + bifenthrine, metalaxyl-m + thiacloprid, metalaxyl-m + thiametoxam, and metalaxyl-m + imidacloprid. Two-way ANOVA and Duncan's multiple range tests were performed. Field emergence was not influenced by the treatment. Sumo 2 OR and Oliva emergence did not differ significantly among the treatments (78.3-88.3%; 83.0-91.3%, respectively), but for Novak it was significantly lower (79.3%) when treated with metalaxyl-m. The lowest percent of damaged plants was in the treatment with metalaxyl-m + thiametoxam (1.1-2.4%). However, it did not differ significantly among other treatments (2.4-3.9%), regardless on the hybrid. Novak had the highest average yield (3,938.1 kg/ha), followed by Sumo 2 OR (3,566.1 kg/ha), and Oliva (3,199.8 kg/ha), regardless on the applied seed treatments. The highest 1,000-seed weight was measured for Oliva. Given indicates that currently registered insecticides for the seed treatment of sunflower, such as Sonido and Semafor, can be adequate substitute to the banned neonicotinoids like Cruiser and Gaucho.

Keywords: filed emergence, plant damages, seed treatment, sunflower, yield, wireworms

SAŽETAK

Tretiranje semena suncokreta je nezaobilazna mera koja obezbeđuje zaštitu od insekata i patogenih organizama u početnim fazama razvoja biljaka. Zbog zabrane upotrebe insekticida na bazi neonikotinoida za tretiranje semena, u praksi se realizuju ispitivanja efikasnosti tržišno dostupnih. Cilj ovog rada je bio da se ispita efikasnost trenutno registrovanih insekticida za suzbijanje žičara (posmatrano preko nicanja i procenta oštećenih biljaka), kao i njihov uticaj na osobine prinosa (prinos, sadržaj ulja i masu 1000 semena) hibrida suncokreta (Sumo 2 OR, Oliva i Novak), u poređenju sa prethodno korišćenim neonikotinoidima. Seme je tretirano različitim kombinacijama: metalaksil-m, metalaksil-m + bifentrin, metalaksil-m + tiakloprid, metalaksil-m + tiametoksam i metalaksil-m + imidakloprid. Podaci su obrađeni dvofaktorskom analizom varijanse i Dankanovim testom višestrukog poređenja. Pesticidni tretmani nisu uticali na nicanje u polju. Nicanje

Sumo 2 OR i Olive se nije značajno razlikovalo između tretmana (78,3-88,3%, 83,0 -91,3%, respektivno), dok je nicanje Novaka bilo znatno slabije (79,3%) kada je seme tretirano samo sa metalaksil-m. Najniži procenat oštećenih biljaka bio je u tretmanima metalaksil-m + tiametoksam (1,1-2,4%). Međutim, oštećenja se nisu značajno razlikovala između ostalih tretmana (2,4-3,9%), bez obzira na hibrid. Novak je postigao najveći prosečni prinos (3938,1 kg/ha), zatim Sumo 2 OR (3566,1 kg/ha), pa Oliva (3199,8 kg/ha), bez obzira na primenjene tretmane semena. Oliva je imala najveću masu 1000 semena. Izneti rezultati ukazuju na to da trenutno registrovani insekticidi za tretman semena suncokreta, kao što su Sonido i Semafor, mogu biti adekvatna zamena za zabranjene neonikotinoide kao što su Cruiser i Gaucho.

Ključne reči: oštećenje biljaka, poljsko nicanje, prinos, suncokret, tretman semena, žičari

INTRODUCTION

During the early stages of development, plants are the most susceptible to insect attack, disease infection, as well as the influence of environmental factors. To prevent the damages caused by different biological agents, chemical treatments, i.e. the use of pesticides, especially for seed treatments, has become an important and inevitable cultivating practice for a number of reasons (Dan et al., 2012). From the economic and environmental point of view, treating seeds with fungicides and insecticides provides the adequate protection of crops from the diseases and pests at the beginning of plants development. The higher standards in terms of rentability of crop production and the environmental protection impose the necessity for the implementation of ecologically more selective methods of pesticide application (Čamprag, 1988). Namely, when the pesticide is applied directly on the seeds, considerably smaller amount of chemical is needed compared to the foliar or soil treatments, whether across the entire field or in strips (Sekulić et al., 2000; Marjanović-Jeromela et al., 2008). This implies the lower risk for environmental contamination. The application of the seed treatments is a simple and low-cost measure (Goulart, 1999; Machado, 2000; Dan et al., 2012). Additionally, researchers found that the seed treatments are as effective in controlling wireworms as the application of granular insecticides during sowing and planting (Wilde et al., 2004).

