

Pecan quality in high-density orchards subject to two pruning systems and tree thinning

Cristiano Geremias Hellwig^{1,*} , Carlos Roberto Martins² , Antonio Davi Vaz Lima¹ , Roseli de Mello Farias³ , Marcelo Barbosa Malgarim¹ 

1. Universidade Federal de Pelotas  – Departamento de Fitotecnia – Pelotas (RS), Brazil.

2. Empresa Brasileira de Pesquisa Agropecuária  – Centro de Pesquisa Agropecuária do Clima Temperado – Pelotas (RS), Brazil.

3. Universidade Estadual do Rio Grande do Sul  – São Borja (RS), Brazil.

Received: Apr. 26, 2025 | **Accepted:** Aug. 18, 2025

Section Editor: Alberto Cargnelutti Filho 

***Corresponding author:** cristiano.hellwig@gmail.com

How to cite: Hellwig, C. G., Martins, C. R., Lima, A. D. V., Farias, R. M. and Malgarim, M. B. (2025). Pecan quality in high-density orchards subject to two pruning systems and tree thinning. *Bragantia*, 84, e20250091. <https://doi.org/10.1590/1678-4499.20250091>

ABSTRACT: This study aimed to evaluate the effect of two semi-mechanized pruning systems and a tree thinning method on the quality of pecan fruit grown in a mature pecan orchard at high density. The experiment was carried out in a commercial pecan orchard composed of 'Pitol 1' trees at the density of 204 trees per hectare. A completely randomized block design with four treatments—hedge pruning, central pruning, tree thinning, and control (neither pruning nor thinning)—was used. Variables under evaluation were fruit per kilo, fruit mass, kernel mass, shell mass, percent kernel, fruit length, kernel length, fruit diameter, kernel diameter, classification of fruit size, shell thickness, kernel color, kernel lightness (L^*), and commercial kernels. Pruning and thinning treatments significantly increased pecan quality by increasing fruit and kernel size and weight. Hedge and central pruning decreased the number of fruits per kilogram by 14 and 15, respectively, while thinning reduced it by 23, by comparison with the control. Moreover, the treatments under study led to a high ratio of extra-large and oversize pecans. Semi-mechanized pruning and tree thinning are cultural practices which improve fruit quality by increasing pecan size and weight in 10–15-year-old 'Pitol 1' trees grown with no irrigation.

Key words: *Carya illinoensis*, cultivar Pitol 1, fruit size.

INTRODUCTION

Pecan is a fruit tree that was introduced in subtropical areas in southern and southeastern Brazil in the 1870's (Poletto et al. 2020). Even though Brazil's production is much lower than the ones of the main world producers, *i.e.*, Mexico and the United States of America (USA), the country ranks fifth among the largest pecan producers globally. In the 2023/24 cycle, Mexico, USA, South Africa, China, and Brazil recorded 70,925, 69,571, 11,500, 3,000 and 2,200 ton, respectively (INC 2024). It should be highlighted that the 2023/24 cycle was harmed by floods in production sites. Thus, pecan production and harvest were affected. Regarding the consumer market, 300,000 kg out of 4,300 ton was exported in 2021 (Casagrande et al. 2025). Concerning the area, there are no official data, but the estimate is that pecan is raised in about 8–12 thousand ha in Brazil (Martins et al. 2024). The expansion of the culture in the country has been driven by several factors, such as increasing demand for healthy food, which include pecan (Tong et al. 2022, Wu et al. 2022), and their production longevity (Fronza et al. 2018).

Pecan density practiced by producers varies a lot. According to Wells (2017), it ranges from 6 m × 6 m (278 trees/ha) to 30 m × 30 m (11 trees/ha) in the USA. However, the most common spacing in Brazil is 10 m × 10 m (100 trees/ha), which is an intermediate density, since high density means a larger number of trees (Hellwig et al. 2025b). Therefore, some spacings, such as 9 m × 7 m (158 trees), 7 m × 7 m (204 trees), and 5 m × 7.5 m (267 trees), are classified into high density (Zhu and Stafne 2019, Fernández-Chávez et al. 2021).

Several high-density pecan orchards have been established in Brazil over the last 20 years to maximize area-based production. However, unlike other fruit trees, such as apple and olive trees, whose dwarf cultivars and rootstocks facilitate high-density planting (Rallo et al. 2013, Díez et al. 2016, Reig et al. 2020), there are neither dwarf cultivars nor dwarfing rootstocks for pecan trees, a factor that hinders the use of high-density planting (Zhu and Stafne 2019). In addition, the lack of proper pruning practices has resulted in orchards with excessive shading, which decreases their production potential and fruit quality and causes basal branch dieback (Hellwig et al. 2022). It occurs because photosynthesis is primarily restricted to the lowest branches (Arreola Ávila et al. 2010). Considering these problems, such as low productivity, deformation in tree structures due to branch drying and low-quality fruit due to competition among trees and to difficult phytosanitary control, alternatives must be proposed.

Pruning and tree thinning have been investigated as management alternatives to be used in high density and excessively shaded pecan orchards. The most common pruning method in the USA is mechanical pruning, called hedge pruning, which consists in cutting sides of the canopy (Wood 2009, Wells 2018, Toledo et al. 2024). Another type of pruning is the central one, which aims at removing whole branches from the interior of canopies to favor air circulation and increase sunlight within them (Lombardini 2006). Some studies have shown that pruning results in variable outcomes in the years under evaluation and depends on the cultivars (Worley 1985, Lombardini 2006), a fact that emphasizes the importance of studies of pruning applied to different cultivars. Pitol 1 is one of the most common cultivars in Brazilian orchards (Martins et al. 2023), but, due to its vegetative characteristics—vigorous appearance and large and compact leaflets—, it is subject to severe problems related to shading in the vegetative canopy and among trees (Hellwig et al. 2022).

In addition to pruning, the tree thinning method or tree removal is a drastic management technique which aims at removing trees from the orchard. It may be carried out by suppression or transplant to a new area and results in decrease in yield in the following years (Gong et al. 2020). By comparison with the pruning management, tree thinning has the advantage of being performed in a single step, which enables better development of the remaining plants in the area (Arreola Ávila et al. 2010).

