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Original article

*Effect of hydrated phenolic foam on the survival of **Pinus leiophylla** Schiede ex Schltdl. & Cham and **Pinus teocote** Schltdl. & Cham*

*Efecto de la espuma fenólica hidratada en la supervivencia de **Pinus leiophylla** Schiede ex Schltdl. & Cham y **Pinus teocote** Schltdl. & Cham*

*Efeito da espuma fenólica hidratada na sobrevivência de **Pinus leiophylla** e **Pinus teocote** Schltdl. & Cham*

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ABSTRACT

Countries like Mexico make significant efforts to reforest, but the results are not good due to the low survival rates caused by drought and water stress. Therefore, the effect of applying hydrated phenolic foam at plantation moment, on the survival and growth in *Pinus leiophylla* and *Pinus teocote* was assessed. Two trials were established, one for each species, with five treatments of different volumes of hydrated phenolic foam. The variables measured were survival, growth in height and diameter. The analyzes showed that hydrated phenolic foam significantly increases survival and height growth in *Pinus leiophylla*, but not in *Pinus teocote*. No effect was shown on diameter for any of the species. The application of hydrated phenolic foam at planting moment increase the survival of pine.

Keywords: water stress; Pine tree; Forest plantations; reforestation; drought.

RESUMEN

Países como México realizan importantes esfuerzos para reforestar su territorio, pero los resultados no son buenos debido a sus bajas tasas de supervivencia provocadas por la sequía y el estrés hídrico. Por lo que se evaluó el efecto de aplicar espuma fenólica de célula abierta hidratada al momento del trasplante en la supervivencia y el crecimiento en altura y diámetro en plantas de *Pinus leiophylla* y *Pinus teocote*. Se establecieron dos ensayos (uno para cada especie) con cinco tratamientos de diferente volumen de espuma fenólica hidratada. Las variables medidas fueron la supervivencia, el crecimiento en altura e incremento en diámetro. Los análisis mostraron que la espuma fenólica hidratada aumenta significativamente la supervivencia y el crecimiento en altura en plantas de *Pinus leiophylla*, pero no así en altura en *Pinus teocote*. No se detectó efecto sobre el diámetro para ninguna de las especies. La aplicación de espuma fenólica hidratada al momento del trasplante aumenta la supervivencia.

Palabras clave: estrés hídrico; pino; plantaciones forestales; reforestación; sequía.



RESUMO

Países como o México fazem esforços importantes para reflorestar seu território, mas os resultados não são bons devido às baixas taxas de sobrevivência causadas pela seca e pelo estresse hídrico. Portanto, o efeito da aplicação de espuma fenólica hidratada de célula aberta no momento do transplante sobre a sobrevivência e o crescimento em altura e diâmetro de *Pinus leiophylla* e *Pinus teocote* realizados dois testes (um para cada espécie) com cinco tratamentos de diferentes volumes de espuma fenólica hidratada. As variáveis medidas foram sobrevivência, crescimento em altura e incremento em diâmetro. As análises mostraram que a espuma fenólica hidratada aumentou significativamente a sobrevivência e o crescimento em altura nas plantas de *Pinus leiophylla*, mas não nas plantas de *Pinus leiophylla*. Não foi observado efeito sobre o diâmetro em nenhuma das espécies: a aplicação de espuma fenólica hidratada no transplante pode ser capaz de aumentar a sobrevivência de algumas espécies de pinheiro.

Palavras-chave: Estresse hídrico; pinheiro; plantações florestais; reflorestamento; seca.

INTRODUCTION

It is estimated that, during the years 2001 and 2012, 125,000 km² of forests and rainforests were lost annually (Winkler *et al.*, 2021). This process of deforestation is mainly due to the fact that people tend to prefer the economic benefits offered by other land uses to those provided by forests, such as carbon storage, species habitat, biodiversity, water filtration, wood and non-wood products, food and medicine, and recreation (Busch and Ferretti-Gallon 2017). Since forests are a key element in mitigating the effects of climate change, reforestation activities are gaining importance around the world. However, due to the effects of climate change, many countries are facing a difficult outlook, as droughts are becoming more severe and rainfall patterns are changing, causing plants to be exposed to greater stress. water, growth problems and even death (FAO 2018).



