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Comparative effect of different insecticides on the growth and yield of soybeans

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Abstract: The yield of soybeans, an economically important crop worldwide, is substantially reduced by different abiotic and biotic factors, including insect pests. Different insecticides are applied to control soybean insect pests. The application of insecticides may also affect the plants along with the pests. The effects of four insecticides (fenitrothion, etofenprox, thiamethoxam, and lambda-cyhalothrin-cum-thiamethoxam; LT) on the growth and yield of two soybean cultivars over two years were investigated. The plant height (PH), pod number, shoot dry matter without seed (SDWS), total shoot dry matter, seed yield per plant (SYP), harvest index (HI), and hundred-seed weight significantly varied with the insecticides. However, the primary branch number was not significantly affected by the insecticides. Significant interactions between the year and insecticide, except for the SDWS and HI, indicated that the growing environment also affected the influence of the insecticides. The PH was significantly tall in the thiamethoxam (50.07 cm) and short for the LT (46.66 cm) application. The SYP was significantly high for the LT (20.51 g) and low for the fenitrothion (11.51 g). This study showed that the type of insecticide could significantly affect the plant growth and yield of the soybean.

Keywords: crop; insecticide spray; harvest index; plant height; pod number; shoot dry matter

The soybean [*Glycine max* (L.) Merrill] is an important crop as it supplies half of the global oil and vegetable protein. Different abiotic and biotic factors, including insect pests, substantially reduce the worldwide soybean yield. Piercing-sucking bugs are among the most notorious insects which directly damage the pods and cause substantial yield loss (Corrêa-Ferreira & Azevedo 2002). Various pest management practices have been adopted to minimise the economic losses caused by insect pests. Adoption of some cultural practices, sometimes even with the use of resistant cultivars, may not provide the desired level of crop protection alone, and, thus, supplemental control measures in the form of synthetic chemical applications may be essential. Various chemicals, in different formulations, have been extensively used to manage harmful insects of crops for decades. The application of pesticides not only controls the target pests, but may also influence the physiology and biochemistry of the non-target host plants in different ways. A pyriproxyfen application reduced the root and shoot dry biomass, leghaemoglobin, chlorophyll and seed protein contents in chickpeas; the nodule numbers in peas; the shoot nitrogen and root phosphorus in

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green grams; and the nodule biomass, root nitrogen, root phosphorus, shoot phosphorus and seed yield in lentils (Ahemad 2014). Organophosphate insecticides also reduce the germination of annual grasses and annual forb species (Gange et al. 1992). Rice seed treatment with the pyrethroid, organophosphate, and fipronil insecticides does not affect the germination, but coleoptile growth is significantly reduced (Moore & Kröger 2010). The foliar application of organophosphate and carbamate insecticides reduces cucumber plant growth (Gafar et al. 2013). The rate and speed of wheat seed germination are reduced as a result of the seed treatment with an organophosphate insecticide (Ahmad et al. 2014). Not all insecticides always affect the plant growth in negative ways, but they can also influence the plant growth in favourable ways. The seed treatment of soybeans with neonicotinoid increases the seed germination under water deficit conditions (Cataneo et al. 2010). The germination rate of spring wheat is also significantly enhanced with a neonicotinoid insecticide treatment (Larsen & Falk 2013). Photosynthetic leaf pigments in rice (Macedo et al. 2013a) and cotton and okra (Preetha & Stanley 2012) are increased with increased doses of thiamethoxam (neonicotinoid). Seed treatment with thiamethoxam also increases the number of fertile tillers, which results in the yield increment of spring wheat (Macedo & Castro 2011). The soil application of lower doses of aldicarb, carbofuran, phorate, fensulfothion, and fenamiphos in chickpeas favours higher pigment accumulation, but exhibits phytotoxicity with higher doses (Tiyagi et al. 2004).

Although several reports have been available on the effect of insecticides on the mortality of target insect pests, there has very few literature pieces been published on the comparative action of different insecticides on the growth and physiology of soybeans. A study on the comparative effect of insecticides on the soybean (Dhungana et al. 2016) showed that different classes of insecticide have a differential influence on the germination, early plant growth, and antioxidant activities. The application of different pesticides in various concentrations in the soil, before seed sowing, significantly affects the soybean plant growth and nutritive composition of the seeds in different ways (Siddiqui & Ahmed 2006). The seed treatment with a neonicotinoid insecticide increased the soybean yield (North et al. 2016). Similarly, the foliar application of different insecticides significantly affected the leaf-level spectral reflectance of the soybean (Alves et al. 2017). There are no reports about the comparative effects of a foliar application of different insecticides on the growth and yield of the soybean. In the present study, the foliar application of four different classes of insecticide was carried out on soybean plants with the objective of investigating their influence on the growth and yield components. This study could provide useful information on the effect of the different types of pesticides on the growth and yield of crops.

