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Plant thinning recovers fruiting of *Myrciaria dubia* in the Peruvian Amazon

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ABSTRACT: Camu camu (*Myrciaria dubia*) is a fruit tree native to the Peruvian Amazon. The first plantations were grown at high densities. However, after 20 years of cultivation, the trees exhibit low flowering and fruiting. The objective of this study was to determine the effect of different thinning densities (3 x 3 m; 6 x 3 m; 4.24 x 4.24 x 6 m, and 6 x 6 m) and fruiting pruning on fruit production in 20-year-old *Myrciaria dubia* plants. The study evaluated several variables, including the number of flower buds, green and harvested fruits, as well as the mass (g) and equatorial diameter (mm) of the harvested fruits, fruit yield (t ha^{-1}), and light intensity (lux). The best results were observed in *Myrciaria dubia* plants that were influenced by a thinning density of 6 x 3 m and were not pruned. These plants had the highest number of flower buds, green and harvested fruits, fruit yield, and light intensity, with values of 18805, 7522, 2820.75, 13.3 t ha^{-1}, and 57395.00 lux, respectively. The spacing of 6 x 3 m resulted in favorable conditions for space and light, allowing the productive characteristics of 20-year-old *Myrciaria dubia* plants to recover. The plants were in a state of ecodormancy due to the suspension of their physiological activities caused by the absence of agronomic management.

Key words: camu camu; fruit yield; luminous intensity; planting density

O desbaste de plantas recupera frutificação de *Myrciaria dubia* na Amazônia peruana

RESUMO: Camu camu (*Myrciaria dubia*) é uma árvore frutífera nativa cultivada na Amazônia peruana. As primeiras plantações foram plantadas em densidades muito elevadas. Porém, após 20 anos de cultivo apresentan pouca floração e frutificação. O objetivo deste trabalho foi determinar o efeito de diferentes densidades de desbaste (3 x 3 m; 6 x 3 m; 4,24 x 4,24 x 6 m e 6 x 6 m) e podas de frutificação na produção de frutos em plantas com 20 anos de idade de *Myrciaria dubia*. As variáveis avaliadas foram: número de botões florais, frutos verdes e de colheita; também foram avaliadas a massa (g) e o diâmetro equatorial (mm) dos frutos colhidos, bem como a produtividade de frutos (t ha^{-1}) e a intensidade luminosa (lux). As plantas de *Myrciaria dubia* influenciadas pela densidade de desbaste de 6 x 3 m e sem poda apresentaram os melhores resultados em número de botões florais, frutos verdes, frutos colhidos, produção de frutos e intensidade luminosa com 18.805; 7522; 2.820,75; 13,3 t ha^{-1} e 57.395,00 lux, respectivamente. A densidade de desbaste de 6 x 3 m permitiu condições favoráveis de espaço e luminosidade para recuperar as características produtivas de plantas de *Myrciaria dubia* com 20 anos de idade que se encontravam em estado de ecodormência devido à suspensão de suas atividades fisiológicas devido à ausência de atividades agronômicas.

Palavras-chave: camu-camu; densidade de plantio; intensidade luminosa; produção de frutos

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Introduction

Camu camu (*Myrciarua dubia*) is a shrub that grows in the Amazon basin of Peru, Brazil, Colombia, and Venezuela in rivers, lakes, and lagoons. It can withstand temporary flooding that occurs between January and April during the rainy season (Yuyama & Valente, 2011; Pinedo et al., 2010).

Therefore, *Myrciaria dubia* has significant value for riverside dwellers and native communities because it is the only fruit tree that is not affected by flooding. Perennial crops occupy and value riverside lands, promoting the consolidation of family agriculture in the Amazon's flooded soils. This helps to avoid deforestation of forests and migration from the countryside to the city (MIDAGRI, 2000).

The species is notable for its high concentrations of vitamin C in the pulp, peel, and seed, making it a valuable raw material for the cosmetics, pharmacy, and food industries (Nowak et al., 2023; Fidelis et al., 2020). In Peru, plantations located in Loreto and Ucayali have reported values of up to 3133 mg of vitamin C per 100g of pulp (Abanto-Rodríguez et al., 2016; Pinedo et al., 2010).

