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Tree thinning affects the physicochemical characteristics and bioactive compounds in 'Barton' and 'Melhorada' pecan cultivars

O desbaste de plantas afeta as características físico-químicas e compostos bioativos das cultivares de noz-pecã 'Barton' e 'Melhorada'

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ABSTRACT

The production and consumption of pecan nuts have been on the rise in recent times, which renders it necessary to study the best production practices to increase the yield, enhance the flavor, and maintain the bioactive components in the final product. The present study, therefore, aimed to verify the effects of tree thinning on the physicochemical characteristics and bioactive components in pecan under the cultivation conditions of Santa Rosa, Rio Grande do Sul. The pecan plants were submitted to two types of management – with thinning and without thinning, following which the fruits were evaluated for physical (size, weight, and color) and chemical (physicochemical composition, oxidative stability, fatty acid profile, and tocopherols) attributes. The results revealed that the thinning of plants increased the size and mass of both nuts and kernels while reducing the acid content and peroxides in the kernels and increasing the γ-tocopherol levels. The other quality evaluations did not reveal any significant alterations after plant thinning.

Index terms: *Carya illinoinensis*; luminosity; post-harvest quality; bioactive compounds.

RESUMO

A produção e consumo de nozes vem aumentando nos últimos tempos, e com isso, há de se estudar as melhores práticas de produção, que aumentem a quantidade produzida e favoreçam ou mantenham os compostos bioativos presentes. Nesse sentido, esse trabalho teve como objetivo verificar a interferência do desbaste de plantas nas características físico-químicas e compostos bioativos da noz-pecã nas condições de Santa Rosa, Rio Grande do Sul. Para isso, as plantas foram submetidas a dois tipos de manejo: com desbaste e sem desbaste de plantas e os frutos foram avaliados quanto a características físicas (tamanho, peso e cor) e químicas (composição físico-química, estabilidade oxidativa, perfil de ácidos graxos e tocoferóis). O desbaste das plantas aumentou o tamanho e a massa das nozes, assim como, reduziu o índice de acidez e peróxidos e aumentou o conteúdo de γ-tocoferol. As demais avaliações de qualidade não foram alteradas significativamente com o desbaste das plantas.

Termos para indexação: *Carya illinoinensis*; luminosidade; qualidade de pós-colheita; compostos bioativos.

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Introduction

Pecan tree (*Carya illinoinensis* (Wangenh.) K. Koch) cultivation has increased in recent years across various regions of the world. The planting and agro-industrial processing of nuts has facilitated income diversification, particularly in the southern region of Brazil (Hamann et al., 2018). The popularization of fresh pecan nuts and their products is a result of their practicality, sensory characteristics, and nutritional properties. In particular, the lipid profile of pecan nuts, which comprises over 80% of unsaturated fatty acids and other bioactive compounds such as tocopherols that have health benefits, contribute to the increased demand for these nuts and their products (Salvador et al., 2016; Atanasov et al., 2018; Ribeiro et al., 2020a; Tong et al., 2022). However, the overall quality of pecan nuts is influenced by various factors, such as soil condition, climate, and the management practices adopted in the orchard.

Recent studies aimed at developing pecan cultivation and production as a viable alternative for productive diversification have attempted to develop novel technologies or adapt the existing ones to improve the production and quality of the genetic materials planted in Brazil (Bilharva et al., 2018; Crosa et al., 2020; Martins et al., 2021). The composition of bioactive compounds in a plant relies on, in addition to the genetic characteristics of the cultivar, the edaphoclimatic conditions and the management practices employed in the orchard (Villarreal-Lozoya, Lombardini, & Cisneros-zevallos, 2007; Bouali et al., 2020; Ferrari et al., 2022). However, little information is available regarding the local management techniques employed in the orchards traditionally and the relationship of these practices with the quality of the nuts produced. In particular, information on the bioactive components and the physicochemical characteristics of these nuts is lacking.