MATERIAL AND METHODS

Plant materials and insecticides. Two cultivars of soybean [*Glycine max* (L.) Merrill], Saedanbaek and Taekwangkong, were used to investigate the effect of four different classes of insecticide, which were sprayed to control piercing-sucking bugs. Fenitrothion (trade name: Mepthion; chemical name: *O*,*O*-dimethyl *O*-4-nitro-*m*-tolyl phosphorothioate; formulation: emulsifiable concentrate; chemical class: organophosphate), etofenprox (trade name: Myungtaja; chemical name: 2-(4-ethoxyphenyl)-2-methylpropyl-3-phenoxybenzyl ether; formulation: emulsion, oil in water; chemical class: pyrethroid), thiamethoxam (trade name: Actara; chemical name: 3-(2-chloro-thiazol-5-ylmethyl)-5-methyl-[1,3,5]oxadiazinan-4-ylidene-N-niroamine; formulation: granule; chemical class: neonicotinoid), and lambda-cyhalothrin-cum-thiamethoxam (LT) (trade name: Stonate; chemical name: cyano-(3-phenoxyphenyl)methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2dimethyl cyclopropane carboxylate-cum-3-(2-chloro-thiazol-5-ylmethyl)-5-methyl-[1,3,5]oxadiazinan-4-ylidene-N-niroamine; formulation: granule; chemical class: pyrethroid-cum-neonicotinoid) were the four insecticides used in this study.

Growing conditions and insecticide application. This study was conducted in the open space of the greenhouse premises of Kyungpook National University in Daegu, the Republic of Korea. Soybean seeds were sown in seedling trays, the seedlings were grown in the trays until 21 days and then two seedlings were transplanted in 8-L pots on June 11 and 4 in 2014 and 2015, respectively. The pots were filled with soil from a crop field. The use of a chemical fertiliser was replaced by the addition of 80 g of organic fertiliser (Yasimchan Taechang Biotech, Korea) in each pot before transplanting. Seven pots, kept in a row, were considered as a treatment. The pots were regularly watered to keep the soil moist during the plants' growth and development.

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The spray solutions of four different insecticides – fenitrothion, etofenprox, thiamethoxam, and LT were prepared in tap water as per the dose (2 mL/L, 1 mL/L, 0.5 g/L, and 0.5 g/L, respectively) instructed on their labels. The spraying of the insecticides was started at R4 (full pod) stage and continued until the next 40 days at 10-day intervals as per the instructions provided with the insecticides. The plants were thoroughly sprayed until the runoff point was reached using a knapsack sprayer. In order for the reduction of the insecticide drift across the treatments, the rows of different treatments were partitioned using a 2 m high double-layered landscape fabric for 24 h after the insecticide was sprayed.

Measurement of growth and yield parameters. The plant height (PH) was measured from the soil surface to the tip of the main stem. The plants were harvested at maturity and a single plant was kept into an onion bag and then dried in a greenhouse (50 °C) until it had a constant weight. The shoot dry matter without seed (SDWS) and total shoot dry matter (TSD) were considered without the leaves. The seed yield of each plant was recorded and the harvest index (HI) was calculated by dividing seed weight (g) by the TSD (g). All these parameters were recorded in the 10 plants. The hundred-seed weight (HSW) was measured in five replications. The plants grown without the insecticide spray were severely affected by the insect pests and did not produce good seeds. The senescence in those plants was also delayed compared to the other insecticide-sprayed plants. Therefore, the non-sprayed insecticide control plants were not considered in this report.

Statistical analysis. All the data were analysed using the SAS (version 9.4) statistical package to generate ANOVA and the significant differences among the treatment means were identified by the LSD (least significant difference) test at 5% probability.

RESULTS

Plant height. The ANOVA study showed that the soybean plant height varied significantly ($P \leq 0.0001$) with the cultivar, year, and insecticide. The cultivar × year and year × insecticide interactions were also significant ($P = 0.0002$), whereas the cultivar × insecticide interaction was not significant ($P = 0.2203$). The non-significant interaction of the cultivar and insecticide indicated that the height of the soybean plant was influenced by the insecticide irrespective of the cultivar (Supplementary Table S1). The significant year × insecticide interaction implied that the effect of insecticide may vary temporally. As long as both the year mean and cultivar mean values were considered, thiamethoxam (50.07 cm) significantly ($P < 0.05$) increased the plant height (Table 1).

