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ORIGINAL PAPER

FOLIAR APPLICATION OF SOME GROWTH BIOREGULATORS AND THEIR EFFECT ON THE YIELD AND NUT QUALITY IN PECAN

Laura Raquel Orozco-Meléndez[1], Ofelia Adriana Hernández-Rodríguez[1], Oscar Cruz-Alvarez[1], Raquel Cano-Medrano[2], Juan Luis Jacobo-Cuellar[1], Rafael Ángel Parra-Quezada[1], Jorge Jimenez-Castro[1], Damaris Leopoldina Ojeda-Barrios[1]

[1] Faculty of Agrotechnological Sciences
Universidad Autonoma de Chihuahua, Mexico
[2] Postgraduate College, State of Mexico, Mexico

Abstract

The pecan [*Carya illinoinensis* (Wangenh.) K. Koch.] is a deciduous species with high economic importance and nutritional value that exhibits alternate bearing. The mitigation of alternate bearing through the floral initiation of pistillate flowers is very important to improve the yield and nut quality. The aim of this research was to evaluate the effect of the application of some growth bioregulators on the yield and nut quality in pecan. The application of gibberellic acid (GA3 - 50 mg L^{-1}), thidiazuron (TDZ - 10 mg L^{-1}) and prohexadione calcium (PCa - 500 mg L^{-1}) was carried out during two years (2017 and 2018) on young Western Schley pecan trees from an orchard located in Chihuahua, Mexico. The foliar application of growth bioregulators minimized alternate bearing by maintaining the number of fruits set before harvest between the evaluation years. Between the evaluated production cycles, the data obtained indicate that the application of growth bioregulators affected the yield, although the nut weight per kilogram remained similar with TDZ (5.6 and 5.7 g). PCa was the best treatment for both parameters. Likewise, significant variation in the alternate bearing index with respect to the control was observed. On the other hand, the kernel percentage showed the best behavior between years and treatments with the use of GA3 and PCa. The use of the evaluated growth bioregulators could be an agronomic management strategy to minimize alternate bearing in Western Schley pecan trees.

Keywords: *Carya illinoinensis*; alternate bearing index; prohexadione calcium; gibberellic acid; thidiazuron.

Damaris Leopoldina Ojeda-Barrios, Assoc. Prof. PhD., Faculty of Agrotechnological Sciences, Universidad Autonoma de Chihuahua, Mexico, e-mail: dojeda@uach.mx

INTRODUCTION

The pecan [*Carya illinoinensis* (Wangenh.) K. Koch] is a crop of great profitability and socioeconomic importance worldwide (Ojeda-Barrios et al. 2016). Pecan trees take ten years to develop into mature trees capable of nut production (Randall et al. 2015). Mature pecan trees exhibit a phenomenon known as alternate bearing, that is variation in annual nut production between high nut yield years and low nut yield years (Smith 2012). This phenomenon causes economic losses to pecan producers (Kumar et al. 2016). Alternate bearing is linked to the concentration of carbohydrates stored during the winter (Rohla et al. 2007), which affects the formation and development of female flowers in the next year (Randall et al. 2015).

The production process, which comprises flowering, fruit setting and fruit filling, inhibits the flowering and fruiting of the next cycle because it is energy intensive. Furthermore, in years of low production, there is greater development of vegetative structures, which help to accumulate more reserves (nutrients and carbohydrates) to produce intense flowering and high yield in the next cycle (Rebolledo, Romero 2011, Wood 2011, Sharma et al. 2019). Growth bioregulators also cause flower induction (Zuo et al. 2018), and the presence of flowers determines nut productivity (Smith 2012).

Growth bioregulators are natural or synthetic substances that influence the growth and development of the plant (Martínez-Damián et al. 2019). Among these, there are hormones (auxins, gibberellins, cytokinins, ethylene and abscisic acid), which are categorized according to structural similarities and their effects on plant physiology (Smith 2012). In perennial crops, a variety of bioregulators influence the enhancement or reduction of bud growth, flowering, formation of fruit, ripening, fruit quality, and defoliation (Wood 2011, Rademacher 2015).

The timely use of floral promoters, such as gibberellic acid (GA3), prohexadione calcium (PCa) and thidiazuron (TDZ), has been shown to be helpful in "on" years to promote the return of flowering the following "off" year, while the use of gibberellic acid in "off" years helps decrease the subsequent year's flowering. It is unknown whether these promoters and inhibitors affect pecan flowering in the same way (Wood 2011). The application of TDZ regulates the initiation of the floral organ and the floral architecture, turning a determined flower into an inflorescence (Han et al. 2014). In temperate deciduous fruit trees, such as the cultivar Golden Delicious apple, PCa reduces shoot length and increases production and the number of fruits set (Pérez-Barraza et al. 2016). GA3 increases the number of fruits harvested in mango crop (Pérez-Barraza et al. 2009, Pérez-Barraza et al. 2015).

