Action of auxin inhibitors on growth and grain yield of soybean

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ABSTRACT

Soybean genotypes grown in sub-tropical climate may exhibit lodging. The plant lodging is influenced by soil type and fertility level, sowing date, latitude and altitude of the location, plant population and conditions of crop development. Plant regulators and herbicides are able to avoid or reduce plant lodging. This study aimed to verify the effects of the growth regulators TIBA and daminozide on vegetative growth and yield of soybean cultivar CD 214 RR. The experiment was carried out at a field in randomized block design with four replications in a factorial scheme. The A factor was represented by the combination of regulators TIBA and daminozide and its concentrations, and the Factor B was seven times of evaluation of injury and plant height or eight times of evaluation of lodging. In the range of doses used, the application of daminozide resulted in greater injury to soybean plants than TIBA. The smaller plant height was achieved by the application of 6 g ha^{-1} of TIBA and 1200 g ha-¹ of daminozide. Treatments with daminozide (100 g ha-¹) and TIBA (10 g ha^{-1}) stood out due to the reduced lodging of soybean plants. Grain weight increased linearly when the levels of TIBA increased. There was a negative correlation between lodging and grain yield and a positive correlation between plant height and lodging. There was also a negative correlation between injury caused by the application of plant regulators and lodging.

Key words: lodging, injury, height, harvest index.

RESUMO

Ação de inibidores de auxina sobre o desenvolvimento e rendimento de plantas de soja

Genótipos de plantas de soja, cultivados em regiões de clima subtropical, podem apresentar acamamento acentuado. O acamamento de plantas é influenciado pelo tipo de solo e pela fertilidade, época de semeadura, latitude e altitude do local, população de plantas e condições gerais de desenvolvimento do cultivo. Reguladores vegetais e alguns herbicidas são capazes de evitar ou reduzir o acamamento. Este trabalho teve o objetivo de avaliar os efeitos da aplicação dos reguladores de crescimento TIBA e daminozide sobre o desenvolvimento vegetativo e o rendimento de grãos do cultivar de soja CD 214 RR. O experimento foi conduzido em campo, em delineamento de blocos ao acaso, com quatro repetições, em esquema bifatorial, sendo o fator A os reguladores TIBA e daminozide e suas concentrações e, o fator B, sete épocas de avaliação da injúria e altura de planta, ou oito épocas de avaliação do acamamento. Na faixa de doses utilizada, a aplicação de daminozide resultou em maior injúria às plantas de soja do que a aplicação de TIBA. As menores alturas de plantas foram alcançadas com a aplicação de 6 g ha^{-1} de TIBA e 1200 g ha^{-1} de daminozide. Os

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tratamentos com daminozide (100 g ha^{-1}) e TIBA (10 g ha^{-1}) destacaram-se pela redução do acamamento de plantas de soja. O peso de grãos aumentou linearmente com a elevação das doses de TIBA. Houve correlação negativa entre acamamento e rendimento de grãos de soja, e positiva, entre altura de planta e acamamento. Também foi constatada correlação negativa entre injúria à soja, causada pela aplicação dos reguladores vegetais, e peso de grão.

Palavras-chave: acamamento, injúria, altura, índice de colheita.

INTRODUCTION

Growth retardants are plant growth regulators that lower division and cell elongation in meristematic tissues, and physiologically regulate plant height (Cathey, 1964), without decreasing grain yield (Rademacher, 2000). Its use can prevent the excessive growth of soybean plants, minimizing the lodging. However, plant growth regulators can cause injury or phytotoxicity to plants, so it is important that these issues do not decrease the crop yield.

The 2,3,5-triiodobenzoic acid (TIBA) and succinic acid-2,2-dimethylhydrazide (daminozide) are well-known plant growth regulators. The TIBA is an inhibitor of basipetal auxin transport (Geldner *et al*. 2001). The daminozide inhibits the action of tryptamine oxidase in the endogenous indolylacetic acid biosynthesis (Castro & Appezzato-da-Glória, 1993). According to Rademacher (2000), daminozide is an inhibitor of 2-oxoglutarate dioxygenase and blocks the formation of gibberellic acid (GA).