In Mexico, the situation is not simple, since it is estimated that 155,000 hectares of forests and rainforests are lost annually (Gao *et al.*, 2016) and reforestation programs only achieve 48 % survival. Multiple causes contribute to this: poor quality of plants, poor choice of planting dates, poor transportation practices and drought (Burney *et al.*, 2015).

One product that could help mitigate the effects of drought is the use of open cell phenolic foam. This is a thermostable synthetic resin capable of storing up to 40 times its own weight in water without deforming. Due to its physical structure, plant roots can easily pass through it and extract the water stored within it (Gardziella, Pilato and Knop 2015). This type of materials is composed of phenol-formaldehyde resins that have been expanded by exothermic reactions caused by mixing organic acids and highly volatile expansion agents. They are an inert and safe material for the environment (Liang *et al.*, 2016; Gardziella, Pilato and Knop 2015).

Open cell phenolic foam is mainly used as hydroponic substrates in greenhouses and has been shown to be able to increase survival and drastically reduce irrigation water consumption in seedlings of *Lactuca sativa*, *Eucalyptus urophylla*, *Eucalyptus sp.* and *Mentha x villosa* (Paulus *et al.*, 2005; Bezerra Neto *et al.*, 2010; Muller da Silva *et al.*, 2012).

Despite the results shown in greenhouse conditions, the effect of this material on survival and growth in field studies has been little studied by the scientific community (Palacios *et al.* 2015). The few studies carried out indicate that this material is capable of significantly increasing the survival of *Pinus leiophylla* (Palacios Romero *et al.*, 2015) due to the water reservoir effect near the rhizosphere

Besides, *Pinus leiophylla* it is one of the pine species with the greatest distribution in Mexico, capable of establishing itself in poor and degraded soils. Its wood is in high demand in the construction and paper industries (Palacios-Romero *et al.* 2017). *Pinus teocote* have wide distribution in the state of Hidalgo and that can establish itself in places with little rainfall and has a wood that is highly valued in the forestry industry (Hernández Ramos *et al.*, 2013).



Because it is increasingly important to increase survival in reforestation programs and taking into account the effect that climate change will have on drought and precipitation patterns, it is necessary to find materials that help mitigate water stress in the field. Therefore, the objective of this study was to evaluate the effect of applying hydrated open cell phenolic foam at the time of transplant on the survival and growth in height and diameter of *Pinus leiophylla* and *Pinus teocote*.

MATERIALS AND METHODS

In the month of September 2014, a trial was established in the community of "El Aserradero" belonging to the municipality of Cuatepec de Hinojosa, located in the state of Hidalgo, which is located at the coordinates 19°56'57.31" N and 98° 20'22.72" Or and at an altitude of 2,691 m (Figure 1).

The study area was approximately 1 hectare, with no slope (because the community residents had previously carried out work to reduce the runoff that affected the communities that were in lower areas) and northern exposure. The climate is type Cw with an average annual temperature of 15°C and a rainy season that runs from March to October and an average annual precipitation between 600 and 1,100 mm (INAFED 2010). The predominant vegetation in the region is pine forests. (Fonseca-González *et al.*, 2014). The soil in the area has the characteristics mentioned in Table 1. The soil analysis was carried out in the agricultural sciences research department (DICA) of the Benemérita Universidad Autónoma de Puebla.



