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EFFECTS OF DIFFERENT SUBSTRATES, COVERING, AND FAMILIES ON MINICUTTING PRODUCTION AND ROOTING OF *Pinus taeda* L.

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Resumo

Efeitos de diferentes substratos, cobertura e famílias na produção e no enraizamento de miniestacas de Pinus taeda L. Este estudo avaliou como as condições de manejo influenciam a produção e o enraizamento de miniestacas de três famílias selecionadas de *Pinus taeda* L. Os fatores testados incluíram a presença ou ausência de cobertura e três composições de substrato de minijardins. O objetivo foi identificar condições que aumentem a eficiência da propagação vegetativa. O experimento seguiu um delineamento inteiramente casualizado, em esquema fatorial 2 × 3 × 3 (dois níveis de cobertura, três substratos, três famílias). Foram avaliadas a produtividade de brotações por minicepa, porcentagem de enraizamento, sobrevivência após saída da casa de sombra e altura e diâmetro das miniestacas. Os dados foram analisados por ANOVA e teste de Tukey. Observou-se interação significativa entre cobertura e substrato. Minijardins sem cobertura, especialmente com uso exclusivo de areia grossa, apresentaram maior produtividade de brotações e melhor enraizamento. A ausência de cobertura aumentou a produtividade de miniestacas por minicepa em 76,22% e favoreceu a sobrevivência após a casa de sombra. Em contrapartida, a presença de cobertura reduziu ambos os parâmetros. As famílias F3 e F1 superaram a F2 quanto à produção de brotações, crescimento e enraizamento das miniestacas, indicando forte influência genética sobre o potencial de propagação. Os resultados ressaltam a importância de práticas de manejo específicas em minijardins clonais. O uso de areia grossa não é recomendado com cobertura, mas sem cobertura proporciona melhores resultados. Além disso, a seleção de materiais genéticos superiores, como as famílias F3 e F1, pode otimizar a propagação clonal em programas de melhoramento de *P. taeda*.
Palavras-chave: sistema de manejo; silvicultura clonal; percentual de enraizamento; propagação vegetativa.

Abstract

This study evaluated how management conditions affect the production and rooting of minicuttings from three selected families of *Pinus taeda* L. The factors tested included the presence or absence of covering and three substrate compositions of mini-gardens. The aim was to identify conditions that improve the efficiency of vegetative propagation. The experiment followed a completely randomized 2 × 3 × 3 factorial design (two covering, three substrates, three families). Measured variables included shoot productivity per mini-stump, minicutting rooting percentage, post-shade-house survival, and minicutting height and diameter. ANOVA and Tukey's test were used for statistical analysis. A significant covering × substrate interaction was observed. Mini-gardens without covering, particularly those using only coarse sand, yielded higher shoot productivity and better rooting. The absence of mulch increased mini-cutting productivity per mini-stump by 76.22% and enhanced survival after removal from the shade house. Conversely, covering presence reduced both productivity and survival. Families F3 and F1 consistently outperformed F2 in shoot production, minicutting size, and rooting, indicating a strong genetic influence on propagation potential. These findings highlight the importance of tailored management in clonal mini-gardens. Specifically, coarse sand is not recommended when covering is used, but in the absence of mulch, it enhances propagation outcomes. Moreover, selecting superior genetic materials, such as families F3 and F1, can significantly improve clonal propagation efficiency in *P. taeda* breeding programs.
Keywords: Management system; clonal silviculture; mini-cutting; rooting percentage; vegetative propagation.

INTRODUCTION

P. taeda is one of the most economically important species in the United States, the country with the world's largest economy in terms of GDP (Gross Domestic Product). In Brazil, another country that is among the world's largest economies, it is one of the most planted forest species in the southern region (HIGA *et al.*, 2008). *P. taeda* wood is used to produce paper, compressed panels and sawmills. Its timber productivity in Brazil is one of the highest in the world.

In the latter country, the regeneration of this species is artificial, through the planting of seedlings or rooted mini-cuttings. Advances in knowledge about the production of mini-cuttings of *P. taeda* are needed to meet the cost reduction and increase corporate profits, in addition to optimizing the artificial regeneration of this species to meet the goal of increasing the area of planted forests by 4 million hectares, as planned by the Brazilian state through the National Plan for the Development of Planted Forests (PNDR) (BRASIL, 2024).