The TIBA can promote changes in vegetative and reproductive characteristics of soybean. The height reduction is associated with the shortening of the internode of the plant (Hicks, 1967). The application of TIBA in soybean resulted in higher grain yield (Pankaj *et al.*, 2001). In contrast, different doses of TIBA applied in soybean resulted in no significant differences in the number of grains and pods and weight of 100 grains (Cato & Castro, 2006).

The daminozide is widely used in horticultural and floral species (Pinto *et al.*, 2006; Neves, 2009), with the primary purpose to reduce the height and preserve desirable characteristics of marketing. The application of daminozide in beans, in the stage of three leaves, or early flowering, reduced plant height, increasing the number of pods per plant, weight of 1000 seeds and grain yield (Castro *et al*., 1990).

In southern Brazil, especially in areas with altitude above 700 m, some soybean cultivars are more prone to lodging, such as the cultivar CD 214 RR. Therefore, in these areas, it is common the preference for short stature cultivars that exhibit reduced lodging (Embrapa, 2008).

The present study aimed to evaluate the effects of plant growth regulators, inhibitors of auxin transport and synthesis, in the development and grain yield of soybean cultivar CD 214 RR.

MATERIAL AND METHODS

The experiment was carried out in field, at Universidade Tecnológica Federal do Paraná, located in Pato Branco, Paraná State, with a latitude of 26°10‘27“ S, longitude of 52°41‘10“ W and altitude of 720 m. The climate of the municipality, according to Köppen, is classified as Cfa – mesothermal humid subtropical. The soil of the experimental area is the type Latossolo Vermelho distroférrico úmbrico.

The experimental design was a randomized block with four replicates. The treatments were arranged in a factorial scheme, where the first factor corresponded to plant regulators and their concentrations, as it follows: untreated control, 2,3,5-triiodobenzoic acid (TIBA commercial product) in concentrations 6, 8 and 10 g ha^{-1} applied at R_1 stage, and daminozide (B-Nine commercial product), at doses 100, 300, 400, 1200 g ha^{-1}, applied at stage V_5. The factor B corresponded to seven evaluation periods for the variables injury and plant height (7, 14, 21, 28, 35, 42, 49 days after application) and eight lodging evaluation periods (7, 14, 21, 28, 35, 42, 49 e 56 days after application).

Each experimental unit was composed of five sowing lines, occupying 4.7 m long and 2.0 m wide. Soybean CD 214 RR seeds were sown at 5 cm of depth, 0.40 m of spacing and density of 400,000 plants ha^{-1}. The density used in this experiment aimed to maximize the plants lodging, based on the observations made in soybean crops in the southwest region of Paraná State.

The plant growth regulators were sprayed using a backpack equipment pressurized with CO_2, with flat fan type nozzles 110.02, calibrated for a flow of 200 L ha^{-1}. Necessary cautions regarding the application of plant growth regulators and other pesticides were observed during the experiment, such as relative humidity greater than or equal to 60%, temperatures within the range of 20-30° C and wind speed less than 8

km/h. Moreover, the minimum recommended intervals between the product application and rainfall occurrence were considered, in order to avoid loss of efficacy of plant growth regulators. During the experiment, the main pests and diseases were monitored and controlled, when necessary, in accordance with the technical recommendations for the soybean crop.

Plant height, lodging and the injuries of products for soybean were determined along the crop cycle. To determine the height, ten plants were selected randomly in each parcel, in which the distance was measured from the neck of the plant until the last expanded leaf. The lodging was determinated considering the useful area, grading the lodging according to Bernard *et al*. (1965) scale: Grade 1 – all the plants erect; Grade 2 - Some plants slightly inclined or lodged; Grade 3 - All plants moderately inclined or 25-50% lodged; Grade 4 - All plants severely sloped or 50-80% lodged; and Grade 5 - All the plants lodged.