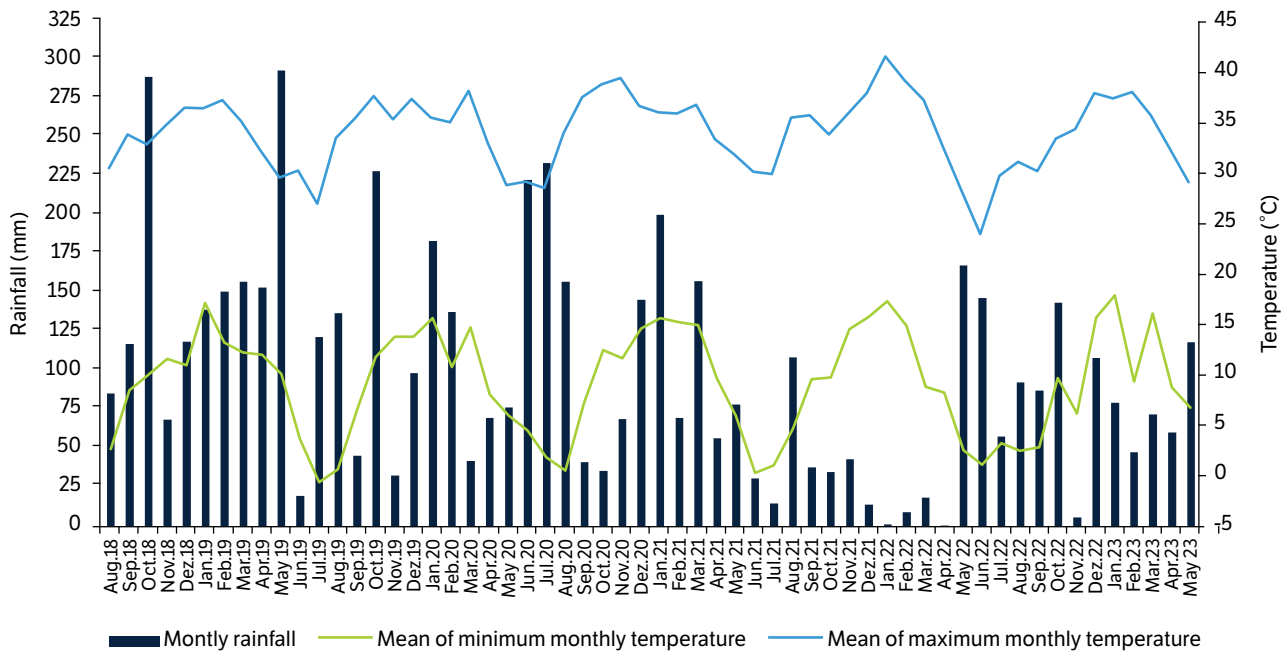
Strategies to avoid shading may affect pecan quality, mainly some factors, such as percent kernel, fruit size, fruit mass and defects, which influence price paid to its producers (Martins et al. 2023). Therefore, this study aimed to evaluate the effect of two semi-mechanized pruning systems and a tree thinning method on the quality of 'Pitol 1' pecan fruit grown in a mature pecan orchard at high density.

MATERIAL AND METHODS

The experiment was carried out in a commercial pecan orchard in Santa Rosa (RS), Brazil (27°55'15"S; 54°32'37"W and altitude 330 m). The climate is Cfa, according to the Köppen-Geiger classification (Alvares et al. 2013). The soil of the orchard is classified into typic dystroferric red latosol (Santos et al. 2018) (equivalent to typic hapludox in the soil taxonomy). Data on monthly rainfall and maximum and minimum air temperatures in the five production cycles under evaluation were provided by the meteorological station Santa Rosa—TRMM.291/AgriTempo (Fig. 1).

The orchard was established in 2008 with the density of 204 trees per hectare (7 m × 7 m spacing). Seedlings were grafted on non-identified rootstocks. In the experimental area, the orchard consists of 66.6% 'Pitol 1' trees and 33.3% 'Barton' trees. Trees are disposed in rows in which there are two 'Pitol 1' trees for a 'Barton' tree. This ratio was kept after tree thinning, the method that is detailed below. In other areas of the orchard, there were some 'Shawnee' and 'Success' trees. Only 'Pitol 1' was used in the experiment. The orchard, which lacks an irrigation system, had its fertilization management conducted in agreement with technical recommendations, following soil and foliar analyses. Phytosanitary control was carried out by five or six fungicide applications per cycle.

At the beginning of the experiment, 10-year-old trees were used. Five production cycles were evaluated: 2018/2019, 2019/2020, 2020/2021, 2021/2022, and 2022/2023. The experiment had a randomized block design with four treatments with three blocks and five trees per parcel, resulting in 60 trees under evaluation. Treatments in the orchard were hedge pruning, central pruning, tree thinning, and neither pruning nor thinning (control). Control trees, just like the whole orchard, had not been pruned after they were 5 years old. Thus, it resulted in excessive shading under tree canopies, overlapping of branches from adjacent trees leading to dry branches in the basal part, low production, low-quality fruit, and difficulty in phytosanitary management. Consequently, it triggered studies of pruning and tree thinning methods.



Source: Agrometeorological Monitoring System (Agritempo).

Figure 1. Monthly rainfall and mean minimum and maximum air temperatures in Santa Rosa, RS, Brazil, from August 2018 to May 2023.

Hedge pruning was done in two years: one side was pruned in August 2018, while the other side was pruned in August 2019. Both sides were pruned again in 2021 and 2022. It consisted in lateral pruning of trees, 2.5 m from the trunk, East-West orientation in rows. It enabled light to penetrate between rows since pruning was also carried out on the borders. Central pruning was only carried out in August 2018, when whole secondary branches were removed from the interior of canopies. Both pruning systems were semi-mechanized with the use of a pole saw and a tractor with a coupled hoisting platform (or adapted trailer) to reach the branches that were pruned. Tree thinning comprised the removal of trees with a chainsaw in August 2018, when trees were 10 years old. It was carried out alternately in the row, with staggered removal in the adjacent row. Thus, 102 out of 204 trees per hectare were thinned out.

Harvest was conducted in accordance with the producer's recommendations when more than 75% of fruit shucks were open in the plants. It was carried out with a tractor equipped with a shaker from May 26 to 29, 2019, June 2 to 4, 2020, June 15 to 18, 2021, May 20 to 25, 2022, and May 23 to 26, 2023. Fruit production per tree and productivity per hectare were evaluated, and results have already been published (Hellwig et al. 2025b). After harvest, pecan samples—about 1.4 kg per plant—were dried by a Rovler® (Brazil) forced air oven to reach about 4% moisture. After drying, the number of fruit correspondent to 1 kg was evaluated by a high-precision digital scale (Gehaka®, Brazil). Fruit length, fruit diameter, kernel length, kernel diameter, shell thickness, fruit mass, kernel mass, shell mass, percent kernel, color, and commercial classification of kernel (excluding defective kernel) were evaluated. Evaluations were carried out in a 25-fruit sample in agreement with the method proposed by Poletto et al. (2018).