In Peru, there are approximately 8,554.95 ha of land, consisting of 1,345 ha of natural areas and 7,209 ha of cultivated plantations. Productive plantations can yield over 10 tons of fruit per hectare. However, due to insufficient agronomic management in recent years, fruit yields have decreased to as low as 1.5 tons per hectare. This has resulted in economic losses for farmers and a shortage of fruit in both local and national markets (DRSAU, 2017).

The decrease in fruit yield is primarily attributed to issues arising from high planting densities. According to Oliva et al. (2005), 80% of the plantations were established with spacings of 3 x 3 m, 3 x 2 m, 2 x 1.5 m, 1 x 1.5 m, and 2 x 2 m between lines and plants, respectively. Delgado & Yuyama (2010) suggest that high planting densities in the initial years of cultivation are acceptable as they result in a greater number of plants per hectare and adequate fruit yield. However, as the plantation ages, the availability of light within the plot decreases, leading to ecodormancy in flower buds. This results in decreased flowering, fruit set, size, color, and vitamin C content in the fruits.

Light management is crucial for the growth and development of *Myrciaria dubia* plants at all stages.

Therefore, it is necessary to develop agronomic management technologies to recover the productivity of 20-year-old *Myrciaria dubia* plantations. One alternative is plant thinning. This technique involves reducing the number of trees and/or shrubs to increase the availability and use of light by the remaining plants (Meza & Torres, 2006). On the other hand, there is fruiting or production pruning, which involves removing the apical branches of the plant in an organized manner to stimulate the development of new fruit branches, maintaining a balance between leaf area growth and fruit production, and ensuring adequate exposure to sunlight. This study aimed to investigate the impact of varying densities of tree thinning and fruiting pruning on the vegetative and productive aspects of *Myrciaria dubia* plants in the Peruvian Amazon.

Materials and Methods

Study location

The study was conducted from August 2020 to November 2021 in a 20-year-old *Myrciaria dubia* plantation located on the "Anaika" farm, 7 de Junio hamlet, Yarinacocha district, Coronel Portillo province, Ucayali Region, Peru, and located at 8° 17' 26'' South latitude, 74° 37' 59'' West longitude and at an altitude of 144 m.a.s.l. (Figure 1).

Physiographically it belongs to low floodable terrace soils (restinga) and slightly flat relief, with a flood level of 2.65 m between January and April. Air temperature fluctuates

Figure 1. Location of the *Myrciaria dubia* plantation in the hamlet of 7 Junio, Yarinacocha, Ucayali, Peru.

between 20 to 32 °C with an average of 25.5 °C; rainfall, relative humidity, and wind speed are 2093.30 mm, 80%, and 1.4 m s^{-1}, respectively (SENAMHI, 2021).

Study plant material

The plantation was established using botanical seed from natural stands in the Loreto region. The planting density was 1111 plants per hectare (3 x 3 m, between rows and between plants). Fruit production began at 3.5 years, reaching a maximum yield of 12 tons per hectare at 10 years. After 15 years, the yield decreased and the plants became unproductive, leading the farmer to abandon the plantation.

Experimental design

The study utilized a completely randomized block design with a factorial arrangement (3 x 2). Factor A consisted of three levels of tree thinning densities: 1) 6 x 3 m; 2) 4.24 x 4.24 x 6 m; and 3) 6 x 6 m. Factor B was pruning, with two levels: 1) fruiting pruning and 2) non-fruiting pruning. An additional treatment without thinning (3 x 3 m) was also included. The experiment was distributed across five blocks with three plants per experimental plot.

Studio installation

The experimental design was used for the installation of the experiment in the plantation of *Myrciaria dubia*. The plants were planted at a density of 1111 plants per hectare (3 x 3 m). Before proceeding with the thinning of trees according to the experimental design, all harmful plants were removed from the soil surface using a motorized weed cutter. Additionally, all parasitic plants, such as *Pthirusa pyrifolia* (Loranthaceae) and *Psittacanthus cucullaris*, were removed from the branches and trunks of the *Myrciaria dubia* plants. Nests of termites, ants, wasps, and spiders were also eliminated.