The injury was determined based on the scale for visual assessment of injury caused by herbicides, proposed by Frans *et al*. (1986), where: 0 – no effects or no injury; 10 – light effect, slight discoloration or atrophy; 20 – light effect, some discoloration and atrophy; 30 – light effect, injury more pronounced, but not definitive; 40 - Moderate effect, moderate injury, usually recovers; 50 - Moderate effect, more permanent injury, doubtful recovery; 60 - Moderate effect, and permanent damage without recovery; 70 - Severe effect, heavy injury and loss of stand; 80 – Severe effect, plants almost destroyed, few surviving plants; 90 – Severe effect, occasionally a few surviving plants; 100 - Full effect (death), total destruction of the crop.

At the end of the experiment, the harvest of the plots was performed in an area of 4.05 m², to determine the grain yield. A sample of 1 m linear belonging to this area was harvested separately to obtain the number of plants m^{-2}, number of pods $plant^{-1}$, number of grains pod^{-1} and grain weight. To obtain the grain yield and weight of 400 grains, the moisture content was adjusted to 13%.

Data were subjected to analysis of variance by F test, considering 5% probability. The relationship between the independent and dependent variables was adjusted by polynomial regression model. The averages between treatments for injury, height and lodging, were compared within each season by the DMS test at 5% of probability. The averages of grain yield were compared by Tukey test at 5% of probability. The values of injury were transformed to $\sqrt{x} + 5$ and root lodging, number of plants m^{-2}, number of pods $plant^{-1}$ and number of grains pod^{-1}, to $\sqrt{x}$.

The programs GENES and WINSTAT were used to perform statistical analysis and Sigma-plot 10.0 to build the graphs.

RESULTS AND DISCUSSION

Plants treated with TIBA, at all concentrations showed no injury, and thus, no differences compared to the control treatment at any evaluation time. The doses from 300 to 1200 g ha^{-1} of daminozide caused little injury to soybean, differing significantly from TIBA treatments and from the control (Figure 1 and Table 1).

In the first evaluation, at seven days after application (DAA), the injury caused by daminozide, at any dose, was classified as light, characterized by a slight chlorosis primarily in younger leaves. The daminozide at the dose of 1200 g ha^{-1}, caused greater injury than that presented by the control, by treatment with TIBA and also for daminozide in lower concentration (100 g ha^{-1}) (Figure 1).

In all treatments with daminozide, the plants showed a reduction in injury in the second (14 DAA) and third times (21 DAA), with complete recovery, ie, the absence of injury, from 21 DAA. These data contrast with those obtained by Castro & Moraes (1980) according to which the daminozide did not cause damage to the foliage of soybean plants.

Treatment with 1200 g ha^{-1} of daminozide promoted the greater reduction in soybean height (average 9.7%), observed in all assessment times, compared to the control and other treatments. The dose of 1200 g ha^{-1} daminozide promoted greater height reduction compared to the dose of 400 g ha^{-1} of the same regulator, although there was a significant difference only at 21 and 28 DAA (Figure 2 and Table 2). In general, these two treatments with daminozide were those with the greatest ability to reduce plant height, mainly from the 35th DAA. The dose of 6 g ha^{-1} of TIBA was the one that produced the greater reduction on plant height for the same growth regulator, with emphasis on the 21^{th} and 28^{th} DAA.

The plants treated with daminozide at concentrations 100 and 300 g ha^{-1}, and TIBA, at the concentration of 8 g ha^{-1}, were inefficient in reducing plant height.

Thus, it was noticed that higher doses of daminozide resulted in greater reduction in the soybean plants height. For TIBA, the higher dose caused lower height reduction than the lowest dose tested (6 g ha^{-1}). Special attention should be given to the fact that TIBA was applied on stage V_5 and daminozide on growth stage R_1. Therefore, it cannot be said that the different behavior is due only to the attributes of the molecule applied, but due to the interaction between molecular and physiological state of the soybean plant.