Plant thinning is an agronomic management practice that generally involves eliminating certain plants strategically to favor the development of other plants due to the benefits of reduced plant density, increased ventilation, and decreased competition for water, light, and minerals. This management practice may also include transplanting trees to another location for their use (Arreola-Ávila et al., 2010). Plant thinning has been beneficial as several of the pecan tree orchards were initially established with relatively small spacing between the seedlings for better land usage, which, however, led to the problem of excessive shade later (Fronza et al., 2018; Martins et al., 2021). This excess of shade due to nearby branches led to a decline in production in the long run, as photosynthesis without sufficient light and aeration in the orchard favored the proliferation of pests and diseases, ultimately affecting the production and quality of the trees (Madero, 2017). In addition, the lower stratum of the plant canopy encountered problems such as drying of the branches due to the lack of sunlight (Hellwig et al., 2020). The literature does not, to the best of the author's knowledge, report any study on the effect of plant thinning on nut quality, particularly the effects on the bioactive components and nutraceutical properties of the plants, considering the high content of antioxidant compounds reported in its fruit (Atanasov et al., 2018; Alvarez-Parrilla, 2018; Descalzo et al., 2022).

Therefore, the present study aimed to provide data on the quality of pecan cultivars produced in the region by verifying the effects of tree thinning on the physicochemical characteristics and bioactive components in pecan under the cultivation conditions of Santa Rosa, Rio Grande do Sul state, Brazil.

Material and Methods

Plant material

Nuts from 'Barton' and 'Melhorada' ('Pitol 1') cultivars produced at a commercial orchard in Santa Rosa, Rio Grande do Sul (27° 55'15" S; 54° 32'37" W) were used in the present study. The concerned orchard was established in 2008 with a spacing of 7 m x 7 m between seedlings, which is considered dense planting for this crop. The orchard soil was the typical dystroferric red latosol (Santos et al., 2018). The data on the minimum and maximum temperatures and the monthly rainfall in the study region during the 2020/2021 cycle, between July 2020 and June 2021, were obtained from the Estação Meteorológica Santa Rosa - TRMM.291/ Agritempo (Figure 1).

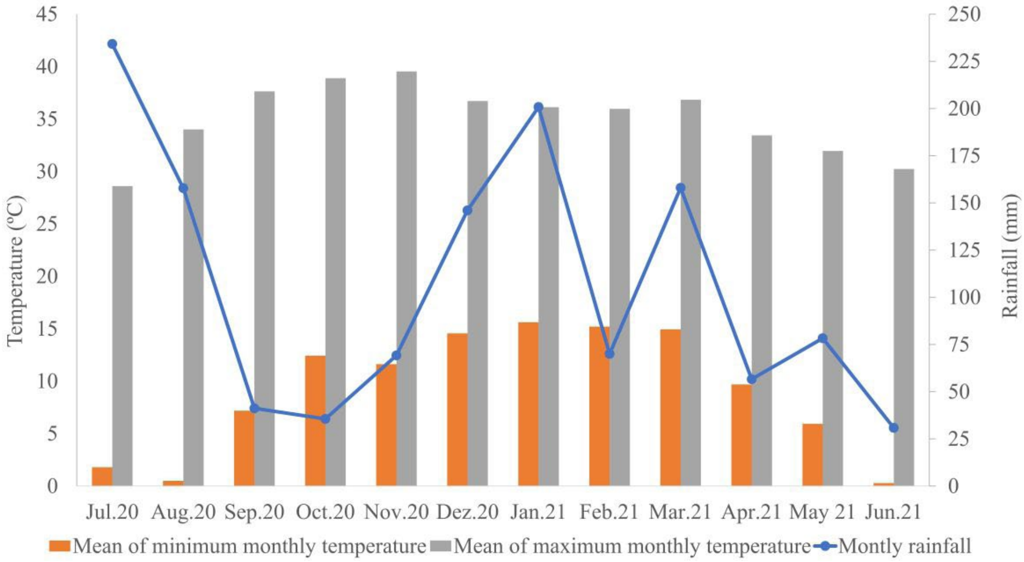

Figure 1: The average values of the minimum and maximum monthly temperatures and monthly rainfall in Santa Rosa, RS, Brazil, during the 2020/2021 cycle. Source: The data issued by the Agritempo - Sistema de Monitoramento Agrometeorológico.

Nuts were obtained from plants that were submitted to two types of management – with the thinning and without the thinning of plants. Thinning was conducted in August 2018 and comprised alternate cutting of adult plants, altering the plant density from 204 plants per hectare to 102 plants per hectare. The pecan nuts were harvested in May 2021, and a total of 1.4 kg of samples were dried in a Rovler® forced-air oven at 40 °C until a moisture content of 4% was reached. Subsequently, 25 pecan nuts were randomly selected from each sample and evaluated for their size and mass. The samples with kernels were transported to the Instituto Tecnológico em Alimentos para a Saúde for chemical analyses. The kernels were weighed, and 100 g of kernels were crushed in a food processor (Oster® OMPR670) for 1 min and 30 s at room temperature. The grounded samples were finally stored in plastic packaging at –20 °C until used in subsequent analyses.