In pecan, the timely application of growth bioregulators can act directly on pistillate flower buds (Wood 2011). Applying PCa in years of high flowering further promoted flowering, while the use of GA3 during a low flowering year decreased high flowering in the following year (Smith 2012). Therefore, the aim of this research was to evaluate the effect of the application of some growth bioregulators on the yield and nut quality in pecan.

MATERIAL AND METHODS

The study was conducted during two consecutive years (2017-2018) in Sacramento, Chihuahua, Mexico, at 28°57′1.44″ N, 106°14′2.73″ W and altitude of 1,440 meters above sea, with precipitation and average annual temperature of 366.5 mm and 17.8°C, respectively. The soil was characterized as having sandy loam texture, with 0.95% organic matter, pH 7.6 and EC 2.5 dS m^{-1}. The chemical composition was the following (mg kg^{-1}): 18 N-total, 8 P, 275 K^+, 5,406 Ca^{2+}, 320 Mg^{2+}, 139 Fe^{2+}, 180 Mn^{2+}, 13 Zn^{2+} and 4 Cu^{2+}. The trees were 12-year-old cultivar Western Schley, on native graft carriers. The orchard spacing was 6 x 12 m (139 trees per hectare). The mineral composition of the leaflets of the trees used was obtained (Table 1). April 15, 2017 marked the beginning of the experiment.

Table 1

Mineral composition in leaflets of pecan trees cultivar Western Schley selected for this experiment

Year	Macronutrients (g kg^{-1})				
	N-total	P	K^+	Ca^{2+}	Mg^{2+}
2017	18.91	1.85	15.30	27.30	3.18
2018	24.70	1.92	17.00	25.30	3.35
	Micronutrients (mg kg^{-1})				
	Fe^{2+}	Cu^{2+}	Mn^{2+}	Zn^{2+}	Ni
2017	154.00	5.85	215.20	38.50	3.70
2018	175.00	4.35	224.30	34.55	4.10

During the first week of March, the orchard was fertilized with 150 units of nitrogen, in the form of ammonium sulfate (20.5% N and 24% SO_4). The first foliar application of Zn^{2+} (250 mg L^{-1}) was performed once the trees showed 80% sprouting and subsequently every two weeks, with a total of six applications. To control the borer worm (*Acrobasis nuxvorella* Neunzig), 0.5 L of Intrepid ™ per hectare was applied. Irrigation was carried out by micro sprinkling in a circumference of 7 m around the trees. The total water irrigation volume was approximately 16,800 m^3 ha^{-1} per vegetative cycle (sprouting to harvest).

A completely randomized experimental design was used with ten replications. The treatments were T1: 50 mg L^{-1} GA3 (ProGibb®, Bayer Crop Science, USA), T2: 500 mg L^{-1} PCa (Apogee®, BASF, USA), T3: 10 mg L^{-1} TDZ

(Revent® 500 SC, Bayer Crop Science, USA) and T4: control (water). The experimental unit consisted of a tree. A total of 40 trees were selected according to the trunk perimeter (57.5±10 cm) and flowering (≥60%). Each tree was supplied with 1 ml L^{-1} of surfactant INEX-A™ (Cosmocel, Mexico) and 1% foliar urea for penetration, as part of the treatment. The pH of the solution was adjusted to 5.8 with hydrochloric acid. The treatments were applied foliarly for two years (2017-2018) at 0, 56, 70 and 84 days after full bloom.

To determine the count of female flowers during annual growth for each experimental unit, a main branch with a diameter of 34 to 39 cm was selected; whereafter, three secondary branches were used to determine the average number of clusters of pistillate flowers. The phenological stages are shown in Figure 1. The samplings were carried out in flowering, pollination, nut growth, aqueous state of the nut, hardening of the shell and filling of the nut. Each of those stages were sampled between 2017 and 2018 on April 20th (B – receptive flower), May 15th (C – pollinated flower), June 15th (D – after pollination), July 15th (E, F, nut growth), August 15th (G – filled with kernel), and September 15th (H – splinter split), respectively. The total fruits set before harvest (FTBH) were counted in the terminal shoots (H).