Primary branch. Unlike the plant height, the insecticide did not cause significant ($P = 0.1506$) variation in the number of primary branches (Table S1). The year mean value of the number of primary branches in the etofenprox-treated (4.25) Saedanbaek plants was significantly ($P < 0.05$) higher than that of the LT (3.75) and thiamethoxam (3.75), however, the value was not significant ($P > 0.05$) for the Taekwangkong plants (Table 1). The differential effect of the particular insecticide on the number of primary branches was temporal while considering the cultivar mean: in 2014, fenitrothion (5.45) significantly increased the number of primary branches compared to the other three insecticides; however, in 2015, etofenprox (4.40) and LT (4.25) significantly increased the number when compared to fenitrothion (3.70). Considering the cultivar mean and year mean, etofenprox (4.60) significantly increased the number of primary branches when compared to thiamethoxam (4.22) (Table 1).

Number of pods. The number of pods per plant varied significantly ($P = 0.0005$) with the type of insecticide applied. Similarly, the year × insecticide interaction was also significant ($P = 0.0167$); however, the interactions of the cultivar × year as well as the cultivar × insecticide was not significant (Table S1). As in the number of primary branches, the effect of etofenprox (43.50) on producing a large number of pods was significantly higher than that of thiamethoxam (38.39) in the Saedanbaek cultivar; however, fenitrothion (64.08) outweighed the other three insecticides in the Taekwangkong cultivar, when considering the year mean values (Table 1). Fenitrothion (55.68) and LT (53.01) significantly enhanced the pod number in 2014, whereas fenitrothion (51.85) and etofenprox (51.80) accounted for more pods in 2015, while considering the cultivar mean. The result of year mean of the cultivar mean showed that fenitrothion (53.77), followed by etofenprox (49.87) and LT (48.63), might enhance the pod formation (Table 1).

Shoot dry matter without seed. The ANOVA study indicated that the SDWS was significantly ($P \leq 0.0001$) affected by the type of insecticide sprayed, but not with the cultivar, year, and their interactions (Table S1). The effect of fenitrothion on the higher SDWS was consistently significant, while

Table 1. The growth and yield components of two soybean cultivars with four insecticides applications in 2014 and 2015