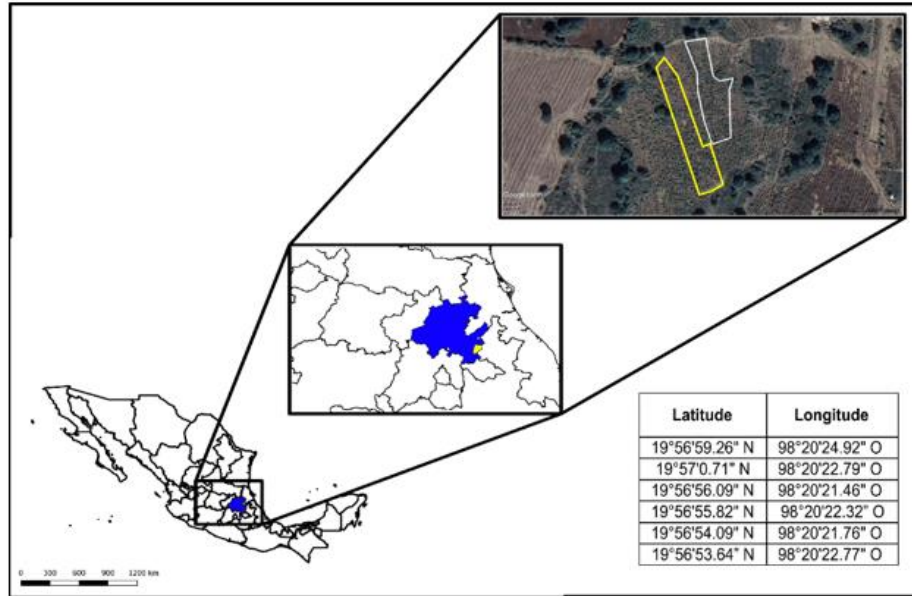


Figure 1. - Geographic location of the study area. The *P. leiophylla* plantation is shown in yellow line and the *P. teocote* plantation in white

Table 1. - Results of soil analysis of the study area

Variable	Unit	Worth
pH	-	4.9
Organic material	%	1.8
Nitrogen	%	0.075
Sand	%	19.4
Silt	%	40.0
Clay	%	40.6
Texture	-	Clayey

Plantlets of *P. leiophylla* and *P. teocote* were obtained from the commercial nursery "Vivero y Asesoría Forestal de Hgo" located in the municipality of Acaxochitlán, in the state of Hidalgo. They were produced in 170 cm³ plastic containers. The substrate consisted of a mixture of peat moss, perlite and vermiculite (3:1:1) and six grams of Osmocote plus™ slow release (09-15-12) for each liter of mixture.



The plants used were one-year-old (height of 20-25 cm), plants were selected that were free of diseases, with lignified stems and with fully developed fascicles (it was checked visually). Finally, the phenolic foam used in this test was from the Smithers-Oasis® brand that is biodegradable.

At the time of transplantation, five treatments were applied: treatment one (T1) consisted of a block of hydrated phenolic foam measuring 3.3x7x10 cm; Treatment two (T2) consisted of a 4.4x7x10 cm block of hydrated phenolic foam; Treatment three (T3) consisted of two blocks of hydrated foam 3.3x7x10 cm; Treatment 4 (T4) consisted of two 4.4x7x10 cm hydrated foam blocks; Treatment five (T5) was the control. All treatments were placed next to the root ball of the plant, trying to maximize the contact surface (Table 2).

In September 2014, the trial for *P. leiophylla* was established, 5 blocks were delimited (one block for each treatment) and in each block 35 trees were planted, with their respective treatments. The plants were placed with a separation of 3 x 3 meters between them. For each block, 3 repetitions were carried out (giving a total of 525 trees in the test).

In the case of *P. teocote*, a trial was established on the same date and with the same conditions as in the trial with *P. leiophylla*. The beds were dug with approximate dimensions of 30 x 30 x 30 cm and were made on the same date as the plantation. The soil was extracted and separated into two portions so that when the plant was placed, the surface soil (with the greatest amount of nutrients and organic matter) was in the deepest part of the vine. The rocks were removed, the lumps were pulverized and the soil was lightly compacted to avoid the presence of macropores in the soil. Both plantings were done using a true frame planting system.

The experimental design used was randomized blocks and the variables evaluated were survival and height and diameter. Survival was evaluated visually: if the plant showed signs of wilting, loss of turgor or lack of the characteristic coloration of the species, it was considered dead.