In Serbia, the fungicidal treatment of hybrid sunflower seeds represents a long-applied practice. The most commonly used fungicide is metalaxyl (Shirshikar, 2005; Miklič et al., 2008), which controls the causal agent of downy mildew (*Plasmopara halstedii* (Farl.) Berl et De Toni).

However, the use of insecticides for the sunflower seed treatment does not have such a long tradition (Sekulić et al., 1998; Mrđa et al., 2011a), but this practice is gaining in importance. The most important, widespread soil-dwelling pests in the sunflower crops are wireworms, i.e. larvae of family Elateridae (Ministry of Agriculture, Fisheries and Food, 1983; Parker and Howard, 2001; Toscano et al., 2017). They are mainly controlled by the soil insecticides and seed treatments (Bača et al., 2008; Landl, 2010). As a result of underground feeding activity, the larvae cause severe damages of the lower part of the stem and roots. Wireworms are pests of great economic importance due to their polyphagous preferences and ability to inhabit different types of habitats (Laznik et al., 2014; Toscano, 2015; Toscano et al., 2017). The most sensitive phenophase of sunflower plants to the insect attack is the phase of emergence up to the formation of two pairs of leaves (Sekulić et al., 1998). In Serbia, the highest damages are recorded in maize, sunflower and sugar beet (Čamprag et al., 1987, 1988). According to Landl et al. (2010) the level of damages is highly dependent on the number of larvae in the soil. One larva per m^2 can destroy 4-6% of maize plants, while 10 larvae per m^2 can damage 40-60% of plants. Strong infestation leads to the obligatory re-sowing (Sekulić et al., 1998).

The infestation level and damage caused by the wireworms depend on many factors, including the composition of insect species and population density, as well as the plant species, its growth stage, plant vigor under attack and plant density (Anonymous, 1983; Platia and Gudenzi, 2005; Lawrence et al., 2007; Platia, 2011). According to Vujaković et al. (2013), to overcome the initial problems with insects and pathogens in the field, seed must have good germination, the ability to absorb water quickly and to form the above- and underground plant organs as soon as possible.

Many wireworm control studies focus on evaluating insecticide efficacy. Studies show that certain active ingredients, such as the neonicotinoids thiamethoxam and imidacloprid, are as effective in controlling wireworms as the organophosphates (Kuhar and Alvarez, 2008) that are being linked to environmental and wildlife persistence (Elliott et al., 2011). Nevertheless, since these compounds are applied directly to seeds, several negative effects have been demonstrated over the years. Changes in the germination of the seeds treated with insecticides and/or fungicides were recorded by many authors (Klokočar-Šmit et al., 1993; Vujaković et al., 2006; Stevanović et al., 2009; Mrđa et al., 2010a). As seed vitality (germination energy, total germination and emergence in field conditions) is crucial in determining the plant number per hectare, which is one of the three main components of the yield (Mrđa et al., 2010b), it is important to apply seed treatments without negative effect on the mentioned parameters.

Currently, in Serbia and the entire Europe, due to the heavy restriction of neonicotinoid based insecticides for the sunflower seed treatments (Commission Regulation 2013/485), this field of work remains undefined. Having in mind the more frequent problems with wireworms, increased abundance of pests, economic damages they cause annually, restrictions for insecticides use in sunflower, there is a necessity in evaluating and comparing the efficacy of currently registered insecticides with the previously used and restricted ones.

The aim of this work was to assess the efficacy of currently registered insecticides in Serbia for sunflower seed treatments for the wireworm control (Semafor and Sonido) in comparison with previously used neonicotinoids (Cruiser and Gaucho) under conditions of moderate and/or heavy wireworm infestations.

MATERIAL AND METHODS

Wireworm abundance assessment

The number of wireworms was assessed based on the number of collected specimens in the soil pits. At the beginning of spring, entomological soil probes according to a standard square method (50 x 50 cm, to the depth of the parent layer of approximately 40 cm) were performed (one pit per ha, in total, 10 pits on the surface where the experiment will be performed). The number of collected wireworms in soil probes was multiplied 4 times to obtain the abundance per m^2.