Trait/ insecticide	Cv. Saedanbaek			Cv. Taekwangkong			Cultivars mean		
	2014	2015	year mean	2014	2015	year mean	2014	2015	year mean
Plant height (cm)									
Fenitrothion	53.80^{a}	40.68^{b}	47.24^{a}	55.70^{b}	42.19^{b}	48.95^{b}	54.75^{ab}	41.44^{b}	48.09^{b}
Etofenprox	47.86^{c}	44.81^{a}	46.33^{ab}	55.82^{b}	44.07^{ab}	49.95^{b}	51.84^{c}	44.44^{a}	48.14^{b}
Thiamethoxam	51.45^{ab}	44.23^{a}	47.84^{a}	56.02^{b}	45.91^{a}	52.31^{a}	55.08^{a}	45.07^{a}	50.07^{a}
LT	49.93^{bc}	39.19^{b}	44.56^{b}	58.70^{a}	41.51^{b}	48.76^{b}	52.98^{bc}	40.35^{b}	46.66^{c}
LSD$_{0.05}$	2.927	3.420	2.212	2.519	2.786	1.846	1.898	2.168	1.428
Number of primary branches									
Fenitrothion	5.30^{a}	3.10^{b}	4.20^{ab}	5.60^{a}	4.30^{a}	4.95^{a}	5.45^{a}	3.70^{b}	4.56^{ab}
Etofenprox	4.60^{ab}	3.90^{a}	4.25^{a}	5.00^{ab}	4.90^{a}	4.95^{a}	4.80^{b}	4.40^{a}	4.60^{a}
Thiamethoxam	3.80^{b}	3.70^{a}	3.75^{b}	4.78^{b}	4.60^{a}	4.69^{a}	4.29^{b}	4.15^{ab}	4.22^{b}
LT	3.80^{b}	3.70^{a}	3.75^{b}	5.56^{a}	4.80^{a}	5.12^{a}	4.68^{b}	4.25^{a}	4.46^{ab}
LSD$_{0.05}$	0.823	0.524	0.480	0.679	0.894	0.552	0.525	0.509	0.363
Number of pods									
Fenitrothion	43.70^{ab}	43.20^{a}	43.45^{ab}	67.67^{a}	60.50^{a}	64.08^{a}	55.68^{a}	51.85^{a}	53.77^{a}
Etofenprox	42.00^{ab}	45.00^{a}	43.50^{a}	53.89^{b}	58.60^{a}	56.24^{b}	47.94^{b}	51.80^{a}	49.87^{b}
Thiamethoxam	40.22^{b}	36.56^{a}	38.39^{b}	52.80^{b}	52.10^{a}	52.45^{b}	46.51^{b}	44.33^{b}	45.42^{c}
LT	47.22^{a}	37.10^{a}	42.16^{ab}	58.80^{b}	51.40^{a}	55.10^{b}	53.01^{a}	44.25^{b}	48.63^{bc}
LSD$_{0.05}$	5.415	8.795	5.076	6.941	9.904	5.944	4.326	6.509	3.875
Shoot dry weight without seed (g)									
Fenitrothion	25.24^{a}	25.82^{a}	25.53^{a}	28.41a	25.12^{a}	26.76a	26.83^{a}	25.47^{a}	26.15^{a}
Etofenprox	20.79^{b}	21.21^{ab}	21.00^{b}	19.89^{b}	22.15^{ab}	21.02^{b}	20.34^{b}	21.68^{b}	21.01^{b}
Thiamethoxam	15.43^{c}	18.70^{b}	17.06^{c}	17.94^{b}	19.01^{bc}	18.47^{c}	16.68^{c}	18.85^{bc}	17.77^{c}
LT	19.40^{b}	18.45^{b}	18.92^{bc}	19.10^{b}	18.16^{c}	18.63^{bc}	19.25^{b}	18.30^{c}	18.78^{c}
LSD$_{0.05}$	3.113	5.199	2.978	3.466	3.733	2.504	2.290	3.145	1.929
Seed yield per plant (g)									
Fenitrothion	9.32^{c}	6.79^{b}	8.05^{c}	16.80^{b}	13.14^{c}	14.97^{c}	13.06^{c}	9.96^{c}	11.51^{c}
Etofenprox	14.67^{b}	13.71^{a}	14.187^{b}	16.89^{b}	18.92^{b}	17.91^{b}	15.78^{b}	16.31^{b}	16.05^{b}
Thiamethoxam	13.56^{b}	15.12^{a}	14.34^{b}	18.89^{b}	21.15^{ab}	20.02^{b}	16.23^{b}	18.13a^{b}	17.18^{b}
LT	20.31^{a}	16.05^{a}	18.18^{a}	23.06^{a}	22.62^{a}	22.84^{a}	21.68^{a}	19.34^{a}	20.51^{a}
LSD$_{0.05}$	2.382	2.903	1.846	4.103	3.188	2.554	2.331	2.119	1.562
Total shoot dry matter (g)									
Fenitrothion	34.57^{b}	32.61^{a}	33.59^{ab}	45.20^{a}	38.26^{a}	41.73^{a}	39.88^{a}	35.43^{a}	37.66^{ab}
Etofenprox	35.46^{ab}	34.92^{a}	35.19^{ab}	35.38^{c}	41.07^{a}	38.23^{a}	35.42^{b}	37.99^{a}	36.71^{ab}
Thiamethoxam	28.99^{c}	33.81^{a}	31.40^{b}	36.29^{bc}	40.16^{a}	38.23^{a}	32.64^{b}	36.99^{a}	34.81^{b}
LT	39.71^{a}	34.50^{a}	37.10^{a}	42.16^{ab}	40.78^{a}	41.47^{a}	40.93^{a}	37.64^{a}	39.29^{a}
LSD$_{0.05}$	5.024	7.214	4.321	6.615	6.152	4.440	4.083	4.660	3.071
Harvest index									
Fenitrothion	0.271^{d}	0.214^{c}	0.243^{d}	0.369^{c}	0.341^{c}	0.355^{c}	0.320^{d}	0.277^{c}	0.299^{d}
Etofenprox	0.416^{c}	0.393^{b}	0.405^{c}	0.457^{b}	0.460^{b}	0.458^{b}	0.436^{c}	0.426^{b}	0.431^{c}
Thiamethoxam	0.465^{b}	0.445^{ab}	0.455^{b}	0.517^{a}	0.528^{a}	0.522^{a}	0.491^{b}	0.487^{a}	0.489^{b}
LT	0.510^{a}	0.472^{a}	0.491^{a}	0.546^{a}	0.555^{a}	0.551^{a}	0.528^{a}	0.514^{a}	0.521^{a}
LSD$_{0.05}$	0.0288	0.0576	0.0317	0.0425	0.0414	0.0292	0.0253	0.0349	0.0214

