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Phenology, production and quality of fruit borne by pecan cultivars

Fenologia, produção e qualidade de frutos de cultivares de nogueira-pecã

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ABSTRACT: Since cultivation of pecan trees is recent in Brazil, production and quality parameters have not been well elucidated. Agronomic characterization of cultivars is essential for the consolidation of their cultivation in southern Rio Grande do Sul (RS) state, Brazil. This study aimed to evaluate phenology, production and quality of fruit borne by seven pecan cultivars. The experiment was conducted in a commercial orchard and at the Embrapa Clima Temperado in Pelotas, RS, throughout three production cycles (2018-19, 2019-20 and 2020-21). Regarding production, a completely randomized design with 10 replicates was used for evaluating phenology, effective fruiting, production per plant, productivity and accumulated production. Concerning nut quality, a completely randomized design with 25 replicates per plant was used for evaluating the number of fruits per kg, fruit length, fruit diameter, fruit mass, almond mass, shell mass, shell thickness and yield. Agronomic characteristics, both productive and qualitative ones, varied among cultivars and production cycles. Cultivars under investigation were 'Shawnee', 'Barton', 'Mohawk', 'Desirable', 'Elliott', 'Farley' and 'Success'. 'Shawnee' showed precocity in both vegetative and flowering stages in the 2018-19 cycle. Cultivars showed delay in the 2019-20 phenological cycle. Some cultivars showed dichogamy exchange. 'Mohawk' had the highest effective fruiting in the 2018-19 cycle while 'Barton' had the lowest effective fruiting in the 2019-20 cycle. 'Barton' showed decrease in its production and productivity in the years under evaluation. Regarding accumulated production, 'Desirable', 'Elliott' and 'Shawnee' reached the highest production. 'Mohawk' exhibited the largest fruit.

Keywords: *Carya illinoinensis*; Dichogamy; Flower; Postharvest; Productivity.

RESUMO: O cultivo de nogueira-pecã no Brasil é recente, e os parâmetros produtivos e qualitativos não são bem elucidados. A caracterização agronômica das diferentes cultivares são primordiais para a consolidação do cultivo na região Sul do RS. O objetivo deste trabalho foi realizar a avaliação da fenologia, da produção e da qualidade dos frutos de sete cultivares de nogueira-pecã. O experimento foi conduzido em pomar comercial na região de Pelotas (RS) e na Embrapa Clima Temperado, por três ciclos produtivos 2018-19, 2019-20 e 2020-21. Para a caracterização produtiva, foi empregado o delineamento inteiramente casualizado, com 10 repetições, avaliando-se a fenologia, frutificação efetiva, produção por planta, produtividade e produção acumulada. Para caracterização qualitativa das nozes, foi utilizado o delineamento inteiramente casualizado, com 25 repetições planta avaliando-se número de frutos por kg, comprimento de frutos, diâmetro de frutos, massa de frutos, de amêndoas, da casca, espessura da casca e rendimento. As características agronômicas, tanto produtivas quanto qualitativas variaram entre as cultivares e ciclos de produção. A cultivar 'Shawnee' apresentou precocidade nas fases vegetativa e de floração no ciclo 2018-19. As cultivares apresentaram um atraso no ciclo fenológico 2019-20. Algumas cultivares apresentaram troca de dicogamia. A cultivar 'Mohawk' apresentou a maior frutificação efetiva no ciclo 2018-19, no ciclo 2019-20 a cultivar 'Barton' obteve o menor resultado de frutificação efetiva. A cultivar 'Barton' apresenta redução em sua produção e produtividade nos anos avaliados. Na produção acumulada as cultivares 'Desirable', 'Elliott' e 'Shawnee' apresentam maiores produções. A cultivar 'Mohawk' apresenta os maiores frutos.

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Palavras-chave: *Carya illinoinensis*; Dicogamia; Flores; Pós-colheita; Produtividade.

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1 INTRODUCTION

Pecan tree (*Carya illinoinensis*) cultivation has expanded significantly in Brazil where about 5.500 t nuts was produced in 2021. It has made the country stand out worldwide since it now ranks fourth in the group of producers, following the United States of America (USA), Mexico and South Africa (INC, 2020). An estimate shows that the cultivated area increased 10-fold, by comparison with 2004 when it stretched over 930 ha while pecan trees grow in about 10,000 ha nowadays (Crosa *et al*., 2020). The main Brazilian states that produce pecan are Rio Grande do Sul (RS), Santa Catarina (SC) and Paraná (PR) (Garcia *et al*., 2019). RS accounts for about 70% of the cultivated area and has nurseries and agroindustries to process nuts (Martins *et al*., 2024).

