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# Applications of cold compensators in pecan trees (*Carya illinoienensis* Wangenh. K. Koch)

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## ABSTRACT

**Objective**: In northern Mexico, pecan cultivation is a key economic activity; however, in recent years, climate change has led to a reduction in nut yield due to insufficient chill hour accumulation during increasingly mild winters. This study aimed to identify effective chill compensators to mitigate this issue and improve early-season development and productivity in pecan trees.

**Design/methodology/approach**: The experiment was conducted in Aldama, Chihuahua, during the 2020 growing cycle using a randomized complete block design. Various conventional chill compensating products were applied to evaluate their effect on yield and quality parameters.

**Results**: The average yield was 2.21 t ha$^{-1}$, with 184 nuts per kilogram and 57.1% edible kernel content. The mean Alternate Bearing Index (ABI) was 29.56%, and the Long-Term Productivity Index (LTPI) was 14.56%. Treatments that produced the greatest positive impact on these variables were, in order of effectiveness: hydrogen peroxide ($H_2O_2$), Erger® + $Ca(NO_3)_2$, TA + TO + TDZ (Tecno Agro + Tecno Oil + Thidiazuron), and Dormex.

**Limitations/implications**: Although not explicitly addressed in the study, results may vary depending on regional climate, orchard age, or cultivar, suggesting a need for site-specific evaluation before broad application.

**Findings/conclusions**: The application of chill compensators significantly improved pecan productivity and quality. $H_2O_2$ was the most effective treatment, increasing yield by 100%, kernel percentage by 2.64%, and LTPI by 135.82%, while reducing nut count per kilogram by 17.37% and ABI by 51.69%. Conversely, $CaSO_4$ increased ABI by 107.69% relative to the control, leading to higher alternate bearing intensity and substantially reduced productivity.

**Keywords**: Budbreak agents, yield, kernel percentage, alternate bearing index, long-term productivity index.

## INTRODUCTION

In northern Mexico, the pecan tree (*Carya illinoinensis*) is one of the most economically significant deciduous species, with the state of Chihuahua leading national production, contributing approximately 60% as of 2013 (SIAP-SAGARPA, 2014). However, climate change has become a key factor in reducing yields across agroecosystems. Between 1980

and 2013, global temperatures increased notably, with 19 of the 30 hottest years on record exceeding 38 °C (NOAA, 2013). Prior to this period, nearly 50 years of cooler temperatures were recorded. The most pronounced warming has occurred in northern latitudes, yet average temperatures in both the United States and northwestern Mexico regions where pecan cultivation is integral to agricultural systems have also risen by approximately 1.0 °C (Mexal *et al.*, 2013).