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Table 1 to be continued

Trait/ insecticide	Cv. Saedanbaek			Cv. Taekwangkong			Cultivars mean		
	2014	2015	year mean	2014	2015	year mean	2014	2015	year mean
Hundred-seed weight (g)									
Fenitrothion	22.87^{a}	22.93^{a}	22.90^{a}	24.08^{a}	27.46^{a}	25.77^{a}	23.47^{a}	25.19^{a}	24.33^{a}
Etofenprox	21.37^{ab}	23.14^{a}	22.25a^{b}	24.54^{a}	26.82^{a}	25.68^{a}	22.95^{a}	24.98^{a}	23.97^{a}
Thiamethoxam	20.37^{b}	20.91^{b}	20.64^{c}	24.89^{a}	24.23^{a}	24.56^{b}	22.63^{a}	22.57^{b}	22.60^{b}
LT	21.67^{ab}	21.14^{b}	21.40^{bc}	25.03^{a}	24.58^{a}	24.81^{ab}	23.35^{a}	22.86^{b}	23.10^{b}
$LSD_{0.05}$	2.0637	0.4483	0.9707	1.4049	1.8485	1.0672	1.1475	0.8743	0.6931

LT – lambda-cyhalothrin-cum-thiamethoxam; $LSD_{0.05}$ – least significant difference at $P \leq 0.05$

considering the year mean and cultivar mean values (Table 1). The results of the SDWS strongly supported the hypothesis that the insecticides of different classes might differentially influence the growth and development of plants. The year mean values of the SDWS significantly increased with the application of fenitrothion, followed by etofenprox. The other two insecticides, LT and thiamethoxam, reduced the SDWS production.

Seed yield per plant. The soybean seed production was significantly affected by the insecticide and cultivar ($P \leq 0.0001$) and the year × insecticide interaction ($P = 0.0049$) (Table S1). In contrast to the effect on the SDWS, fenitrothion reduced the seed yield, as far as the year mean and cultivar mean values were taken into account. On the other hand, LT significantly increased the seed yield followed by thiamethoxam and etofenprox, while considering the year mean values (Table 1). In both cultivars, the year mean value indicated that LT and fenitrothion could positively and negatively affect the seed yields, respectively.

Total shoot dry matter. The ANOVA study showed similar results for the TSD production as seen in the seed yield — a statistically significant variation with the cultivar, the insecticide, and the interaction of year × insecticide (Table S1). Although the effect of insecticides on the TSD was significant, it was not consistent between the cultivars over two years. The significantly high cultivar mean TSD was found with LT (40.93 g) and fenitrothion (39.88 g) in 2014; however, in 2015, the effect was not significantly different among the insecticides (Table 1).

Harvest index. The HI value significantly varied with the cultivar, year, insecticide, and their interactions, except for the year × insecticide (Table S1). The HI of the fenitrothion- and etofenprox-treated plants of both cultivars was significantly ($P < 0.05$) low when compared to that of the other two insecticides, except for the Saedanbaek variety in 2015. The results were also similar to those obtained in 2014 and 2015 with the cultivar mean values (Table 1). Taking the year mean of the cultivar mean data, the HI of the four insecticides was significantly different with the highest value for LT (0.521) followed by thiamethoxam (0.489), etofenprox (0.431), and the lowest for fenitrothion (0.299).

Hundred-seed weight. The HSW significantly varied with the cultivar, year, insecticide, and the interaction for the year × insecticide (Table S1). The HSW value for the year mean of the cultivar mean was significantly high with the fenitrothion (24.33 g) and etofenprox (23.97 g) treatments (Table 1). Although the HSW of the cultivar mean was not significantly different in 2014, the value was significantly high for fenitrothion (25.19 g) and etofenprox (24.98 g) when compared to that for thiamethoxam (22.57 g) and LT (22.86 g) in 2015 (Table 1).

DISCUSSION

The application of insecticides has, generally, become inevitable in crop protection. Under such widespread use of chemicals for pest suppression, their effect on the target and non-target organisms needs to be examined. In this study, the effect of four insecticides on the growth and yield components of two soybean cultivars over two years was investigated.