The experimental plots were delimited by treatment. Within each plot, *Myrciaria dubia* plants that remained were marked with green tape, while those that were removed were marked with red tape. Fruiting pruning was performed using telescopic pruning shears, and thinning was done with a Husqvarna 61® chainsaw. The plants were cut 30 cm from the soil surface, and the cut plants were chopped. The residues were then removed from the plantation and stored as plant waste. We carried out weeding every 30 days to allow technical personnel to evaluate the vegetative and productive characteristics of the *Myrciaria dubia* plants.

Variables evaluated

To determine the initial state of the plants, we measured plant height (in meters), crown diameter (in g), and the number of secondary branches. During the experimental phase, we counted 100% of the flower buds, green fruits, and harvested fruit at 110, 179, and 210 days after thinning the trees, respectively, using a manual counter. This variable was used to calculate the yield and characteristics of biomass (in g) and equatorial diameter (in mm) of the fruits in the plants that underwent thinning and fruit pruning treatments.

The fruit's biomass was measured using an Ohaus® Adventurerpro AV412 model digital balance with a capacity of 410 g and a precision of 0.01 g. The fruit yield measurements were conducted at the biological testing laboratory and biotherium of the Instituto de Investigaciones de la Amazonica Peruana (IIAP), Ucayali branch.

To obtain the yield per hectare (t ha^{-1}), the average biomass of 20 fruits was multiplied by the total number of fruits harvested per plant, expressed in grams, and converted into kilograms. This value was then multiplied by the number of plants per hectare and divided by 1000 kg. At the beginning, during, and at the end of the study, light intensity was recorded at the base, middle, and top of the plants at 8:00 a.m., 1:00 p.m., and 5:00 p.m. using the LX-1330B® digital lux meter.

Statistic analysis

The data was tabulated using Microsoft Excel® (version 2019). To verify the assumptions of normality and homogeneity of variances for the analysis of variance, the Shapiro-Wilk and Bartlett tests were used, respectively. Since the data was normal and homogeneous, it was subjected to analysis of variance using the F test. Finally, the means of the treatments were compared using the Tukey and Dunnett tests ($p \leq 0.05$). Sunlight intensity (Lux) means were compared using the Scott-Knott test ($p \leq 0.05$). The assumptions of variance analysis were verified using the RStudio Team Program (2020), and the analysis of variance and mean tests were performed using the SISVAR program (Ferreira, 2014).

Results and Discussion

Initial vegetative characteristics

The average plant height and crown diameter were 5.22 and 5.28 m, respectively, with a range of 3.8 to 6.9 m and 3.8 to 7.5 m. This suggests that the 20-year-old plants grew excessively in both height and width due to high planting density. The number of secondary branches averaged 6, with a range of 4 to 13. Arquero et al. (2013) suggest that inadequate agronomic management of fruit trees can lead to several issues, including excessive branch emission and intertwining, which can limit light entry into the canopy and cause deficiencies in the photosynthetic process.

Production characteristics

Statistical analysis revealed significant differences in the number of flower buds (NFB), number of green fruit (NGF), number of harvested fruit (NHF), and fruit yield (FYI) due to the interaction of thinning density and fruit pruning (TD x FP) and additional treatment (Tad) with factorial (Tad x (TD x FP)) (Table 1).

Table 2 presents the Tukey and Dunnett mean test ($p \leq 0.05$) results for the variables: number of flower buds (NFB), number of green fruits (NGF), number of harvested fruits

Table 1. Summary of the analysis of variance for the number of flower buds (NFB), number of green fruits (NGF), number of harvested fruits (NHF), and yield (FYI) of 20-year-old Myrciaria dubia plants by effect of different tree thinning densities and fruiting pruning.

Source of variation	DF	Mean squares			
		NFB	NGF	NHF	FYI (t ha^{-1})
Block	4	3160325.31	505652.05	71107.31	0.44
Thinning density (TD)	2	89772498.43*	14363599.75*	2019881.21*	96.84*
Fruit pruning (FP)	1	340493600.09*	54478976.01*	7661106.00*	125.63*
TD x FP	2	117102361.76*	18736377.88*	2634803.13*	65.37*
Tad vs Factorial (TDxFP)	2	319585462.55*	51133674.00*	7190672.91*	105.66*
Residue	24	10095619.39	1615299.10	227151.43	2.66
CV (%)		36.79	36.79	36.79	32.84

* Significant according to the F test (p ≤ 0.05).