Brazil has introduced some American superior pecan cultivars and implanted orchards in southern Brazil since the 1970's, mainly in the mid-2000's. There are about 1,000 cultivars, but most cultivars used in Brazil come from the USA. Besides, there is genetic material that was selected in Brazil and ended up being grown by farmers (Martins *et al*., 2024). The Ministry of Agriculture, Livestock and Food Supply in Brazil has registered 42 pecan cultivars so far (MAPA, 2023).

Cultivars used in Brazil and in other countries have certain characteristics, such as dichogamy and fluctuation, depending on where they are grown (De Marco *et al*., 2021). Dichogamy results from separate staminate and pistillate inflorescences, i. e., maturation of male and female parts of flowers takes place at different times, a fact that requires cross-pollination (De Marco *et al*., 2024). Knowledge about phenological behavior and floral compatibility of cultivars is fundamental in pollination and good fruiting, since both factors lead to lack of fruiting, bad nut quality and alternate bearing when they are not carefully considered (De Marco *et al*., 2021). Evaluation of cultivars in production areas throughout time is an important strategy to estimate distinct genotypic responses in different environmental conditions (genotype-environment interaction).

Pecan productivity is a characteristic determined by genetic characters (Wu *et al*., 2022), such as need for cold and heat (Crosa *et al*., 2021) and the xenia effect (Yang *et al*., 2023), which are influenced by edaphoclimatic conditions and orchard management. Fruit production and quality depend on several factors, such as phytosanitary control (Standish *et al*., 2021), fertility management (Wells, 2021), ground cover plants, irrigation (De Marco *et al*., 2021) and pruning management, which reflect directly all technological levels applied to orchards (Gonçalves *et al*., 2014; Helwig *et al*., 2022). Regarding nut commercialization, not only almond yield, mass and size, but also shell thickness (ease of processing) has influenced product valuation (Polleto *et al*., 2019).

Pecan is a perennial fruit tree, both deciduous and monoecious, which has pistillate and staminate flowers in a plant. It also exhibits a natural mechanism called dichogamy, i.e., periods of release of pollen and stigma receptivity are partially or

completely different. Even though a small amount of self-pollination may take place, pollination is usually anemophilic (De Marco *et al*., 2021).

Studies of the phenology of an exotic species that is introduced into an area with no tradition in its cultivation enable to evaluate its edaphoclimatic adaptation (Anzanello; Biasi, 2016). Knowledge about the phenology of a species is fundamental to understanding plant behavior in distinct stages of development and, consequently, responses given to edaphoclimatic conditions and management (Han; Peng; Marshall, 2018; De Marco *et al*., 2021).

Therefore, this study aimed at evaluating phenology, production and quality of fruit borne by different pecan cultivars in edaphoclimatic conditions found in southern Brazil.

2 MATERIALS AND METHODS

This study was carried out between August 2018 and July 2021. The experiment was conducted in a commercial pecan orchard in Canguçu, RS, Brazil (31°28'32"S; 52°56'23"W; altitude: 446.81 m). In the Köppen-Geiger classification, climate in the area is Cfa, i. e., humid subtropical with well-defined seasons. Mean temperature in the coldest month is below 22°C while mean annual precipitation is 1,476 mm (Debreuil *et al*., 2015). The soil in the orchard is classified into Neosol (Santos *et al*., 2018). Data issued by the National Institute of Meteorology (INMET) showed that there were 543, 457 and 597 chill hours (CH) in 2018, 2019 and 2020, respectively (INMET, 2023).

Since the orchard was implanted in 2010, pecan trees were 8 years old at the beginning of the experiment. Spacing was 7 x 9 m, pruning was conducted in winter, fertilization followed the manufacturer's recommendations for the crop, phytosanitary treatments were used whenever necessary, and no irrigation was employed.

Agronomic characteristics of seven pecan cultivars – 'Barton', 'Desirable', 'Elliott', 'Farley', 'Mohawk', 'Shawnee' and 'Success' – were evaluated in the 2018-2019, 2019-2020 and 2020-2021 cycles. Parameters under evaluation were phenology, production and quality of their fruit.

To characterize production, the experiment had a completely randomized design (CRD) with seven treatments (cultivars) and 10 replicates. Every unit comprised a plant. To carry out the phenological evaluation, four twigs were marked per plant; a mark was left in every quadrant of pecan trees. Evaluations took place once per week throughout their vegetative development. In the flowering stage, they happen every two days. The Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale, adapted by Han *et al*. (2018), was used for following the phenological stages. The main phenological stages were classified into the following phases: dormant bud, swollen bud, beginning of budbreak, open bud, first visible leaves and all open leaves, which characterized vegetative development. Throughout flowering, the following phases with the following phenological stages were observed (depending on the types of flowers): staminate flower - opening of male inflorescences, beginning of pollen release, full flowering (when 50% of twigs under evaluation had flowers releasing pollen) and end of pollen release; pistillate flower – opening of female flowers, beginning of stigma

receptivity, full female flowering (when 50% of twigs under evaluation had receptive flowers) and end of receptivity.

