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Review Paper

Pecan: from research to the Brazilian reality

ABSTRACT

Cultivation of pecan trees has increased in Brazil, mainly in the south, in recent years. Despite investments – triggered by the demand and promising market for pecans – made by both small and large farmers, actual productivity has still been below its potential. Lack of technical information not only about the culture of pecan trees but also about the development and adequacy of technologies, which are appropriate to the edafoclimatic conditions found in the south of Brazil, corroborate low productivity and poor investments in the sector, mainly preventing production from supplying the internal market. Some pioneering initiatives in the south of Brazil and positive experiences in neighboring countries, such as Argentina and Uruguay, have shown the potential to cultivate pecan in the region. This study aimed at introducing and analyzing the development of researches, general characteristics of the culture, the evolution of cultivation and dissemination of pecan trees in Brazil, mainly in the south of the country.

Keywords: Carya illinoinensis; Cultivar; Management; Pecan tree.

1. INTRODUCTION

Interest in cultivation and consumption of nuts, such as pecans, has increased considerably worldwide in recent years [1]. Scientific evidence of benefits of nuts, since they are healthy and nutritive food in the human diet, has increased consumption and, consequently, its demand [1,2,3,4]. Interest in cultivating pecan trees (*Carya illinoinensis*) and producing pecans, mainly in southern Brazil, has increased [5] due to favorable climatic conditions and as the result of increasing consumption and fruit appreciation [6,7]. Even though Brazil has been a reference in the cultivation of several fruit trees [8] and has got international recognition, the same does not happen regarding pecan production, which is below the amount needed for the country's consumption. The Brazilian market has been historically supplied by other countries; in the last 10 years, there was 40% increase in expenses with nut importation [9].

The pecan tree (*Carya illinoinensis* (Wangenh.) K. Koch (Jungladaceae) is an important fruit species which predominates in temperate regions in the northern hemisphere [5,10,11]. It is a high deciduous tree that fruits for a long time. It is native to the United States and Mexico but, when it got popular, it triggered cultivation in several countries in different continents, such as South America, where it spread to Uruguay, Argentina, Chile, Peru and Brazil [6,12,13,14,15]. The culture has expanded in China, South Africa, Australia, Argentina, Uruguay and Brazil lately [16].

In Brazil, it was introduced in São Paulo (SP) state in 1870 by North-American immigrants but it only started to be commercially explored around 1960-70, from Minas Gerais (MG) to Rio Grande do Sul (RS) states [17,18]. At that time, several orchards – which stretched over 17,000 ha [19] – were implemented, mainly in the south of Brazil. However, the project was affected by lack of support, information and research that could base cultivation [20,21,22]. The estimate is that there are about 10 thousand ha of pecan trees, mostly cultivated by small farmers and their families, whose properties

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range from 4 to 15 ha. Production in RS state stands out since it is the largest producer of pecans in Brazil in more than 5 thousand ha, followed by Paraná (PR) and Santa Catarina (SC) states [7].

Even though technologies used for cultivating pecan trees have been established for more than 100 years in Brazil [21], there is scarcity of scientific publications which take into account the country's edafoclimatic conditions [23]. It shows needs and obstacles related to pecan cultivation and production.

This review paper aimed at introducing information about the evolution of pecan culture in recent years. It highlights some studies that were carried out in Brazil and discusses some production bottlenecks, besides pointing out some challenges and opportunities regarding pecan production in the country.

2. NUTS: "DRY FRUITS"

Nuts, also known as dry fruits, have been defined as the portion of edible seeds, with low water content and considerable amount of oil, which are usually consumed dry [24]. Peanuts (*Arachis hypogaea* L.), almonds (*Prunus dulcis*), hazelnuts (*Corylus avellana*), Brazil nuts (*Bertholletia excelsa* H.B.K.), cashew nuts (*Anacardium occidentale* L.), macadamia nuts (*Macadamia integrifolia* Maiden & Betche), walnuts (*Juglans regia* L.), pine nuts (*Araucaria* spp.), pistachio (*Pistacia vera* L.) and pecans [*Carya illinoinensis* (Wangenh) K. Koch] are the most common nuts, according to the [25].

In Brazil, the main ones are cashew nuts, Brazil nuts, macadamia nuts and pecans [26], even though they have adapted to regions with different conditions. Regarding cashew and Brazil nuts, they have developed in the north and northeast, where the climate is tropical, while macadamia nuts and pecans are more common in the south and southeast, in regions whose climate is subtropical and temperate (usually mild temperatures).

Dry fruits have considerable contents of unsaturated fat, proteins, vitamins (A, B and C), minerals (calcium, phosphorus, iron, sodium and potassium) (Table 1).

Table 1. Nutritional properties of dry fruits (hazelnut, Brazil nut, macadamia nut, pecan, walnut and pistachio).

Components (%)	Hazelnut[1]	Brazil nut[2]	Macadamia nut[13]	Pecan[23]4	Walnut[1]	Pistachio[13]
Water	5.0 – 5.8	4.0	1.1 – 2.0	3.4 -6.0	3.0 – 5.0	5.3
Protein	12.6 – 15.0	15.0	7.9 – 9.3	9.2 -14.0	14.8	19.3
Lipid	61.0 – 62.4	63.0	76 – 78.6	59.0 – 72.0	64.0	52 – 53.7
Carbohydrate	16.7 – 17.0	29.0	7.5 – 13.8	15.0 – 18.0	16.0	19.0
Vitamins and minerals	%	%	MG	mg	%	Mg
Vitamin A	<1	-	-	130	0,6	230
Thiamine, B1	43	-	0.215	0.86	24	0.67
Riboflavin, B2	7	-	118	0.13	8.1	-
Niacine, B3	9	-	1.59	0.9	5.0	1.4
Vitamin C	10	-	-	2	4,4	-
Calcium	11	0.15	0.06*	73	12	131
Phosphorus	41	0.88	0.24*	289	48	500
Iron	26	0.0023	-	2.4	31	7.3
Sodium	0	0.001	-	Traces	-	-
Potassium	19	0.67	-	603	9.6	972

[1][27]; [2][28]; [3][29]; [4][30].

Fatty acids in pecans, mainly oleic and linoleic ones, have from 16 to 18 carbons. Besides, pecans contain tocopherol, which is a natural antioxidant [31,32], and phytochemicals (flavonoids, carotenoids and phytosterols). They also have cardioprotective, anticarcinogenic and anti-inflammatory activities. [33] points out that pecans have polyphenols, which exhibit antioxidant activity.

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According to [30], pecan consumption mitigates the incidence of certain diseases, such as Alzheimer's, Parkinson's and other degenerative ones.

Besides the fruit itself, pecan shell can also be used, since it has antioxidant activity [33,34] and considerable amount of fiber, i. e., 48.6% [32]. Gallic acid accounts for 78% of the phenolic composition [33].

[33] studied the effect of the aqueous extract of pecan shell on the mitigation of the effect of cyclophosphamide, in situations in which it is used as a chemotherapeutical substance that is toxic to some organs. [35] stated that the aqueous extract of pecan shell exerts an effect on the protection against signs of anxiety during abstinence of secondhand smoke in mice.

A recent meta-analysis of nut consumption provided more evidence of the fact that it may mitigate risks of stroke, cardiovascular diseases and cancer, besides mortality due to diabetes, respiratory and infectious diseases [1].