Table 2. Number of flower buds (NFB), number of green fruits (NGF), number of harvested fruits (NHF), and fruit yield (FYI) in 20-year-old *Myrciaria dubia* plants by effect of different densities of tree thinning and fruiting pruning with pruning (WP) and without pruning (WOP).

Source of variation	NFB		NGF		NHF		FYI (t ha^{-1})	
Densities	WP	WOP	WP	WOP	WP	WOP	WP	WOP
6 x 3 m	4716.0 Bb [1]	18805.0 Aa [1]	1886 Bb [1]	7522 Aa [1]	707 Bb [1]	2821 Aa [1]	3.36 Bab [1]	13.3 Aa [1]
4.24 x 4.24 x 6 m	8033.3 Aa [1]	8633.3 Ab [1]	3233 Aa [1]	3453 Ab [1]	1213 Aa [1]	1295 Ab [1]	4.15 Aa [1]	4.61 Ab [1]
6 x 6 m	3000.0 Bb [1]	8574.7 Ab [1]	1200 BC [1]	3430 Ab [1]	450 BC [1]	1286 Ab [1]	1.25 Bb [1]	3.13 Ab [1]
Average of the interaction (Thinning density vs Pruning)	8635.4 a [2]		3454.0 a [2]		1295.0 a [2]		4.9 a [2]	
Tad - (3 x 3 m)	0.0 b [2]		0.0 b [2]		0.0 b [2]		0.0 b [2]	

[1] Means followed by different capital letters in the line and lowercase letters in the column differ significantly according to Tukey test (p ≤ 0.05). [2] Means followed by a different lowercase letter in the column differ according to Dunnett test (p ≤ 0.05).

(NHF), and fruit yield (FYI - t ha^{-1}) in 20-year-old *Myrciaria dubia* plants.

The statistical analysis shows that the highest yields of NFB, NGF, NHF, and FYI were achieved by *Myrciaria dubia* plants that were planted at a density of 6 x 3 m and were not subjected to fruiting pruning. Specifically, the highest yields were 18805, 7522, 2821, and 13.3 tons for NFB, NGF, NHF, and FYI, respectively. Conversely, the lowest yields were obtained from plants that were planted at a distance of 6 x 6 m and were subjected to fruiting pruning, with an average yield of 3000.0, 1200, 450, and 1.25 tons for NFB, NGF, NHF, and FYI, respectively (refer to Table 2).

The results suggest that fruiting pruning may not be suitable for plantations with these characteristics. This is because the shoots that emerged after pruning did not reach physiological maturity for flower bud differentiation. Similar findings were reported by Durand-Valencia et al. (2018) when working with pruning and thinning on 20-year-old *Myrciaria dubia* plants in the Loreto region of Peru.

When using the Dunnet test (p ≤ 0.05) to compare the results of the interaction between the factors thinning density (TD) and fruit pruning (FP) with the additional treatment (Tad), significant statistical differences were found in all the variables under study. It is worth noting that the control plot did not develop flowers or fruit. The application of tree thinning to create spaces between plants resulted in the recovery of phenological phases of flowering and fruiting after 7 months, as shown in Table 2.

Fronza et al. (2018) found that excessive shading caused by branch growth led to decreased production in *Carya illinoinensis* trees older than 10 years. Similarly, in the USA, plantations of *Carya illinoinensis* experienced the same problem from the age of 12 years due to the crowding of plants (Mceachern, 2020).

Post-harvest variables

Statistical analysis revealed significant differences in the fruit diameter (FD) and fruit biomass (FB) variables due to the interaction between the additional treatment (Tad) and the thinning density and fruit pruning factors (TDxFP). Additionally, the thinning density factor had a significant effect on the FB variable. See Table 3 for details.

Table 4 shows that the various tree thinning densities did not cause significant differences in the FD, with an average of 2.42 cm. However, the fruits of the plants influenced by the thinning density of 6 x 6 m presented the highest FB results, averaging 10.07 g, which was significantly higher according to Tukey test (p ≤ 0.05) than the other treatments that obtained an average of 8.8 g.