A 1.0 °C increase in average temperature is associated with longer growing seasons and an increase in the number of hot nights. According to the National Assessment Synthesis Team (N.A.S.T., 2000a, b, c), the growing season could lengthen by 40 to 50 days, and the number of hot nights could rise by up to 80 days. This presents a challenge for pecan producers, as Baldocchi and Wong (2008) projected a 50% decrease in chill hour accumulation by the year 2100. Pecan trees require between 500 and 600 chill hours for dormancy release (McEachern *et al.*, 1978), or between 300 and 400 hours for uniform bud break (Amling & Amling, 1980), with a minimum of 400 hours necessary for rapid bud burst (Sparks, 1993). Warm climates may limit chill hour accumulation, leading to uneven bud break not due to the lack of bud formation, but due to the lack of synchrony in the process. A staggered or irregular bud break after mild winters, as observed in pecan, has been reported to delay bud burst, increase fruit drop, and reduce yield (Finch & Van Horn, 1939; Gammon & Sherman, 1972; Waite, 1925; Nasr & Hartsan, 1975; Van Horn, 1941). The N.A.S.T. (2000b) also projects a transition toward reduced cold hardiness zones within the next 30 years, which may prevent sufficient chill accumulation for rapid and complete bud break ultimately affecting flower production and nut set (Mexal *et al.*, 2013). In this context, the application of exogenous compounds to compensate for insufficient chill accumulation is proposed. Therefore, the objective of this study was to evaluate the effectiveness of foliar sprays with various bud break promoters on pecan trees during the 2008-2012 cycles. Hydrogen cyanamide (HCN) is commonly used as a chill compensator; however, due to its high toxicity, research has been directed toward identifying alternative active ingredients for deciduous fruit crops. HCN acts as a growth regulator applied post-winter pruning to initiate metabolic activity, disrupt winter dormancy, and induce early bud break (Bonnaire & Rinder, 1985). Chemically, it is the amide of cyanic acid, weakly acidic, highly soluble in water and other polar organic solvents, stable in aqueous solution, and non-toxic to humans under standard usage (Ortiz, 1987). Although its mechanism of action is not fully understood, several studies confirm its efficacy (Fuchigami & Nee, 1987; Ortiz *et al.*, 1987; Erez, 1987). In moist soil, it degrades into urea, ammonium, nitrate, and other nitrogenous compounds (Fuchigami & Nee, 1987). HCN treatment has been shown to increase nitrogenous compounds in treated trees, including dry matter, proteins, and amino acids, suggesting its involvement in nitrogen metabolism (Fuchigami & Nee, 1987). With calcium cyanamide application, a rise in both soluble and insoluble nitrogen is observed after 15 days, particularly with soluble nitrogen shortly before bud break (Yang *et al.*, 2003). Furthermore, HCN application has been linked to arginine concentration dynamics and bud break percentage trees with higher arginine concentrations at the time of application showed increased bud break (Ortiz, 1987). Once applied, HCN is rapidly metabolized and incorporated into amino acids (Bonnaire & Rinder, 1985). In apple trees, the synthetic cytokinin thidiazuron (TDZ; N-phenyl-N'-1,2,3-thidiazol-5-ylurea) has been shown to break ecodormancy (Wang *et al.*, 1994), reducing the chill unit requirement for bud break (Faust *et al.*, 1991). When applied during summer in warm climates, TDZ induced flowering in peach ('Diamante' cultivar) as effectively or more so than HCN (Calderón & Rodríguez, 1996). Its presumed efficacy lies in altering cell membrane permeability, increasing unsaturation in the sterol-phospholipid balance (Wang *et al.*, 1994), and thereby elevating the free-to-bound water ratio within bud cells (Faust *et al.*, 1991). TDZ also enhances floral organ vigor by promoting cell division, elongation, and differentiation (Van Standen & Cook, 1986). Seeking less toxic dormancy breakers, Petri (2014) demonstrated that Erger® combined with calcium nitrate ($Ca(NO_3)_2$) yields similar bud break results to HCN in apple trees, especially under insufficient chill accumulation. Erger® interrupts dormancy and enhances physiological responses, improving bud break and flowering uniformity. Pang *et al.* (2007), in grapevine buds, suggested that HCN stimulates bud break via calcium ion ($Ca^{2+}$) signaling, and that exogenous $Ca^{2+}$ may assist dormancy release. HCN also reduces catalase activity without affecting peroxidase, leading to elevated $H_2O_2$ levels, which stimulates bud break (Settimi *et al.*, 2005). Direct application of 5% hydrogen peroxide ($H_2O_2$) to buds has shown strong effects in deciduous fruit trees, achieving up to 100% bud break and advancing vegetative development (González & Ortega, 2015). Accordingly, the aim of this study was to evaluate the effects of dormancy-breaking compounds on yield and fruit quality in pecan trees, as well as on the alternate bearing index (ABI) and long-term productivity index (LTPI).

## MATERIALS AND METHODS

### Experimental area and treatments

The study was conducted during the 2020 pecan growing season in a mature 'Western' cultivar orchard, 40 years of age, located in the municipality of Aldama, Chihuahua, Mexico. This cultivar requires approximately 400 chill units to initiate bud break (Díaz, 1987). The orchard followed a square planting design of 12 × 12 m, with a planting density of 69 trees per hectare.