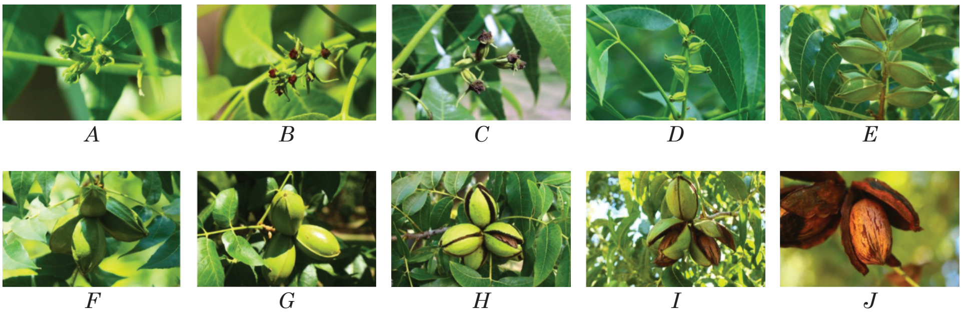

Fig. 1. Phenological stages of a female pecan flower in the cultivar Western Schley. Phenology of the female pecan flower (*A*) flowering; (*B*) receptive flower; (*C*) pollinated flower; (*D*) after pollination, fruit set (*E*, *F*, *G*) growth and development of the fruit, in which two stages intervene, the nut growth, development of the liquid endosperm, filling with kernels and growth of the embryo; (*H*) splinter split; (*I*) wheel opening; (*J*) fall of nut

On November 20th of each year (2017 and 2018), the trees were mechanically vibrated to assess the yield of nuts (kilograms per tree) (Wood 2011). The nut weight per kilogram was evaluated, according to Mexican standards of non-industrialized food products for human consumption – shelled pecan [*Carya illinoensis* (Wangenh) K. Koch)] – specifications and test methods of 2009 (NMX-FF-084-SCFI-2009). Kernel percentage was determined by weighing 300 g of pecan nuts, then separating the shell from the kernel and weighing each separately (NMX-FF-084-SCFI-2009). In order to observe and analyse the alternate bearing phenomenon and the effect growth bioregulators have on it, the alternate bearing index was determined by the coefficient of variation regarding the yield in the cycles evaluated (Wood 2011).

The data (fruits set before harvest, yield, weight of nut per kilogram and kernel percentage) were analysed using GLM procedure of SAS software (Version 9.1) to assess the significance of the main factors and the significance of interactions. Significant differences were tested at $P \leq 0.05$ using Tukey multiple range test. Before statistical analysis, the data, now expressed in percentages, were subjected to transformation with $\log_{10}$ and presented along its original values.

RESULTS AND DISCUSSION

The fruits set before harvest are indicative of the total nut yield in the pecan tree (Wood 2011). In this research, the fruits set before harvest were statistically significant for treatment and year ($P \leq 0.05$). It was found that the application of growth bioregulators minimized alternate bearing with respect to the control, since the fruits set before harvest were similar for both years. It should be noted that among treatments, GA3 showed best results (10.4 and 12.2 FTBH). In this regard, the findings coincide with ones reported by Wood (2011). Other studies show that TDZ produced a similar effect, promoting a greater number of set fruits (Smith 2012) by increasing endogenous concentrations of cytokinins (Nisler et al. 2016). Alternatively, the return of flowering will depend on the number of fruits set in the cycle, which increases the alternate condition in trees (Sharma et al. 2019).

Some authors report that gibberellins can be considered inhibitors of flowering, thereby minimizing the number of fruit (Cano-Hernandez et al. 2019, Sharma et al. 2019). In *Malus domestica* Borkh, three doses of GA3 (100, 300 and 500 mg L^{-1}), were sprayed in three separate applications in off-season. Only the application of 100 mg L^{-1} decreased the flowering density between 20 to 40%, which impacted the yield of the next year (Schmidt et al. 2009). Conversely, foliar sprays of 500 mg L^{-1} PCa in pecan tree in high yield years, resulted in a 38% increase in yield compared to the control in the following year (Wood 2011). Rebolledo and Romero (2011) found that the application of GA3 to the cultivar Hass avocado (*Persea americana* Mill.) during a high-yield season decreased the number of fruits set in high-yield years. However, it also increased the flowering and fruits set in the following, low-yield season. The effect of gibberellins included a reduction of flowering in high-yield years. According to Pérez-Barraza et al. (2015), PCa is a floral promoter that blocks the biosynthesis of gibberellins and inhibits their action. Application of different growth bioregulators (GA3, TDZ, and PCa) should be planned according to the growth stages of the fruit (Chao et al. 2011).