Physical evaluation

The masses of nuts and their parts were determined for 25 fruits per sample. Each fruit was weighed individually first, followed by shelling of the fruits and then weighing the kernels and shells. Mass was determined using a precision digital balance. The length and diameter of each shell and fruit were evaluated for 25 fruits per sample using an MTX® digital caliper with a measurement range of 0 to 150 mm. Using the masses determined for the fruits, kernels, and shells, the kernel yield was calculated using the following equation:

Kernel yield (%) = (Kernel mass * 100)/Fruit mass

The color of each fruit was determined in the CIE-L*a*b* standard format using a colorimeter (Minolta Chromometer Model CR 300), which provided the L*, a*, and b* values. The L* value represented brightness (L* = 0 indicated black and L* = 100 indicated total brightness), while the a* and b* values were utilized to determine the Hue angle [°Hue = tan – 1 (b*/a*) and Chroma $C^* = (a^{*2} + b^{*2})^{0.5}$]. The color parameters were determined for 10 fruits from each cultivar.

Physicochemical composition

The centesimal composition of the nuts (moisture, ash, proteins, lipids, and carbohydrates by difference) was determined according to the Association of Official Agricultural Chemists - AOAC (2012). The results were expressed in g/100 g.

Oil extraction and analysis

Pecan nut oil was extracted using the method described by Bligh and Dyer (1959). The extracted oil was then evaluated for acidity, peroxide level, specific extinction coefficient (K_{232} and K_{270}), fatty acid profile, and tocopherols.

In order to determine the acid content, the pecan nut oil was dissolved in a solution of ethyl ether and ethyl alcohol (2:1, v/v) in an oil-to-solvent ratio of 1:10 (w/v), followed by the addition of phenolphthalein and then performing titration using the 0.1 N KOH solution (American Oil Chemists Society - AOCS, 1992). The results were expressed in mg KOH/g.

In order to determine the peroxide number, 5 g of the extracted oil was dissolved in 30 mL of a solution of acetic acid and chloroform (3:2, v/v), followed by stirring the mixture. Next, 0.5 mL of saturated potassium iodide solution was added, and the flask was placed in the dark for one minute. Afterward, 30 mL of distilled water and 0.5 mL of starch solution (1%) were added, followed by titration using sodium thiosulphate (0.1 N) until the blue color disappeared (AOCS, 1992). The results were expressed in meq O_2/kg.

The specific extinction coefficients (K_{232} and K_{270}) were determined next, for which the absorbance of 100 mg of oil (cleaned, filtered, and dissolved in isooctane and then placed in a 10 mL volumetric flask) was measured using a spectrophotometer at 232 nm and 270 nm. The absorbance values were then utilized to calculate the specific extinction coefficients K_{232} and K_{270} (AOCS, 1992).

Further, the fatty acid composition (%) and the α-, δ -, and γ -tocopherol contents (mg/100 g) in the oil were determined using gas chromatography–mass spectrometry and liquid chromatography, respectively, using the protocols reported by Crizel et al. (2020).

Statistical analysis

All chemical analyses were performed in triplicate (n = 3), and the results were expressed as mean ±standard deviation. Analysis of variance was performed, and in the case of statistical significance ($P < 0.05$), a t-test was conducted to determine the difference between thinning and no-thinning samples from the same cultivar.

Results and Discussion

Physical parameters

The weights of the fruits, kernels, and shells evaluated were higher with tree thinning in both cultivars (Table 1). Kernel yield was consequently higher with thinning in the ‘Barton’ cultivar, although it was lower with thinning in the ‘Melhorada’ cultivar. Heavier nuts are better evaluated in the market based on classification, which is determined by the number of nuts per kilogram and the weight of the nut. In the case of the Barton cultivar, 128 nuts per kilogram were required with thinning and 154 nuts per kilogram without thinning. In the case of the Melhorada cultivar, 100 nuts per kilo were required with thinning and 117 nuts without thinning. Therefore, the rating for ‘Melhorada’ was ‘extra-large’, the rating for ‘Barton’ with thinning was large, and the rating for ‘Barton’ with no thinning was medium in agreement with the Mexican norm NMX-FF-084-SCFI-2009. The kernel yield was greater than 50%, which is considered acceptable for the industry. The difference in the kernel yield between the two cultivars could be associated with the differences in the fruit size between the cultivars. In the Melhorada cultivar with thinning, better kernel filling was required compared to the Barton cultivar, which resulted in a lower percentage of kernels than the nuts without tree thinning.