### Yield estimation

During harvest (early November 2020), trees were mechanically shaken, nuts were collected, and individual tree yield was measured in kilograms. Yield per hectare was extrapolated by multiplying the per-tree yield by the number of trees per hectare, adjusted by a correction factor of 0.95 to account for individual tree production variability. Nut yield and quality were evaluated according to the Mexican Standard NMX-FF-084-SCFI-2009.

### Number of nuts per kilogram

A 300 g sample was used to count the number of nuts, and the value was extrapolated to nuts per kilogram. According to NMX-FF-084-SCFI-2009, nut size classification is based on the number of nuts per kg: giant ($\leq$122), extra large (123-139), large (140-170), medium (171-210), and small ($\geq$211).

### Edible kernel percentage

To determine the edible kernel content, 300 g of nuts were selected, and the shells were manually separated from the edible portion. Both components were weighed individually, and the edible fraction was expressed as a percentage of the total nut weight. According to the same standard, nuts with ≥54% edible kernel are classified as Quality I, and those with 50-54% as Quality II.

### Alternate bearing index (ABI)

The ABI was calculated using the formula:

$$ABI = \left( \frac{Standard\ deviation\ of\ yield\ across\ analyzed\ years}{Mean\ yield\ of\ analyzed\ years} \right) \times 100$$

### Long-term productivity index (LTPI)

The LTPI was calculated using the formula:

$$LTPI = \left( Mean\ yield\ across\ analyzed\ years \right) / \ ABI$$

### Statistical analysis

A completely randomized block design was employed, with each treatment applied over an approximate area of 1 ha. Each treatment included six replications, and each replication comprised three sampling units. Treatment means were compared using Tukey's multiple range test ($\alpha = 0.05$), with calculations performed in Microsoft Excel.

## RESULTS AND DISCUSSION

Deciduous fruit trees enter a state of dormancy during winter, a physiological condition that allows them to withstand cold temperatures by minimizing metabolic activity and growth (Díaz, 1987). During this period, the tree must accumulate sufficient chilling to eliminate growth inhibitors and initiate the production of internal growth promoters (Garza, 1993). When chilling requirements are not met, trees exhibit deficiencies in phenological development and reduced productivity, the severity of which depends on the extent of the chilling deficit (Westwood, 1982; Erez & Lavee, 1971). Table 1 presents the statistical analysis results. The average yield across treatments was 2.13 t $ha^{-1}$, which surpasses the national average of 1.7 t $ha^{-1}$ reported by SAGARPA (2018). Similarly, Vázquez *et al.* (2018) reported a mean yield of 1.73 t $ha^{-1}$ in the Comarca Lagunera region from 2001 to 2013. Among treatments, hydrogen peroxide ($H_2O_2$) had the most significant effect, achieving 4.0 t $ha^{-1}$ —representing a 100% increase compared to the control. This was followed by Erger + $Ca(NO_3)_2$ with 3.60 t $ha^{-1}$ (80% increase), TA + TO + TDZ with 3.3 t $ha^{-1}$ (65% increase), and Dormex with 3.1 t $ha^{-1}$ (55% increase). Regarding nut count per kilogram, a lower number corresponds to larger nut size. In this study, $H_2O_2$ treatment resulted in 157 nuts $kg^{-1}$, classifying the nuts as "large" according to the Mexican Standard FF-084-SCFI-2009. This value matches the findings of Noperi *et al.*

(2020), who also reported 157 nuts kg$^{-1}$. Compared to the control group, which registered 190 nuts kg$^{-1}$, this represents a 17.37% reduction. However, the improvement did not change the size classification. The most significant effect on this variable was observed with Erger + $Ca(NO_3)_2$, producing a 20% reduction in nut count per kilogram, followed by $H_2O_2$ with 17.37%.