The taller soybean plants obtained with the thiamethoxam application might be due to the effect of the thiamethoxam molecule, which plays the role of a growth regulator (Macedo & e Castro 2011). Similar results were also found in previous studies, for instance, the seed treatment with thiamethoxam increased the plant height of cotton and okra (Preetha & Stanley 2012), rice (Almeida et al. 2014a; Hum-

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mel et al. 2014), and common beans (Almeida et al. 2014b). Soybean seed treatment with thiamethoxam also enhanced the seedling vigour (Dhungana et al. 2016). The application of thiamethoxam caused a significant increase in the fresh and dry weights of the roots and shoots of the common bean (Almeida et al. 2014b). Reports show that the application of thiamethoxam in plants increases the soluble protein content, which enhances the plants ability to effectively fix carbon dioxide and, thus, accelerates photosynthesis (Preetha & Stanley 2012) and plant growth (Kirschbaum 2011), although a negative effect of thiamethoxam on a plant's metabolism, including shoot growth, was also found in a previous study (Macedo et al. 2013b). On the other hand, the reduced plant height with the fenitrothion treatment might be due to its toxic effect (Weinberger et al. 1978; Pomber et al. 1979) because fenitrothion inhibits the utilisation of reserve materials and suppresses the hydrolytic enzyme activities and disrupts the protein metabolism in plants (Dalvi et al. 1972). A significant decrease in the available nitrogen and phosphorus contents in the soil treated with the organophosphate insecticide (Sardar & Kole 2005) might also have played a role in reducing the height of the fenitrothion treated plants. The increased plant height in 2014 might be due to the favourable weather conditions for the soybean growth (data not shown).

There might be different factors, along with the effect of insecticides, responsible for the variation in the number of primary branches. Shoot branching is dependent on a plant's genotype, developmental stage, and the environment in which it is growing, and the integration of these multiple factors is likely to be mediated by a network of interacting hormonal signals (Ongaro & Leyser 2007; Müller & Leyser 2011). Although not specifically examined in the present study, the activation of different hormones might have accounted for the variation in the number of primary branches. Insecticides may influence the concentration and biosynthesis of plant hormones such as salicylic acid (Shen et al. 2013). Although shoot branching is a highly plastic developmental process in which three classes of plant hormones, auxins, cytokinins, and strigolactones are central (Domagalska & Leyser 2011), the precise balance between the plant hormones is important for their biosynthesis and responses, which ultimately regulate the growth and development in the plants (Kumar et al. 2014; Schaller et al. 2015). The significantly higher number of primary branches obtained in 2014 (4.80) than in 2015 (4.13) was possibly due to the good plant growth.

The higher pod number obtained with the fenitrothion application might be due to the higher number of primary branches (Table 1) and the fewer number of undamaged pods produced (data not shown) which is also verified by the lower seed yield (Table 1). There might be some kinds of relationship between the seed yield and pod number to compensate for the insect damage through an increased number of pods tending to produce more seeds as hypothesised for the seed size (Rogers & Brier 2010). The soybean is also known to recover from pod damage until the full pod stage (Kogan & Herzog 1980). In addition, the application of different classes of insecticide might have influenced the concentration and biosynthesis of the plant hormones (Shen et al. 2013) and, consequently, the flowering and pod formation. Moreover, the pod number was possibly regulated by the pod initiation and/or abortion of the initiated pods (Board & Tan 1995) due to the toxic effect of fenitrothion (Weinberger et al. 1978; Pomber et al. 1979).

The higher SDWS for fenitrothion and etofenprox might be due to the reduced seed yield obtained with these insecticides (Table 1). The sink limitation hypothesis (Paul & Foyer 2001; Woodward 2002), which implies that a reduced seed production might promote a higher biomass accumulation, also supports the speculation of a higher dry matter accumulation in the fenitrothion and etofenprox applications in which the seed yield was lower (Table 1).

The varied seed yields for the different insecticides might be due to their influence on the concentration and biosynthesis of the plant hormones (Shen et al. 2013) resulting in variations in the flowering and pod formation. Furthermore, the possible toxic effect of fenitrothion (Weinberger et al. 1978; Pomber et al. 1979) might have regulated the pod initiation and/or abortion of the initiated pods (Board & Tan 1995). The difference in the soybean seed yield due to the type of insecticide applied was also inconsistent with the year and location (Regan et al. 2017) which was not clear whether the difference was due to the insect pest suppression alone or the physiochemical effect on the host plants as well.

The increased HI value in 2014 might be due to the better yield in that year as a result of favourable weather conditions as mentioned earlier. The higher HI for the LT and thiamethoxam treatment was

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possibly due to the higher seed yield, but the lower SDWS for these two insecticides compared to the fenitrothion and etofenprox (Table 1).

A positive effect of fenitrothion and etofenprox was also observed in the HSW (Table 1) as in the shoot dry matter production. The increased HSW for fenitrothion and etofenprox might be due to the reduced seed yield, but elevated SDWS. The increased seed size for fenitrothion and etofenprox might be due to a compensation for the low seed yield with large seeds (Rogers & Brier 2010). The size of the undamaged seeds significantly increased with the insect injury level (Suzuki et al. 1991; Lopes et al. 1997), implying a relationship between the size and yield of the seed. A review report (Bennett et al. 2011) further supports the hypothesis for the seed size in a way that the pod may play role in the reallocation of reserves from damaged seeds to the undamaged ones which might consequently increase the size and weight of the undamaged seeds.