Fruit length, fruit diameter, kernel length, kernel diameter, and shell thickness were evaluated by an MTX® digital caliper (China). Fruits were classified into size in agreement with the adapted Mexican norm (Hellwig et al. 2025a). Mass of all fruit evaluated in the five cycles was used to assess the percentage of fruit distributed in the following categories: small (< 4.76 g), medium (4.76 to 5.84 g), large (5.85 to 7.14 g), extra-large (7.15 to 8.13 g), and oversize (> 8.13 g). Average fruit, kernel, and shell masses were determined by a high-precision digital scale. To separate parts of the fruit, they were shelled by a manual KeHome® nutcracker (Brazil). Percent kernel was determined by Eq. 1:

$$\text{Percent kernel (\%)} = [\text{kernel mass (g)} / \text{fruit mass (g)}] \times 100 \quad (1)$$

Kernel color ($^{\circ}$ Hue) and kernel lightness (L^*) were evaluated by a Konica Minolta CR 410 colorimeter with a D65 light source. Evaluation of commercial kernels consisted in analyzing them visually, counting the ones that had no defects (neither oxidated, strained by insects, shriveled) and expressing it as percentage.

Results were subject to the analysis of variance, and averages were compared by the Tukey's test at 5% significance level by the Sisvar program version 5.6 (Ferreira 2014).

RESULTS AND DISCUSSION

The statistical analysis of pruning and thinning treatments evaluated by this study showed that hedge and central pruning, as well as tree thinning, increased fruit size (Table 1) and weight (Table 2), reduced the number of fruits per kilogram (Fig. 2) and increased the percentage of fruit in the largest size categories (Fig. 3).

Table 1. Size of pecan fruit and kernels under pruning and thinning treatments*.

Cycle	Treatment	Fruit length (mm)	Fruit diameter (mm)	Kernel length (mm)	Fruit diameter (mm)
2018/2019	No pruning and thinning	48.21 ± 0.94 b	23.48 ± 0.30 b	37.73 ± 0.63 ns	18.25 ± 0.71 b
	Hedge pruning	48.92 ± 1.14 ab	23.43 ± 0.61 b	37.90 ± 1.39	18.47 ± 0.23 ab
	Central pruning	49.70 ± 0.79 a	24.02 ± 0.56 ab	38.92 ± 0.97	18.52 ± 0.38 ab
	Tree thinning	49.60 ± 1.03 a	24.27 ± 0.49 a	38.72 ± 1.52	19.12 ± 0.76 a
	<i>p</i> -value	0.0169	0.0012	0.0958	0.0253
2019/2020	No pruning and thinning	43.46 ± 1.00 ns	23.23 ± 0.46 ns	34.35 ± 1.19 ns	19.17 ± 0.47 b
	Hedge pruning	43.88 ± 1.90	23.12 ± 0.66	35.18 ± 1.92	19.54 ± 0.53 ab
	Central pruning	44.04 ± 0.84	23.17 ± 0.48	35.28 ± 0.76	19.39 ± 0.29 ab
	Tree thinning	44.02 ± 0.60	23.56 ± 0.21	35.55 ± 0.78	19.82 ± 0.47 a
	<i>p</i> -value	0.6893	0.0684	0.1659	0.0147
2020/2021	No pruning and thinning	43.87 ± 0.78 b	24.00 ± 0.24 c	34.46 ± 0.32 c	20.71 ± 0.23 b
	Hedge pruning	45.40 ± 1.48 a	24.50 ± 0.43 b	35.61 ± 1.27 b	20.85 ± 0.27 b
	Central pruning	45.27 ± 0.98 a	24.55 ± 0.25 b	35.94 ± 0.64 ab	20.88 ± 0.34 b
	Tree thinning	45.91 ± 0.66 a	25.16 ± 0.16 a	36.60 ± 0.43 a	21.26 ± 0.24 a
	<i>p</i> -value	0.0023	< 0.0001	< 0.0001	0.0009
2021/2022	No pruning and thinning	34.22 ± 0.97 b	19.08 ± 0.50 b	26.32 ± 0.85 b	17.17 ± 0.41 b
	Hedge pruning	39.60 ± 1.82 a	21.06 ± 0.87 a	30.40 ± 1.71 a	18.48 ± 0.53 a
	Central pruning	39.05 ± 2.06 a	21.55 ± 0.80 a	30.13 ± 1.89 a	18.56 ± 0.50 a
	Tree thinning	38.46 ± 1.35 a	21.36 ± 0.36 a	29.87 ± 1.14 a	18.58 ± 0.39 a
	<i>p</i> -value	0.0001	< 0.0001	< 0.0001	< 0.0001
2022/2023	No pruning and thinning	36.73 ± 0.98 b	20.25 ± 0.53 b	29.84 ± 0.64 b	17.17 ± 0.53 b
	Hedge pruning	40.51 ± 1.37 a	21.15 ± 0.74 a	32.84 ± 1.33 a	18.12 ± 0.64 a
	Central pruning	40.94 ± 1.25 a	21.27 ± 0.80 a	33.35 ± 0.87 a	18.19 ± 0.67 a
	Tree thinning	41.65 ± 0.97 a	21.73 ± 0.41 a	33.89 ± 0.72 a	18.75 ± 0.27 a
	<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2019–2023	No pruning and thinning	41.30 ± 0.38 b	22.01 ± 0.23 c	32.54 ± 0.20 b	18.49 ± 0.20 c
	Hedge pruning	43.66 ± 1.23 a	22.65 ± 0.54 b	34.39 ± 1.31 a	19.09 ± 0.34 b
	Central pruning	43.80 ± 0.80 a	22.91 ± 0.46 ab	34.72 ± 0.51 a	19.11 ± 0.29 b
	Tree thinning	43.93 ± 0.73 a	23.21 ± 0.09 a	34.93 ± 0.63 a	19.50 ± 0.21 a
	<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

*Means followed by the same letter in the column do not differ by the Tukey's test at 5% significance; ns: non-significant.