The following parameters were used for evaluating production: number of flowers (flowers.twig^{-1}).number of fruit (fruit.twig^{-1}) = effective fruiting (%), production per plant (kg.plant^{-1}) and productivity (kg.ha^{-1}). To evaluate the number of flowers and fruit, four twigs were marked per plant and, in the flowering stage, flowers on marked twigs were counted. Fruit was counted 15 days after the end of the flowering stage. Effective fruiting was found by multiplying the number of fruits by the number of flowers. Production was found by weighing fruit borne by every plant on a digital scale. Productivity was based on data on plant production and density. Accumulated production in 2019, 2020 and 2021 crops resulted from the sum of respective production values.

To characterize the quality of fruit, the experiment had a CRD with seven treatments (cultivars) and 25 replicates. Every unit comprised a randomly chosen fruit, totaling 250 nuts per cultivar. Samples were taken to the laboratory at the Embrapa Clima Temperado, where fruit per kg, fruit length (mm), fruit diameter (mm), fruit mass (g), almond mass (g), shell mass (g), thickness (mm) and yield (%) were evaluated. Shell length, diameter and thickness were measured by a digital pachymeter while masses were weighed on an analytical scale. The number of nuts needed to produce a kilogram was also estimated by values of mean nut mass.

Results were subject to the analysis of variance and means were compared by the Scott-Knott test at 5% probability by the Sisvar® software program.

3 RESULTS AND DISCUSSION

The beginning of budbreak and flowering of cultivars was more precocious in the 2018-19 cycle than in the following one. In the 2018-19 cycle, 'Shawnee' was precocious in its vegetative and flowering stages. Cultivars exhibited more uniform phenology in the 2019-20 cycle than in the previous one; 'Desirable', 'Elliott' and 'Success' were the most precocious cultivars (Table 1). It should be highlighted that 'Barton' is the main cultivar grown in Brazil (Nagel *et al*., 2022), mainly because of its tolerance to scab (*Venturia effusa*). 'Barton' begins budbreak later than the other cultivars, i. e., opening of inflorescences and flowering starts between October and November (Frusso *et al*., 2018). This behavior was also observed in the evaluation carried out by this study.

Regarding flowering of pecan trees, 'Desirable' was the first cultivar to exhibit male and female flowers in the 2018-19 cycle. Cultivars started to exhibit flowers later in the 2019-20 cycle than in the previous one. 'Desirable' and 'Shawnee' were the first cultivars to exhibit male flowers while 'Success' was the first one to exhibit female flowers.

Phenological alterations that take place over the years may be attributed to certain factors, such as CH (there were 543 CH in the 2018-19 cycle while there were 457 CH in the 2019-20 cycle), which are connected to different needs for cold accumulation that cultivars have (Anzanello; De Souza; Coelho, 2012; Rovanni; Wollmann, 2018; Saretta, 2021). Need for CH varies among cultivars.

Table 1. Phenological characteristics of seven pecan cultivars in two production cycles (2018-19 and 2019-20), Rio Grande do Sul, Brazil

Cultivar	SB	BB	OB	FL	OSF	OPF	FOL
2018-2019							
'Barton'	17-Sep	25-Sep	5-Oct	14-Oct	9-Oct	18-Oct	19-Jan
'Desirable'	12-Sep	19-Sep	2-Oct	10-Oct	5-Oct	14-Oct	10-Jan
'Elliott'	15-Sep	23-Sep	1-Oct	10-Oct	7-Oct	16-Oct	28-Jan
'Farley'	19-Sep	27-Sep	5-Oct	19-Oct	13-Oct	31-Oct	28-Jan
'Mohawk'	19-Sep	28-Sep	7-Oct	20-Oct	15-Oct	29-Oct	28-Jan
'Shawnee'	9-Sep	15-Sep	23-Sep	5-Oct	5-Oct	13-Oct	10-Jan
'Success'	15-Sep	24-Sep	5-Oct	15-Oct	9-Oct	27-Oct	28-Jan
2019-2020							
'Barton'	10-Sep	1-Oct	6-Oct	27-Oct	24-Oct	8-Nov	9-Jan
'Desirable'	10-Sep	24-Sep	3-Oct	25-Oct	15-Oct	26-Oct	9-Jan
'Elliott'	10-Sep	24-Sep	3-Oct	24-Oct	24-Oct	28-Oct	9-Jan
'Farley'	24-Sep	3-Oct	24-Oct	6-Oct	24-Oct	1-Nov	19-Jan
'Mohawk'	24-Sep	3-Oct	24-Oct	27-Oct	24-Oct	1-Nov	19-Jan
'Shawnee'	23-Sep	2-Oct	22-Oct	25-Oct	24-Oct	18-Oct	19-Jan
'Success'	10-Sep	24-Sep	3-Oct	24-Oct	18-Oct	24-Oct	9-Jan