Experimental design

The trial was set up as a split-plot design, in three replications, in 2017 at locality Rimski šančevi (S 45°19'41.2" E 19°49'35.7", altitude 84 m), on the experimental field of Institute of Field and Vegetable Crops in Novi Sad, Serbia. The seeds of sunflower hybrids Sumo 2 OR, Oliva and Novak, produced in vegetation season in 2016, were used in the trial. Hybrid seed was produced at the Institute of Field and Vegetable Crops. Three different hybrids were used to check the different attractiveness for wireworms and also to check the influence of seed treatments to seed performance in the field. The seed material was produced respecting agro-technical measures required by the technology of sunflower hybrid seed production. Regular cultivation practices required by the technology of sunflower production were applied in the experiment. The applied seed treatments of fungicides and insecticides are presented in Table 1.

The amount of commercial product applied was according to manufacturer's recommendation (Table 1) with addition of polymer and colorant Sepiret (0.3 L per 100 kg seeds), according to the regular sunflower seed processing procedure at the Institute of Field and Vegetable Crops (Novi Sad, Serbia).

The experimental unit consisted of 4 rows 5 m in length and 70 cm inter-row spacing. The swing was done manually, by putting 3 seeds per spot.

Table 1. Experimental treatments, product information and rates

Treatments	Active ingredient	Rate (L/100 kg seeds)
Apron XL 350 ES	350 g/L metalaxyl-m	0.3
Apron XL 350 ES + Semafor 20 ST	350 g/L metalaxyl-m + 200 g/L bifenthrin	0.3 + 0.2
Apron XL 350 ES + Sonido	350 g/L metalaxyl-m + 400 g/L thiacloprid	0.3 + 2 L
Apron XL 350 ES + Cruiser 350 FS	350 g/L thiamethoxam	0.3 +1
Apron XL 350 ES + Gaucho 600 FS	600 g/L imidacloprid	0.3 +1.75
Control	Untreated seeds	/

Soil on experimental field was calcareous chernozem. The following parameters were recorded: field emergence - FE (%), damaged plants by wireworms (%), yield (kg/ha), oil content (%) and the 1,000-seed weight (g). The field emergence and the number of damaged plants were evaluated by counting the sunflower plants when they developed the first pair of leaves. After counting, the plant stand was reduced to one plant per spot. Sunflower seed yield was calculated to kg/ha and corrected to 11% seed moisture, after pre-cleaning. One thousand-seed weight was determined in eight replications, each replicate contained 100 seeds, and the results were expressed to the nearest 0.01 g. Oil content (%) was determined in naturally dried seeds using nuclear magnetic resonance (NMR).

Statistical analysis

The data were statistically analyzed using the IBM SPSS Statistics 21 software package (IBM, 2012). Duncan's multiple range tests were performed to analyze the differences in tested parameters between three sunflower hybrids in different seed treatments. Two-way ANOVA analyzed the influence of factors (hybrids and seed treatments) and their interaction on the observed parameters. The confidence interval was 95%.

RESULTS

Number of wireworms

In the soil probes, the average of 3 wireworms per m^2 was detected. The number indicates at high abundance of wireworms at this site, since the threshold for sunflower is 2 specimens per m^2 (Savez društava za zaštitu bilja Jugoslavije, 1983).

Field emergence

The field emergence (FE) of Sumo 2 OR and Oliva hybrids did not differ significantly among the treatments (F=1.72NS; 0.59NS, P>0.05) and it ranged from 78.3 to 88.3% in the case of the first hybrid and 83.0 to 91.3% in the case of the second one (Table 2), respectively. However, FE of Novak was significantly lower (79.3%) when seed were treated only with the fungicide Apron (F=3.32*, P<0.05), while in other treatments it ranged from 83.3 to 91.7%. When comparing the emergence among the different hybrids within the same treatment, it was significantly lower FE (78.3 and 79.3%, respectively) for Sumo 2 OR and Novak, when Apron was applied, compared to Oliva, 91.3% (F=4.95*, P>0.05). Given indicates that the currently registered insecticides for the sunflower seed treatment, such as Sonido and Semafor, can be adequate substitute to the banned neonicotinoids like Cruiser and Gaucho.