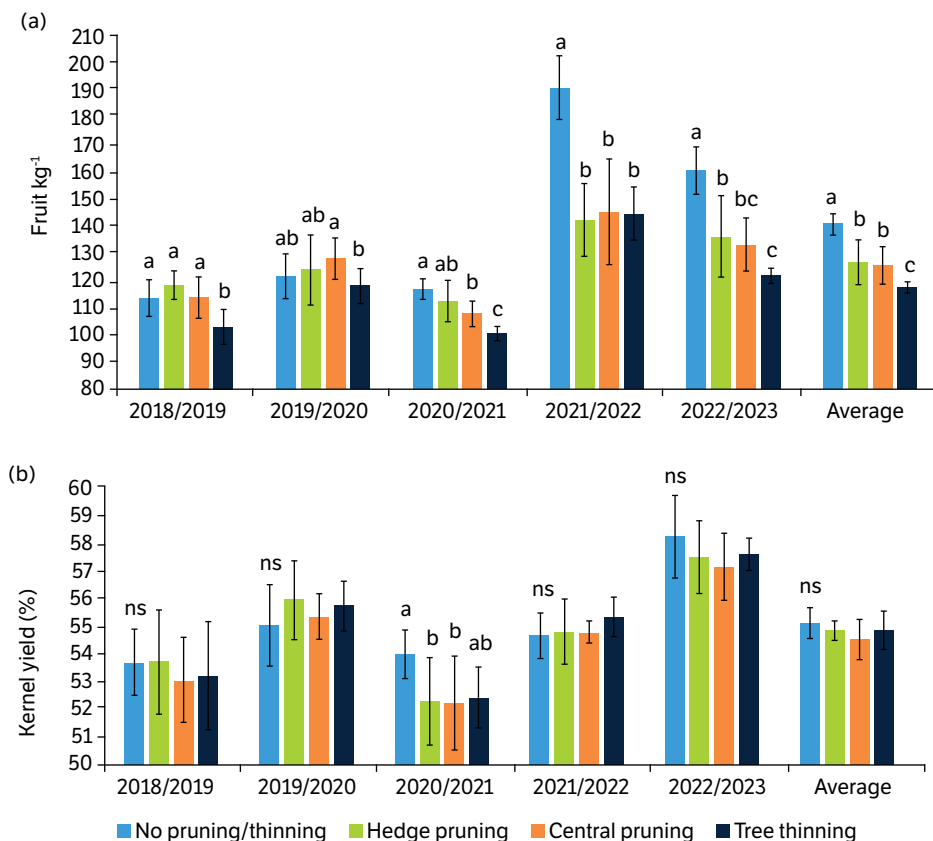
Table 2. Shell thickness, fruit mass, kernel mass, and shell mass of pecan under pruning and thinning treatments*.

Cycle	Treatment	Shell thickness (mm)	Fruit mass (g)	Kernel mass (g)	Shell mass (g)
2018/2019	No pruning and thinning	1.08 ± 0.10 a	8.96 ± 0.44 b	4.76 ± 0.23 ab	4.19 ± 0.25 b
	Hedge pruning	0.88 ± 0.08 b	8.70 ± 0.40 b	4.61 ± 0.34 b	4.08 ± 0.21 b
	Central pruning	0.91 ± 0.16 b	9.10 ± 0.63 ab	4.80 ± 0.43 ab	4.25 ± 0.20 b
	Tree thinning	0.94 ± 0.07 ab	9.76 ± 0.65 a	5.17 ± 0.49 a	4.58 ± 0.21 a
	<i>p</i> -value	0.0027	0.0021	0.021	0.0001
2019/2020	No pruning and thinning	0.99 ± 0.03 ns	8.42 ± 0.57 b	4.66 ± 0.36 b	3.75 ± 0.24 b
	Hedge pruning	0.92 ± 0.03	8.77 ± 0.93 ab	4.94 ± 0.59 ab	3.83 ± 0.35 ab
	Central pruning	0.90 ± 0.04	8.72 ± 0.40 ab	4.85 ± 0.24 ab	3.87 ± 0.18 ab
	Tree thinning	0.90 ± 0.03	9.28 ± 0.45 a	5.19 ± 0.25 a	4.08 ± 0.22 a
	<i>p</i> -value	0.7258	0.0120	0.0114	0.0284
2020/2021	No pruning and thinning	0.84 ± 0.02 ns	8.55 ± 0.27 c	4.65 ± 0.19 b	3.91 ± 0.10 c
	Hedge pruning	0.87 ± 0.04	8.91 ± 0.58 bc	4.72 ± 0.29 b	4.19 ± 0.33 b
	Central pruning	0.86 ± 0.03	9.29 ± 0.40 b	4.91 ± 0.27 b	4.38 ± 0.21 b
	Tree thinning	0.87 ± 0.04	9.96 ± 0.26 a	5.28 ± 0.17 a	4.67 ± 0.16 a
	<i>p</i> -value	0.3420	< 0.0001	< 0.0001	< 0.0001
2021/2022	No pruning and thinning	0.72 ± 0.03 b	5.24 ± 0.32 b	2.88 ± 0.19 b	2.36 ± 0.13 b
	Hedge pruning	0.79 ± 0.03 a	7.07 ± 0.72 a	3.89 ± 0.47 a	3.18 ± 0.26 a
	Central pruning	0.82 ± 0.04 a	6.98 ± 0.87 a	3.83 ± 0.48 a	3.14 ± 0.39 a
	Tree thinning	0.82 ± 0.03 a	6.92 ± 0.46 a	3.84 ± 0.29 a	3.08 ± 0.18 a
	<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2022/2023	No pruning and thinning	0.66 ± 0.02 c	6.23 ± 0.33 c	3.63 ± 0.24 c	2.60 ± 0.14 c
	Hedge pruning	0.72 ± 0.03 b	7.40 ± 0.76 b	4.27 ± 0.50 b	3.14 ± 0.28 b
	Central pruning	0.77 ± 0.02 a	7.53 ± 0.56 b	4.31 ± 0.31 b	3.22 ± 0.28 b
	Tree thinning	0.78 ± 0.02 a	8.21 ± 0.18 a	4.73 ± 0.10 a	3.47 ± 0.10 a
	<i>p</i> -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2019–2023	No pruning and thinning	0.86 ± 0.01 ns	7.48 ± 0.15 c	4.12 ± 0.10 c	3.36 ± 0.07 c
	Hedge pruning	0.84 ± 0.02	8.17 ± 0.48 b	4.49 ± 0.26 b	3.68 ± 0.23 b
	Central pruning	0.85 ± 0.04	8.32 ± 0.36 b	4.54 ± 0.20 b	3.77 ± 0.19 b
	Tree thinning	0.86 ± 0.02	8.82 ± 0.16 a	4.84 ± 0.12 a	3.98 ± 0.07 a
	<i>p</i> -value	0.5376	< 0.0001	< 0.0001	< 0.0001

*Means followed by the same letter in the column do not differ by the Tukey's test at 5% significance; ns: non-significant.