Table 2. - Description of the phenolic foam treatments used and how they were applied

Description	Placement
T1 A block of hydrated phenolic foam measuring 3.3x7x10 cm. Absorbed water volume: 227.5 ml	On one side of the plant's root ball and placed 7 cm below the surface.
T2 A block of hydrated phenolic foam measuring 4.4x7x10 cm. Volume of water absorbed: 287 ml.	On one side of the plant's root ball and placed 7 cm below the surface.
T3 Two hydrated phenolic foam blocks measuring 3.3x7x10 cm. Absorbed water volume: 455.1 ml.	On the sides of the plant's root ball and placed 7 cm below the surface.
T4 Two blocks of hydrated phenolic foam measuring 4.4x7x10 cm. Volume of water absorbed: 574 ml.	On the sides of the plant's root ball and placed 7 cm below the surface.
T5 Control (without phenolic foam blocks)	The plant was transplanted in the traditional way and without adding any other element

Height (measured in cm) and diameter (measured in cm) were evaluated through digital images according to Pereira Padrón (2014). For this, a Nikon Coolpix S2800 digital camera was used and the ImageJ version 1.48 program was used to process the images. The photographs were taken parallel to the plants at a distance of 50 cm and with a one-meter ruler as a reference. This method was chosen to speed up measurements and thus optimize time in the field. During the first six months after planting, evaluations were carried out every four weeks. After this period, two quarterly measurements and finally two semiannual measurements were carried out. Giving a total of two years after the plantation is established

The survival data were subjected to a survival analysis using the Kaplan-Meier estimator and if significant differences were present, the Log-Rank test was used to determine the best treatment. An analysis of variance was used with the variables height and diameter using a generalized linear model. To detect significant differences, Tukey's multiple comparison test of means was used as a post hoc test.



RESULTS AND DISCUSSION

Survival

The Kaplan-Meier analysis for *P. leiophylla* showed significant differences between treatments ($P=0.004$), showing a similar behavior to that reported for *Eucalyptus urophylla*, *Eucalyptus resinifera* and *P. leiophylla* (Palacios Romero *et al.*, 2015). In those studies, applying hydrated phenolic foam significantly increased plant survival under water stress conditions. The Log-Rank analysis confirmed that the control had the lowest survival compared to the rest of the treatments. On the other hand, there were no significant differences between the treatments in which the phenolic foam was used (Table 3).

Although previous studies showed that using large volumes of hydrated phenolic foam proportionally increased plant survival (Palacios Romero *et al.*, 2015), this was not the case in the present study. This can be attributed to the difference in conditions in which the studies were carried out: Palacios *et al.* (2015) established their trial in another region with different environmental and climatic conditions than those of the present study; since while in the trial by Palacios *et al.* (2015) was located in an area at 2,200 m altitude and during the time the test was carried out it reported an average of 56 mm of precipitation, while in the present study it was at an altitude of 2,691 m and with an average precipitation 64.4 mm.

During the first 150 days after transplanting, survival in *P. leiophylla* for plants with 287 ml and 455.1 ml phenolic foam (T2 and T3) was 78 and 76 %, while in the rest of the treatments it was below 72%. On the other hand, the control had a high mortality rate after 180 days after the transplant, since it went from having a survival rate of 72 % to less than 50 %. This trend lasted until 540 days after transplant, at which time survival in the control stabilized and remained at 35 % (Figure 2).



Table 3. - Log-Rank analysis of *P. leiophylla* plants with different hydrated phenolic foam treatments

Log-Rank Matrix

	T1-PF 227.5 ml	T2-PF 287 ml	T3-PF 455.1 ml	T4-PF 574 ml	T5-Control
T1-PF 227.5 ml		0.43395	0.37985	0.84210	0.00612
T2-PF 287 ml	0.43395		0.99286	0.64344	0.00023
T3-PF 455.1 ml	0.37985	0.99286		0.52940	0.00025
T4-PF 574 ml	0.84210	0.64344	0.52940		0.00406
T5-Control	0.00612	0.00023	0.00025	0.00406	

* Results less than 0.05 indicate significant differences

P. leiophylla plants with phenolic foam also had a decrease in survival after 180 days after the transplant (although this was not as pronounced as in the control). However, mortality throughout the trial was less pronounced and at the end of the experiment the survival for plants with phenolic foam of 227.5 ml and 574 ml was 58 % (10 % above that reported by Burney *et al.*, 2015) while the survival for plants with phenolic foam of 455.1 ml and 287 ml was 65 % (17 % above that reported by Burney *et al.*, 2015). The decrease in survival at 180 after transplanting can be attributed to the fact that this period of time coincided with the winter season, in which the presence of cold fronts and frosts that cause plant death is common.