The foliar application of 6, 8 and 10 g ha^{-1} of TIBA in soybean cultivar Pintado, which has determined growth habit, at stage V_5, resulted in reduction in height at all concentrations tested (Cato & Castro, 2006). These authors

found that the lower concentrations of the plant growth regulator (6 g ha^{-1}) produced 54% of reduction in height compared to that observed in control, but the higher concentration (10 g ha^{-1}) was more effective in reducing plant high, contrasting to this experiment. The differences between the studies, regarding to the response to concentrations of TIBA, may be related to the specific behavior of the cultivar studied or to the distinct stage of development from soybeans at the time of the application, or to a combined response of these two factors.

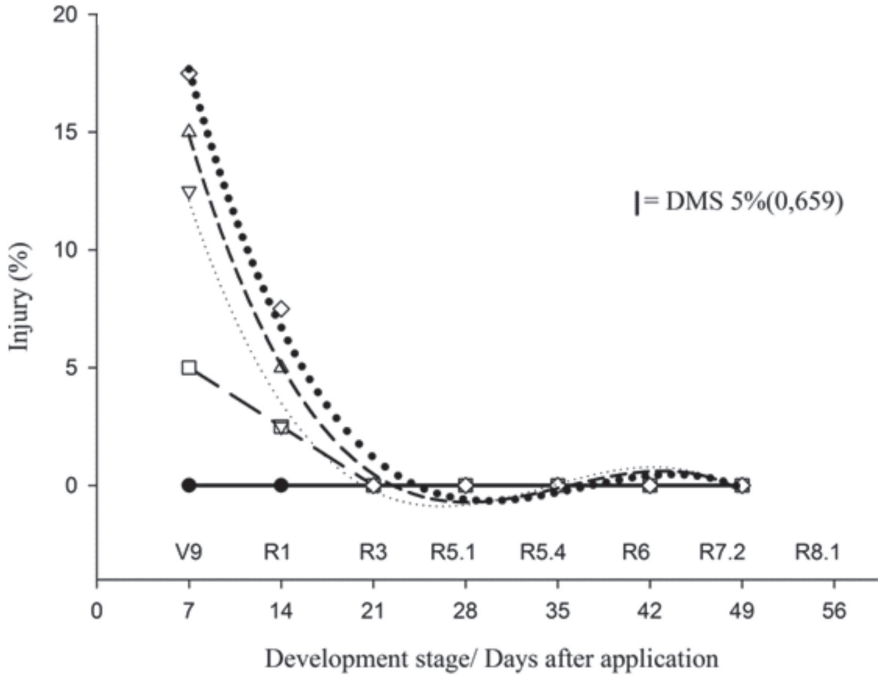

Figure 1. Injury (%) in soybean plants (*Glycine max* (L.) Merrill), cultivar CD 214 RR, due to the treatments with control (—●—), TIBA at 6 (-•-), 8 (—▲—), and 10 g ha^{-1} (••▼••), and, daminozide at 100 (—□—) , 300 (••▽••), 400 (—△—) and 1.200 (●◇●) g ha^{-1} in differet development stage/assessment time. UTFPR, Campus Pato Branco.

Table 1. Adjusted polynomial equations and coefficients of determination of injury in soybean plants influenced by the action of auxin inhibitors in different development stages/assessment time. UTFPR, Campus Pato Branco

Treatments	Polynomial equations	R^2
Control	n.s.	
Daminozide 100 g ha^{-1}	$\hat{Y} = 4{,}702 - 2{,}5x + 0{,}297\ x^2$	0,9359
Daminozide 300 g ha^{-1}	$\hat{Y} = 12{,}083 - 11{,}537x + 3{,}244x^2 - 0{,}277x^3$	0,9795
Daminozide 400 g ha^{-1}	$\hat{Y} = 14{,}881 - 12{,}876x + 3{,}392x^2 - 0{,}277x^3$	0,9938
Daminozide 1200 g ha^{-1}	$\hat{Y} = 17{,}678 - 14{,}216x + 3{,}541x^2 - 0{,}277x^3$	0,9902
TIBA 6 g ha^{-1}	n.s.	-
TIBA 8 g ha^{-1}-^{1}	n.s.	-
TIBA 10 g ha^{-1}	n.s.	-

n.s. = regression not significant by F Test.