In addition, the vegetative propagation of species such as *P. taeda* is a strategic alternative to accelerate genetic improvement programs and meet the need for high-quality seedlings. Vegetative propagation contributes to standardizing the quality standard of propagules and the massive production of genotypes with high genetic superiority. Vegetative propagation carried out by mini-cutting of families can increase the juvenility of propagules, increasing the rooting, survival, and productivity of mini-cuttings compared to cuttings.

Cuttings are still used mainly in the selection for improvement of tree species occurs during harvesting, as this is the period when the characteristics of commercial interest show maximum expression. However, advancing age, maturity, and physiological state of these selected trees relate to low rooting abilities of the propagules extracted from the mother plant (XAVIER *et al*., 2013). This is particularly applicable to species of *Pinus* such as *Pinus taeda* L. that have little or no aptitude for sprouting and rooting when vegetative rescue techniques are applied (ANDREJOW; HIGA, 2009; RIVERA-RODRÍGUEZ *et al.*, 2016).

Family silviculture was developed for such situations. Like clonal silviculture, this process uses genetic tests to select the superior families, as opposed to specific trees, since low-level cloning is not a viable method or when there are little seeds, thus the mini-garden is formatted for plants of seeds as some forest species (WHITE *et al*., 2007). Once the optimal families are selected, the seeds produce seedlings that are placed in structures similar to clonal mini-gardens that assume the role of the propagule donor plant (mini-stump). Since mini-stumps have youthful characteristics, mini-cutting rooting rates are generally high in the apex or side shoots (STUEPP *et al*., 2018).

Maintaining the vegetative vigor of the mini-stump is essential for mini-cutting and determination of the rooting rate, root formation speed and maintaining of high productivity of mini-garden (XAVIER *et al.*, 2013). Productivity can be expressed as the total number of mini-cuttings harvested per mini-stump (PIMENTEL *et al.*, 2019) or area (m²), thereby providing a management dimension of the productive unit. The productivity of mini-stumps is influenced by seasonality, nutritional management, and clonal mini-garden type (ALFENAS *et al*., 2009).

Clonal mini-gardens range from those utilizing hydroponics with polyethylene trays to fiber cement tile, (FERNANDES *et al*., 2018). A cover is often used to protect the mini-stumps from rainfall, since excess water can cause nutrients to leach and act as a vector for phytopathogens (ALFENAS *et al*., 2009). The addition of a cover also allows for better control of temperature variations in temperate regions.

Substrates of mini-garden require adequate drainage to avoid waterlogging and algae and cyanobacteria formation and to facilitate desalination. However, as drainage increases, nutrients close to the roots are secreted, and fertigation must be more frequently implemented (ALFENAS *et al*., 2009). Therefore, it is recommended to use sand with various granulometries that has good drainage and is practically inert (ALFENAS *et al*., 2009). However, a mixture of other components, such as gravel and commercial seedling substrate, is also used.

Productivity is also dependent on genotype behavior during vegetative propagation. Rooting abilities differ by genotype because gene expression is a factor in rhizogenesis (ALFENAS *et al.*, 2009), and since rooting is a required phenotypic expression, it can be used as a secondary trait for selection (WHITE *et al*., 2007). Therefore, investigating the ability and efficiency of the selected families for vegetative propagation production is a critical aspect of pine family silviculture.

The main hypothesis is that environmental conditions of clonal mini-gardens affect the efficiency of the production of propagules, rooting of mini-cuttings, and production of vegetatively propagated mini-cuttings. In this context, we aimed to acess variations in the environmental conditions of the mini-garden and the efficiency of selected families of *P. taeda* for the production of propagules, rooting of mini-cuttings and production of vegetatively propagated mini-cuttings.

MATERIAL AND METHODS

Study site

The experiment was conducted in a forestry research nursery owned by Klabin, a pulp and paper industry (24°13′34″ S; 50°32′44″ W), in Telêmaco Borba, Paraná, Brazil, between 2016 and 2018. The region has an altitude of approximately 768 m.a.s.l., a humid subtropical climate with hot to moderately-hot summers, and a climate classification of Cfa/Cfb (mixed), according to the Köppen system. The average temperature is 19.5°C, and June to July average approximately 14°C (MANOSSO *et al.*, 2013). The total annual precipitation is 1700 mm, there are not present dry season, with July to August presenting less accumulated precipitation (MANOSSO *et al.*, 2013).

Environmental Variations and Experimental Design

The mini-gardens were formed by planting 150-day-old seminal seedlings of each family into mini-stumps. All mini-gardens were maintained on suspended benches made of fiber cement tile approximately 1 m wide with mini-stump spacing of 0.1 m × 0.1 m. The experiment followed a completely randomized design in a factorial scheme of 2 × 3 × 3 represented by the presence or absence of covering, three substrate formulations, and three families.