When comparing survival with precipitation in the region we can see that they are directly related. It is important to note that in the period from May to August (2015) despite the high precipitation, survival continues to decrease; This can be attributed to the dog days that cause an increase in temperature, evaporation and evapotranspiration, which generated water stress in the plants and therefore could have affected survival (Hartmann *et al.*, 2022) (Figure 3).



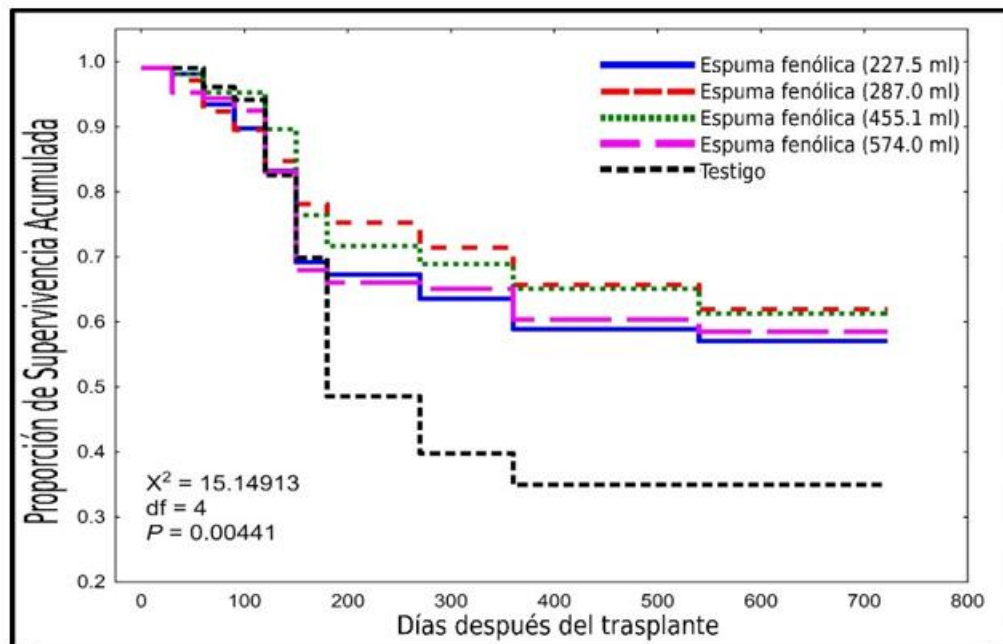


Figure 2. - Survival of *P. leiophylla* plants with different hydrated phenolic foam treatments

When comparing the results of this study with those obtained in other tests that use other materials as water reservoirs, it is observed that the phenolic foam has excellent performance, since when applied it increased the survival of the plants above what was achieved in other essays. It has been reported that applying hydrogel on *Pinus halapensis* at the time of transplanting in silty soils negatively affected its survival (Abdallah 2019). In another study, when hydrogel was applied to *Pinus sylvestris* seedlings survival decreased by 18 %. It has also been observed that applying hydrogel to *Pinus taeda* seedlings can increase mortality by 28 %. In addition to these results, there are reports that indicate that after rains the hydrogel tends to unearth the seedlings from the soil, thereby causing their death (Chang *et al.*, 2020). Something important to note is that, in all these studies, survival was lower than that obtained when applying hydrated phenolic foam at the time of transplant, which reinforces the idea that it is a viable material to use in reforestation programs and thus increasing the survival of pine plants.



Regarding *P. teocote*, Log-Rank analysis showed that there were no significant differences between treatments ($P=0.42$). However, a trend towards lower survival can be seen in the control compared to the rest of the treatments used in the trial (Figure 4).