Table 2. Polynomial equations and coefficients of determination regarding the height of soybean plants, influenced by TIBA and daminozide in different development stage/assessment time. UTFPR, Campus Pato Branco

Treatment	Polynomial equations	R^2
Control	$\hat{Y} = 88{,}392 + 48{,}241x - 12{,}748x^2 + 1{,}049x^3$	0,9879
TIBA 6 g ha-^{1}	$\hat{Y} = 92{,}192 + 28{,}998x - 6{,}489x^2 + 0{,}502x^3$	0,9147
TIBA 8 g ha-^{1}	$\hat{Y} = 89{,}862 + 41{,}802x - 10{,}427x^2 + 0{,}833x^3$	0,9858
TIBA 10 g ha-^{1}	$\hat{Y} = 90{,}2595 + 43{,}772x - 12{,}080x^2 + 1{,}04x^3$	0,9635
Daminozide 100 g ha-^{1}	$\hat{Y} = 99{,}285 + 34{,}005x - 7{,}818x^2\ 0{,}548x^3$	0,9723
Daminozide 300 g ha-^{1}	$\hat{Y} = 97{,}017 + 35{,}641x - 8{,}136x^2 + 0{,}561x^3$	0,9669
Daminozide 400 g ha-^{1}	$\hat{Y} = 95{,}029 + 36{,}661x - 9{,}419x^2 + 0{,}753x^3$	0,9743
Daminozide 1200 g ha-^{1}	$\hat{Y} = 85{,}937 + 33{,}812x - 7{,}885x^2 + 0{,}576x^3$	0,9848

Regarding the reduction of lodging, the highlight was obtained with treatment with daminozide (100 g ha^{-1}), which differed significantly from that observed with control at 14, 21, 28, 35 and 56 DAA. The lodging caused by the higher level of daminozide (1200 g ha^{-1}) differed significantly from that observed on the control only at 14 and 21 DAA (Figure 3 and Table 3).

Plants treated with TIBA (10 g ha^{-1}) showed significant reduction in lodging, at 14, 21, 28, and 49 DAA in relation to the control treatment (Figure 3 and Table 3), while the lowest dose (6 g ha^{-1}), only 14 and 28 DAA.

Significant reductions in lodging of soybean plants using TIBA and daminozide, had been reported in studies conducted during the decades of 60 and 70 (Burton &

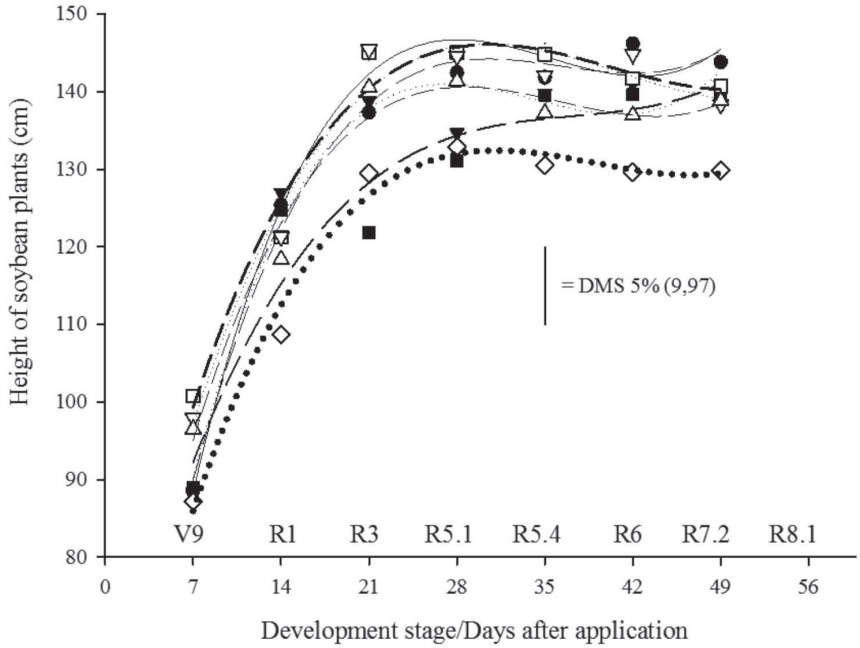

Figure 2. Height of soyben plants (*Glycine max* (L.) Merrill), cultivar CD 214 RR, due to the treatments with control (—●—), TIBA at 6 (+), 8 (— ▲ —), and 10 g ha^{-1} (‥▼‥), and, daminozide at 100 (—□—), 300 (‥▽‥), 400 (— △ —) and 1.200 (● ◇ ●) g ha^{-1} in differet development stage/assessment time. UTFPR, Campus Pato Branco.