Damaged plants

The highest percent of damaged plants was recorded in the control plot (14.0-17.5%), depending on the tested hybrid. Also, the difference between hybrids within the same seed treatment was statistically significant (F=85.26**, P<0.01) with Oliva having the highest number of damaged plants in average (6.85), followed by Sumo 2 OR (6.1%) and Novak (5.52%). Among different seed treatments, significantly the lowest number of damaged plants was in the treatment with Apron+Cruiser (1.1-2.4%). However, the wireworm damages did not differ significantly among seeds treated with the combinations Apron + Semafor (2.7-3.8%), Apron + Sonido (2.5-3.9%) and Apron + Gaucho (2.4-3.2%). The highest percent of damaged plants, aside from the Control, was in the treatment with Apron (8.6-10.7%). The differences were statistically highly significant between the percent of damaged plants among treatments, for all three hybrids (F=315.71**, 773.48**, 638.91**, P<0.01, respectively).

Yield

The yield was not under the influence of different seed treatments. The amount of harvested seeds per hectare for all three hybrids (Sumo 2 OR, Oliva and Novak) was at the same level of significance (F=2.18NS; 0.48NS, 0.12NS, P>0.05, respectively) regardless on the applied fungicide or mixtures of fungicides and insecticides. However, the significant difference in the yield was recorded among the hybrids within the same treatment. The highest average yield was measured for Novak (3,938.1 kg/ha), followed by Sumo 2 OR (3,566.1 kg/ha) and Oliva (3,199.8 kg/ha), regardless on the applied seed treatments (F=17.52**, P<0.01). On the other hand, when seeds were treated with the combination of Apron + Semafor, Oliva had significantly lower yield (3,152 kg/ha) compared to Sumo 2 OR (3,480 kg/ha) and Novak (3,847 kg/ha) and the differences between all three hybrids are statistically highly significant (F=9.45**, P>0.01). The same results were obtained when the seeds were treated with Apron + Cruiser (Table 3). The average yield of Oliva, regardless on the applied seed treatments, was 3,193.7 kg/ha, which was significantly lower than Sumo 2 OR (3,898 kg/ha) and Novak (3,922.7 kg/ha) (F=10.55*, P>0.01).

Oil content

The oil content was not under the influence of seed treatments in the case of Oliva and Novak (F=0.31NS, 0.69NS, P>0.05, respectively). It ranged from 47.12-48.07% for Oliva and from 49.66 to 50.81% for Novak, respectively. However, the insecticidal and fungicidal treatments affected the oil content in seeds of Sumo 2 OR, since significantly lower content (44.44%) was measured in the control (F=3.67*, P<0.05), compared to the other treatments in which it ranged from 45.67 to 46.42%. The results are presented in Table 3.

1,000-seed weight

The weight of 1,000 seeds was under the strong influence of hybrids but did not differ significantly between the treatments (Table 4). The highest average of 1,000-seed weight was measured for Oliva hybrid (63.25-65.97 g), while Novak had the lowest 1,000-seed weight (49.81-52.93 g) depending on the treatment. Among the same seed treatment, the highest 1,000-seed weight was measured for Oliva (63.25-65.97 g), followed by Sumo 2 OR (55.92-60.24 g) and the lowest for Novak (49.81-53.71 g). The differences are statistically highly significant (F=89.19**, P<0.01).

The results of Two-way ANOVA (Table 5) indicate that FE was not influenced by either of observed factors (hybrid and applied pesticide) or their interaction. However, the percent of damaged plants was significantly influenced by the treatments (F=111.5**, P<0.01) and the interaction treatment*hybrid. The yield, oil content and 1,000-seed weight were influenced only by the hybrid, while the treatment with fungicide and insecticides was not a factor of influence.

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Table 2. Field emergence (%) and damaged plants (%) of sunflower hybrids depending on the seed treatment