The Dunnett test (p ≤ 0.05) revealed significant differences in the fruit diameter (FD) and fruit biomass (FB) variables when comparing the interaction of thinning density and pruning

Table 3. Summary of the analysis of variance for the variable fruit diameter (FD) and fruit biomass (FB) of 20-year-old *Myrciaria dubia* plants under the effect of different tree thinning densities and fruiting pruning.

Source of variation	DF	Mean square	
		FD (mm)	FB (g)
Block	4	0.0258	26,086
Thinning density (TD)	2	0.0297 NS	4.0281 *
Fruit pruning. (FP)	1	0.0015 NS	0.0465 NS
TD x FP	2	0.0031 NS	2.2803 NS
Tad x Factorial (TDxFP)	1	25.0123 *	347.0906 *
Residue	24	0.0116	117,042
CV (%)		4.46	11.74

*, NS - Significant and not significant according to the F test (p≤0.05).

factors with the additional treatment (Tad-control (3 x 3 m)). Therefore, it was determined that the fruits of the remaining plants after thinning reached a diameter and biomass of 2.42 cm and 9.21 g, respectively. In contrast, in the plot where no thinning was applied (Tad-control (3 x 3 m)), the plants did not produce flower buds. As a result, they did not progress to the flowering and fruiting stages (see Table 4).

Regarding the light intensity, the values in the crown of *Myrciaria dubia* plants were statistically higher than those recorded in the middle and basal positions at all thinning densities. Likewise, when analyzing the light intensity at the different recording times, it was observed that, regardless of the thinning density, the values recorded at 1:00 p.m. were statistically higher than those recorded at 8:00 a.m. and 5:00 p.m. (Table 5).

Thus, when comparing the effect of thinning densities on light intensity in each hour of the recording and each plant position, it was found that thinning densities of 6 x 6 m; 4.24 x 4.24 x 6 m, and 6 x 3 m, at the base of the plants presented an available light intensity of 72048 (63.2%); 65,860 (57.8%) and 79,668 lux (69.9%), respectively, statistically higher than the values recorded in the additional treatment (Tad control (3 x 3 m)), which presented an average of 7,949 (7%) lux, at 1:00 p.m. (Table 5). At the same thinning densities and in half of the plants, higher values of 80016 (70.2%), 63436 (55.6%), and 81842 (71.8%) lux were recorded, but in the additional treatment, only 9952 (8.7%) lux were recorded. In the canopy, values of 97860 (85.8%); 95344 (83.6%), and 100100 (87.8%) lux were recorded in the thinning densities 6 x 6 m; 4.24 x 4.24 x 6 m, and 6 x 3 m, respectively, while in the control treatment only 56908 (49.9%) lux was recorded (Table 5).

In this regard, Yamori (2020) mentions that the Thus, plant growth is closely related to both photosynthesis and respiration. There is no growth without photosynthesis and respiration. Therefore, an understanding of the physiological processes of photosynthesis and respiration is necessary for a basic understanding of maximizing crop yield

In the canopy of the plants, the thinning density 6 x 6 m at 8:00 p.m. presented the best light intensity values, being statistically higher than the other two thinning densities. At

Table 4. Means for the variables fruit diameter (FD) and fruit biomass (BF) of 20-year-old *Myrciaria dubia* plants under the effect of different thinning densities of trees with and without fruiting pruning.

Thinning densities	FD (cm)			FB (g)		
	CP [1]	SP [1]	Average	CP [1]	SP [1]	Average
6 x 3 m	2.33	2.38	2.35 a [1]	8.54	8.63	8.58 b [1]
4.24 x 4.24 x 6 m	2.43	2.44	2.43 a [1]	8.80	9.16	8.98 b [1]
6 x 6 m	2.47	2.45	2.46 a [1]	10.29	9.86	10.07 a [1]
Mean of the factorial (Thinning density vs Pruning)	2.42 a [2]			9.21 a [2]		
Tad - control (3 x 3 m)	0.00 b [2]			0.00 b [2]		

[1] Means followed by different capital letters in the line and lowercase in the column show significant differences by Tukey test (p ≤ 0.05). [2] Means followed by different lowercase letters in the column differ by Dunnett test (p ≤ 0.05).