Fruit length increased over the five-year period after hedge and central pruning and tree thinning, by comparison with the control (Table 1). As an exception, in the first year, only central pruning and thinning showed significant differences and, in the second year, there were no differences among treatments. Although there was no difference in diameter in the second cycle, in the remaining years, tree thinning outperformed the other treatments. Central pruning and tree thinning resulted in larger diameters than unmanaged plants in harvest conducted in 2020/2021, 2021/2022, and 2022/2023. On average, in the five-year period, thinning outperformed the other treatments, followed by central and hedge pruning.

Regarding kernel length, results indicated that the pruning and tree thinning methods positively influenced fruit size only from the third cycle onwards (Table 1). Kernel diameter was larger after tree thinning, by comparison with the control in the first two cycles, and larger by comparison with results of pruning treatments in the third cycle. In the 2021/2022 and 2022/2023 cycles, both pruning and thinning treatments resulted in larger diameters by comparison with the ones of unmanaged trees. On average, thinning produced kernels with the largest diameters, followed by central and hedge pruning. Removal of biomass as the result of pruning may have affected carbohydrate reserves in trees; it also affected fruit size and levels of plant hormones (Liu et al. 2024). In the case of tree thinning, low competition for nutrients, water and light allowed for greater tree development and allocation of photoassimilates to fruit (Hoffmann et al. 2024).



*Means followed by the same letter for the treatments do not differ by the Tukey's test at 5% significance; ns: non-significant. Each value indicates treatment mean ± standard deviation.

Figure 2. Evaluation of fruit quality based on (a) the number of fruits per kg, and (b) percent kernel of fruit borne by 'Pitol 1' pecan trees grown at high density and subject to hedge and central pruning, tree thinning, and no pruning and thinning in the 2018/2019, 2019/2020, 2020/2021, 2021/2022, and 2022/2023 cycles*.

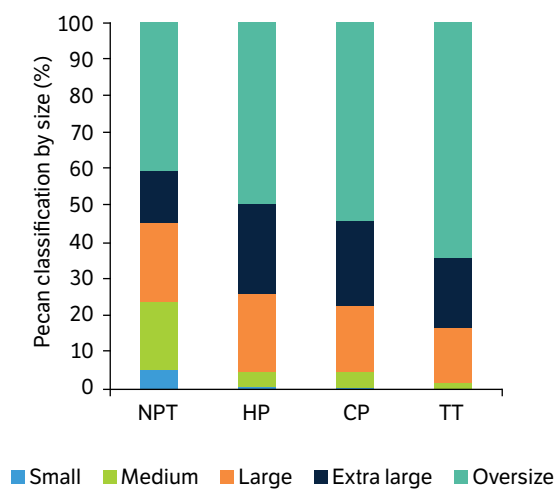


Figure 3. Classification of pecans borne by 'Pitol 1' pecan trees grown at high density and subject to hedge pruning (HP), central pruning (CP), tree thinning (TT), and no pruning and thinning (NPT).

Shell thickness exhibited variability among treatments and across cycles (Table 2). In the 2018/2019 cycle, the control treatment led to significantly thicker shells than the ones resulting from central and hedge pruning. From 2021/2022 onwards, both pruning and thinning treatments resulted in thicker shells by comparison with the control, while in 2022/2023,



thinning and central pruning led to thicker shells than hedge pruning and the control. The 2019/2020, 2020/2021, and average cycles did not show significant differences among treatments. Interestingly, in the last two years, shell thickness followed the same trend as fruit length and diameter, *i.e.*, thinning and pruning treatments resulted in thicker shells than the control. Shell thickness may be evaluated from two perspectives: on one hand, thinner shells facilitate kernel extraction and are associated with higher kernel yields, as observed by Conner (2014). On the other hand, as also noted in *Juglans regia* L., thicker shells, which contain more lignin, provide higher mechanical resistance to fruit (Zhao et al. 2019) and may enhance quality during harvest, transportation, and storage.

Fruit and shell mass were significantly higher in trees subject to thinning by comparison with unpruned and non-thinned trees in all cycles under evaluation (Table 2). Kernel mass was significantly higher only from the second cycle onwards. Hedge and central pruning showed variable results across cycles, surpassing the control only from the third cycle onwards in terms of fruit mass. Wells (2018) observed that hedge pruning only resulted in heavier pecans in the third cycle under investigation. Worley (1991) evaluated different intensities of selective pruning and observed that removal of two or three branches significantly increased nut size. Therefore, results of this study are consistent with those reported by those authors. Increases in fruit mass, by comparison with the control, were 17.91, 11.23, and 9.22% for tree thinning, central pruning, and hedge pruning, respectively. Similar results were observed in kernels and shells.

Fruit per kilogram was significantly influenced by pruning and thinning treatments (Fig. 2). Thinning consistently reduced the number of fruits per kilogram across all cycles under evaluation by comparison with control trees. Pruning treatments, in turn, had more gradual effects, with significant differences from the control starting in the third cycle, mainly after central pruning. In 2021/2022, both thinning and pruning resulted in a significantly lower number of fruits per kilogram than the control. This trend persisted in the last cycle, when thinning and pruning treatments showed the lowest values. On average across cycles, thinning reduced the fruit count to 23, central pruning to 15, and hedge pruning to 14 per kilogram by comparison with the control, due to increase in fruit size and weight. These results demonstrated that thinning induced a more rapid increase in nut size and weight than pruning. While pruning promotes the development of productive structures, its effects on fruit size and weight are more evident in the long term, suggesting an adaptation period for trees to pruning treatments.

It should be highlighted that this study was conducted in an orchard with no irrigation system. In the 2021/2022 and 2022/2023 cycles, rainfall during the critical months of nut growth and filling was below that of the first three cycles (Fig. 1) and affected fruit size and weight. Additionally, control trees were more adversely affected by the drought than by the other treatments. In 2021/2022, when the rainfall volume was only 42.80 mm between December and April, 191 fruit were required per kilogram, while tree thinning, central pruning, and hedge pruning needed 145, 145, and 143 fruit, respectively. These results suggested that both water deficit and excessive shading contribute to a low-quality fruit. They also demonstrated the importance of irrigation, especially in years when the requirement of water needed by the crop is not met (Saretta 2021).