The length and diameter values of the nuts and kernels were also higher with tree thinning (Table 1). The thinning of plants increased the mass and size values of the nuts and kernels, which was attributed to less competition between the plants for solar energy, nutrients, and water due to this management practice.

Table 2 presents the results of the kernel color parameters. No significant differences in the analyzed parameters were noted for both cultivars. Color is an important indicator of pecan quality, and the luminosity values indicate the degree of darkening of the pecan kernels. The lowest values, being closer to black (zero value), indicate the greatest darkening. The "a" value indicates the green to red color range, while the "b" value indicates the blue to yellow color range. It is desirable that the "b" parameter of nuts (indicating yellowish tones) is high while the "a" parameter (indicating red and brown tones) should remain low. Darker nuts indicate greater oxidation, and consequently, a further pronounced rancid flavor and aroma (Siebeneichler et al., 2023). The color parameter values determined in the present study were consistent with those reported previously for nuts. For instance, Ribeiro et al. (2020b) reported luminosity values ranging from 37 to 41, "a*" values ranging from 8 to 9, and "b*" values ranging from 20 to 24 for 'Barton' pecans after six and twelve months of storage under various O_2 partial pressures and temperatures.

Figure 2 depicts the appearance of kernels. Fruit color is an important parameter reflecting fruit quality, although it may vary with the cultivar and harvest and also with the post-harvest processes such as drying and storage. The market generally prefers lighter nuts (Hellwig et al., 2020).

Physicochemical composition

Thinning did not influence the centesimal composition of the nuts in both Barton and Melhorada cultivars (Table 3). A lower moisture content and a higher carbohydrate content were noted in the Barton cultivar with thinning, which was attributed to the drying time of the products. Therefore, standardization is important at this stage. Pecan is characterized as a fruit with a high lipid content (52.70%–78.07%), medium protein (6.00%–17.84%) and carbohydrate (4.92%–17.74%) contents, and low moisture (2.13%–6.36%) and ash (1.10%–1.79) contents (Rodrigues et al., 2013; Ribeiro et al., 2020a; Siebeneichler et al., 2023). In the present study, the fiber content was not evaluated separately, and the carbohydrate content was determined to be in the range of 20% (Table 3).

Table 1: Fruit and kernel mass, shell mass, kernel yield, length, and diameter with and without tree thinning during the 2020/2021 harvest.

Cultivar	Thinning	Fruit mass (g)	Kernel mass (g)	Shell mass (g)	Kernel yield (%)
Barton	With	7.81 ± 0.31 *	4.23 ± 0.23 *	3.57 ± 0.18*	53.91 ± 1.86*
	Without	6.48 ± 0.23	3.39 ± 0.20	3.09 ± 0.10	51.39 ± 1.86
Melhorada	With	9.96 ± 0.25*	5.28 ± 0.16 *	4.67 ± 0.15 *	52.42 ± 1.04*
	Without	8.55 ± 0.26	4.65 ± 0.18	3.91 ± 0.10	53.97 ± 0.82
Cultivar	Thinning	Fruit length (mm)	Fruit diameter (mm)	Kernel length (mm)	Kernel diameter (mm)
Barton	With	38.62 ± 0.45*	24.61 ± 0.39*	24.86 ± 0.34*	19.91 ± 0.47*
	Without	37.74 ± 0.75	23.74 ± 0.28	20.61 ± 0.49	18.52 ± 0.34
Melhorada	With	45.78 ± 1.02*	25.02 ± 0.28*	36.46 ± 0.40*	21.26 ± 0.22*
	Without	43.88 ± 0.79	24.02 ± 0.44	34.46 ± 0.30	20.71 ± 0.22

Values presented are mean ±standard deviation (n = 25). * Significant by t-test. ns = not significant by the t-test, comparing thinning in the same cultivar ($P < 0.05$).