	Field emergence (%)					Damaged plants (%)				
	Sumo 2 OR	Oliva	Novak	X	F	Sumo 2 OR	Oliva	Novak	X	F
Control	86.3 ±2.89[aA]	88 ±1[aA]	84.8 ±4.62[abA]	86.4[a]	0.81[ns]	14.0 ±1.25[aC]	17.5 ±1.68[aA]	15.8 ±2.12[aB]	15.8[a]	21.4**
Apron	78.3 ±7.64[aB]	91.3 ±3.51[aA]	79.3 ±4.93[bB]	83[a]	4.95*	9.9 ±1.62[bB]	10.7 ±1.11[bA]	8.6 ±3.22[bC]	9.73[b]	48.85**
Apron+Semafor	81.7 ±2.51[aA]	86.7 ±9.51[aA]	91.7 ±2.08[aA]	86.7[a]	0.4[ns]	3.5 ±1.23[cAB]	3.8 ±2.2[cA]	2.7 ±1.3[cB]	3[c]	27.9*
Apron+Sonido	86 ±1.73[aA]	83 ±9.62[aA]	88.3 ±6.5[aA]	85.8[a]	0.42[ns]	3.9 ±1.6[cA]	3.6 ±2.2[cAB]	2.5 ±1.8[cB]	3.33[c]	9.18*
Apron+Cruiser	88.3 ±2.08[aA]	90.3 ±5.5[aA]	89.7 ±3.51[aA]	89.4[a]	0.2[ns]	2.1 ±1.72[dA]	2.4 ±2.05[dA]	1.1 ±0.99[dB]	1.86[d]	22.17**
Apron+Gaucho	86 ±7.93[aA]	89.7 ±5.86[aA]	83.3 ±2.89[abA]	86.3[a]	0.86[ns]	3.2 ±2.11[cA]	3.1 ±1.4[cdA]	2.4 ±1.8[cB]	2.9[c]	7.43*
X	84.44[a]	88.17[a]	86.17[a]		2.11[ns]	6.1[b]	6.85[a]	5.52[c]		86.26*
F	1.72[ns]	0.59[ns]	3.32*	0.72[ns]		315.71**	773.48**	638.91**		

Mean values ±SD. Values in the same column followed by the same lowercase letter are at the same level of significance between treatments. Values in the same row followed by the same uppercase letter are at the same level of significance between hybrids. **P<0.01, *P<0.05, [ns]P>0.05.

Table 3. Yield (kg/ha) of sunflower hybrids depending on the seed treatment

	Yield (kg/ha)				
	Sumo 2 OR	Oliva	Novak	X	F
Control	3,833.3 ±142.5^{aA}	3,441.7 ±423.8^{aA}	4,043 ±264.8^{aA}	3,772.7^{a}	3.01^{ns}
Apron	3,360.3 ±145.6^{aA}	3,126 ±444.7^{aA}	3,861 ±534.5^{aA}	3,449.1^{a}	2.51^{ns}
Apron+Semafor	3,480 ±301.8^{aB}	3,152 ±213^{aC}	3,847 ±250^{aA}	3,493^{a}	9.45**
Apron+Sonido	3,389 ±548.9^{aA}	3,310.3 ±429.2^{aA}	4,040.7 ±425.8^{aA}	3,580^{a}	2.17^{ns}
Apron+Cruiser	3,898 ±73.6^{aA}	3,193.7 ±314.3^{aB}	3,922.7 ±205^{aA}	3,671.5^{a}	10.55*
Apron+Gaucho	3,443 ±92.79^{aA}	2,974.6 ±510.7^{aA}	3,914.3 ±681.4^{aA}	3,444^{a}	2.71^{ns}
X	3,566.1^{b}	3,199.8^{c}	3,938.1^{a}		17.52**
F	2.18^{ns}	0.48^{ns}	0.12^{NS}	0.35^{ns}	

Mean values ±SD. Values in the same column followed by the same lowercase letter are at the same level of significance between treatments. Values in the same row followed by the same uppercase letter are at the same level of significance between hybrids. **P<0.01, *P<0.05, ^{ns}P>0.05.