Pruning and tree thinning did not increase average percent kernel over the five experimental years (Fig. 2). In the 2020/2021 cycle, unpruned trees reached higher percent kernel than trees that were subject to hedge and central pruning. It may be explained by a larger number of poorly filled fruit (shriveled) in samples evaluated after both pruning treatments.

Percent kernel is one of the criteria used for evaluating pecans in the industry; it must be above 50% to be well evaluated, which was observed in all treatments and cycles. Lombardini (2006), Wood (2009), and Wells (2018) reported increase in kernel yield in 'Desirable' with hedge pruning. Lombardini (2006) did not find any benefit to cultivars Cape Fear and Kiowa. Therefore, responses to pruning, in terms of percentage of kernel, depend on the cultivar used in the orchard.

In the fruit size classification, there was significant increase in the ratio of extra-large and oversize nuts (Fig. 3). While the control trees had 54.63% of fruit in these categories, hedge pruning, and central pruning yielded 73.81 and 77.09%, respectively. Tree thinning was the most effective treatment, with 83.09% of fruit classified into extra-large and oversize. In practice, increase in the percentage of larger fruit classified into higher categories represents increase in competitiveness in the international market and higher economic value. Kernel lightness was affected in harvests following the initial pruning in 2018/2019. After hedge pruning on one side of the tree and central pruning, trees produced darker kernels than thinning and control treatments (Table 3). In the following cycle, only hedge pruning was performed on the other side of the trees, and kernels resulting from this treatment, along with unpruned and non-thinned trees, were darker than those from central

pruning. Reduction in kernel lightness after pruning may be justified by reduction in plant reserves immediately after management practices. However, in subsequent cycles, with the growth of productive branches, trees no longer exhibited this characteristic. On average, tree thinning resulted in lighter kernels than laterally pruned trees.

Table 3. Kernel characteristics of pecan under pruning and thinning treatments*.

Cycle	Treatment	Lightness (L*)	Hue angle (Hue°)	Commercial kernels (%)
2018/2019	No pruning and thinning	43.09 ± 0.78 a	66.58 ± 0.82 ns	89.44 ± 6.62 ns
	Hedge pruning	41.26 ± 1.73 b	66.14 ± 1.00	91.11 ± 5.21
	Central pruning	41.48 ± 1.17 b	66.20 ± 0.82	91.11 ± 7.15
	Tree thinning	43.40 ± 1.43 a	66.61 ± 1.02	91.44 ± 7.60
	<i>p</i> -value	0.0001	0.5497	0.9266
2019/2020	No pruning and thinning	46.31 ± 1.61 b	71.59 ± 0.91 ab	92.00 ± 4.47 ns
	Hedge pruning	45.94 ± 1.68 b	70.60 ± 2.15 bc	91.55 ± 2.40
	Central pruning	48.65 ± 0.97 a	73.17 ± 0.82 a	94.22 ± 5.33
	Tree thinning	46.74 ± 2.42 ab	69.43 ± 1.99 c	95.11 ± 3.33
	<i>p</i> -value	0.0059	< 0.0001	0.2334
2020/2021	No pruning and thinning	40.73 ± 1.57 ns	68.47 ± 0.66 a	88.00 ± 6.92 ns
	Hedge pruning	41.56 ± 1.17	67.30 ± 0.99 b	88.44 ± 7.05
	Central pruning	41.17 ± 1.19	68.74 ± 0.65 a	89.33 ± 5.66
	Tree thinning	42.14 ± 0.97	68.58 ± 0.76 a	87.55 ± 4.67
	<i>p</i> -value	0.1579	0.0011	0.9447
2021/2022	No pruning and thinning	43.11 ± 0.42 ns	70.51 ± 0.56 ns	97.33 ± 2.82 ns
	Hedge pruning	42.43 ± 1.31	70.34 ± 1.54	96.44 ± 3.71
	Central pruning	42.68 ± 1.33	70.61 ± 1.43	96.89 ± 3.89
	Tree thinning	43.36 ± 1.65	70.89 ± 1.71	99.55 ± 1.33
	<i>p</i> -value	0.3519	0.8653	0.1770
2022/2023	No pruning and thinning	47.21 ± 1.40 ns	68.15 ± 0.73 ns	93.78 ± 5.70 b
	Hedge pruning	46.58 ± 1.18	68.39 ± 0.76	99.11 ± 1.76 a
	Central pruning	46.18 ± 2.19	67.89 ± 0.67	98.22 ± 2.11 a
	Tree thinning	47.44 ± 2.27	67.93 ± 1.12	98.66 ± 2.00 a
	<i>p</i> -value	0.5129	0.6004	0.0072
2019–2023	No pruning and thinning	43.09 ± 0.39 ab	68.06 ± 0.22 ab	92.11 ± 2.29 ns
	Hedge pruning	42.55 ± 0.90 b	67.55 ± 0.86 b	93.33 ± 2.19
	Central pruning	43.03 ± 0.86 ab	68.32 ± 0.53 a	93.95 ± 2.97
	Tree thinning	43.61 ± 0.82 a	67.69 ± 0.81 ab	94.47 ± 2.24
	<i>p</i> -value	0.0194	0.0160	0.2703

*Means followed by the same letter in the column do not differ by the Tukey's test at 5% significance; ns: non-significant.

Kernel color showed significant differences in only two out of five cycles (Table 3). In the second cycle, central pruning resulted in lighter kernels, by comparison with tree thinning and hedge pruning, whereas in the following cycle, hedge pruning led to darker kernels than the other treatments. On average across cycles, central pruning outperformed hedge pruning in this variable. Like lightness, kernels resulting from the hedge pruning treatment had the lowest scores. However, while lightness evaluates how light or dark kernels are, color evaluation measures the yellowness of kernels, *i.e.*, high values indicate yellower kernels, while low values indicate redder ones.

High values are expected from color and lightness, which means clearer and yellowish kernels, rather than dark and brown-reddish ones. Light colors show freshness whereas dark ones show old age, rancidity and may be associated with the Maillard reaction, in which sugar and protein are primary reagents (Prabhakar et al. 2022).

Regarding the percentage of commercial fruit, significant differences were observed only in the 2022/2023 cycle (Table 3). In this cycle, hedge pruning, central pruning, and tree thinning resulted in 4.88, 4.44, and 5.33% more defect-free fruit, respectively, by comparison with the control. No significant differences were found among treatments in other cycles. The 2022/2023 cycle experienced water deficit due to a drought in the orchard coupled with shading issues and resulted in lower commercial quality kernels in control trees. Fruit quality characteristics, such as weight, size, kernel percentage, and appearance, are crucial for market acceptance and value.