Table 2: The color parameter values for the 2020/2021 Pecan harvest with and without tree thinning.

Cultivar	Thinning	Luminosity	a*	b*	Chroma	°Hue
Barton	With	47.1 ± 2.2^{ns}	6.9 ± 1.1^{ns}	6.9 ± 1.1^{ns}	13.1 ± 2.6^{ns}	58.0 ± 2.2^{ns}
	Without	46.6 ± 2.3	6.4 ± 1.7	10.6 ± 3.1	12.4 ± 3.3	58.4 ± 4.8
Melhorada	With	46.7 ± 2.3^{ns}	6.8 ± 0.9^{ns}	10.4 ± 2.2^{ns}	12.4 ± 2.3^{ns}	56.5 ± 3.4^{ns}
	Without	45.6 ± 1.1	6.9 ± 0.8	9.2 ± 1.1	11.5 ± 1.2	53.3 ± 2.3

Values presented are mean ±standard deviation (n = 10). * Significant by t-test. ns = not significant by the t-test, comparing thinning in the same cultivar ($P < 0.05$).

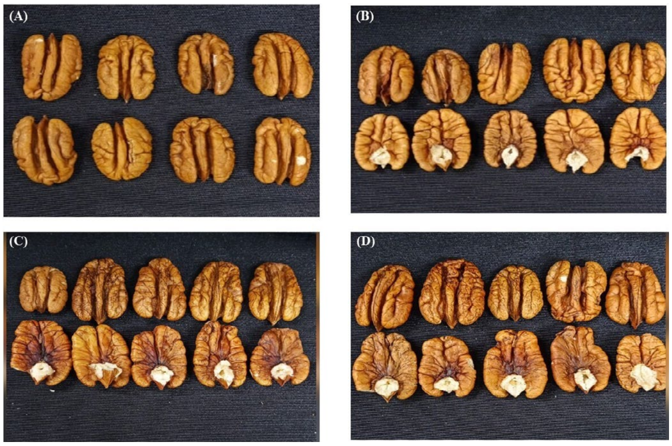

Figure 2: Photographs of pecan kernels from the 2020/2021 Pecan harvest with and without tree thinning. (A) 'Barton' cultivar with thinning. (B) 'Barton' cultivar without thinning. (C) 'Melhorada' cultivar with thinning. (D) 'Melhorada' cultivar without thinning.

Variations in the nutritional composition of pecan are associated with genetic, edaphoclimatic, and agronomic factors. The lipid content depends upon several factors, such as horticultural practices (monitoring the soil for nitrogen and potassium levels, for example), growing conditions (accumulated rain volume), maturity, cultivar, and past productivity of the tree. Irregular bearing may also influence lipid content. In general, low-yielding trees produce nuts with higher oil content while high-yielding trees produce nuts with a lower oil content (Siebeneichler et al., 2023). In the southern region of Brazil, Barton and Melhorada are the most commonly planted varieties as these have floral synchrony and good productivity. Barton is known for its high productivity while Melhorada has medium productivity (Casagranda et al., 2023).

Oxidative stability of nuts

Nuts of Barton and Melhorada cultivars submitted to plant thinning exhibited lower acid levels and peroxide content compared to those without thinning (Table 4). No significant difference was noted in the extinction coefficient. The legislation stipulates a maximum acid level of 4 mg KOH/g and a peroxide content limit of 15 meq/kg for unrefined oils (Brasil, 2021). The acid index in both cultivars and the peroxide index in the Melhorada cultivar were higher in the plants without thinning. This result was attributed to the lack of light and ventilation in the orchard, which increased the humidity, leading to susceptibility to microbial proliferation (Siebeneichler et al., 2023). Microorganisms, particularly fungi, are known to produce lipolytic enzymes that facilitate the production of free fatty acids (Li et al., 2010; Mehta et al., 2017). These free fatty acids are highly susceptible to oxidation, particularly in the presence of atmospheric oxygen. The free fatty acids produced in the oxidation process increase the acidity and react with oxygen to form lipid peroxides.

Table 3: Physicochemical composition of pecans from the 2020/2021 Pecan harvest with and without tree thinning.