3. THE GENUS *CARYA*

The pecan tree [*Carya illinoinensis* (Wangenh) K. Koch] belongs to the family Juglandaceae, which has six genera and approximately 100 species [36].

Regarding the genus *Carya*, it has about 20 species, even though few of them yield edible nuts. The following species yield edible nuts: *C. cordimorfis* (Wang) Koch, *C. glabra* (Mill) Sweet and *C. laciniosa* (Wang) Sarg.. Their common names are bitternut, sweet pignut and kingnut, respectively [29].

[11] has reported that pecan trees originate from indigenous regions that lie along the Mississippi river in the United States of America. Their fruits are part of the diets of several animals, such as birds, foxes, squirrels, opossums, wild pigs and raccoons, besides humans who have eaten them for more than 10,000 years due to their nutritional value, which is the reason that enabled their geographic dispersion [37]. According to [12], *C. illinoinensis* is native to the United States of America and stretches over a broad region from the south of Texas to the north of Iowa. The author also mentions that, because it is a vast region, there is also much disparity among ripening levels of nuts in the country's different regions.

There are more than a thousand varieties that have different fruit shapes, nut quality, tree architecture and reproductive features [38]. This fact is due to the high gene segregation index, as the result of sexual reproduction by seeds, which is the main propagation method [39].

The arrival of pecan trees in Brazil is related to the American Civil War. After the war that reduced the American population, some families decided to leave the United States. Dom Pedro II, the Brazilian emperor, searched for men who were specialized in cotton cultivation and offered inexpensive land and tax exemption. As a result, Americans came to Brazil, lived in Santa Bárbara d'Oeste and Americana, two cities located in São Paulo state, and developed the cotton culture, besides introducing other cultures, such as watermelon, peach and pecan [16].

4. CHARACTERISTICS OF THE PECAN TREE FRUIT

Fruits of pecan trees have been characterized as drupes which grow in bunches that may hold from three to eight nuts. Fruits are dark brown with black spots [40]. Shells (the epicarp) are elliptic; their outermost layer is convex whereas their inner one is concave. Their shapes vary from globelike to ovoid and the epicarp usually consists of four sections [41].

According to [42], self-pollination occurs when there is increase in endogamy; it results in production of small fruits, low yield of almonds and increase in the thickness of the nut shell. Pecan tree cultivation has increased in Brazil in recent years, mainly in Rio Grande do Sul. Despite investments – triggered by the demand and promising market for pecans – made by both small and large producers, actual productivity has still been below its potential. Annual yield is estimated to be between 600 and 1000 $kg.ha^{-1}$, whereas other countries outyield this production, e. g., Chile: from 1500 to 3000 ($kg.ha^{-1}$); Australia, from 2000 to 2500 ($kg.ha^{-1}$); USA, from 1500 to 3000 ($kg.ha^{-1}$); Mexico, from 700 to 1500 ($kg.ha^{-1}$); and Argentina, 2000 ($kg.ha^{-1}$) [22,43,44,45,46]. In many countries, a semi-extractivist system, with no adequate plant management, yields nuts of poor quality and creates problems regarding culture alternation. Even though some factors may lead to low productivity, quality and yield, lack of technical information about the pecan tree culture, such as the need to implement grafted seedlings and different and complementary varieties in pollination, ends up contributing to this situation.

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5. CULTIVARS

The following 41 cultivars can be found in the national index of registered cultivars (RNC, in Portuguese) [47]: Barton, Brooks, Caddo, Cape Fear, Cherokee, Chetopa, Chickasaw, Choctaw, Clark, Curtis, Davis, Desirable, Elliott, Farley, Forkert, Giles, Gloria Grande, Gormely, Jackson, Jenkins, Jubilee, Kiowa, Mahan, Major, Moneymaker, Moore, Oconee, Owens, Patricks, Pawnee, Peruque, Pitol 1, Pitol 2, Posey, Prilop of Lavaca, Shawnee, Shoshoni, Sioux, Stuart, Summer and Woodroof. Only two out of 41 cultivars were selected in Brazil: Pitol 1 and 2.

Besides these cultivars, both Imperial and Success have been cultivated, even though they are not registered in the RNC. Some authors disagree regarding the most common cultivars used in Brazil. [48] highlights American cultivars Barton, Caddo, Cape Fear, Choctaw, Moneymaker and Shawnee. [26] designates cultivars as producers (Barton, Desirable and Melhorada) and pollinators (Choctaw, Imperial, Importada, Shawnee and Stuart). [49] states that Barton, Choctaw, Shawnee and Stuart are important cultivars in Brazil. [50] report that Burkett, Frotscher and Moneymaker are the most common ones in Paraná state. There is consensus regarding the fact that a set of cultivars, which is adequate to the technological level, has neither been defined, mainly regarding adaptation and tolerance to climatic and biological adversities, nor had its productive and qualitative potential studied in the region. Thus, good production levels cannot be reached in a sustainable production system. Besides, some factors, such as cultivation in excessively humid places, problems with plagues and diseases and inadequate use of practices and culture management, individually or collectively, show the technological level that reflects decrease in production and quality of harvested fruit.

Pecan trees undergo a morphological phenomenon called dichogamy, in which staminate and pistillate flowers are feasible in different periods, so as to avoid self-pollination. There are protandrous cultivars (Group I), whose staminate inflorescences release pollen before pistillate ones get receptive. In protogynous cultivars (Group II), pistillate inflorescences get receptive before catkins (staminate inflorescence) release pollen. Since this phenomenon is common in the species, pollinating cultivars must be implemented in the orchard so as to offer pollen to the pollination of the cultivar called “producer” [51].

Fundamental criteria for the choice of cultivars to be implemented are their resistance to scab and preferably precocious production. Above all, it is essential to know the characteristics, such as size, nut yield and quality, of the cultivar fruits [26].

Some authors have already characterized the fruits of some cultivars implemented in Brazil, as shown in Table 2. [49] recommended the cultivar Stuart in case direct sales of fruits are linked to yield, since it needs fewer number of pecans than others to yield a kilogram. However, in process industries, both cultivars Barton and Shawnee are recommended mainly because their fruits have lower amount of shell than others. [52] evaluated sample dimensions of pecan mass and diameter. The cultivars that had the highest fruit mass (FM), Nut mass (NM) and shell mass (SM) were Barton, Importada and Melhorada.

Table 2. Fruit Mass (FM); Hazelnut Mass (HM); Shell Mass (SM); Yield (Y) and the number of nuts per kilogram

CULTIVARS	FM	HM	SM	Y	NUTS/KG
Barton[1]	7,52 – 11,72	4,08 – 4,71	3,43 – 4,71	54,19	132,97
Choctaw[1]	9,87	5,21	4,66	52,65	101,52
Imperial[2]	10,02	5,46	4,56	54,49	100,45
Importada[2]	7,37	4,09	3,28	55,50	137,53
Mahan[2]	7,93	4,54	3,39	57,12	128,61
Melhorada[2]	9,45	5,22	4,23	55,24	107,05
Moneymaker[2]	7,41	3,51	3,89	47,36	137,41
Shawnee[1]	8,28	4,7	3,57	56,69	122,15
Stuart[1]	10,72	5,38	5,33	49,84	93,31

[1][49] [2][52].