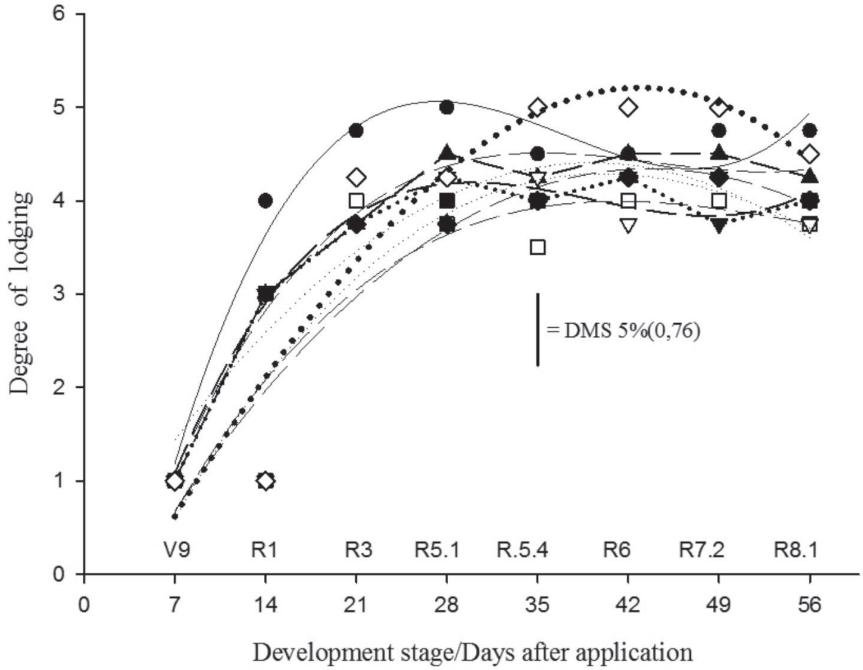

Figure 3. Lodging in soybean plants (*Glycine max* (L.) Merrill), cultivar CD 214 RR, due to the treatments with the control (—●—), TIBA at 6 (+), 8 (— ▲ —), and 10 g ha^{-1} (‥▼‥), and daminozide at 100 (—□—), 300 (‥▽‥), 400 (— △ —) and 1.200 (● ◇ ●) g ha^{-1} in different development stage/assessment time. UTFPR, Campus Pato Branco.

Curley, 1966; Hicks, 1967; Gowda, 1972). Probably, the lowest plant height and the increase of stem diameter in treated soybean plants, contribute to the diminish of lodging. It is possible that the effects of TIBA and daminozide in plants are due to the lower transportation and reduction of indoleacetic acid synthesis in treated plants (Geldner *et al.*, 2001; Perr *et al.*, 2004; Muller & Leyser, 2011).

The application of the growth regulators did not result in plant mortality and therefore, no differences were found for the number of plants per squared meter on the R_9 evaluation (Table 4). Furthermore, there were no significant differences among treatments for the number of pods per plant, number of seeds per pod and grain yield (Table 4).

In general, the treatment with TIBA resulted in larger grain weight, compared to the daminozide treatments (Table 4). It was observed a gain of the weight of soybeans with increasing dose of TIBA (Figure 4), and a trend to the opposite effect with increasing dose of daminozide. However, the change produced in grain weight was not enough to cause significant differences in grain yield between treatments with daminozide (Table 4). The increased number of seeds per plant with the application of TIBA was reported by Pankaj *et al.* (2001). However, as in this experiment, the works conducted by Castro (1981) and Cato & Castro (2006) found no effect on grain yield.