SB: swollen bud; BB: beginning of budbreak; OB: open bud; FL: first leaves; OSF: opening of staminate flower; OPF: opening of pistillate flower; FOL: fully open leaves.

Several authors who study and work with pecan trees (Grageda *et al*., 2016) have highlighted that the crop requires more than 400 CH to be able to overcome dormancy. However, other authors have stated that pecan trees may be grown in areas where the number of CH ranges between 250 and 550 (Grageda *et al*., 2016) and even between 50 and 100 (Ojeda-Barrios *et al*., 2016). Regarding this factor, the literature has broad data, since estimates range from 50 to about 500 CH. Bud opening may take place when there are 100 CH – or fewer – but it may trigger unequal budbreak and subsequent pollination problems (Crosa *et al*., 2021). Carbonieri and Morais (2015) carried out an experiment with apple trees and showed that factors related to micro and mesoclimate vary quite a lot over the years and that they influence plant phenology significantly.

Cultivars under study exhibited incomplete dichogamy in the years under evaluation. In the 2018-19 cycle, most of them had protogenic behavior while 'Farley' was the only one that had protandrous behavior. It should be highlighted that 'Barton' had complete overlapping of beginning-end of pollen release and beginning-end of stigma receptivity. In the 2019-20 cycle, four cultivars had protogenic behavior while two had protandrous behavior and 'Farley' exhibited overlapping of beginning of stigma receptivity and pollen release.

Variable dichogamy in production cycles was also reported by other studies (Zhang *et al*., 2016; Lange Junior *et al*., 2020; Borda *et al*., 2020). Dichogamy is usually complete in cold climate and incomplete in warm climate (Rovani; Wollmann, 2018). Borda *et al*. (2020) mentions studies which show that dichogamy patterns have seasonal differences, depending on environmental conditions in spring (temperature, precipitation, wind and relative humidity of air), plant height and plant age. Pecan cultivars exhibit self-incompatibility, intercompatibility and xenia effect (Yang *et al*., 2023; Borda *et al*., 2020), which may lead to pollination problems and affect nut production.

In both production cycles, Shawnee' stands out because of its precocity in the phase of stigma receptivity (Figures 1 and 2). 'Desirable' and 'Shawnee' started pollen release together, before the other cultivars, in the 2018-2019 cycle while 'Farley' started it before the other cultivars in the 2019-20 cycle.