The foliar application of various classes of insecticides had different effects on the growth and yield of the soybeans. Among the four insecticides applied, the lowest seed yield was obtained with the fenitrothion application in spite of an increased number of the pods that we observed. It is important to note that we did not investigate the effect of the foliar application of the different insecticides in an insect-free environment. Despite the limitation, the present research illustrated how significantly the commonly used insecticides could regulate the growth and physiology of a non-targeted host plant.

REFERENCES

Ahemad M. (2014): Growth suppression of legumes in pyriproxyfen stressed soils: a comparative study. Emirates Journal of Food and Agriculture, 26: 66–72.

Ahmad K.A., Dwivedi H., Dwivedi P. (2014): Residual impact of triazophos on the germination of wheat (*Triticum aestivum* L.) Var. Lok-1. Advances in Life Science and Technology, 21: 18–20.

Almeida A.S., Deuner C., Borges C.T., Meneghello G.E., Jauer A., Villela F.A. (2014a): Treatment of rice seeds with thiamethoxam: reflections on physiological performance. Journal of Seed Science, 36: 458–464

Almeida S.A., Villela F.A.V., Meneghello G.E., Deuner C., de Tunes L.M., Zimmer P.D., Jauer A. (2014b): Physiological performance of common bean seeds treated with bioactivator with and without moisture restriction. American Journal of Plant Sciences, 5: 3769–3776.

Alves T.M., Marston Z.P., MacRae I.V., Koch R.L. (2017): Effects of foliar insecticides on leaf-level spectral reflectance of soybean. Journal of Economic Entomology, 110: 2436–2442.

Bennett E.J., Roberts J.A., Wagstaff C. (2011): The role of the pod in seed development: strategies for manipulating yield. New Phytologists, 190: 838–853.

Board J., Tan Q. (1995): Assimilatory capacity effects on soybean yield components and pod number. Crop Science, 35: 846–851.

Cataneo A.C., Ferreira L.C., Carvalho J.C., Andréo-Souza Y., Corniani N., Mischan M.M., Nunes J.C. (2010): Improved germination of soybean seed treated with thiamethoxam under drought conditions. Seed Science and Technology, 38: 248–251.

Corrêa-Ferreira B.S., De Azevedo J. (2002): Soybean seed damage by different species of stink bugs. Agricultural and Forest Entomology, 4: 145–150.

Dalvi R.R., Singh B., Salunkhe D.K. (1972): Influence of selected pesticides on germination and associated metabolic changes in wheat and mung bean seeds. Journal of Agricultural and Food Chemistry, 20: 1000–1003.

Dhungana S.K., Kim I.D., Kwak H.S., Shin D.H. (2016): Unraveling the effect of structurally different classes of insecticide on germination and early plant growth of soybean [*Glycine max* (L.) Merr.]. Pesticide Biochemistry and Physiology, 130: 39–43.

Domagalska M.A., Leyser O. (2011): Signal integration in the control of shoot branching. Nature Reviews Molecular Cell Biology, 12: 211–221.

Gafar M.O., Elhag A.Z., Abdelgader M.A. (2013): Impact of pesticides malathion and sevin on growth of Snake Cucumber (*Cucumis melo* L. var. Flexuosus) and soil. Universal Journal of Agricultural Research, 1: 81–84.

Gange A.C, Brown V.K., Farmer L.M. (1992): Effects of pesticides on the germination of weed seeds: implications for manipulative experiments. Journal of Applied Ecology, 29: 303–310.

Hummel N.A., Mészáros A., Ring D.R., Beuzelin J.M., Stout M.J. (2014): Evaluation of seed treatment insecticides for management of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), in commercial rice fields in Louisiana. Crop Protection, 65: 37–42.

Kirschbaum M.U. (2011): Does enhanced photosynthesis enhance growth? Lessons learned from CO_2 enrichment studies. Plant Physiology, 155: 117–124.

Kogan M., Herzog D.C. (1980): Sampling Methods in Soybean Entomology. New York, Springer.

Kumar R., Khurana A., Sharma A.K. (2014): Role of plant hormones and their interplay in development and ripening of fleshy fruits. Journal of Experimental Botany, 65: 4561–4575.

https://doi.org/10.17221/77/2019-PPS

Larsen R.J., Falk D.E. (2013): Effects of a seed treatment with a neonicotinoid insecticide on germination and freezing tolerance of spring wheat seedlings. Canadian Journal of Plant Science, 93: 535–540.