Table 4. Oil content (%) and 1,000-seed weight depending on the seed treatment

	Oil content (%)					1,000 seed weight (g)				
	Sumo 2 OR	Oliva	Novak	X	F	Sumo 2 OR	Oliva	Novak	X	F
Control	44.44 ±0.9^{bB}	47.94 ±1.92^{aAB}	50.07 ±0.52^{aA}	47.5^{a}	18.05*	58.98 ±1.02^{aB}	64.59 ±3.5^{aA}	52.93 ±5.58^{aC}	58.8	13.7**
Apron	45.67 ±0.17^{aB}	48.07 ±0.7^{aA}	49.66 ±0.61^{aA}	47.8^{a}	30.51**	58.51 ±2.29^{aB}	65.25 ±2.85^{aA}	49.81 ±7.04^{aC}	57.8	28.8**
Apron+Semafor	46.13 ±0.21^{aB}	47.81 ±0.19^{aB}	50.26 ±1.26^{aA}	48.1^{a}	15.12**	57.45 ±1.63^{aB}	64.55 ±0.8^{aA}	53.73 ±4.85^{aC}	58.6	333.71**
Apron+Sonido	46.42 ±0.46^{aB}	47.73 ±1.71^{aB}	50.81 ±0.61^{aA}	48.3^{a}	19.53**	55.92 ±0.8^{aB}	63.25 ±2.88^{aA}	51.49 ±5.9^{aA}	56.9	9.43*
Apron+Cruiser	45.89 ±0.34^{aB}	47.12 ±0.71^{aB}	50.39 ±0.39^{aA}	47.8^{a}	30.3**	60.24 ±1.65^{aB}	65.97 ±2.27^{aA}	52.2 ±6.47^{aC}	59.5	17.83**
Apron+Gaucho	45.84 ±1.03^{aC}	47.77 ±0.73^{aB}	50.26 ±0.54^{aA}	47.9^{a}	23.3**	58.65 ±4.32^{aAB}	64.72 ±2.37^{aA}	52.53 ±6.19^{aC}	58.6	7.98*
X	45.73^{c}	47.74^{b}	50.24^{a}		134.88**	58.28^{b}	64.72^{a}	52.11^{c}		89.19**
F	3.67*	0.31^{NS}	0.69^{NS}	0.04^{ns}		1.27^{NS}	0.36^{NS}	0.19^{NS}	0.06^{ns}	

Mean values ±SD. Values in the same column followed by the same lowercase letter are at the same level of significance between treatments. Values in the same row followed by the same uppercase letter are at the same level of significance between hybrids. **P<0.01, *P<0.05, ^{ns}P>0.05.

Table 5. Sources of variation for observed parameters analyzed with Two-way ANOVA

Source	df	Field emergence (%)		Damaged plants (%)		Yield (kg/ha)		Oil yield (%)		1,000 seed weight (g)	
		SS	F	SS	F	SS	F	SS	F	SS	F
Corr. model	14	781.04[a]	1.55	541.184[a]	1.54[ns]	6,217,685.3[a]	2.61**	194.74[a]	16.802[ns]	1,501.389[a]	11.07**
Hybrid	2	124.926	2.107[ns]	105.026	2.55[ns]	4,906,321.3	17.52**	183.928	134.9**	1,429.958	89.19**
Treatment	4	190.593	1.286[ns]	408.860	111.5**	775,500.77	1.11[ns]	3.57	1.049ns	35.575	0.89[ns]
Hyb*Treat	8	465.519	1.570[ns]	27.298	10.9*	535,863.3	0.38[ns]	7.24	1.062[ns]	35.865	0.45[ns]

Corr. model – corrected model; aR Squared=0.93 (Adjusted R Squared=0.897); nsP>0.05, *P<0.05; **P<0.01; SS-Type III sum of squares; df-degrees of freedom

DISCUSSION

Seed germination under field conditions (field emergence) directly determines the number of plants per hectare, which is one of the three basic components of yield (Mrđa et al., 2011a). According to Ahmad (2001), the seed quality is one of the most important factors for plant vitality and for obtaining the adequate number of plants per unit. The damages caused by soil dwelling insects directly affect the number of plants per ha, plant stand and yield (Miklič et al., 2008).

In this work, the percent of damaged plants was dependent on the applied treatment. The results indicate at satisfactory efficacy of all applied seed treatments with insecticidal component, against wireworms, due to the low percent of damaged plants.

Literature data on the efficacy of neonicotinoids like thiamethoxam and imidacloprid are numerous. Sekulić (1991, 1993, 1998) and Senn et al. (1998) reported that the insecticides based on thiamethoxam and imidacloprid expressed strong efficacy against wireworms, which was proven in this work. The same was presented by Larsen et al. (2013), reporting that thiamethoxam increases wheat germination when applied on seeds. Mrđa et al. (2010b, 2011b) report that the highest number of emerged plants was in the treatments containing imidacloprid (fludioxonyl + metalaxyl-m + imidacloprid), which is in accordance with the results obtained in this work.