6. PHENOLOGICAL ISSUES

Since pecan trees are native to North America, mainly to the United States and Mexico, their phenology is well characterized. Because Brazilian conditions differ from the ones of their origin, relevant studies are needed. However, they are still scarce in Brazil. Knowledge about phenological

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behavior and floral compatibility among cultivars is an essential factor in pollination and good fruiting [53].

However, [16] carried out a comparison between the weather in the south of Brazil and in the south of Georgia (GA), USA, and showed that it is similar, thus, enabling information on this state to be used in Brazil.

Tolerance to temperatures of pecan trees varies greatly, since, in winter, they demand temperatures below 7°C, whereas in the dormant period they need from 50 to 600 chill hours, at temperatures below 7.2°C [20,44,54,55].

Since few chill hours lead to irregular budding, droopy leaves, few ramifications and disuniform flowering, pecan trees may have low yield.

Pecan tree budding is developed during ecodormancy and is related to alpha-amylase activity [56]. Productive potential of nuts is determined when dormancy ends and entirely connected to growth conditions in the season of the previous year. Nut production is related to the end of dormancy, which is determined by the climate factors of the growth season of the previous year, mainly, the female flowering stage, since it depends on substrates accumulated in the crop of the previous year [57].

Besides, the colder the winter, the less heat is needed for budding in spring [11]. According to [58], the phenological cycle takes place due to the vegetative and reproductive growth and ends in senescence.

Pecan trees are monoicous plants whose staminate and pistillate inflorescences are separated, but both are found in a plant. According to [59], the catkin-like staminate inflorescence bears two or three catkins. They have from 72 to 123 individual flowers [22]. According to [19], the period of pollen dispersal may range from 8 to 15 days, depending on the cultivar. Pistillate inflorescences show little evidence, since they are distributed on lateral terminal branches, and have from two to ten flowers, whose variable colors depend on the cultivar [41].

In the fruiting period, the ideal temperature (monthly average) is between 24ºC and 30ºC. In summer, mainly in the period of pecan filling, high maximum temperatures lead to decrease in fruit size and affect oil accumulation. In addition, they promote premature fruit drop [20].

Most cultivars have a long fruit ripening period, i. e., between 180 and 210 days, from fecundation to harvest [11,20]. Pecan ripening takes place from March to May, even though there are some differences among harvest periods in distinct regions in Rio Grande do Sul. For instance, harvest in the region where Santa Maria (latitude 29°S) is located occurs about 15 days before the one in the region around Pelotas (latitude 31° S).

7. EDAFOCLIMATIC ZONING OF PECAN TREES

[26] carried out a study of pecan tree zoning in Rio Grande do Sul state and classified them into two classes of risk: low and very low. The latter was then divided into low-A and low-B. In Rio Grande do Sul, 41.8% of the territory has very low risk whereas 51.6% has low-A risk, whose characteristic is the possibility of draught and excess of air relative humidity. Low-B risk accounts for 6.6% of the state and means lack of chill hours. The author highlights that cultures may be grown at both risks (low-A and low-B), even though pecan yield may be affected. Besides, studies of cultivars that endure adverse conditions are needed so as to better adapt them to certain regions.

In addition to this investigation, studies of the edafoclimatic zoning of the culture must be carried out not only in order to guide public policies and financial, extension and technical assistance institutions, but also to conduct land-use planning in areas that can be sustainably explored. Since edafoclimatic zoning takes into account phenological, climatic and soil characteristics simultaneously, it mitigates risks because of the regionalized scale. Definition of edafoclimatic zoning of pecan trees in southern Brazil is premised on the sustainable management of the culture because it guides land-use planning [40] and provides information – about areas where sustainable cultivation can be better developed – to financial institutions, public policies, technical assistance and the whole society. So far, pecan trees have been planted with no orientation, a fact that has often led to economic and/or environmental losses because cultivation occurs in inappropriate areas and affects natural ecosystems.

8. PROPAGATION

Pecan tree seedlings are obtained by a vegetative propagation process, i. e., grafting [60]. In the USA, production of pecan tree seedlings by grafting started in 1822 due to increase in producers' demands [16]. Rootstocks are yielded by sexual propagation, i. e., by pecan germination [60]. Seeds that are selected to yield rootstocks must be collected from healthy and vigorous plants [61]. These

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researchers reported that pecan seeds exhibit dormancy, thus, they must go through a process to end it.

[62] evaluated the activity of scarification and stratification in seeds of the cultivar Barton at different storage periods up to sowing. Results showed that the highest emergence took place when both techniques were used and the material was stored for 90 days.

According to [40], the highest impact on the cost of a pecan tree orchard is the seedling. Therefore, careful selection of seedlings, which should be as uniform as possible, increases the chances of germination after they have been planted. In Brazil, nurseries yield covered-root seedlings (or wrapped-root seedlings) and bare-root seedlings. The former means that seeds are planted in plastic containers, at a depth of 2 cm, whereas the latter means that seeds are directly planted on beds, in open fields. After grafting, they are removed and sold with bare roots.

9. CULTIVATION SYSTEM

[44] reported that areas with potential to yield pecan trees are mainly located at latitudes south and north, between 25º and 35°. It encompasses the south and part of the southeast in Brazil.

The soil has to have good drainage and pH between 6 and 6.5. Above all, pecan trees require soils with effective depth and neither physical nor chemical constraints which favor radicular growth and development. Soils with high pH should be avoided since it hampers the availability of zinc, an important element for pecan trees [20].

Nitrogen is a macronutrient required by pecan trees. The Manure and Liming Manual of Rio Grande do Sul and Santa Catarina [63], which issues guidelines in southern Brazil, recommends at least three applications of this nutrient along the cycle.

Pecan trees also require much zinc [64]. In the USA, zinc is applied every 15 days to supply their needs [44]. In Brazil, some pecan tree farmers have carried out leaf application of zinc. Even though this practice is still poorly known, it has been used with no real knowledge of its need in Brazil.

Concerning spacing, it is recommended that pecan trees should be spaced 7 x 7m, even 15 x 15m, apart [49,65,66,67]. Spacing varies, depending on the cultivars, i. e., at least 10 m is recommended between the ones that yield late (between 8 and 10 years) while less space is needed between the ones that produce earlier, since they need pruning to decrease shading. However, there are reports of dense orchards, whose trees are spaced 3 x 3m apart [68]. In this case, harvest is not feasible, mainly because pecan trees need a period to start producing. Besides, these orchards may not have had any technical assistance. Implementation can be carried out by positioning plants in square, rectangular, triangular and quincunx systems [20].

Precipitation required by the culture ranges between 760 and 2,010 mm. However, 200 plants per hectare are planted in orchards where precipitation is above 1,200 mm, whereas from 50 to 100 trees per hectare occupy areas where precipitation varies from 700 to 1,000 mm [11,26]. Precipitation is related to pecan quality, i. e., poor precipitation leads to disuniform filling of the nut and may even result in fruit abortion [69].

The ideal period to plant an orchard ranges from June to mid-August [67]. At least 4 cultivars are recommended to start a pecan tree orchard: one is the “producer” while the other three are pollinators [42]. [20] reports that an orchard has to comprise from 3 to 5 cultivars and that pollinators should represent 15% of the plants.