The two covering conditions tested were the presence of covering in a greenhouse and the absence of covering in an open courtyard. The three substrate formulations were S1 (100% coarse sand; 1.0 mm particles); S2 (80% soil + 20% coarse sand); and S3 (70% decomposed pine bark +30% carbonized rice husk). *P. taeda* trees were separated into Family 1 (F1; seeds originating from a controlled pollination matrix selection in Paraná; local breed Fazenda Monte Alegre, originating in North Carolina/South Carolina, USA); Family 2 (F2; seeds from an open pollination matrix selection in Santa Catarina; sourced from South Africa and originating in North Carolina/South Carolina, USA); and Family 3 (F3; a mix of open-pollinated seeds selected in Paraná; from Marion County, Florida, USA). The physical and chemical attributes of the soils are listed in Table 1.

Table 1. Physical and chemical attributes of the Dystrophic Red Latosol clayey texture soil at 0–20 cm depth in Telêmaco Borba, Paraná, BR

Tabela 1. Atributos físicos e químicos de Latossolo Vermelho Distrófico de textura argilosa na profundidade de 0–20 cm em Telêmaco Borba, Paraná, BR

Attribute	Value	Attribute	Value
Clay (%)	54	%SAT.CEC (Bases)	19
pH-H_2O	4.75	%SAT.CEC (Al)	26.75
pH-SMP	5.15	Ca/Mg	4.8
P(mg/dm^3)	3.9	Ca/K	18
K(mg/dm^3)	49.5	Mg/K	3.65
O.M. (%)	2.95	S (mg/dm^3)	22
Al (cmolc/dm^3)	1	Zn (mg/dm^3)	2.95
Ca (cmolc/dm^3)	2.15	Cu (mg/dm^3)	3.65
Mg (cmolc/dm^3)	0.45	B (mg/dm^3)	0.4
Al+H (cmolc/dm^3)	11.6	Mn (mg/dm^3)	13.5
CEC (cmolc/dm^3)	14.3		

Legend: SMP: Shoemaker, McLean, and Pratt method; O.M.: organic matter; CEC: cation exchange capacity; % SAT.CEC: CEC saturation percentage.

Mini-cutting protocol

Mini-cuttings with a minimum height of 5 to 8 cm and presenting needles were collected 60 days after planting. Thermal boxes were used to transport the samples from the collection area to the staking region to keep the mini-cuttings hydrated. The number of staked shoots varied depending on the collection, management system, and collected genotype, with a minimum of 15 mini-cuttings per plot. The mini-cuttings were staked in 77 cm³ paper pots filled with 80% Carolina Soil® commercial substrate + 20% carbonized rice husks and 1.5 kg/m³ of Osmocote® NPK 15-09-12.

The mini-cuttings were maintained for 90 days in a greenhouse for rooting, with a controlled temperature of 25–28°C and a constant relative humidity of 70%, regulated by micro-sprinkler irrigation. Mini-cuttings with one or more observable roots were kept in a shade house for 60 days, with a 50% shading screen and sprinkler irrigation. In the final productive cycle, mini-cuttings remained on benches in full sun for 60 days, where fertirrigation of a mixture of macro and micronutrients was administered by spraying.

Variables analyzed and sample size

The production of shoots per mini-stump (SM) was quantified by considering the total number of suitable shoots per collection (i.e., disease-free and 5–8 cm in height), number of mini-stumps, and area of the mini-garden in the first experiment, also the mini-cuttings were evaluated according to their percentage of rooted mini-cuttings (RMC) and survival after leaving the shade house (SSH) based on the number of mini-cuttings, that were introduced in greenhouse. At the end of the production cycle, the height was evaluated using a ruler graduated in centimeters, and the diameter of the collar was measured using a digital caliper (in millimeters) of 15 mini-cuttings randomly selected from the rooted mini-cuttings in the second experiment.

To evaluate the shoot production per mini-stump were used plots of 50 mini-stumps with nine replications, while to evaluate the rooted mini-cutting percentage (RMC) and survival after leaving the shade house (SSH) were used plots of 50 mini-cuttings, were used plots of 15 mini-cuttings and six replications were used for the mini-cuttings height and diameter measurements, this latter was the second experiment to evaluate the heght and diameter of mini-cuttings with the same degree of treatment that the previous.