Lopes E.C.A., Destro D., Montalván R., Ventura M.U., Guerra E.P. (1997): Genetic gain and correlations among traits for stink bug resistance in soybean. Euphytica, 97: 161–166.

Macedo W.R., e Castro P.R.d.C. (2011): Thiamethoxam: Molecule moderator of growth, metabolism and production of spring wheat. Pesticide Biochemistry and Physiology, 100: 299–304.

Macedo W.R., Araújo D.K., e Castro P.R.d.C. (2013a): Unravelling the physiologic and metabolic action of thiamethoxam on rice plants. Pesticide Biochemistry and Physiology, 107: 244–249.

Macedo W.R., Fernandes G.M., Possenti R.A., Lambais G.R., e Castro P.R.d.C. (2013b): Responses in root growth, nitrogen metabolism and nutritional quality in Brachiaria with the use of thiamethoxam. Acta Physiologiae Plantarum, 35: 205–211.

Moore M., Kröger R. (2010): Effect of three insecticides and two herbicides on rice (*Oryza sativa*) seedling germination and growth. Archives of Environmental Contamination and Toxicology, 59: 574–581.

Müller D., Leyser O. (2011): Auxin, cytokinin and the control of shoot branching. Annals of Botany, 107: 1203–1212.

North J.H., Gore J., Catchot A.L., Stewart S.D., Lorenz G.M., Musser F.R., Cook D.R., Kerns D.L., Dodds D.M. (2016): Value of neonicotinoid insecticide seed treatments in mid-south soybean (*Glycine max*) production systems. Journal of Economic Entomology, 109: 1156–1160.

Ongaro V., Leyser O. (2007): Hormonal control of shoot branching. Journal of Experimental Botany, 59: 67–74.

Paul M.J., Foyer C.H. (2001): Sink regulation of photosynthesis. Journal of Experimental Botany, 52: 1383–1400.

Pomber L., Weinberger P., Prasad R. (1979): Some phytotoxic effects of fenitrothion on the germination and early seedling growth of *Picea glauca* (MOENCH) Voss and *Betula alleghaniensis* Britton. Bulletin of Environmental Contamination and Toxicology, 22: 494–499.

Preetha G., Stanley J. (2012): Influence of neonicotinoid insecticides on the plant growth attributes of cotton and okra. Journal of Plant Nutrition, 35: 1234–1245.

Regan K., Ordosch D., Glover K.D., Tilmon K.J., Szczepaniec A. (2017): Effects of a pyrethroid and two neonicotinoid insecticides on population dynamics of key pests of soybean and abundance of their natural enemies. Crop Protecion, 98: 24–32.

Rogers D.J., Brier H.B. (2010): Pest-damage relationships for *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) on soybean (*Glycine max*) and dry bean (*Phaseolus vulgaris*) during pod-fill. Crop Protection, 29: 47–57.

Sardar D., Kole R.K. (2005): Metabolism of chlorpyrifos in relation to its effect on the availability of some plant nutrients in soil. Chemosphere, 61: 1273–1280.

Schaller G.E., Bishopp A., Kieber J.J. (2015): The yin-yang of hormones: cytokinin and auxin interactions in plant development. Plant Cell, 27: 44–63.

Shen W., Cevallos-Cevallos J.M., Nunes da Rocha U., Arevalo H.A., Stansly P.A., Roberts P.D., van Bruggen A.H.C. (2013): Relation between plant nutrition, hormones, insecticide applications, bacterial endophytes, and *Candidatus* Liberibacter Ct values in citrus trees infected with Huanglongbing. European Journal of Plant Pathology, 137: 727–742.

Siddiqui Z.S., Ahmed S. (2006): Combined effects of pesticide on growth and nutritive composition of soybean plants. Pakistan Journal of Botany, 38: 721–733.

Suzuki N., Hokyo N., Kiritani K. (1991): Analysis of injury timing and compensatory reaction of soybean to feeding of the southern green stink bug and the bean bug. Applied Entomology and Zoology, 26: 279–287.

Tiyagi S.A., Ajaz S., Azam M.F. (2004): Effect of some pesticides on plant growth, root nodulation and chlorophyll content of chickpea. Archives of Agronomy and Soil Science, 50: 529–533.

Weinberger P., Pomber L., Prasad R. (1978): Some toxic effects of fenitrothion on seed germination and early seedling growth of jack pine, spruce, and birches. Canadian Journal of Forest Research, 8: 243–246.

Woodward F.I. (2002): Potential impacts of global elevated CO_2 concentrations on plants. Current Opinion in Plant Biology, 5: 207–211.

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