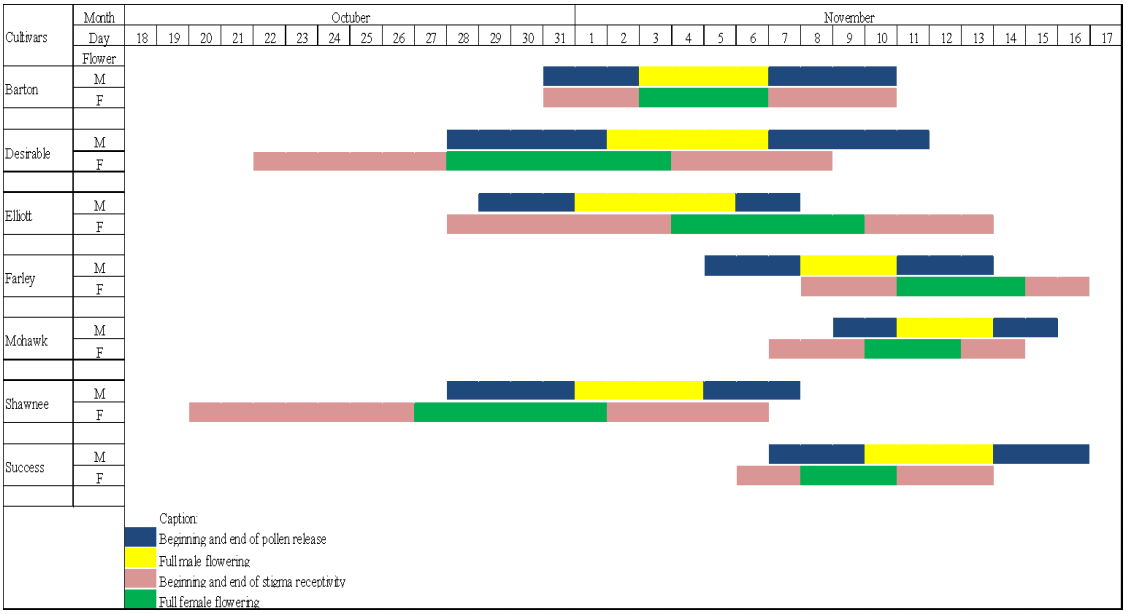

Figure 1. Flowering phenogram of pecan cultivars in the 2018-2019 cycle, Rio Grande do Sul, Brazil

Variation in behavior of floral maturation is common in pecan cultivars, mainly due to production areas where some cultivars may exhibit fluctuating dichogamy, i. e., alterations may take place over the years (De Marco *et al*., 2021). About seven months are needed from bud swelling to fruit harvest and about nine months to complete the cycle, from bud swelling to leaf senescence (De Marco *et al*., 2021). In other words, pecan crops have a relatively long cycle and require pecan farmers to provide much care, treatments and orchard management by comparison with other traditional fruit trees.

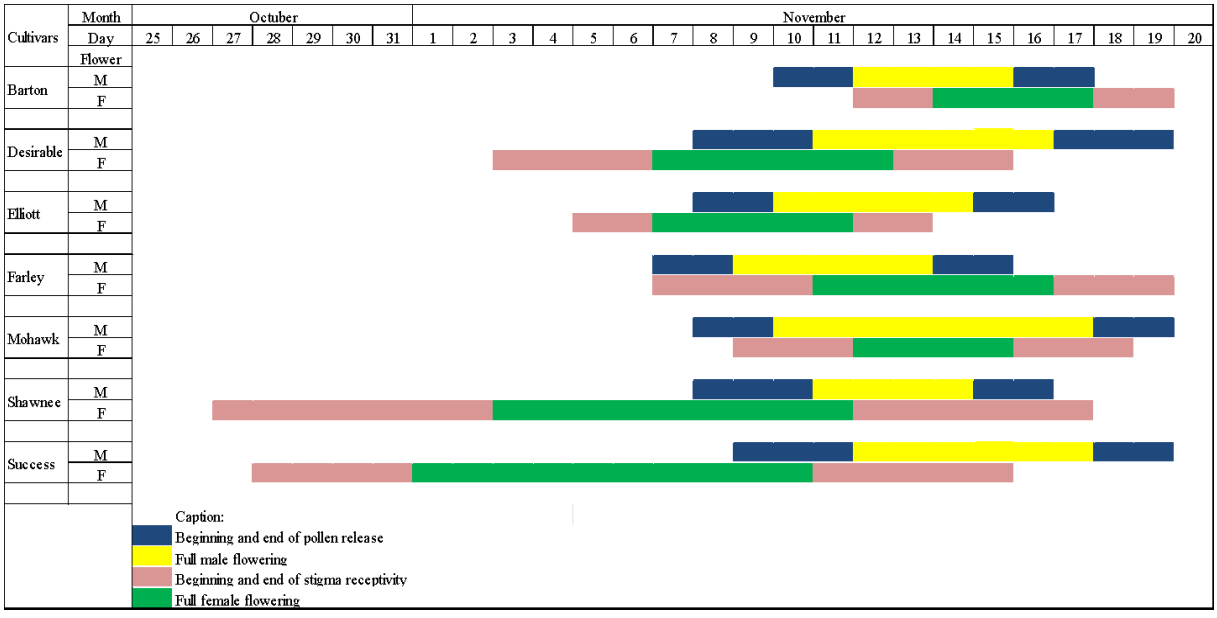

Figure 2. Flowering phenogram of pecan cultivars in the 2019-2020 cycle, Rio Grande do Sul, Brazil

Hot and dry periods with strong winds during this period can anticipate and shorten pollen release, while cold and wet periods can delay and lengthen pollen release (Han *et al*., 2018). In dry wind conditions, stigmatic surfaces can be rapidly desiccated, with effective periods of receptivity considerably reduced. If the stigma receives pollen under these conditions, the stigma cells collapse and dry out after hydration and pollen germination (De Marco *et al*., 2024).

Effective fruiting of pecan trees kept between 30 and 60% in both cycles. 'Barton' and 'Mohawk' were the cultivars that exhibited the highest percentages in the first cycle (Table 2). In the second cycle, effective fruiting reached by 'Barton' was below the expected percentage, by comparison with the other cultivars. Even though 'Barton' had phases of release and receptivity that coincided with other cultivars in the second cycle, the high volume of precipitation (Figure 3) in this cycle may have corroborated low effective fruiting and, consequently, low productivity.