Statistical Analysis

The data of the SM, RMC, and SSH variables were transformed using the square root to meet the assumptions of analysis of variance (ANOVA). ANOVA was performed at a 5% probability of error, and when significant, the Tukey's test was conducted at a 5% probability of error. All analyses were conducted using SISVAR software (Ferreira, 2019).

RESULTS

There was a significant interaction between substrate and covering effects when analyzing the percentage of rooted mini-cuttings (RMC) (Table 2). The presence or absence of cover in the clonal mini-garden significantly affected all analyzed variables, except for the height of the mini-cuttings at the end of the cycle. The families presented significant variations in the production of mini-cuttings per production area (SM) and the height and diameter of the mini-cuttings at the end of the productive cycle.

Table 2. Summary of the analysis of variance for shoot per production area (SM), rooted mini-cuttings (RMC), survival after leaving the shade house (SSH), and height and diameter of mini-cuttings, as functions of the substrate and cover of the mini-garden in three families of *Pinus taeda*.

Tabela 2. Resumo da análise de variância para produção de brotos (SM), miniestacas enraizadas (RMC), sobrevivência após sair da casa de sombra (SSH), altura e diâmetro das miniestacas, em função do substrato e cobertura do minijardim em de três famílias de *Pinus taeda*.

Source of variation	**DF**	**Mean square**			**DF**	**Mean square**	
		SM	RMC	SSH		Height	Diameter
Substrate (S)	2	8.26	0.110*	0.07	2	20.6	0.78
Cover (C)	1	275.47*	0.117*	0.39*	1	2.81	0.81*
Family (F)	2	82.57*	0.001	0.02	2	45.79*	1.54*
S*C	2	22.79	0.100*	0.12	2	4.95	0.21
S*F	4	1.88	0.007	0.01	4	9.45	1.35
C*F	2	7.73	0.006	0.04	2	3.07	0.16
S*C*F	4	14.54	0.007	0.03	4	1.99	0.7
Error	144	16.13	0.027	0.07	90	12.4	21.03
CV (%)		43.45	18.27	36.19		25.55	16.15

* $p < 0.05$ for the F test; CV: Coefficient of variation; DF: degrees of freedom.

The interaction between substrate and the presence or absence of cover in the mini-garden affected percentage of rooting of the mini-cuttings (Figure 1). The interaction occurred due to the low RMC from the mini-garden containing Substrate 1 (100% coarse sand) and the presence of covering (78.2%). The other treatments did not differ, with rooting rates of 91.7% to 95.6% (Figure 1).

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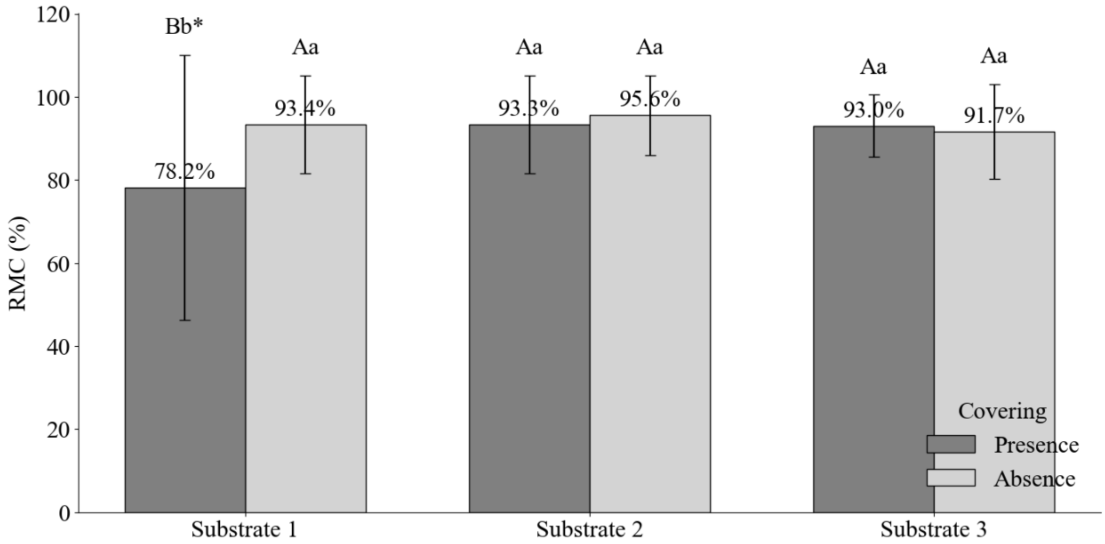

Figure 1. Effect of mini-garden substrate formulation and presence or absence of covering on the percentage of rooted mini-cuttings (RMC) of *Pinus taeda* in Telêmaco Borba.
Figura 1. Efeito da formulação do substrato de minijardim e presença ou ausência de cobertura na porcentagem de miniestacas enraizadas (RMC) de *Pinus taeda* em Telêmaco Borba.
*Means followed by the same letters, uppercase in the substrate and lowercase in the covarege, do not differ statistically by Tukey's test at a 5% error probability.