Dan et al. (2012) presented results showing that the treatment of soybean seeds with insecticides thiamethoxam, fipronil and imidacloprid provided adequate quality of the seeds and did not negatively affect the early development of plants. Thiamethoxam might even promote growth, biomass accumulation, increase seed vigor, plant height enhance flowering (Castro and Pereira, 2008; Cataneo et al., 2010; Almeida et al., 2013). It is reported by many authors, although for different crops, that thiamethoxam and imidacloprid can express phytotoxic effects and negatively affect germination and plant growth, when applied directly on seeds (Wilde et al., 2001; Castro et al., 2008; Stevens et al., 2008, Mrđa et al., 2011a). However, Tamindžić et al. (2016) concluded that these two active ingredients did not adversely affect seed germination of several maize inbred lines, moreover they had a positive impact on the root growth.

In this work, only field emergence of Novak was significantly decreased in the treatment with Apron compared to the other treatments as well as the Control. These results are similar to the results presented by Mrđa et al. (2010b; 2011b) indicating that insecticidal treatments of sunflower seeds, with thiamethoxam and imidacloprid combined with fungicides, significantly increased the field germination, compared to the fungicide treatment and the control. Also, Mrđa et al. (2010b) published the results on the influence of chemical treatments of sunflower seeds on the field emergence of three commercial sunflower hybrids. All hybrids achieved the highest field emergence (88.79-91.84%) when treated with fludioxonil + metalaxyl-m + imidacloprid. Miklič et al. (2008) reported the positive effect of insecticides Gaucho 600 FS and Cruiser 350 FS on the number of plants per hectare and field germination of sunflower seeds which is also in accordance with the results of this research.

Nevertheless, the data on the effects of novel seed treatment insecticides like the ones based on thiacloprid (Sonido) and bifentrine (Semafor), are scanty. In this work, the efficacy of the mentioned insecticides (combined with Apron fungicide), based on the plant stand and the percent of damaged plants, was satisfactory and at the same level of significance with neonicotinoids (Gaucho and Cruiser). The applied pesticide mixtures did not cause the reduction of germination or yield. Also, no other phytotoxic effects on sunflower plants were recorded. The opposite results were presented by Baldini et al. (2018) that reported negative effect of thiacloprid (a.i. of Sonido), when combined with systemic fungicides on maize seeds. The effects of fungicides in combination with thiacloprid were detrimental to maize seed germination compared to non-treated control. Vujošević et al. (2017) presented similar results. Namely, when treated with fungicide - insecticide combination (including metalxyl-m and thiacloprid), several different maize hybrids reacted with the delayed germination, which also is in consistency with the results obtained by Tamindžić et al. (2013). Although primary goal of seed treatment is to protect the seeds from soil pathogens and insect pests, prolonged germination and emergence, as a result of applied pesticides, exposes seed to a longer infestation period. Therefore, according to Vujošević et al. (2017), in order to provide the fast and uniform emergence under different conditions, further examination of the response of different genotypes to the specific seed treatment should be performed.

The results of this work show that the tested insecticides and fungicide did not affect yield because the plant stand was reduced from tree plants per spot to final stand, although percent of damages was higher in the untreated control. If the sowing was done on the final stand (one seed per spot), under the conditions of high wireworm abundance, the percent of damaged plants would probably be high and would lead to the reduction of yield, unless seeds are treated. This is in accordance with the results of Miklič et al. (2008), reporting that Gaucho 600FS and Cruiser 350FS significantly increased yield compared to the control, which is not the case with the new insecticides (Semafor and Sonido). The yield performance is an important target in the sunflower hybrid breeding. This property, in addition to the yield stability, is the crucial for producers and it depends on many factors. One of these factors is the plant number per area unit. This property is greatly influenced by the polyphagous soil-dwelling insects like wireworms. These damages decrease the crop stand and yield. Although the treated seed is more expensive, but a reduced number of treatments during growing season, better plant stand and improved yield performance compensate for the higher price (Miklič et al., 2008).

CONCLUSION

The obtained results indicate that the selection of hybrids and pesticides for the seed treatment should be obligatory measure in the sunflower production.

The results showed that the yield, oil content and 1,000-seed weight are under strong influence of tested hybrids. Also, very important conclusion is that the newly registered insecticides for sunflower seed treatment, such as Sonido and Semafor, provide good/acceptable field emergence and on the other side, satisfactory control of wireworms, based on the number of damaged plants in the field.

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