'Pitol 1', characterized by its vigorous growth and compact leaflets (Hellwig et al. 2022), responded well to pruning and to increase in spacing provided by thinning. Despite variable effects across the cycles, tree thinning was the most prominent management practice to decrease resource competition and improve nut quality. The evaluation of production per tree (previously published data) showed that tree thinning stood out, by comparison with the other treatments, and resulted in the highest accumulation of production per tree (45 kg), followed by central pruning (35.29), and hedge pruning (34.61 kg), while the control exhibited 25.23 kg (Hellwig et al. 2025b). Central and hedge pruning, which also improved quality and accumulated production of trees, stood out due to their average productivity, which was higher than the one of the control, since it increased 39.85 and 37.20%, respectively. On the other hand, tree thinning led to statistically similar productivity to the area with no pruning at high density (control) because 50% of trees was removed (Hellwig et al. 2025b).

Therefore, since hedge and central pruning led to increase in productivity and fruit quality, they have proven to be producers' more immediate alternatives. However, tree thinning, which decreases competition among trees and favors development to enable better fruit quality (as shown by this study), is the management practice that must be considered to reach sustainable production in the medium and long terms.

CONCLUSION

'Pitol 1' pecan trees grown at high density, when subject to hedge and central pruning and tree thinning, bear fruit of larger size and mass. Thus, fewer fruit are needed per kg, and the percentage of fruit classified into the largest size categories increases.

Information on fruit quality introduced by this study and previously published data on production show that both pruning practices are recommended because they increase productivity and fruit quality; thus, good results are reached in the short term. Tree thinning, by means of suppression, is a more radical management practice whose disadvantage is that it only equals productivity per hectare to high-density areas with no pruning after five cycles. However, because it increases fruit size and weight, it enables producers to achieve higher added value and better vegetative development, thus becoming a promising management practice in the medium and long terms.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION


Conceptualization: Hellwig, C. G., Martins, C. R., Malgarim, M. B. and Farias, R. M.; **Methodology:** Hellwig, C. G., Martins, C. R., Malgarim, M. B. and Farias, R. M.; **Investigation:** Hellwig, C. G. and Lima, A. D. V.; **Project administration:** Hellwig, C. G., Martins C. R. and Malgarim, M. B.; **Supervision:** Martins, C. R. and Malgarim, M. B.; **Writing – original draft:** Hellwig, C. G.; **Writing – Review and Editing:** Hellwig, C. G., Martins, C. R., Farias, R. M. and Malgarim, M. B.; **Final approval:** Hellwig, C. G.



DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

FUNDING

Conselho Nacional de Desenvolvimento Científico e Tecnológico 
Grant No.: 140748/2020-2

ACKNOWLEDGMENTS

The authors thank the producer for enabling the experiment to be evaluated, and the Embrapa Clima Temperado and Universidade Federal de Pelotas for the facilities for evaluation.

REFERENCES

- Agritempo. Portal. Agritempo. Available at: <https://www.agritempo.gov.br/>. Accessed on: October 20, 2024.
- Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M. and Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22, 711-728. <https://doi.org/10.1127/0941-2948/2013/0507>
- Arreola Ávila, J. G., Lagarda Murrieta, A., Borja de la Rosa, A., Valdez Cepeda, R. and López Ariza, B. (2010). Disponibilidad de luz y producción de nuez después del aclareo de árboles de nogal pecanero (*Carya illinoensis*). *Revista Chapingo. Serie Ciencias Forestales y del Ambiente*, 16, 147-154. <https://doi.org/10.5154/r.rchscfa.2009.11.047>
- Casagrande, D. G., Stulp, S. and Ethur, E. M. (2025). O cultivo da noz-pecã no estado do Rio Grande do Sul: perspectivas econômicas e suas particularidades. *Revista Observatorio de la Economía Latinoamericana*, 23, e8637. <https://doi.org/10.55905/oelv23n1-101>
- Conner, P. J. (2014). Performance of nine pecan cultivars in southern Georgia. *Journal of the American Pomological Society*, 68, 118-124.
- Díez, C. M., Moral, J., Cabello, D., Morello, P., Rallo, L. and Barranco, D. (2016). Cultivar and tree density as key factors in the long-term performance of super high-density olive orchards. *Frontiers in Plant Science*, 7, e01226. <https://doi.org/10.3389/fpls.2016.01226>
- Fernández-Chávez, M., Guerrero-Morales, S., Palacios-Monárrez, A., Uranga-Valencia, L. P., Escalera-Ochoa, L. and Pérez-Álvarez, S. (2021). Análisis de diversos aspectos económicos de la producción en huertas de nogales de alta y baja densidad. Estudio de caso. *Cultivos Tropicales*, 42, e01.
- Ferreira, D. F. (2014). Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, 38, 109-112. <https://doi.org/10.1590/S1413-70542014000200001>
- Fronza, D., Hamann, J. J., Both, V., Anese, R. O. and Meyer, E. A. (2018). Pecan cultivation: general aspects. *Ciência Rural*, 48, e20170179. <https://doi.org/10.1590/0103-8478cr20170179>
- Gong, Y., Pegg, R. B., Kerrihard, A. L., Lewis, B. E. and Heerema, R. J. (2020). Pecan kernel phenolics content and antioxidant capacity are enhanced by mechanical pruning and higher fruit position in the tree canopy. *Journal of the American Society for Horticultural Science*, 145, 193-202. <https://doi.org/10.21273/JASHS04810-19>