The presence of covering in the clonal mini-garden of *P. taeda* caused a significant reduction in the production of mini-cuttings per mini-stump (SM), lower survival on exiting the shade house (SSH), and smaller diameters of the mini-cuttings (Figure 2). The removal of the covering in the clonal mini-garden provided increases of 33% in the production of shoots per mini-stump 10% in the survival of the mini-cuttings after exiting the shade house, and 6% in the diameter of the mini-cuttings produced (Figure 2).

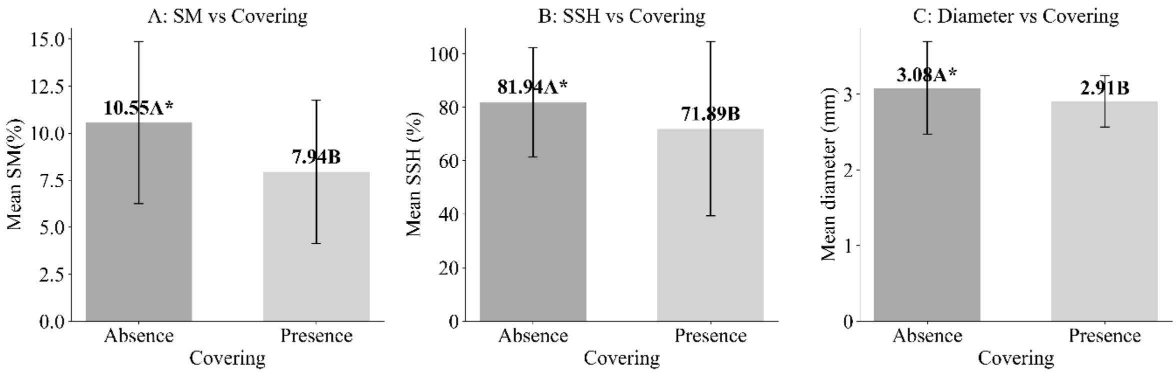

Figure 2. Mean production and standard deviation of variables: mini-cuttings per mini-stump (SM) (A), survival after leaving the shade house (SSH) (B), diameter of (C) *Pinus taeda* mini-cuttings, in the presence or absence of covering in the clonal mini-garden in Telêmaco Borba.
Figure 2. Produção média e desvio padrão das variáveis: miniestacas por minicepa (SM) (A), sobrevivência após saída da casa de sombra (SSH) (B), diâmetro (C) das miniestacas de *Pinus taeda*, na presença ou ausência de cobertura no minijardim clonal em Telêmaco Borba.
*Legend: Means followed by the same letters in the column do not differ statistically by Tukey's test at 5% error probability.

REVISTA FLORESTA
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Family 3 presented the highest absolute values for the production of mini-cuttings (SM) and a growth in height and diameter of mini-cuttings that was statistically superior to that of Family 2 (Figure 3). Family 1 presented intermediate values between F2 and F3 that were not statistically different from either family, except for the diameter of the cuttings, which was greater than that of F2 (Figure 3).

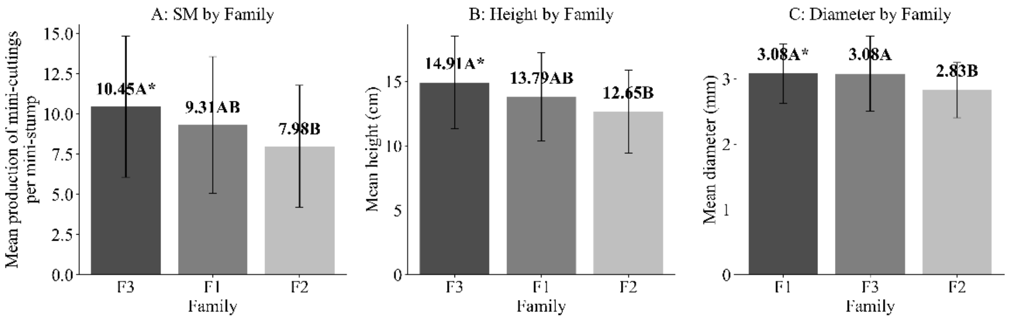

Figure 3. Means and standard deviations of variables that do not show differences between treatment: mini-cutting per area (SM) (A), height (B) and diameter (C) of three families of *Pinus taeda* mini-propagated cuttings in Telêmaco Borba.