Cultivar	Thinning	Water content (%)	Ash content (%)	Protein content (%)	Lipid content (%)	Carbohydrate content (%)
Barton	With	5.80 ± 0.10 *	1.49 ± 0.09^{ns}	7.17 ± 0.11^{ns}	60.69 ± 0.01ns	24.86 ± 0.10*
	Without	6.85 ± 0.02	1.68 ± 0.03	7.35 ± 0.41	61.67 ± 1.13	20.61 ± 0.60
Melhorada	With	6.12 ± 0.11^{ns}	1.50 ± 0.05^{ns}	7.28 ± 0.08^{ns}	64.91 ± 2.12^{ns}	20.17 ± 1.38*
	Without	6.13 ± 0.10	1.59 ± 0.04	7.73 ± 0.24	60.39 ± 3.35	24.16 ± 2.27

Values presented are mean ±standard deviation (n = 10). * Significant by t-test. ns = not significant by the t-test, comparing thinning in the same cultivar (P < 0.05).

Table 4: Acid level (mg KOH/g), peroxide content (meq O_2/kg), and extinction coefficient (K_{232} and K_{270}) of the pecans from the 2020/2021 Pecan harvest with and without tree thinning.

Cultivar	Thinning	Acid value (mg KOH/g)	Peroxide index (meq/kg)	K_{232}	K_{270}
Barton	With	0.73 ± 0.04*	4.16 ± 0.20^{ns}	0.01 ± 0.00^{ns}	0.02 ± 0.01^{ns}
	Without	0.84 ± 0.02	4.23 ± 0.18	0.01 ± 0.01	0.02 ± 0.01
Melhorada	With	0.80 ± 0.05*	2.60 ± 0.20*	0.01 ± 0.00^{ns}	0.01 ± 0.00^{ns}
	Without	0.87 ± 0.01	8.15 ± 0.20	0.02 ± 0.00	0.02 ± 0.00

Values presented are mean ±standard deviation (n = 10). * Significant by t-test. ns = not significant by the t-test, comparing thinning in the same cultivar (P < 0.05).

Fatty acid and tocopherol profile

The tree thinning practice did not influence the fatty acid profile of pecans (Table 5). The major fatty acids in both cultivars were oleic acid (C18:1), linoleic acid (C18:2), and palmitic acid (C16:0). A prevalence of unsaturated fatty acids was noted in the pecans, accounting for an average of 85% of the total lipid content. Ribeiro et al. (2020a) reported that unsaturated fatty acids accounted for 90.73% of the total fatty acid composition in 'Barton' and 89.51% of the total fatty acid composition in the 'Melhorada' cultivar. This difference in the results of the present study compared to previous studies could be related to the differences in the location and the planting and management conditions (Siebeneichler et al., 2023).

Pecan, similar to other edible nuts, is a kernel rich in fat, with the fat content reaching 78.07%, and compared to other types of nuts (Brazil nuts, pistachios, walnuts, cashews, and pine tree nuts), pecans have a high ratio of unsaturated to saturated fatty acids (Ribeiro et al., 2020a; Ryan et al., 2006). The main fatty acids present in pecan oil are oleic (C18:1), linoleic (C18:2), palmitic (C16:0), and stearic (C18:0). In addition, pecans contain small amounts of α-linolenic (C18:3), arachidonic (C20:0), elaidic (C20:1), palmitoleic (C16:1), margaric (C17:0), myristic (C14:0), and heptadecenoic (C17:1) acids. Together, the contents of oleic and linoleic fatty acids in pecans may reach up to 90% of the total lipid content, while the saturated fatty acid content is below 11% (Siebeneichler et al., 2023). Despite being rich in fat, pecans have a predominance of monounsaturated and polyunsaturated fatty acids, which are associated with reduced levels of LDL cholesterol and the consequent risk of coronary artery disease (Fernandez & Webb, 2008; Hu & Willett, 2002).

Tocopherols exist in four different isoforms, namely, α (alpha), β (beta), γ (gamma), and δ (delta) tocopherols. Antioxidant activity is the main mechanism of action of tocopherol when it blocks the proliferation of lipid peroxidation in membranes at the expense of a hydrogen (H) atom provided to the lipid peroxyl radicals (Ali et al., 2022). The tocopherol detected in higher quantities in the nuts of the Barton and Melhorada cultivars evaluated in the present study was γ-tocopherol (Table 5). In both cultivars, the γ -tocopherol content was approximately 10% higher with plant thinning. The tocopherol content in plants is influenced by genetic and environmental factors, particularly light, drought, and high temperature (Ali et al., 2022). Light is reported as a factor that increases the concentration of tocopherols. This is because, besides their antioxidant functions, tocopherols also function as a membrane component and split within the hydrophobic phase of the lipid bilayer of the membrane, reducing the fluidity of the membrane through the physical stabilization of the membrane structure (Spicher et al., 2017). Therefore, plant thinning leads to a higher tocopherol content.