Depending on the climatic conditions of the area where the orchard is located, its density should be analyzed and an irrigation system may be needed, taking into account that drought may occur. In addition, in order to mitigate water loss from the soil, implementing forage crops is feasible to cover the soil in the orchard [26]. [70] studied the amount needed to irrigate regions located in Rio Grande do Sul state, from October to January, and concluded that it ranges from 13 to 262 mm.

Pruning is needed for commercial cultures of pecan trees. [71] reported that the following types of pruning can be carried out: shaping, production/fruiting, green, cleaning, thinning and renewal.

Pecan trees are characterized by alternation between large and small pecan production [26], whose variation depends on the cultivar, but management is important to mitigate this effect.

10. PECAN TREES IN CONSORTIA

Pecan trees are important species in an agroforestry system since they enable fruit and wood production, besides consortia with other cultures [40]. Benefits of the systems, mainly agroforestry ones, are the interaction and the synergism among biological components, which favor the subsistence of the system [72]. In Morro Redondo, RS, there is an agroforest which includes pecan

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trees. This species was chosen due to its rusticity and because spacing enables the use of other species between trees in the rows. It has been reported that small farmers in southwestern Paraná have used pecan trees in an agrosilvipastoral system.

In addition, according to the [65], initial low productivity of pecan trees in Brazilian conditions makes it essential to integrate them with other cultures so as to get some income. Another important factor is the time pecan trees need to start production, i. e., usually after the 5th year. Even so, production is very low and a complementary culture is needed.

There are reports of pecan tree orchards in consortia with corn, manioc, beans, soybeans, besides cattle and sheep [26]. A consortium with erva-mate (*Ilex paraguariensis*) is also feasible because the herb develops in a shaded area and may have its flavor and quality improved [26].

[73] carried out a study of floristic composition in a pecan tree orchard in Botucatu, SP. Since pecan trees are deciduous, i. e., they shed all leaves in dormancy, sunlight penetration is favored and influences *Brachiaria decumbens* and *Panicum maximum* growth to form pasture. However, pecan trees must be observed in fruitpastoral systems because animals cannot be left in the area in the implementation phase, unless pecan tree seedlings are protected.

11. DISEASES AND PLAGUES

Some diseases of pecan trees in Brazil were described by [21]. They pointed out pecan scab, caused by the fungus *Venturia effusa* (synonyms: *Fusicladium effusum* G. Winter; *Cladosporium caryegenum; C. effusum; Fusicladium caryegenum*). This disease attacks young tissues, such as leaves, petioles, epicarp and catkins. The authors also stated that there was no scab in Brazil before the introduction of the cultivar Wichita, which contaminated the cultivar Mahan and led to decline in the pecan culture. Since the fungus can be harmful when it enters the orchard, it affects pecan yield. This is the main disease in Rio Grande do Sul state [36].

The ideal temperature for scab development in spring is between 20 and 25°C. In addition, high humidity along with excessive precipitation favors scab [57,74]. Humidity above 80% for more than two days in a row favors scab development [26].

[18] and [20] recommended that the Bordeaux mixture should be applied to pecan trees in dormancy. According to [74], another important factor is that scab control is more efficient when the whole vegetative canopy is exposed to sunlight.

Anthracnosis, caused by *Glomerela cingulata*, the sexual phase of *Colletrotrichum gloesporioides*, occurs as depressed, round and dark lesions on fruits and results in decrease in nut size and fruit abscission which ends up detaching the epicarp from the nut shell [18].

In Rio Grande do Sul, [48] found *Fusarium* spp. in pecan tree flowers (female and male ones), roots and seeds. Their symptoms were wilt, trunk girdling, low growth and superbudding. Besides this fungus, *Pestalotiopsis* spp. was also found. It develops on leaves and causes leaf stains whose initial characteristic is spots that coalesce and seem to have been burned. When lesions evolve, they may cause partial loss of pecan tree leaves, leading to decrease in the photosynthetically active area and low yield. [75] carried out laboratory experiments in which they investigated 15 isolates of *Trichoderma* as the result of two isolates of *Pestalotiopsis clavispora*. Results showed that the 15 isolates had an antagonistic effect due to the pathogenic fungus. Besides, they collected *Trichoderma* on pecan tree leaves and found antagonistic efficiency to both isolates. Taking into account that there are no registered agrochemicals to control diseases and plagues in Brazil, these results show that the biological control can be used.

[6] were the pioneer researchers that found canker caused by the fungus *Lasiodiplodia subglobosa*, which damages pecan tree trunks. The disease, which was found in Santa Maria, RS, is capable of causing 100% plant loss when the tree has the symptom, i. e., tree bark cracking. [18] carried out a study of pecan tree staminate and pistillate flowers and seeds. In pistillate flowers, they found high incidence of *Alternaria* sp. and *Fusarium* sp., besides *Aspergilus* sp., *Cladosporium* sp., *Curvularia* sp. and *Penicillium* sp.. Staminate flowers had high incidence of *Fusarium* sp.. Pecan tree seeds carried *Cephalosporium* sp., *Colletotrichum* sp., *Fusarium* sp., *Penicillium* sp. and *Verticillium* sp..

Certain diseases occur at the end of the crop and attack mostly fruits. *Aspergillus* sp. and *Penicillium* sp. cause mold and produce aflatoxin [50]. In their experimental evaluation, the authors found the fungi that cause scab and anthracnosis, besides *Rhizopus* sp. and bacteria, in treatments with and without asepsis. *Alternaria* sp. is another fungus that may harm seedlings by propagating through rootstock seeds [18].

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Sooty mold (*Capnodium* sp.) is a disease connected to the blackmargined aphid (*Monellia caryella*) which attacks leaves, fruits and branches. It excretes a yellowish substance, where the fungus develops, and causes physical blockage of photosynthesis [18,75].

In Brazil, 18 pest species were recorded for walnut, highlighting the parasites that cause damage to leaves such as the *Monellia caryella* aphid and the phylloxera species *Phylloxera devastatrix* and *Phylloxera notabilis*. Besides these, leaf-cutting ants (*Atta* sp. e *Acromyrmex* sp.) are among the main leaf stripper pests Recently, damage was reported on fruits caused by phytophagous insects *Leptoglossus stigma*, *Leptoglossus zonatus* and *Loxa deducta* [76].

It is clear that sustainable cultivation of pecan trees is based on the improvement of agricultural practices and on the implementation of new cultivation methods, mainly related to soil and plant management that aim at decreasing losses caused by plagues and diseases. Incidence of diseases in orchards has become a factor that limits production as results of studies have shown the dimension of the problem. Even though there are no official data, production losses due to disease attacks to cultures in the region are estimated to be about 50% [75]. Pecan trees must definitely be considered a culture with insufficient phytosanitary support (minor crops) because it does not have a defined group. The *Instrução Normativa Conjunta* (Joint Normative Instruction) no. 01, issued on June 16th, 2014, whose definition of culture grouping is similar to the one of Codex Alimentarius, also takes into account morphological aspects of cultivars produced in Brazil, their taxonomic proximity, similarity of agricultural practices and forms of consumption. Therefore, pecan trees have not been listed as cultures with insufficient phytosanitary support yet. They do not have any registration of agrochemicals, either. It is an enormous technical fragility that must be solved soon.