Table 5. Values representing the mean solar light intensity (lux) for the effect of the different tree thinning densities, recorded at different times of the day and in each horizontal position of the 20-year-old *Myrciaria dubia* plants.

Thinning densities	Registration time	Position in the plant		
		Base	Half	Canopy
Tad - control (3 x 3 m)	8:00	3368.0 cYB	6828.0 bZA	19392.0 aZB
	13:00	7984.0 bZA	9952.0 bZA	56908.0 aZA
	17:00	2484.0 bZB	3696.0 bYB	14452.0 aZB
6 x 3 m	8:00	24096.0 bXB	34312.0 bYB	72836.0 aYB
	13:00	79668.0 bXA	81842.0 bXA	100100.0 aXA
	17:00	30004.0 cXB	24028.0 bXC	69668.0 aXB
4.24 x 4.24 x 6 m	8:00	33976.0 cXB	48796.0 bXB	68820.0 aYB
	13:00	65860.0 bYA	63436.0 bYA	92344.0 aYA
	17:00	14228.0 cYC	30368.0 bXC	52204.0 aYC
6 x 6 m	8:00	27168.0 bXB	34228.0 bYB	82860.0 aXB
	13:00	72048.0 bYA	80016.0 bXA	97860.0 aYA
	17:00	22480.0 cXB	29028.0 bXC	73412.0 aXC

Lowercase letters a, b, c, on the line express significant statistical differences (SSD) between each thinning density at each recording time within each plant position. Letters X, Y, and Z in the column express the SSD of each plant position at each recording time and each thinning density. Capital letters A, B, and C in the column express the SSD of each position in the plant within the hours of recording each thinning density using the Scott-Knott test (p ≤ 0.05).

1:00 p.m., the 3 thinning densities (6 x 3 m, 6 x 6 m, and 4.24 x 4.24 x 6 m) did not show significant statistical differences, obtaining an average of 97768 (85.8%) lux. However, they were statistically superior to the control treatment (3 x 3 m), which averaged 56,908 (49%) lux (Table 5).

The light intensity available at 5:00 p.m. was similar in the 6 x 3 m and 6 x 6 m densities, averaging 71,540 (62.8%), but was statistically higher than the thinning density 4.24 x 4.24 x 6 m and the control treatment, averaging 52204 (45.8%) and 14452 (12.7%), respectively (Table 5).

The study found that *Myrciaria dubia* plants with a density of 6 x 3 m had the highest fruit production values, averaging 13.3 t ha^{-1}. This was in comparison to the additional treatment (control) which did not show any phenological phases of fruiting. The plants that remained after thinning, except for those from the additional treatment, also had high fruit production values. On average, the light intensity was 80,868 lux, which is equivalent to 71% of the light incident in the canopy of the plants. Adequate fruit production is achieved when the canopy intercepts maximum incident radiation. Good-sized fruit does not require a large number of leaves, but rather well-exposed leaves to the sun (Raffo et al., 2022).

Thinning the surrounding area of *Myrciaria dubia* plants increased the availability of light intensity (lux). However, this effect was not observed in the control treatment, as lower values of luminosity were determined throughout the evaluation period.

Conclusion

The spacing of 6 x 3 m allowed for optimal light and space conditions, promoting the recovery of productive characteristics in 20-year-old *Myrciaria dubia* plants that were in a state of ecodormancy due to the suspension of their physiological activities caused by the lack of agronomic management.

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Compliance with Ethical Standards

Author contributions: Conceptualization: CAR; Data curation: JABN, BIJM; Formal analysis: CAR, HMO; Funding acquisition: JABN; Investigation: JABN, BIJM, NMPT; Methodology: CAR, JSCS; Project administration: JSCS; Resources: JABN; Supervision: NMPT, JSCS; Validation: HMO; Writing – original draft: CAR; Writing – review & editing: CAR, JSCS;

Conflict of interest: The authors declare that they have no conflicts of interest (professional or economic) that could influence the article.

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