Figura 3. Médias e desvios-padrão das variáveis que não apresentaram diferenças entre os tratamentos: miniestaquia por área (MS) (A), altura (B) e diâmetro (C) de três famílias de *Pinus taeda* miniestaqueadas em Telêmaco Borba.

*Legend: Means followed by the same letters in the column do not differ statistically by Tukey's test at 5% error probability.

Figures 4 and 5 show the variables that did not show significant differences between treatments. The SM showed an overall average of 9.24 mini-cutting per mini-stump, while the SSH average was 76.91% and the RMC was 90.86%. The overall average height was 13.79 cm, while the overall average diameter was 2.99 cm.

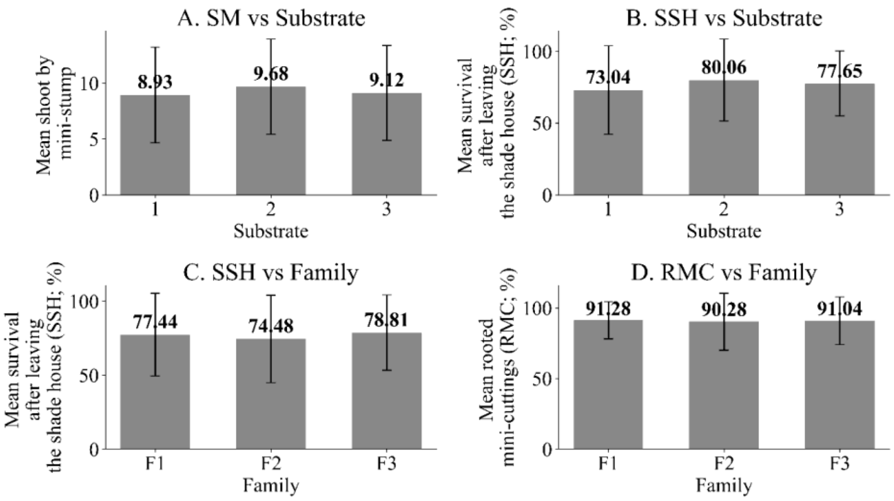

Figure 4. Mean and standard deviation of variables that did not show differences between treatment: shoots per mini-stump (SM) (A), survival after leaving the shade house (SSH) per substrate (B), survival after leaving the shade house (SSH) per family (C), rooted mini-cuttings (RMC) (D) of *P. taeda* in Telêmaco Borba.

Figura 4. Médias e desvios-padrão das variáveis que não apresentaram diferenças entre os tratamentos: brotos por minicepa (SM) (A), sobrevivência após saída da casa de sombra (SSH) por substrato (B), sobrevivência após saída da casa de sombra (SSH) por família (C), miniestacas enraizadas (RMC) (D) de P. taeda em Telêmaco Borba.

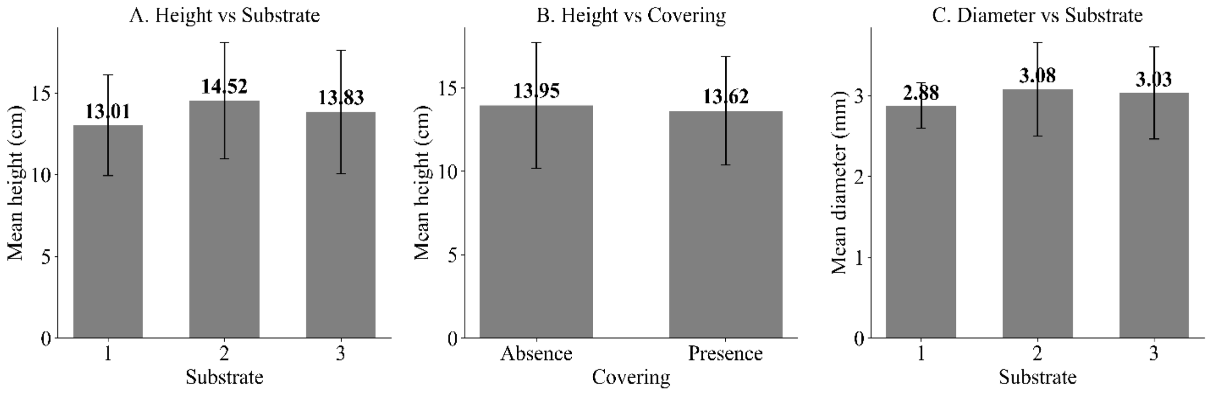

Figure 5. Means and standard deviations of variables that did not show differences between treatment: height (A), survival after leaving the shade house (SSH) per substrate (B), survival after leaving the shade house (SSH) per family (C), rooted mini-cuttings (RMC) (D) of P. taeda in Telêmaco Borba