Table 2. Effective fruiting (%), production (kg.plant^{-1}), productivity (kg.ha^{-1}) and accumulated production (kg.ha^{-1}) of pecan cultivars in the 2018-19, 2019-20 and 2020-21 cycles, Rio Grande do Sul, Brazil

Cultivar	Effective fruiting (%)	Production (kg.plant^{-1})	Productivity (kg.ha^{-1})	Accumulated production (kg.ha^{-1})
		2018-19		
'Barton'	58.10 a	1.71 b	270.73 b	270.73 b
'Desirable'	47.94 b	2.63 a	415.70 a	415.70 a
'Elliott'	41.93 b	1.87 b	294.83 b	294.83 b
'Farley'	30.26 b	1.43 b	226.57 b	226.57 b
'Mohawk'	67.11 a	1.44 b	227.13 b	227.13 b
'Shawnee'	38.36 b	1.73 b	274.05 b	274.05 b
'Success'	31.19 b	2.18 a	343.89 a	343.89 a
CV%	47.23	20.15	20.15	20.15
		2019-20		
'Barton'	4.34 b	1.15 b	182.14 b	452,88 b
'Desirable'	40.16 a	4.03 a	636.15 a	1051,85 a
'Elliott'	44.19 a	3.90 a	615.45 a	910,28 a
'Farley'	37.87 a	1.94 b	307.22 b	533,79 b
'Mohawk'	55.12 a	1.09 b	171.86 b	398,98 b
'Shawnee'	32.70 a	3.72 a	588.46 a	862,51 a
'Success'	56.80 a	2.17 b	342.75 b	686,63 b
CV%	65.53	44.1	5.87	27,07
		2020-21		
'Barton'	-	1.24 b	195.64 b	648,51 b
'Desirable'	-	0.87 c	137.13 c	1188,97 a
'Elliott'	-	2.30 a	362.77 a	1273,05 a
'Farley'	-	0.83 c	131.71 c	665,50 b
'Mohawk'	-	0.64 c	100.42 c	499,40 b
'Shawnee'	-	1.36 b	215.19 b	1077,69 a
'Success'	-	0.87 c	136.76 c	823,40 b
CV%	-	24.02	24.08	19,17

CV: coefficient of variation. Means followed by the same letter on a column do not differ statistically. The Scott-Knott test was applied at 5% probability.

According to Bilharva *et al*. (2018), the phase of pollen dispersion may last from 8 to 15 days, depending on the cultivar. Pistillate inflorescences are not very apparent since they spread on lateral terminal twigs and have from two to ten flowers, whose colors depended on the cultivar. Pecan trees usually need cross-pollination because both phases of pollen release and beginning of stigma receptivity take place at different times in plants and among cultivars. Thus, climate factors are directly associated with fruiting parameters (Rovani; Wollmann, 2018) since they may affect pollination negatively.

The analysis of climate parameters (Figure 3) shows that, in the stage of pollination, there is not only high precipitation but also high relative humidity, which may affect pollination and decrease effective fruiting. Besides, other factors, such as lack of an irrigation system in areas where long droughts may happen (e. g., in 2020) (Figure 3), affect fruit fixation, which may lead to pecan nut drop. An experiment carried out by Saretta (2021) evaluated the influence of irrigation and showed that both excessive rain during the flowering phase and droughts during fruiting are significant to fruit drop.

Even though self-pollination may take place in cultivars with incomplete dichogamy, it is not desired because it increases fruit drop from the end of pollination to the beginning of production (Gonzales; Lemus; Muñoz, 2021) and decreases fruit size and yield (Ajamgard; Rahemi; Vahdati, 2017). Cross pollination is needed to increase effective fruiting and reach high nut production. Therefore, the implantation of at least three cultivars with pollination synchronization in a certain area is recommended (Wells, 2021).