12. POST-HARVEST

The amount of nut in the pecan is an important feature, i. e., the larger, the better. Besides increasing yield and profit, it also has enough reserve for seedling production. In addition, traders and farmers prefer pecans with thin shells, since this fact makes processing and *in natura* consumption easier.

Regarding long storage periods, it is essential that fruits neither lie on the soil nor are exposed to climatic adversities. If pecans lie on the soil, they may lose their color and be infested by fungi [67].

When pecans are picked, their humidity rates range from 20 to 30%. Thus, they must undergo a drying process to reduce humidity to about 4% and preserve the nut [77].

Processing usually uses the initial washing process in cold water and then the one in warm water, Finally, pecans are ready for shelling [40].

Pecan storage at low humidity enables its commercialization in the off-season period, a fact that leads to better prices. [31] carried out a physicochemical and sensory analysis of pecans, whose shelf life was 120 days, stored in polypropylene containers and in vacuum nylon-polyethylene films. The sensory analysis showed that pecan oil storage for 60 days causes no sensory alterations.

13. COMMERCIALIZATION

Nowadays, Rio Grande do Sul cultivates pecans in areas that range from 1 to 300 ha. [48] reports yields of 30 kg per tree. In Argentina, [54] calculated yields in agreement with the ages of pecan trees (12 x 12m spacing; density of 70 trees/ha), as shown in Table 3. [49] estimated yields of pecan trees which were 5, 7 and 10 years old and found low values for 5 and 10-year-old plants. The highest discrepancy was found in 10-year-old plants, i. e., this author found 11.7 kg per plant, about half the value reported in Argentina. In 2015, Emater-RS carried out a study in Anta Gorda, RS, where 1 kg was yielded per plant in the 5th year and the double was picked in the following year [78]. In the 10th year, yield was 18 kg per plant. It is below the value reported in Argentina but close to the minimum value that was established.

Table 3. Year of pecan tree and yield per area and plant in Argentina

Year of tree	Yield (kg/ha)	Yield per plant (kg)
5th to 6th	70 to 140	1 to 2
10th	900 to 1,000	20 to 24
20th to 25th	2.000 to 2,500	35 to 40

[1]By [54].

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Productivity of this standard is related to adult plants. However, the production cycle of pecan trees may live 100 years [22], a fact that compensates the initial investment. Besides, there are reports of trees that lived 200 years [30,49].

Farmers have invested in the pecan tree culture lately, mainly because of the valuation of prices paid for pecans. According to [75], it is one of the most profitable cultures per area in Rio Grande do Sul state. However, current prices range from R$10.00 to R$12.00/kg with shells. In the off-season period, prices tend to rise.

In Brazil, besides pecan (nut) commercialization, processing of the whole nut, pieces, fine and coarse flour is carried out. Pecan oil is also extracted.

An alternative income source is the pecan shell which is consumed as tea and can also be used as substrate. [79] studied this residue and found physical and chemical properties of the pure substrate and mixed with peat. Besides, the authors reported that a company had generated 150,000 kg/year of pecan shell in 2007. It costs R$ 0.50/kg and represents another option of income.

[40] conducted a study of the economic feasibility of pecan trees in western SC, in legal reserve and permanent preservation areas. He succeeded in exploring the culture in these areas and introduced them as alternative income sources. In a legal reserve area, an orchard with 204 plants has had positive financial results in its 7th year. However, the author estimates that plants should yield in the 3rd year (production is low at this age, i. e., about 200 g/planta). In a permanent preservation area, 40 plants were implemented and had positive results in the 8th year. Economic indicators were feasible in both areas.

Another issue that may provide profit is the possibility of selling the wood, even though this market has not been developed in Brazil yet. [80] reported good bend radius, i. e., it is a species that may be used for building furniture. Wood may result from the thinning process and from old orchards, mainly from trees which were non-grafted seedlings.

Finally, pecan trees may also be used as ornamental species and in derivative industries, such as dye extraction in tanning. [54].

14. CHALLENGES AND PERSPECTIVES OF PECAN TREES (CONCLUSION)

The pecan tree culture has been expanding in South Africa, Australia, Argentina, Uruguay and Brazil. In Brazil, a significant percentage of older orchards is based on trees which originate from seeds, but new areas have been prepared with selected varieties.

The development of new orchards along with the existing ones has placed Brazil as a potential supplier of this product worldwide, since, in the future, there may be a larger gap between supply and demand. Therefore, Brazil may be considered a supplier of pecans in the short and in the medium terms. There is also enormous and potential internal consumption in Brazil.

So far, it may be observed that productivity (high yields and high quality) of orchards in general has been below their potential. Even though causes that generate this difference between the current situation and the potential vary much, the most important factor which shows significant deficit is lack of reliable technical information, i. e., scientific knowledge, mainly concerning solutions for phytosanitary problems that affect productivity and product quality.

Therefore, solving obstacles related to production and improving orchard productivity may lead to great opportunities to supply the Brazilian market and increase participation in external markets.

Therefore, the following crucial issues are challenges and opportunities that research institutions should face:

1 – Systematization of nutritional, regional phytosanitary and variety factors that limit productive potentiality and culture expansion;

2 – Acknowledgement of the pecan tree culture as one with insufficient phytosanitary support and its appropriate grouping. It does not have any registration of agrochemicals, an enormous technical fragility that must be immediately solved;

3 – Determination of the edafoclimatic zoning for pecan trees so as to consolidate and expand the culture in southern Brazil;

4 – Identification of ecological cultural practices of soil and water management to provide better plant development along with rational use of natural resources;

5 – Identification of phytosanitary problems and ecologically adequate strategies to live with and manage insect-plagues and pathogens in pecan tree cultures, in compliance with principles of ecological intensification;

6 – Development of input (fertilizers and phytoprotectors) to be used in production systems.

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REFERENCES

1. AUNE, D.; KEUM, N.; GIOVANNUCCI, E.; FADNES, L. T.; BOFFETTA, P.; GREENWOOD, D. C.; TONSTAD, S.; VATTEN, L. J.; RIBOLI, E.; NORAT, T. Nut consumption and risk of cardiovascular disease, total cancer, all-cause and cause-specific mortality: a systematic review and dose-response meta-analysis of prospective studies. BMC Medicine, 2016; 14(207): 1-14. DOI: 10.1186/s12916-016-0730-3. DOI: 10.1186/s12916-016-0730-3

2. PRADO, A. C. P. DO; SILVA, H. S.; SILVEIRA, S. M.; BARRETO, P. L. M.; VIEIRA, C. R. W.; MARASCHIN, M.; et al. Effect of the extraction processo n the phenolic compounds profile and the antioxidant and antimicrobial activity of extracts of pecan nut [*Carya illinoinensis* (Wangenh) C. Koch] shell. Industrial Crops and Products, 2014; 52(1): 552-561.

3. EAGAPPAN, K.; SASIKUMAR, S. Therapeutic effects of nuts in various diseases. International Journal of Recent Scientific Research. 2014; 5(1): 190-197.