- Hellwig, C. G., Lima, A. D. V., Farias, R. M., Martins, C. R. and Malgarim, M. B. (2025a). Central and hedge pruning lead to improvement in pecan production and quality in high-density orchards. *Ciência e Agrotecnologia*, 49, e020224. <https://doi.org/10.1590/1413-7054202549020224>
- Hellwig, C. G., Lima, A. D. V., Farias, R. M., Martins, C. R. and Malgarim, M. B. (2025b). High-density pecan trees subjected to hedge and central pruning and thinning in southern Brazil. *Acta Scientiarum. Agronomy*, 47, e71083. <https://doi.org/10.4025/actasciagr.v47i1.71083>
- Hellwig, C. G., Martins, C. R., Lima, A. D. V., Barreto, C. F., Medeiros, J. C. F. and Malgarim, M. B. (2022). Hedge and central pruning in a high-density pecan orchard in southern Brazil. *Comunicata Scientiae*, 13, e3842. <https://doi.org/10.14295/cs.v13.3842>
- Hoffmann, J. F., Lopes, C. R., Siebeneichler, T. J., Foscarini, S. C., Tamires, S., Ferreira, C. D., Carvalho, I. R., Hellwig, C. G. and Martins, C. R. (2024). Tree thinning affects the physicochemical characteristics and bioactive compounds in 'Barton' and 'Melhorada' pecan cultivars. *Ciência e Agrotecnologia*, 48, e005924. <https://doi.org/10.1590/1413-7054202448005924>
- [INC] International Nut and Fruit Council Foundation (2024). Nuts and dried fruits statistical yearbook 2024. INC. Available at: <https://inc.nutfruit.org/wp-content/uploads/2025/01/Statistical-Yearbook-2024.pdf>. Accessed on: June 27, 2025.
- Liu, X. F., An, X. H., Li, X. M., Zhang, H., Cao, H. B., Chen, H. J. and Tian, Y. (2024). Metabolomic and transcriptomic analyses of peach leaves and fruits in response to pruning. *BMC Genomics*, 25, 666. <https://doi.org/10.1186/s12864-024-10549-y>
- Lombardini, L. (2006). One-time pruning of pecan trees induced limited and short-term benefits in canopy light penetration, yield, and nut quality. *HortScience*, 41, 1469-1473. <https://doi.org/10.21273/HORTSCI.41.6.1469>
- Martins, C. R., Hamann, J. J., Filippini Alba, J. M. and Farias, R. M. (2024). Pecã no Brasil. In C. R. Martins, M. Lazarotto and M. B. Malgarim (Eds.). *Nogueira-Pecã: cultivo, benefícios e perspectivas* (p. 37-52). Brasília: Embrapa.
- Martins, C. R., Hoffmann, A., Nachtigal, J. C., Alba, J. M. F. and Lopes, J. L. (2023). Panorama da produção, processamento e comercialização de noz-pecã no Sul do Brasil. Pelotas: Embrapa Clima Temperado. (Documentos, 535).
- Poletto, T., Fantinel, V. S., Muniz, M. F. B. and Dutra, A. F. (2018). Tamanho de amostra para caracterização de frutos de *Carya illinoensis*. *Agropecuária Científica no Semiárido*, 14, 103-107. <https://doi.org/10.30969/acsa.v14i2.923>
- Poletto, T., Poletto, I., Silva, L. M. M., Muniz, M. F. B., Reiniger, L. R. S., Richards, N. and Stefenon, V. M. (2020). Morphological, chemical and genetic analysis of southern Brazilian pecan (*Carya illinoensis*) accessions. *Scientia Horticulturae*, 261, 108863. <https://doi.org/10.1016/j.scienta.2019.108863>
- Prabhakar, H., Bock, C. H., Kerr, W. L. and Kong, F. (2022). Pecan color change during storage: kinetics and modeling of the processes. *Current Research in Food Science*, 5, 261-271. <https://doi.org/10.1016/j.crf.2022.01.015>
- Rallo, L., Barranco, D., Castro-García, S., Connor, D. J., Del Campo, M. G. and Rallo, P. (2013). High-density olive plantations. *Horticultural Reviews*, 41, 303-384. <https://doi.org/10.1002/9781118707418.ch07>
- Reig, G., Lordan, J., Hoying, S., Fargione, M., Donahue, D. J., Francescatto, P., Acimovic, D., Fazio, G. and Robinson, T. (2020). Long-term performance of "Delicious" apple trees grafted on Geneva® rootstocks and trained to four high-density systems under New York state climatic conditions. *HortScience*, 55, 1538-1550. <https://doi.org/10.21273/HORTSCI14904-20>
- Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., Almeida, J. A., Araújo Filho, J. C., Oliveira, J. B. and Cunha, T. J. F. (2018). Sistema brasileiro de classificação de solos. Brasília: Embrapa.
- Saretta, E. (2021). Efeitos da irrigação de noqueira-pecã no Rio Grande do Sul. *Irriga*, 26, 827-837. <https://doi.org/10.15809/irriga.2021v26n4p827-837>
- Toledo, P. F. S., Phillips, K., Schmidt, J. M., Bock, C. H., Wong, C., Hudson, W. G., Shapiro-Ilan, D. I., Wells, L. and Acebes-Doria, A. L. (2024). Canopy hedge pruning in pecan production differentially affects groups of arthropod pests and associated natural enemies. *Crop Protection*, 176, 106521. <https://doi.org/10.1016/j.cropro.2023.106521>

- Tong, X., Szacilo, A., Chen, H., Tan, L. and Kong, L. (2022). Using rich media to promote knowledge on nutrition and health benefits of pecans among young consumers. *Journal of Agriculture and Food Research*, 10, 100387. <https://doi.org/10.1016/j.jafr.2022.100387>
- Wells, L. (2017). *Southeastern pecan grower's handbook*. Athens: University of Georgia.
- Wells, L. (2018). Mechanical hedge pruning affects nut size, nut quality, wind damage, and stem water potential of pecan in humid conditions. *HortScience*, 53, 1203-1207. <https://doi.org/10.21273/HORTSCI13217-18>
- Wood, B. W. (2009). Mechanical hedge pruning of pecan in a relatively low-light environment. *HortScience*, 44, 68-72. <https://doi.org/10.21273/HORTSCI.44.1.68>
- Worley, R. E. (1985). Effects of hedging and selective limb pruning of Elliott, Desirable, and Farley pecan trees under three irrigation regimes. *Journal of the American Society for Horticultural Science*, 110, 12-16. <https://doi.org/10.21273/JASHS.110.1.12>
- Worley, R. E. (1991). Selective limb pruning intensity influences mature pecan tree and nut characteristics. *HortScience*, 26, 126-129. <https://doi.org/10.21273/HORTSCI.26.2.126>
- Wu, S., Yao, X., Wang, K., Yang, S., Ren, H., Huang, M. and Chang, J. (2022). Quality analysis and comprehensive evaluation of fruits from different cultivars of pecan (*Carya illinoensis* (Wangenheim) K. Koch). *Forests*, 13, 746. <https://doi.org/10.3390/f13050746>
- Zhao, S., Niu, J., Yun, L., Liu, K., Wang, S., Wen, J., Wang, H. and Zhang, Z. (2019). The relationship among the structural, cellular, and physical properties of walnut shells. *HortScience*, 54, 275-281. <https://doi.org/10.21273/HORTSCI13381-18>
- Zhu, H. and Stafne, E. T. (2019). Influence of paclobutrazol on shoot growth and flowering in a high-density pecan orchard. *HortTechnology*, 29, 210-212. <https://doi.org/10.21273/HORTTECH04241-18>