Figura 5. Médias e desvios-padrão das variáveis que não apresentaram diferenças entre os tratamentos: altura (A), sobrevivência após saída da casa de sombra (SSH) por substrato (B), sobrevivência após saída da casa de sombra (SSH) por família (C), miniestacas enraizadas (RMC) (D) de *P. taeda* em Telêmaco Borba

DISCUSSION

According to the results presented, it is worth highlighting that *P. taeda* presented high RMC. This is evident, since the rooting of mini-cuttings from *P. taeda* families was higher than *Pinus radiata* D.Don, which presented 76.6% (CORRÊA *et al.*, 2015). *P. taeda* families showed greater rooting than *Pinus massoniana* Lamb. cuttings, which showed, approximately, 18% to 65% rooting depending on the collection period (PAN *et al.*, 2021). Also showed greater rooting than *Pinus patula* Schiede ex Schl. & Cham cuttings, which showed 1.9% to 37.5% rooting (BAUTISTA-OJEDA *et al.*, 2021). This superiority in relation to cuttings can be explained by the greater juvenility of mini-stems in relation to stems and greater physiological vigor than better management conditions in the mini-garden.

The low percentage of mini-cuttings rooted in Substrate 1 (100% coarse sand) with the presence of covering in the mini-garden (Figure 1) may be closely related to excess humidity. This water excess is a problem, because it is one of the main motives of the proliferation of biotic diseases, particularly in forest nurseries (FERNANDES *et al.*, 2018). Furthermore, water excess in the mini-garden substrate can cause hypoxia in the roots, resulting in reduced growth of the mini-stump roots, reduced absorption of nutrients and causing leaf abscission and reduction of carotenoid content, thus reducing the rooting capacity of shoots from the mini-garden (GOTO *et al.*, 2022).

Although the recommendation of coarse sand for substrate for mini-gardens mainly relates to higher drainage capacity, characteristic of its low water retention (ALFENAS *et al.*, 2009), in this study, the size of the particles, combined with the mild local temperatures and the presence of covering, changed the behavior of this substrate, favoring the accumulation of moisture. This phenomenon emphasizes the importance of considering the characteristics of locally available substrates and their adaptation to the specific conditions of each nursery. In Telêmaco Borba, the use of shorter granule sand with covered mini-gardens should be avoided for *P. taeda*.

What can be adjusted in the management of the mini-garden with this sand is the irrigation depth applied to the mini-garden, an aspect not evaluated in this article, but which may be part of future work. For example, the use of 2.19 mm irrigation in a eucalyptus mini-garden reduced the period required for rooting of a hybrid clone of *Eucalyptus urophylla* S. T. Blake and *Eucalyptus grandis* W. Hill ex Maiden (FERNANDES *et al.*, 2018).

There was no significant difference in the use of any of the substrates tested (S1, S2, or S3) with regard the rooting of the mini-cuttings when the covering was absent (Figure 1). In this situation, Substrate 1, consisting of 100% coarse sand, is highlighted for its accessibility and lower cost (R$ 80.00/m³ to R$130.00/m³ including freight) compared to the cost of the soil components, decomposed pine bark (R$100.00/m³ without freight), and carbonized rice husk (R$70.00/m³ without freight), used in the formulation of Substrates 2 and 3. All values were quoted in May 2022 and when possible, from locations close to Telêmaco Borba. An ideal substrate presents physical and chemical characteristics that are not supplied by a single component. The different components of the substrate can change its physical and chemical characteristics (KRATZ *et al.*, 2013) and can be recommended according to these desirable characteristics. However, coarse sand, which is practically inert and presents good physical-chemical characteristics, has been the most commonly used substrate for the cultivation of mini-stumps, presenting high survival of mini-stumps and productivity of mini-cuttings in forest species (ALFENAS *et al*., 2009).