Highly significant correlation was found between plant height and lodging, with r = 0.8 (Table 5). This indicates that the reduction in plant height is reflected in lodging reduction. It was observed significant negative correlation between injury and height (r = -0.5), and between injury and lodging (r = -0.5). The injury was not correlated with grain yield (Table 5).

There is a significant negative correlation between lodging and grain yield, which means that the reduction of lodging contributed significantly to increase grain yield (Table 5). In conditions that favor high vegetative development of soybean, the plants become very susceptible to lodging. In turn, lodging cause shading of the sheets that used to receive radiation. The shaded leaves with lower radiation interception, have higher respiration /photosynthesis rate than those with good sun exposure, and they can become photoassimilates drains, which can reduce the plant production capacity. Furthermore, should be considered that plants of the plots were harvested manually, and mechanical harvesting produces difficulties in gathering

Table 3. Polynomial equations and coefficients of determination regarding to soybean plants lodging, influenced by TIBA e daminozide in diferente development stage/assessment time. UTFPR, Campus Pato Branco

Treatment	Polynomial equation	R^2
Control	$\hat{Y} = 1{,}182+3{,}224x-0{,}839x^2+0{,}065x^3$	0,9617
TIBA 6 g ha^{-1}	$\hat{Y} = 1{,}076+ 2{,}337x -0{,}555x^2 0{,}040x^3$	0,9843
TIBA 8 g ha^{-1}	$\hat{Y} =1{,}08+ 2{,}141x -0{,}429x^2+ 0{,}027x^3$	0,9829
TIBA 10 g ha^{-1}	$\hat{Y} = 1{,}053+ 2{,}296X -0{,}524X^2 +0{,}037x^3$	0,9827
Daminozide 100 g ha^{-1}	$\hat{Y} = 0{,}659+ 1{,}669x -0{,}264x^2+ 0{,}013x^3$	0,8046
Daminozide 300 g ha^{-1}	$\hat{Y} = 0{,}587+ 1{,}735x -0{,}237x^2 0{,}008x^3$	0,8444
Daminozide 400 g ha^{-1}	$\hat{Y} = 0{,}6875+1{,}402x -0{,}134x^2$	0,8776
Daminozide 1200 g ha^{-1}	$\hat{Y} = 0{,}621+ 1{,}586x -0{,}096x^2 -0{,}008x^3$	0,8931

Table 4. Number of plants per square meter (NPM), number of pods per plant, number of seeds per pod, weight of 400 grains and grain yield of soybean due to the treatments. UTFPR, Campus Pato Branco

Product/ Concentrations	Number of plants (m^{-2})	Number of pods ($planta^{-1}$)	Number of grains (pod^{-1})	Weight of 400 grains (g)	Grain yield (kg ha^{-1})
TIBA (6 g ha^{-1})	29,8 a	49,9 a	1,74 a	48,2abc	2261 a
Daminozide (300 g ha^{-1})	36,3 a	54,2 a	1,36 a	44,9bcd	2190 a
Control	33,9 a	66,5 a	1,34 a	45,7bcd	2111 a
TIBA (8 g ha^{-1})	28,6 a	48 a	1,47 a	49,1ab	2090 a
Daminozide (400 g ha^{-1})	35,1 a	54 a	1,45 a	41,8d	2031 a
Daminozide (100 g ha^{-1})	38,1 a	56,9 a	1,41 a	44,5bcd	2005 a
TIBA (10 g ha^{-1})	25,6 a	86,3 a	1,43 a	53,3a	1937 a
Daminozide (1200 g ha^{-1})	41,1 a	55,7 a	1,41 a	42,6cd	1913 a
Averages	33,56	58,93	1,45	46,3	2068
C.V. %	14,2	16,9	7,7	5,9	11,3

* Averages followed by the same letter do not differ statistically by Tukey test at 5% probablility.

[1] Data transformed by $\sqrt{x}$.