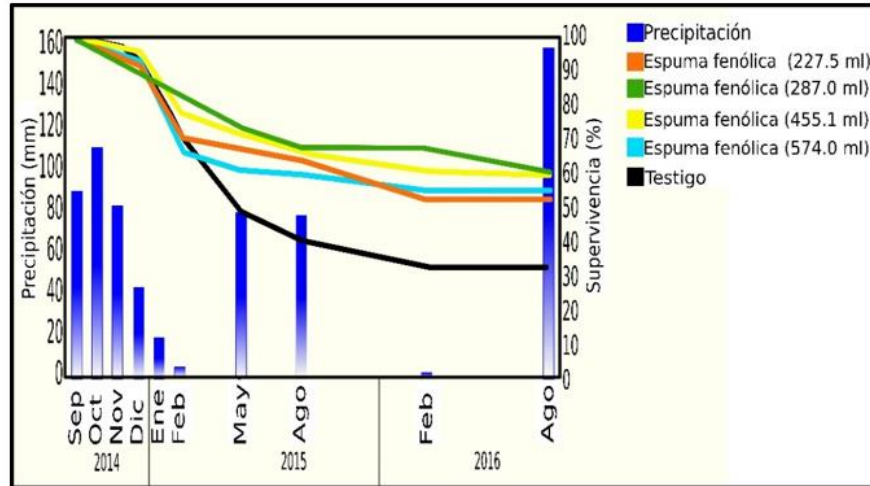


Figure 3. - Survival of *P. leiophylla* plants with different hydrated phenolic foam treatments in relation to precipitation

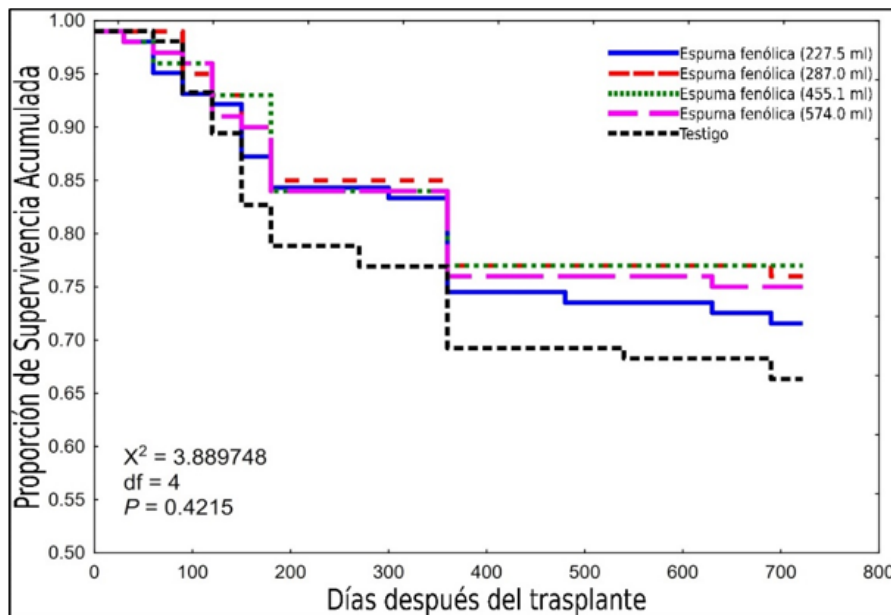


Figure 4. - Survival of *P. teocote* plants with different hydrated phenolic foam treatments



Contrary to what was observed in *P. leiophylla*, the decrease in survival in *P. teocote* was not so pronounced in the first 180 days after transplantation, since all of them maintained a survival of around 85% and remained unchanged until 365 days after transplantation. days after transplantation, at which time survival decreased to 75 % and remained stable until the end of the experiment.

The control behaved similarly to the rest of the treatments applied in *P. teocote*, although its mortality was slightly higher, reaching a survival of 78 % (7 % less than in the rest of the treatments). Also, contrary to the pattern observed in the phenolic foam treatments in the control group after 210 days, survival decreased to 75 % and once 365 days after transplantation survival had decreased to 67 %.