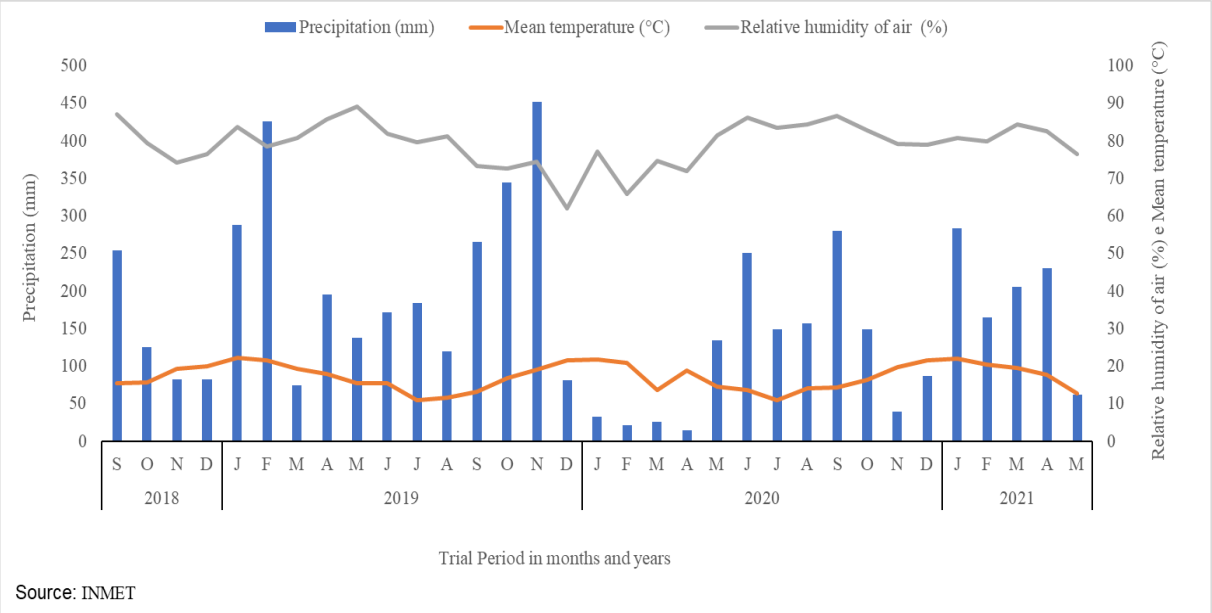

Figure 3. Precipitation (mm), relative humidity of air (%) and mean temperature (ºC) in the 2018-19, 2019-20 and 2020-21 cycles in the orchard, Rio Grande do Sul, Brazil.
Source: INMET (2023).

Pecan nut production varied over the years and among cultivars. In the first two cycles (2018-19 and 2019-20), performance regarding production per plant and productivity was distinct in two groups of cultivars while, in the third cycle (2020-21), three groups were formed (Table 2). In the first cycle, Desirable' and 'Success' exhibited the highest production per plant and productivity. In the following cycle, the highest

production was exhibited by 'Desirable', 'Shawnee' and 'Elliot'. However, variation was higher in the third cycle (2020-21) than in the other cycles. The third cycle exhibited stratification of production in three different groups: 'Elliot' (first group) reached the highest productivity, followed by 'Barton' and 'Shawnee' (second group), while 'Desirable', 'Success', 'Mohawk' and 'Farley' exhibited the lowest productivity.

Alternation in production was found in all cultivars. This physiological phenomenon is typical and takes place naturally in pecan trees as a result of excess of flowers and fruit borne in a production cycle affects the following cycle (Grauke; Wood; Harris, 2012). Differences in yield due to alternation in production were also reported by other studies of pecan production in Brazil (De Marco *et al*., 2021; Hellwig *et al*., 2022). Besides the genetic issue, alternation in production may be determined by extreme adverse situations in the phases of flowering and fruit fixation (Grauke; Wood; Harris, 2012), which may be associated with carbohydrates and the nutritional status of plants (De Marco *et al*., 2021). Another factor is soil humidity which results from climate conditions.

There was a sharp decrease in production in the 2020-21 cycle. It may be due to the severe drought in the previous year (Figure 3) since plants were not capable of storing reserves for the following cycle, i. e., yield of adult trees depends on nutritional reserves stored in the previous year, even though the nutritional contribution of the current year also affects fruiting (Olivas-Tarango; Tarango Rivera; Avala-Quezada, 2021). Pecan yield depends on adequate environmental conditions and management in the production cycle, mainly in every phenological phase, to lead to good production (Gonzales; Lemus; Muñoz, 2021). Therefore, it is fundamental to avoid water stress, mainly during nut growth and fill (De Marco *et al*., 2021).

There was significant variation in nut size (Table 3). 'Mohawk' and 'Elliott' bore the largest and the smallest fruit, respectively, in both years under evaluation. However, there was an increase in nut size when years were compared. 'Shawnee' exhibited a decrease in most parameters under evaluation.

Variability in nut size is common in pecan cultivars. Identification of cultivars may even be based on nut size and shape (Polletto *et al*., 2021). Concerning the increase in size found in most cultivars, it may result from improvement in orchard management, such as pruning and fertility, and climate factors. Wells (2018) reports improvement in quality of pecan nuts as the result of hedge pruning and climate factors which may lead to variation in fruit quality over the years.