4. MOKOCHINSKI, F. M.; WATZLAWICK, L. F.; BOTELHO, R. V.; MOREIRA, V. Randomized branch sampling to estimate fruit production in Pecan trees cv. 'Barton'. Ciência Rural, 2017; 47(4): 1-6. DOI: 10.1590/0103-8478cr20151591

5. WALKER, C.; MUNIZ, M. F. B.; MARTINS, R. R. O.; MEZZOMO, R.; ROLIM, J. M.; BLUME, E. First report of species in the *Cladosporium cladosporioides* complex causing pecan leaf spot in Brazil. Journal of Plant Pathology, 2016; 98(2): 369-377. DOI: 10.4454/JPP.V98I2012

6. POLETTO, T. GONZATTO MACIEL, C.; MUNIZ, M.; BLUME, E.; POLETTO, I. First Report of Stem Canker Caused by *Lasiodiplodia subglobosa* on *Carya illinoinensis* in Brazil. Plant Disease, 2016, 100(5): 1016. DOI: 10.1094/PDIS-08-15-0948-PDN

7. MARTINS, C. R .; FRONZA, D .; MALGARIM, M. B .; BILHARVA, M. G .; DE MARCO, R .; HAMANN, J.J. Cultura da noz-pecã para um agricultura familiar. Em: WOLFF, L. F .; MEDEIROS, C. A. B. (Ed.). Alternativas para a diversificação da agricultura familiar de base ecológica. Pelotas: Embrapa Clima Temperado, 2017. 145p. (Embrapa Clima Temperado, Documentos, 443). p.65-81.

8. FACHINELLO, J.C .; PASA, M .; BETEMPS, D. Situação e perspectivas da fruticultura de clima temperado no Brasil. Revista Brasileira de Fruticultura, 2011; 33 (1): 109-120. DOI: 10.1590 / S0100-29452011000500014

9. SECEX. Secretaria de Comércio Exterior, Ministério do Desenvolvimento Indústria e Comércio Exterior. Sistema de análise das informações de comércio exterior (ALICEweb). Acesso em 12 de setembro de 2017. Disponível: <http://aliceweb.mdic.gov.br/.

10. BRISON, F. R. Pecan culture. Capital Printing, Austin, Texas 300p. 1974.

11. SPARKS, D. A. Adaptability of Pecan as a Species. HortScience, Georgia, 2005; 40(5): 1175-1189.

12. SPARKS, D. A. Geographical origin of pecan cultivars influences time required for fruit development and nut size. Journal of the American Society for Horticultural Science, Georgia, 1991; 116(4): 627-631.

13. WELLS, M. L. Response of pecan orchar soil chemical and biological quality indicators to poultey litter application and clover cover crops. Hortscience, 2011; 46(2): 306-310, 2011.

14. THOMPSON, T. E. & CONNER, P. J. Chapter 20: Pecan. Lincoln, Nebraska: United States Department of Agriculture, 2012. p.771-800. Acessed 20.nov.2017. Available at: http://digitalcommons.unl.edu/usdaarsfacpub/1322.

UNDER PEER REVIEW

15. CASTILLO I. O .; SANGERMAN-JARQUÍN, D .; HERNÁNDEZ-VÁZQUEZ, M .; ROBLES, M. Á .. Produção e Comercialização de NUEZ pecanera (Carya illinoensis Koch) em El norte de Coahuila, México. Revista Mexicana de Ciências Agrícolas, 2013; 4 (3): 461-476.

16. WELLS, L. Pecan America's Native NUT TREE. The University of Alabama Press. 2017. 264p.

17. NAKASU, B. H .; RASEIRA, A. Tratamento fitossanitário para Nogueira-pecã. Embrapa Comunicado técnico, n. 13 de 1981.

18. POLETTO, T .; MUNIZ, M.F. B .; BAGGIOTTO, C; CECONI, D. E .; POLETTO, I. Fungos associados às flores e sementes da nogueira-pecã (Carya illinoinensis). Revista de Ciências Ambientais, 2014; 8 (1): 5-13.

19. BARACUHY, J. B. da C. Determinação do período de floração e viabilidade de pólen de diferentes cultivares de nogueira peca Carya illinoensis (Wang) K. Koch. 1980. 52f. Dissertação (Mestrado em Agronomia) - Curso de Pós-Graduação em Agronomia, Universidade Federal de Pelotas, Pelotas, 1980.

20. RASEIRA, A. A cultura da Nogueira-pecã. Comunicado Técnico. Pelotas: EMBRAPA, nº 63, p. 3, 1990.

21. ORTIZ, E.RN; CAMARGO, L. E A. Doenças da Nogueira Pecan. Em: KIMATI, H .; AMORIM, L .; BERGAMIN FILHO, A .; CAMARGO, L. E. A .; REZENDE, J. A. M. (Eds.). Manual de Fitopatologia: doenças das plantas cultivadas, 4. Ed. São Paulo: Agronômica Ceres, 2005. p.501-505.

22. FRONZA, D. HAMANN, J. Técnicas para o cultivo da nogueira-pecã. Universidade Federal de Santa Maria, Colégio Politécnico da UFSM. 424p. 2016.

23. BOSCARDIN, J .; COSTA, E. C; PEDRON, L; MACHADO, D. DO N; SILVA, J. M. DA. Primer registro de chinches (Hemiptera: Coreidae e Pentatomidae) atacando frutos de nogal pecanero no Brasil. Revista Colombiana de Entomologia, 2016; 42 (1): 12-15.

24. SABATÉ J., ROS E., SALAS-SALVADO J. Nuts: nutrition and health outcomes. Preface. British Journal of Nutr. 2006; 99(2): 447-448.

25. INC. Nuts and Dried Fruits Global Statistical Review 2015/2016, International Nut and Dried Fruit Council Foundation. Acessed 15.jul.2017. Available <https://www.nutfruit.org/>.

26. ROVANI, F. F. M. ZONEAMENTO DE RISCO CLIMÁTICO DO CULTIVO DA NOGUEIRA PECÁ (Carya illinoinensis) PARA O RIO GRANDE DO SUL, 2016. 232 p. Tese (Programa Doutoral em Geografia) - Centro de Ciências Naturais e Exatas, Universidade Federal de Santa Maria, Santa Maria, 2016.

27. RIEGER, M. Introduction to Fruit Crops. New York: food products press, 2006.

28. KINUPP, V. F. PLANTAS ALIMENTÍCIAS NÃO-CONVECIONAIS DA REGIÃO METROPOLITANA DE PORTO ALEGRE, RS, 2007. 562 f. Tese (Programa de Doutorado em Fitotecnologia) - Programa de Pós-graduação em Fitotecnologia, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2007.

29. REYES, M. M .; ARTURO, L. A. Frutales de Nuez, 5 alternativas não tradicionais para o interior do interior do Maule. Instituto de Investigações Agropecuárias, Cauquenes, Chile, 2014. 138 p. (Boletin INIA n ° 301).

30. ORO, T. Composição nutricional, compostos bioativos e vida de prateleira de óleo e óleo prensado a frio de noz-pecã [Carya illinoinensis (Wangenh). C. Koch], 2007. 105f. Dissertação (Mestrado em Ciências dos Alimentos) - Centro de Ciências Agrárias, Universidade Federal de Santa Catarina, Florianópolis, 2007.

UNDER PEER REVIEW

31. ORO, T; OGLIARI, P. J .; AMBONI, R.D. de M. C .; BARRERA-ARELLANO, D .; BLOCK, J. M. Evaluación de la calidad durante o almacenamiento de nueces Pecán [Carya illinoinensis (Wangenh.) C. Koch] acondicionadas em diferentes envases. Grasa y Aceites, 2008; 59 (2): 132-138.