The almond percentage is important, as it is the key parameter for the commercialization of pecan nuts; it serves as the basis for calculating the nut's price (Orona *et al.*, 2013). The treatment with the highest percentage of edible kernel is $KNO_3$, with 59.2%, classifying it as Quality I. This value is higher than that reported by Soto *et al.* (2016), who recorded 58.2% edible nut, and also higher than Yáñez *et al.* (2010), who reported 58.4%. Table 1 shows that the percentage of edible nut increased by 4.41% with $KNO_3$ and by 2.64% with

**Table 1**. Performance parameters in pecan trees treated with chilling compensators. Aldama, Chih., 2020.

| Trat. | Production (tons ha$^{-1}$) | Nuts (kg$^{-1}$) | % Kernel | AI | LTPI |
|---|---|---|---|---|---|
| P-value | <.0001$^{w}$ | <0.0001 | <.0001 | <.0001 | <.0001 |
| Dormex | 3.1 b$^{w}$ | 178 de | 58.4 ab | 13.6 def | 28.8 abc |
| BroStart | 2.1 c | 164 ef | 58.2 ab | 35.6 bc | 8.0 d |
| Erger | 3.60 ab | 152 f | 57.9 ab | 12.5 ef | 30.3 ab |
| Serie Algas | 1.4 d | 158 f | 58.5 ab | 52.1 ab | 3.0 d |
| $H_2O_2$ | 4.0 a | 157 f | 58.2 ab | 15.7 cdef | 31.6 ab |
| $KNO_3$$^{w}$ | 1.7 cd | 164 ef | 59.2 a | 28.1 cdef | 7.2 d |
| Urea | 2.1 c | 200 abc | 55.7 cd | 35.6 bc | 6.7 d |
| TA+TO+TDZ | 3.3 b | 198 bc | 55.7 cd | 11.6 f | 42.0 a |
| TDZ | 0.4 e | 219 a | 57.3 abc | 18.3 cdef | 2.3 d |
| $CaSO_4$ | 2.9 cd | 213 ab | 57.7 ab | 67.5 a | 4.0 d |
| $CaCO_3$ | 0.7 e | 208 abc | 58.2 ab | 34. bc | 2.8 d |
| TO_TDZ | 1.8 cd | 170 ef | 54.2 de | 33.6 bcd | 8.2 d |
| Calcinitus | 1.8 cd | 206 abc | 53.7 e | 23.2 cdef | 12.9 cd |
| Control | 2.0 cd | 190 cd | 56.7 bc | 32.5 bcde | 13.4 cde |
| DMS$^{Y}$ | 0.6 | 19 | 1.9 | 20.4 | 16.4 |
| $\mu^{Vw}$ | 2.13 | 184 | 57.1 | 29.56 | 14.56 |
| C.V$^{W}$ | 26.22 | 8.77 | 2.88 | 59.70 | 97.55 |
| $R^{2\,X}$ | 0.8053 | 0.7193 | 0.5598 | 0.5235 | 0.5247 |

AI, alternate bearing index; LTPI, long-term productivity index; probability Pr>0.05 not significant, 0.05≤Pr≤0.01 significant, <0.01 highly significant; $^{X}$ different letters are statistically different (Tukey $\alpha=0.05$); $^{Y}$ least significant difference (LSD), $\mu$ grand mean, CV coefficient of variation, $R^2$ coefficient of determination. Dormex, Hydrogen cyanamide 49%; BroStart, Total-N 8.0%, Calcium 11.0%, total oxidizable organic carbon 0.5%; Erger, Nitrogen 15% (Ammoniacal-N 3.1%, Nitric-N 5.8%, Ureic-N 6.1%) Ca 4.7% Density 1.14 g/cc, pH 5.9; $Ca(NO_3)_2$ Calcium nitrate 15.5% N (Nitric-N 14.4, Ammoniacal-N 1.1%), CaO 26.3%, Ca 19.0; algae series: Spinning-K (potassium 50.0%, cytokinins 737 ppm, auxins 728 ppm, gibberellins 230 ppm); TurboEnzims (phosphorus 16.0%, potassium 7.0%, nitrogen, 4.0%, fulvic acids 0.1%; cytokinins 498 ppm; auxins 492 ppm; gibberellins 201 ppm); AlZinc (zinc, 10%; boron, 0.5%; auxins 492 ppm; gibberellins 201 ppm; cytokinins, 498 ppm); $H_2O_2$, Hydrogen peroxide 50%; TO, Tecno Oil 100 EW, imported emulsifiable oil pH 6.0-8.0, specific gravity 1.1; TA, Tecno Agro 8010 EW, imported emulsifiable oil pH 6.0-8.0, specific gravity 1.1; TDZ, Thidiazuron N-phenyl-N'-1,2,3-thiadiazol-5-ylurea 42.4%; Urea, 46.0 % nitrogen; $KNO_3$, Potassium nitrate N 12%, $K_2O$ 46%; $CaSO_4{\cdot}H_2O$ soluble calcium sulfate SoluGyp, 31.31% CaO (22.46% Ca), 97.5% purity, $SiO_2$ 1.32%, $Al_2O_3$ 0.4%, MgO 0.75%, $Na_2O$ 0.12%; $CaCO_3$, Calcium carbonate Cementos de Chihuahua $SiO_2$ 7.12%, $Al_2O_3$ 1.81%, $Fe_2O_3$ 0.71%, CaO 49.23% (Ca 35.18%), $K_2O$ 0.16%; AS, Salicylic acid (2-hydroxybenzoic acid) $C_7H_6O_3$; VM apple cider vinegar, total acidity expressed as acetic acid 5%; Calcinitus, 11% N, 44.5 Ca, Boron 0.2%, Zinc 0.2%. Application date: March 11, 2021.