Regarding yield in the 2018-19 cycle, most cultivars reached more than 50%. 'Shawnee' had the highest yield (55.98%) while 'Success' had the lowest one (48.69%). In the 2020-21 cycle, 'Mohawk' had a very low yield value (40.18%) while 'Shawnee' and 'Elliott' decreased their yield values slightly; even so, they kept above 50%. Some cultivars, such as 'Barton', 'Desirable', 'Farley' and 'Success', increased their yield values a little. 'Success' was the one that reached the highest increase in yield.

The other parameters were used for classifying nuts. Concerning the number of nuts needed to produce a kilogram, Mohawk' exhibited the best values in both cycles under evaluation while 'Elliott' exhibited the lowest values in both. These values are used as parameters to classify the following nut sizes: oversize (<121 nuts/Kg), extra-large

(121-139 nuts/Kg), large (140-170 nuts/Kg), medium (171-209 nuts/Kg) and small (>209 nuts/Kg), in accordance with the Mexican standard NMX-FF-084-SCFI-2009.

Table 3: Fruit length (mm), fruit diameter (mm), fruit mass (g), almond mass (g) and shell mass (g)of pecan cultivars in the 2018-19 and 2020-21 cycles, Rio Grande do Sul, Brazil

Cultivar	FL (mm)	FD (mm)	FM (g)	AM (g)	Y (%)	NUK	ST (mm)
'Barton'	35.28 d	19.72 d	5.92 c	3.01 d	50.53 c	170 b	0.76 c
'Desirable'	38.94 c	20.52 c	7.01 b	3.52 c	50.18 c	143 c	0.76 c
'Elliott'	28.55 f	18.75 e	4.43 d	2.37 e	53.39 b	226 a	0.67 d
'Farley'	33.51 e	21.97 b	7.22 b	3.65 c	50.53 b	139 c	0.90 b
'Mohawk'	47.19 a	22.36 b	11.01 a	5.57 a	50.55 c	91 d	1.00 a
'Shawnee'	43.29 b	20.93 c	7.55 b	4.23 b	55.98 a	133 c	0.67 d
'Success'	32.00 e	23.31 a	7.36 b	3.60 c	48.69 c	136 c	0.84 b
CV%	3.21	3.04	4.02	7.11	4.65	3.52	6.16
'Barton'	40.94 b	22.22 b	6.84 d	3.71 c	54.20 a	147 b	0.72 b
'Desirable'	41.90 b	22.72 b	7.93 c	4.21 b	53.17 a	127 c	0.72 b
'Elliott'	30.49 e	21.95 b	5.67 e	2.94 d	52.27 a	182 a	0.71 b
'Farley'	37.74 c	22.92 b	7.82 c	4.09 b	52.26 a	128 c	0.77 b
'Mohawk'	52.83 a	25.32 a	11.33 a	4.56 a	40.18 b	88 d	0.91 a
'Shawnee'	41.87 b	21.92 b	6.92 d	3.68 c	53.23 a	145 b	0.66 b
'Success'	35.86 d	25.22 a	8.78 b	4.95 a	56.36 a	114 c	0.73 b
CV%	3.02	3.58	7.97	9.75	5.26	7.97	7.43

FL: fruit length; FD: fruit diameter; FM: fruit mass; AM: almond mass; Y: yield; NUK: number of units per kilogram; and ST: shell thickness; CV: coefficient of variation. Means followed by the same letter on a column do not differ statistically. The Scott-Knott test was applied at 5% probability.

Regarding shell thickness, Mohawk' is the cultivar that exhibited the thickest shell in both cycles under evaluation while 'Elliott' had the thinnest shell in the 2018-19 cycle but, in the 2020-21 cycle, it did not differ from the other cultivars.

Evaluation of almond percentage is an important parameter of quality since it is directly associated with sale prices of pecan nuts in the market 50% yield is a reasonable value (OROZCO-MELENDEZ, 2021). Variation in yield over the years also affects shell thickness, i. e., decrease in shell thickness was found in years in which yields were high (OROZCO-MELENDEZ, 2021; BALANDRIN-VALLADARES *et al*., 2021) in most cultivars, even though some did not follow this pattern.

4 CONCLUSION

Regarding cultivars under study, Shawnee' was the most precocious one in most vegetative stages and in the flowering phase, by comparison with the other cultivars.

'Success' exhibited the highest effective fruiting while 'Desirable' was more productive than 'Barton', which was considered the main cultivar. 'Mohawk' exhibited the largest fruit with the highest mass but the lowest almond yield while 'Elliot' exhibited the smallest fruit with the lowest mass.

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