32. PRADO, A. C. P. do; SILVA, H. S .; SILVEIRA, S. M .; BARRETO, P. L. M .; VIEIRA, C. R. W .; MARASCHIN, M .; FERREIRA, S. R. S .; BLOCK, J. M. Efeito do processo de extração no perfil de compostos fenólicos e na atividade antioxidante e antimicrobiana de extratos de nozes pecan [Carya illinoinensis (Wangenh) C. Koch]. Culturas e Produtos Industriais, 2009; 52 (1): 552-561.

33. BENVEGNÚ, D. M.; BARCELOS, R. C. S.; BOUFLEUR, N.; RECKZIEGEL, P.; PASE, C. S.; MULLER, L. G.; et al. Protective Effects of a By-Product of the Pecan Nut Industry (*Carya illinoensis*) on the Toxicity Induced by Cyclophosphamide in Rats *Carya illinoensis* Protects Against Cyclophosphamide- Induced Toxicity. Journal of Environmental Pathology, Toxicology and Oncology, 2010; 29(3): 185-197. DOI: 10.1615/J Environ Pathol Toxicol Oncol.v29.i3.30

34. KURECK, I. Obtenção e caracterização de micropartículas de zeína carregadas com extratos antioxidantes de casca de noz-pecã [Carya illinoinensis (wangenh.) C. Koch]. 2014. 102 p. Dissertação (Mestrado em Ciências dos Alimentos) - Programa de Pós-graduação em Ciências dos Alimentos - Centro de Ciências Agrárias, Universidade Federal de Santa Catarina, Florianópolis, 2014.

35. RECKZIEGEL, P .; BOUFLEUR, N; BARCELOS, R. C. S .; BENVEGNÚ, D. M .; PASE, C. S .; MULLER, L.G. et al. Estresse oxidativo e sintomas semelhantes à ansiedade realocados à retirada da fumaça passiva de cigarro em camundongos: Efeitos benéficos do extrato de casca de noz pecan, um subproduto da indústria de nozes. Ecotoxicologia e Segurança Ambiental, 2011; 74 (6): 1770-1778. DOI: 10.1016 / j.ecoenv.2011.04.022

36. LAZAROTTO, M .; BOVOLINI, M. P .; MUNIZ, M.F. B .; HARAKAWA, R .; REINIGER, L. R. S .; SANTOS, A. F. DOS. Identificação e caracterização de espécies pestogênicas de Pestalotiopsis em nogueira-pecã no Brasil. Pesquisa Agropecuária Brasileira, 2014; 49 (6): 440-448. DOI: 10.1590 / S0100-204X2014000600005

37. VÁZQUEZ, N. D. C. R .; LÓPEZ, R. U. Retros e oportunidades para o aproveitamento da Nuez pecanera em México. Centro de Investigación y Asistencia em Tecnología y Desenho do Estado de Jalisco. A. C. (CIATEJ). 112p. 2016. Acessado em 8 de dezembro de 2017. Available: <http://ciatej.mx/docs_noreste/retos_oportunidades_para_el_aprovechamiento_de_la_nuez_pecanera.

38. THOMPSON, T. E. & YOUNG, JR., E. F. Pecan cultivars – past and present. Texas Pecan Growers Association., College Station. 1985. 265p.

39. ALMEIDA, W. A.B. de; NOGUEIRA, N. de L .; ROSSI, M. L; RODRIGUEZ, A. P. M. Anatomia e ultra estrutura de embriões de nogueira (Carya illinoinensis). Magistra, 2002; 14 (1): 45-50.

40. FILIPIN, I. L. Viabilidade econômica do cultivo de nogueira em áreas de reserva legal e de permanente. 2011. 72f. Dissertação de Mestrado (Mestrado em Ciência e Tecnologia de Sementes) - Programa de Pós-graduação em Ciência e Tecnologia de Sementes, Universidade Federal de Pelotas, Pelotas, 2011.

41. SPARKS, D. A. Pecan Cultivars: The Orchard's Foundation. Pecan Production Innovations, Watkinsville, Georgia, 1992, 446p.

42. CONNER, P.J. Pollination Charts Revisited. The Grower Pecan, 2012; 23(4): 34-39.

43. ALMARZA, P.; LEMUS, G.; LUNDSTEDT, J. Nogal: crecimiento y producción inicia. Tierra Adentro, n. 49, p. 29-31, 2003.

44. OJEDA-BARRIOS, D. L .; HERNÁNDEZ-RODRÍGUEZ, O. A .; MARTÍNEZ-TÉLLEZ, J .; NÚÑEZ-BARRIOS, A .; PEREA-PORTILLO, E. Aplicación foliar de quelatos de zinc en nogal pecanero. Revista Chapingo Serie Horticultura, 2009; 15 (2): 205-210.

UNDER PEER REVIEW

45. WELLS, M. L. Produtividade de árvores de nogueira, qualidade de frutos e status de elementos nutrientes utilizando trevos e cama de frango como fontes alternativas de fertilizantes nitrogenados. Hortscience, 2012; 47 (7): 927-931.

46. PARRA, J. M. S .; RAMIREZ, F. J. P .; CHÁVEZ, E. S .; LEAL, P .; SOTELO, M. B. Alternativas orgânicas para desminuir nitrógeno em nogal pecanero. Nova Scientia, 2016; 8 (16): 140-161.

47. MAPA. Ministério da Agricultura Pecuária e Abastecimento. Registro Nacional de Cultivares – RNC. Accessed 23 February 2017. Available: <http://extranet.agricultura.gov.br/php/snpc/cultivarweb/cultivares_registradas.php>.

48. LAZAROTTO, M. Identificação e caracterização de Fusarium spp. associado a uma Carya illinoinensis no Rio Grande do Sul. 2013. 156f. Tese (Doutorado em Engenharia Florestal) - Centro de Ciências Rurais, Universidade Federal de Santa Maria, Santa Maria, 2013.

49. MOKOCHINSKI, F. M. Estimativa de produção, caracterização física e perfil químico de amêndoas de nogueira-pecã. 2015. 67 p. Dissertação (Mestrado em Agronomia) - Programa de Pós-graduação em Agronomia, Universidade Estadual do Centro-Oeste, Guarapuava, 2015.

50. TERABE, N. I; MARTINS, C. M .; HOMECHIN, M. Microrganismos associou um frutos de diferentes cultivares de noz pecan. Ciência e agrotecnologia, 2008; 32 (2): 659-662. DOI: 10.1590 / S1413-70542008000200049

51. WELLS, L. Southeastern Pecan Grower's Handbook. University of Georgia. 2017. 236p.

52. CARGNELUTTI FILHO, A .; POLETTO, T .; MUNIZ, M.F. B .; BAGGIOTTO, C; POLETTO I. Dimensionamento amostral para avaliação da massa e diâmetro de frutos de nogueira-pecã. Ciência Rural, 2015; 45 (5): 794-798. DOI: 10.1590 / 0103-8478cr20140964

53. HAULIK, T. K.; HOLTZHAUSEN, L. C. Anatomy of staminate flower ontogeny of the pecan as determined by scanning electron microscopy. South African Journal of Plant and Soil. 1988; 5(1): 205-208. DOI: 10.1080/02571862.1988.10634986

54. MADERO, E. R .; FRUSSO, E. A .; BRUNO, N. R. Desarollo do cultivo da farinha de nozes na Argentina. ProPecan. Argentina, 2012 (INTA).