The total nut yield expressed in kg per tree is an important parameter due to its economic implications. Yield is dependent on the alternate bearing

Table 2

Fruits set before harvest, yield, alternate bearing index and nut quality in pecan cultivar Western Schley with foliar application of growth bioregulators

T	FTBH		Yield (kg per tree)		ABI (%)	Nut weight per kg (g)		(%) Kernel	
	2017	2018	2017	2018		2017	2018	2017	2018
GA3	10.4±1.04*aA*	12.2±1.04*aA*	11.4±5.12*aA*	16.2±4.37*bC*	38*A*	5.8±0.13*aB*	5.5±0.20*bA*	59.4±2.08*aA*	58.9±1.20*aA*
PCa	8.4±1.04*aB*	10.2±1.04*aB*	11.7±4.06*aA*	18.9±4.55*bA*	36*A*	5.9±0.09*aA*	5.6±0.18*bA*	59.9±1.09*aA*	59.3±1.55*aA*
TDZ	7.0±1.04*aC*	8.6±1.04*aC*	10.9 ± 5.9*aA*	15.6±2.33*bC*	37*A*	5.7±0.2*aB*	5.6±0.16*aA*	60.2±1.68*aA*	58.3±1.63*bA*
Control	7.3±1.04*aC*	11.5±1.04*bA*	5.9±1.42*aB*	21.5±5.85*bA*	65*B*	5.9±0.05*aA*	5.6±0.14*bA*	58.3±1.03*aB*	56.6±0.74*bB*
Significance									
T	*		ns			*		*	
Y	*		*			*		*	
T x Y	ns		*			ns		ns	

T – treatments, Y – years, FTBH – fruits set before harvest, ABI – alternate bearing index, GA3 – gibberellic acid (50 mg L^{-1}), PCa – prohexadione calcium (500 mg L^{-1}) and TDZ – thidiazuron (10 mg L^{-1}). Mean values ± standard deviation (n=10). Different capital and lowercase letters within each column and row represent significant difference between treatments and years (Tukey, $P \le 0.05$). * and ns are significant at $P \le 0.05$ and not significant, respectively.

index as well as agronomic management (irrigation, fertilization, and pest control) (Wood 2011). In this research, the analysis of variance was significant for the year, and its interaction (treatment x year) $P \leq 0.05$. However, production differed statistically each year. From 2017 (low yield) to 2018 (high yield), the production increased in kilograms per tree: 29.87% (4.84) for GA3, 30.53% (4.77) for TDZ, 38.10% (7.21) for PCa, and 72.21% (15.57) for control (Table 2). During the two years evaluated, GA3 and TDZ presented less variation in yield. According to Morales (2006), TDZ application (0, 250 300 and 400 mg L^{-1}) in 16-year-old trees of the cultivar Western Schley pecan is only effective reducing total nut yield in the highest dose. On the other hand, several articles mention that production increases with the application of bioregulators (Pasala et al. 2017).

A study carried out in southeast China on the cultivation of *Jatropha curcas*, where four doses (0, 25, 75 and 225 μM) of TDZ were applied at the appearance of the first, second, third and fourth flower primordia, demonstrated a significant increase in seed yield with the application of TDZ at a dose of 225 μM, which caused as an increase in the number of female flowers. Conversely, the lowest doses (25 and 75 μM) resulted in a lower number of female flowers (Pan et al. 2016). An experiment carried out on the cultivar d'Anjou' pear, where PCa (125 mg L^{-1}) was applied during early spring and (125 + 250 mg L^{-1}) growth return, showed that production increased by 25% compared to the control (Einhorn et al. 2014). During 2012, a study conducted in Nayarit, Mexico, regarding the use of GA3 (50 mg L^{-1}) in the cultivar Ataulfo mango (*Mangifera indica* L.), with applications at 0, 15, 30, 45 and 60 days after full flowering, evidenced an increase in kilograms of fruit per tree with an average of 47.5 kg against 27.5 kg produced by the control (Pérez-Barraza et al. 2015). Another study by Pérez-Barraza et al. (2016) included PCa applied to the cultivar Ataulfo mango at 150, 250, 500 mg L^{-1} in three or four applications and 1500 mg L^{-1} in one application. The supply of PCa 500 mg L^{-1} in three applications and 1500 mg L^{-1} in one application increased production by 40% and 38%, respectively, against the control (Pérez-Barraza et al. 2015). Although an increase in fruit quantity was not observed, the size of strawberry fruit increased with applications of GA3 (300, 600 and 900 mg L^{-1}) in intervals of 15 days after the fruit had reached a size of 2 to 3 mm in length (Viasus-Quintero et al. 2013). Throughout 2013 and 2014, lime crop from the state of Guerrero, Mexico, was supplied with doses of GA3 (30 mg L^{-1}) and TDZ (1 mg L^{-1}) by motorized sprinkler through the end of August. Both treatments were statistically the same, presenting a 50% decrease in production compared to the control (Ariza-Flores et al., 2015), which further agrees with the results shown in this investigation, in which growth bioregulators regulate yield and attenuate alternate bearing.