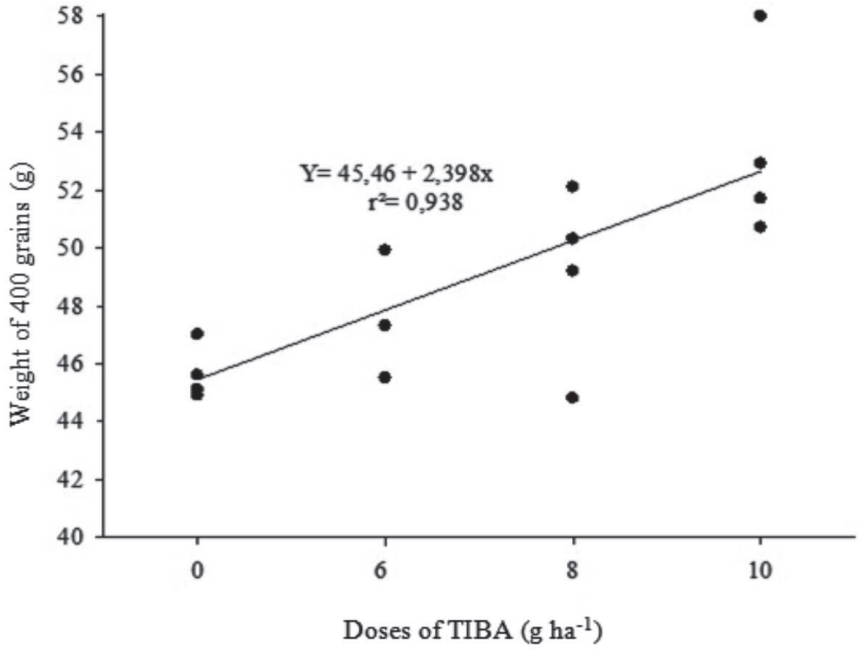

Figure 4. Weight of soybean grains (*Glycine max* (L.) Merrill), cultivar CD 214 RR, due to doses of TIBA. UTFPR, Campus Pato Branco.

Table 5. Pearson correlation coefficient between the assessed characteristics: plants lodging (PL), plant height (HEI), injury related to all treatments (INJ), number of plants per square meter (NPM), number of pods per plant (NPP), number of grains per pod (GP), mass of 400 grains (HG, g), harvest index (HI) and grain yield (YIELD) in the treatments with inhibitors of auxin. UTFPR, Campus Pato Branco

	HEI	PL	INJ	NPM	NPP	GP	HG	HI
PL	0,8**							
INJ	-0,5**	-0,5**						
NPM	-0,49**	0,09	0,13					
NPP	0,2	-0,12	-0,1	-0,64**				
GP	-0,07	-0,09	-0,3	-0,002	-0,28			
HG	0,2	-0,3	-0,6**	-0,4	0,3	0,1		
HI	-0,26	-0,28	-0,4*	-0,17	0,42*	0,36*	0,5**	
YIELD	-0,18	-0,4*	-0,25	0,2	-0,19	0,23	0,08	0,3

*, ** Significant at 5 and at 1% of probability by test t, respectively.

the fallen plants, which could result in more pronounced losses in grain yield.

A highly significant negative correlation between injury and grain weight and its reasonable magnitude (-0.6), indicates that the lower grain weight, in the treatments with daminozide, was determined by the injury caused by these treatments. There was also a negative correlation between injury and harvest index, which can be explained by the metabolic cost of the plants to recover from the injury caused, by reducing investment in reproductive structures. The harvest index, in turn, was positively correlated with the components number of pods per plant, number of seeds per pod and weight of 400 grains, as expected, since it expresses the increase of the ability of assimilates allocation to reproductive organs.

CONCLUSIONS

The plant growth regulator TIBA caused higher injury symptoms on soybean plants, while daminozide caused mild toxicity to the crop than daminozide.

Specific concentrations of TIBA and daminozide were able to reduce plant height and lodging in soybean.

In general, the plant growth regulators TIBA and daminozide did not affect grain yield, but the component grain weight presented an increment directly proportional to the dose of TIBA.

The reduction of height of soybean plants was strongly associated to the lodging reduction, which contributed to the increase in grain yield of the crop.

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