Tocopherols are antioxidants considered important from the perspective of health and are, therefore, consumed widely by humans in the form of various oilseeds, such as pecan nuts (Thompson & Cooney, 2020). According to the reference values published by the United States Department of Agriculture (United States Department of Agriculture - USDA, 2018), pecan oil contains an average of 2.53 mg/100 g of α-tocopherol, 0.35 mg/100 g of β-tocopherol, 24.2 mg/100 g of γ-tocopherol, and 1.07 mg/100 g of δ-tocopherol. The tocopherol content determined in the present study was within the same ranges.

Table 5: The fatty acids profile (%) and tocopherol content (mg/100 g) of the pecans from the 2020/2021 Pecan harvest with and without tree thinning.

Cultivar	Thinning	Fatty acid (%)						
		Myristic Acid (C14:0)	Palmitic acid (C16:0)	Stearic acid (C18:0)	Arachidic acid (C20:0)	Oleic acid (C18:1)	Eicosenoic acid (C20:1)	Linoleic acid (C18:2)
Barton	With	0.08 ± 0.01	9.63 ± 0.21	4.15 ± 0.14	0.17 ± 0.02	45.3 ± 30.06	0.36 ± 0.06	37.83 ± 0.34
	Without	0.07 ± 0.01	9.62 ± 0.20	4.12 ± 0.13	0.17 ± 0.01	45.30 ± 0.12	0.34 ± 0.03	37.77 ± 0.34
Melhorada	With	0.09 ± 0.00	9.97 ± 0.12	5.09 ± 0.13	0.16 ± 0.02	42.33 ± 0.33	0.26 ± 0.01	39.32 ± 0.09
	Without	0.08 ± 0.01	9.93 ± 0.12	5.02 ± 0.15	0.19 ± 0.01	42.27 ± 0.35	0.27 ± 0.03	39.29 ± 0.07

Cultivar	Thinning	Fatty acids (%)				Tocopherol (mg/100 g)		
		Linolenic acid (C18:3)	Sum of saturated acids	Sum of monounsaturated acids	Sum of polyunsaturated acids	α-tocoferol	δ -tocoferol	γ -tocoferol
Barton	With	2.57 ± 0.06	14.03 ± 0.34	45.67 ± 0.11	40.40 ± 0.29	3.45 ± 0.07 ns	3.35 ± 0.01 ns	36.30 ± 0.36*
	Without	2.61 ± 0.08	13.98 ± 0.35	45.64 ± 0.09	40.38 ± 0.26	3.45 ± 0.07	3.30 ± 0.00	32.63 ± 0.51
Melhorada	With	2.94 ± 0.10	15.31 ± 0.23	42.59 ± 0.33	42.26 ± 0.00	3.05 ± 0.00*	3.50 ± 0.00*	37.99 ± 0.10*
	Without	2.95 ± 0.12	15.22 ± 0.27	42.53 ± 0.32	42.24 ± 0.05	3.44 ± 0.00	3.38 ± 0.01	32.20 ± 1.82

Values presented are mean ±standard deviation (n = 10). * Significant by t-test. ns = not significant by the t-test, comparing thinning in the same cultivar ($P < 0.05$).

Conclusions

Plant thinning improved various characteristics of pecans, such as increasing the size and mass of nuts and kernels, reducing the acidity and peroxide content of the kernels, and increasing the γ-tocopherol content. The other quality evaluations did not reveal any significant alterations after tree thinning. These findings corroborate that plant thinning is a viable management practice to be adopted in orchards for nut production as it leads to higher productivity and increased levels of bioactive nutrients such as tocopherols.

Author Contributions

Conceptual idea: Hoffmann, J. F; Martins, C.R.; Methodology design: Carvalho, I.R; Hoffmann, J. F; Data collection: Hellwig, C.G., Data analysis and interpretation: Foscarini, S.C.; Silva, T.O.D., and Writing and editing: Crizel, R.L.; Siebeneichler, T.J.; Ferreira, C.D.; Hoffmann, J. F.

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