55. ZERMEÑO-GONZÁLEZ, A .; FLORES-GUERRERO, J. A .; MUNGUÍA-LÓPEZ, J. P .; GIL-MARÍN, J. A .; RODRÍGUEZ-GARCÍA, R .; CATALÁN-VALENCIA, E. A .; IBARRA-JIMÉNEZ, L .; ZERMEÑO-GONZÁLEZ, H. Evapotranspiration and su relación con la evapotranspiración a equilibrio de una huerta de nogal pecanero (Carya illinoinensis) del norte do México. Agrociencia, 2010; 44 (8): 885-893.

56. ARREOLA-ÁVILA, J. G .; MURRIETA, A. L; DE LA ROSA, B. A. Inducción de crecimiento lateral en nogal pecanero (Carya illinoensis K. Koch) mediante despuente de brotes em primavera. Revista Chapingo Serie Horticultura, 2010; 16 (1): 31-36.

57. SPARKS, D. A. A Climatic Model for Pecan Production under Humid Conditions. Journal of the American Society Horticultural Science, Georgia, 1996; 121(5): 908-914.

58. FRUSSO, E. A. Características morfológicas e fenológicas do pecan. Em: LAVADO, R. S .; FRUSSO, E. A. Producción de pecan in Argentina. Buenos Aires: 2007, p.1-18.

59. MARCHIORI, J. N. C. Dendrologia das angiospermas: das magnoliáceas às flacourtiáceas. Santa Maria: Ed. da UFSM, 1997, 271p.

60. NYCZEPIR, A P. Field performance of pecan rootstocks for resistance to *Seloidogyne partityla* in the Southeastern United States. Nematropica, 2013; 43(1): 63-67.

UNDER PEER REVIEW

61. POLETTO, eu. MUNIZ, M.F. B .; POLETTO, T .; STEFENON, V. M .; BAGGIOTTO, C; CECONI, D. E. Germinação e desenvolvimento de mudas de cultivares de nogueira-pecã por estratificação de sementes. Pesquisa Agropecuária Brasileira, 2015; 50 (12): 1232-1235. DOI: 10.1590 / S0100-204X2015001200014

62. POLETTO, T; MUNIZ, M.F. B .; POLETTO, eu. BAGGIOTTO, C. Métodos de Superação de Dormência da Semente de Nogueira-pecã Carya illinoinensis (Wangenh.) K. Koch. Revista Árvore, 2015; 39 (6): 1111-1118. DOI: 10.1590 / 0100-67622015000600014

63. CQFS-RS / SC - COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO - RS / SC. Manual de calibração e adubação para os Estados do Rio Grande do Sul e de Santa Catarina. 11.ed. (S.l): Sociedade Brasileira de Ciência do Solo / Núcleo Regional Sul, 2016. 376p.

64. KIM, T.; MIULLS, H. A.; WETZSTEIN, H. Y. Studies on effects of nitrogen form on growth, development, and nutrient uptake in pecan. Journal of Plant Nutrition, 2002; 25(3): 497-508. DOI: 10.1081/PLN-120013289

65. IAC - INSTITUTO AGRONÔMICO DE CAMPINAS. Pecã. Campinas, 1998 (Boletim 200). Acessado em 13 de novembro de 2016. Disponível: <http://www.iac.sp.gov.br/areasdepesquisa/frutas/frutiferas_cont.php?nome=Pec%C3%A3>.

66. INTA - INSTITUTO NACIONAL DE TECNOLOGIA AGROPECUARIA. Guia para a plantação e cuidado de árvores jóvenes de pecã. Buenos Aires: Ediciones INTA, 2013.

67. LEMUS, G. O cultivo do Pecano (Carya illinoensis). Chile: Ministerio de Agricultura, 2004.

68. LOURENÇON, T. V .; MATTOS, B. D .; GATTO, D. A .; BULIGON, E. A .; HASELEIN, C. R. Determinação da Idade de Transição entre Lenhos Juvenil e Lenho Adulto para Três Espécies Florestais por meio de suas Propriedades Mecânicas. Floram - Revista Floresta e Ambiente, 2014; 21 (2): 251-260. DOI: 10.4322 / floram.2014.021

69. SPARKS, D. A. A Climatic model for predicting Georgia's pecan production. Proc. S. E. Pecan Growers Assn. 1997; 90(1): 32-44.

70. MOTA, F. S. da; AGENDES, M. O. de O .; ALVES, E. G. P .; SIGNORINI, E .; ARAÚJO, S. M. B. Informação climatológica para o planejamento da irrigação de fruteiras no Rio Grande do Sul. Revista Brasileira de Meteorologia, 1991; 6 (1): 471-477.

71. FRONZA, D .; HAMANN, J.J. Poda da nogueira-pecã. Universidade Federal de Santa Maria, Colégio Politécnico da UFSM. 92p. 2017.

72. ALTIERI, M. Agroecologia bases científicas para uma agricultura sustentável. Rio de Janeiro: Expressão popular, 2012.

73. YANAGIZAWA, Y. A. N. P .; MAIMONI-RODELLA, R. C. S. Composição florística e estrutura da comunidade de plantas de estrato herbáceo em áreas de cultivo de árvores frutíferas. Plantas Daninhas, 1999; 17 (3): 459-468.

74. SPARKS, D. A. A Climatic approach to pecan scab control. HortTechnology, 1995; 5(3): 225-230.

75. SILVA, F. B. da; SILVA, F.J.T. da; FERNANDES, F. da S .; LEAL, L. V .; POLETTO, I. Isolamento e seleção de Trichoderma spp. antagonistas à Pestalotiopsis clavispora, patógeno da nogueira-pecã. Revista Brasileira de Agroecologia, 2013; 8 (3): 109-118.

76. BOSCARDIN, J .; COSTA, E. C. A nogueira-pecã no Brasil: Uma revisão entomológica. Ciência Florestal, 2018; 28 (1): 456-468.

77. DORESTE, P. Frutas secas: nuez pecan. Em: GONZÁLES, C. C. Alimentos Argentinos. Argentina: Secretaria de Agricultura, Ganadería y Pesca, 2011.

UNDER PEER REVIEW

78. EMATER-RS-ASCAR. Cultura da noz-pecã em 2015 no Rio Grande do Sul: área total, produção e número de produtores. Porto Alegre: Emater / RS-ASCAR, 2015.

79. FERMINO, M. H; TREVISAN, M; BUSNELLO, A. C. Casca de tungue e noz pecan como alternativa de substrato para horticultura. Horticultura Brasileira, 2015; 33 (1): 459-464. DOI: 10.1590 / S0102-053620150000400009

80. GATTO, D. A .; HASELEIN, C. R .; SANTINI, E. J .; MARCHIORI, J.N. C .; DURLO, M. A .; CALEGARI, L; STANGERLIN, D. M. Características virológicas de Luehea divaricata, Carya illinoinensis e Platanus x acerifolia quando submetidas ao vergamento. Ciência Florestal, Santa Maria, 2008; 18 (1): 121-131.