A perennial fruit tree produces abundant harvests in one season, which depletes the nutrient storages and reduces the production of new shoots, leading to a partial or total decrease of yield in the following season.

The alternate bearing index measured as the coefficient of variation of yield has been widely used to study the tendency for alternate bearing in different fruit trees such as apples, mangoes, coffee, citrus and pistachios (Sharma et al. 2019). In the present investigation, the alternate bearing index was found as the following: GA3 38.15%, PCa 36.55%, TDZ 37.68% and T0 65.30% (Table 2). The foliar application of growth bioregulators is an alternative for agronomic management to minimize alternate bearing in the pecan cultivar Western Schley, with an average result of 37.46%. The control shows a higher alternate bearing index when compared to other treatments. Wood et al. (2003) reports an alternate bearing index of 23% in young pecan trees (15 years old) and 43% in mature trees (≥ 16 years old). In this regard, carbohydrate reserves are related to the alternate bearing index of different fruit crops (Sharma et al. 2019). The magnitude of alternate bearing can vary, since carbohydrate reserves depend on environmental conditions and management of the crop (Randall et al. 2015).

The weight of a nut is an indicator of quality in pecan tree (Balandran-Valladares et al. 2021). The average nut weight found in this research was between 5.961 to 5.552 g, which is considered acceptable by Nmx-Ff-084-Scfi-2009. Variance analysis displayed a significant result for this parameter in year and treatment ($P \leq 0.05$); however, the interaction of both factors was not significant. Treatment behavior differed significantly with the use of GA3 and PCa presenting a decrease (0.257 and 0.289 respectively) from the year 2017 to 2018. Nonetheless, TDZ manifested a different pattern than the other treatments, remaining statistically similar for both years (Table 2). Between treatments, the application of PCa showed the highest nut weight, although it did not statistically exceed that observed in the control. In contrast, Morales (2006), when evaluating three doses (250, 300 and 400 mg L^{-1}) of TDZ in pecan, indicated a reduction in the number of nuts per kilogram, which implies a greater weight and size of a nut. However, with the application of 300 mg L^{-1}, an increase in the nut weight is reported.

The kernel percentage is an important quality parameter, and is directly associated with the sale price of pecan nut in the market. (Ojeda-Barrios et al. 2016). The variance analysis of this criterion was significant in year and treatment ($P \leq 0.05$), and its behavior was similar to that observed for the nut weight. In this study, it was found that the kernel percentage values were above the minimum acceptable, which is 50% according to Nmx-Ff-084-Scfi-2009. A decrease in kernel percentage was observed from 2017 to 2018 for all treatments: GA3 0.67%, PCa 1.05%, TDZ 1.47% and control 2.8%. The application of the products tested showed a significant effect on the kernel percentage with respect to control. This result is consistent with what was reported by Smith (2012) and Wood (2011) – Table 2. Several authors indicate that in years of high yield, the pecans are small with thicker shells and there is a decrease in the kernel percentage (Wood et al. 2003, Morales 2006, Smith 2012, Balandran-Valladares et al. 2021).

CONCLUSIONS

1. The application of gibberellic acid (GA3 – 50 mg L^{-1}), prohexadione calcium (Pca – 500 mg L^{-1}), thidiazuron (TDZ – 10 mg L^{-1}) could be a strategy for the management of alternate bearing in pecan trees of the cultivar Western Schley.

2. The foliar application of growth bioregulators in young pecan trees of the cultivar Western Schley minimized alternate bearing by maintaining the number of fruits set before harvest between the evaluation years with respect to the control treatment.

3. Between the years of evaluation, the data obtained indicate that the application of growth bioregulators affected the yield, although the nut weight per kilogram was similar with TDZ (5.6 and 5.7 g), whereas PCa was the best treatment for both variables. Likewise, significant variation in the alternate bearing index with respect to the control could be observed. Alternatively, the kernel percentage showed the best behavior between years and treatments with the use of GA3 and PCa.

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