$H_2O_2$, which reached 58.2% kernel both treatments compared to the control. Nut quality tends to be lower when nut production is higher; however, even with this reduction, the classification remains Quality I, which is well accepted in the market. Alternate bearing is one of the main biological issues affecting pecan production (Wood *et al.*, 2003). In this study, the average alternate bearing index (ABI) was 29.56%, ranging from 11.6% to 67.5%. This index is lower than that reported in two studies conducted in the Comarca Lagunera region in northern Mexico, where 14 orchards were evaluated from 1995 to 1997. The average ABI was 52%, ranging from 23% to 94% (Santamaría *et al.*, 2002). Treatments that had an impact on this variable included TA+TO+TDZ with 11.6% ABI (a 64.31% reduction compared to the control), Erger-Ca$(NO_3)_2$ with 12.5% ABI (61.54% reduction), Dormex with 13.6% ABI (32.53% reduction), and $H_2O_2$ with 15.7% ABI (51.69% reduction). These values indicate that the lower the index, the less negative the effect of alternate bearing (referring to "on" and "off" years). However, $CaSO_4$ showed an ABI of 67.5%, which is 107.69% higher than the control, indicating severe alternate bearing issues that would greatly reduce pecan productivity. The long-term productivity index (LTPI) is the average yield divided by the alternate bearing index. In this study, the average LTPI was 14.56%. However, the treatment with the highest effect was TA+TO+TDZ, with 42% LTPI and a 213.43% increase over the control; $H_2O_2$ followed with 31.6% LTPI and a 135.82% increase; Erger-Ca$(NO_3)_2$ with 30.3% LTPI and a 126.12% increase; and Dormex with 28.8% LTPI and a 114.92% increase. These factors significantly influenced this variable, indicating that a higher LTPI corresponds to higher production per hectare over a longer period in pecan orchards.

## CONCLUSIONS

Our results clearly demonstrate that production parameters such as t $ha^{-1}$ yield, number of nuts per $kg^{-1}$, kernel percentage, alternate bearing index, and long-term productivity index can be significantly improved using chilling compensators, in the following order of effectiveness: hydrogen peroxide, Erger®-Ca$(NO_3)_2$, Tecno Agro+Tecno Oil+Thidiazuron, and Dormex, respectively. Yield increased by 100%, kernel percentage by 2.64%, and LTPI by 135.82%, while the number of nuts per kilogram decreased by 17.37%, and the alternate bearing index dropped by 51.69%, primarily due to hydrogen peroxide. Nevertheless, other compensators also showed favorable results, highlighting the advantage of using different chilling compensators based on critical stages and annual production monitoring, which could help mitigate the intensity of alternate bearing and simultaneously improve nut quality.

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