The removal of the covering in the clonal mini-garden provided increases in production, survival and morphological characteristics of the mini-cuttings (Figure 2). Coverings for mini-garden structures act as protective layers, reducing environmental variations and protecting mini-stumps from harmful effects such as nutrient leaching and pathogen spread by rainwater (ALFENAS *et al*., 2009). Since the covering is a translucent plastic structure, it has little or no effect on solar radiation; however, the surface of the covering can accumulate excess dust that can affect the incidence of radiation on the structure and the production of shoots (ALFENAS *et al*., 2009).

The presence of the covering can also raise the average air temperature, which is higher than the external temperature by approximately 0.5°C to 9.0°C due to the greenhouse effect (REBOUÇAS *et al*., 2015). This condition can lead to water or thermal stress from the high transpiration of the mini-stumps, which reduces the potential for sprouting, as shown in Table 4. Andrejow and Higa (2009) indicated that higher temperatures in summer provided greater shoot production in *P. taeda*. In contrast, Alcantara, *et al*. (2008) reported that the milder temperatures in winter were more favorable for the collection of shoots in the same species.

The percentage of rooting did not vary between the families tested (Figure 4), corroborating the findings of Andrejow and Higa (2009), who found no variation in the percentage of rooting of mini-cuttings in 10 families of *P. taeda*. It is possible that the low variation in the percentage of rooting between families was related to the high rooting potential of the young mini-cuttings. However, a statistical difference was observed between the *P. taeda* families in shoot production per mini-stump and mini-cuttings growth, indicating that there may be genetic variation between populations for these characteristics.

The higher productivity of mini-stumps in the absence of covering was different from that of *Sequoia sempervirens* (D. Don) Endl., which showed higher productivity of mini-stumps in a shaded environment. However, these authors did not test the type of substrate used in the mini-garden (NAVROSKI *et al*., 2022). The highest production of shoots and the greatest height of mini-cuttings were observed, respectively, in mini-stumps and mini-cuttings of the F3 family from Marion County, Florida, USA, which is an area with climatic characteristics close to that of tropical regions. The F2 family had the lowest shoot production potential per mini-stump and the lowest average mini-cuttings growth.

The mini-cuttings diameter of families of *P. taeda* was higher than seedlings of *P. taeda*, which showed 2.9 mm at 152 days after sowing (MANERICH; LUNARDI NETO; OLIVEIRA, 2022). The plant height of *P. taeda* families (13.78 cm) was higher than *P. pinaster* at 120 days after cut that showed mean of 6.01 cm (CORRÊA *et al*., 2015). Thus, *P. taeda* showed high morphologic growth.

Despite the control of nursery conditions, the best performance of the F3 family may be related to the bioclimatic similarity between Telêmaco Borba, Paraná, BR and Marion County, Florida, USA, since are located close to the tropics and present similar annual minimum temperatures, whereas the other families have origins in more temperate environments (North Carolina/South Carolina, USA). The influence of environmental conditions on the expression of phenotypes is observed in the genotype-environment interactions of certain *P. taeda* traits, such as silvicultural performance (MCKEAND *et al*., 2006) or efficiency in the use of specific resources (ULRICH *et al*., 2020).

The significant interaction between substrate and family, covering and family, triple interaction of factors could occur, since the families are of different origins, as it is understood that they evolved with different adaphoclimatic adaptations. In addition, the breeding populations in which the seedling seeds were collected underwent different crossing procedures (controlled and open) and came from different regions. Despite these differences, the families did not show any significant interaction. The practical implication of this result is that the management conditions can be standardized for all families, without the need for specific adjustments of substrate or covering of the mini-garden. This reduces the management complexity of mini-garden. In addition, this demonstrates that the minicutting technique of *P. taeda* is efficient and adaptable to different substrates and covering conditions, at least for the genetic materials and conditions tested.

Once genetic variation exists, it is possible to select for these traits using a two-step selection method (WHITE *et al*., 2007). The first step is focused on productivity in the field, while the second considers the mass vegetative propagation phase, in which families are selected based on the productivity of the mini-garden. There is a correlation between rooting potential and growth in height at two years of age in *P. taeda* (BALTUNIS *et al*., 2007), thereby allowing for a possibility of indirect selection with gains in both characteristics.

CONCLUSIONS

- Management conditions of clonal mini-gardens affect the efficiency of the production of propagules, rooting of propagules and production of vegetatively propagated mini-cuttings.
- Under the presence of covering, substrate 1 presented the lowest RMC). Thus, it is not recommended to use coarse sand in the presence of cover in the mini-garden.
- The absence of covering provided greater SM, SSH and greater diameter of mini-cuttings.
- The F3 and F1 families showed higher SM and mini-cuttings growth than the F2 family.

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