By relating survival in *P. teocote* with respect to precipitation can be observe that in the months with the least amount of rain the greatest plant mortality occurred (although not as pronounced as in *P. leiophylla*), this can be more easily observed in the control plants. This corroborate the positive effect of applying the hydrated phenolic foam (Figure 5). In the months of May to August (corresponding to the warmest days) the survival of *P. teocote* with hydrated phenolic foam remained unchanged, while in the control it decreased to 75 %. Although it is known that this species has a natural resistance to drought (Gernandt y Pérez-de la Rosa 2014), this event negatively affected the control, while this did not affect the plants with phenolic foam. Therefore, phenolic foam could help mitigate the effects of heatwave.

Growth in height and diameter

For the *P. leiophylla* plants, the analysis of variance (ANOVA) showed significant differences in height growth ($P=0.04$), with the control being the one that presented the lowest growth with respect to the rest of the treatments (not shown). observed significant differences between the phenolic foam treatments) (Figure 6). These results are consistent with those obtained by Palacios Romero *et al.* (2015), which indicate that applying hydrated phenolic foam on *P. leiophylla*. Regarding diameter, there was no significant effect of treatments on diameter ($P=0.68$) (Table 4).



For *P. teocote*, the analysis of variance indicated that there are no significant differences for these variables ($P > 0.05$) (Table 5).

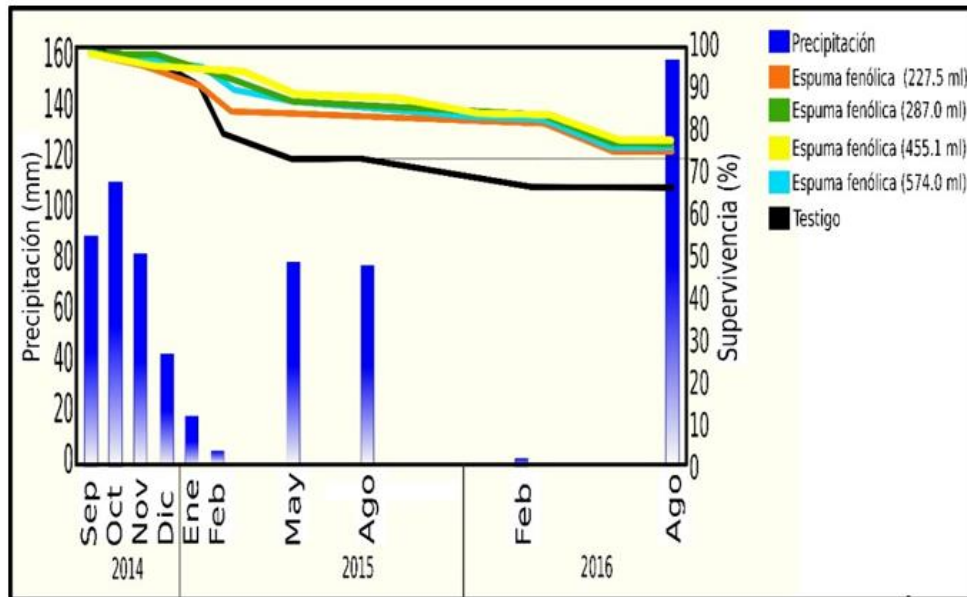


Figure 5. - Survival of *P. teocote* plants with different hydrated phenolic foam treatments in relation to precipitation

Table 4. - Analysis of variance for the height and diameter of *P. leiophylla* plants with different hydrated phenolic foam treatments

Variable	Variance analysis		Pr>F
	Mean squares		
	Treatment	Error	
	(4) ^z	(521) ^z	
Height	503.9	206.8	0.046247
Diameter	0.5435	0.9165	0.667818

^z The degrees of freedom are presented in parentheses.



Table 5. - Analysis of variance for the height and diameter of *P. teocote* plants with different hydrated phenolic foam treatments

Variable	Variance analysis		Pr>F
	Mean squares		
	Treatment (4) ^z	Error (521) ^z	
Height	137.3	153.5	0.467138
Diameter	3.772	7.186	0.106403

^z The degrees of freedom are presented in parentheses.

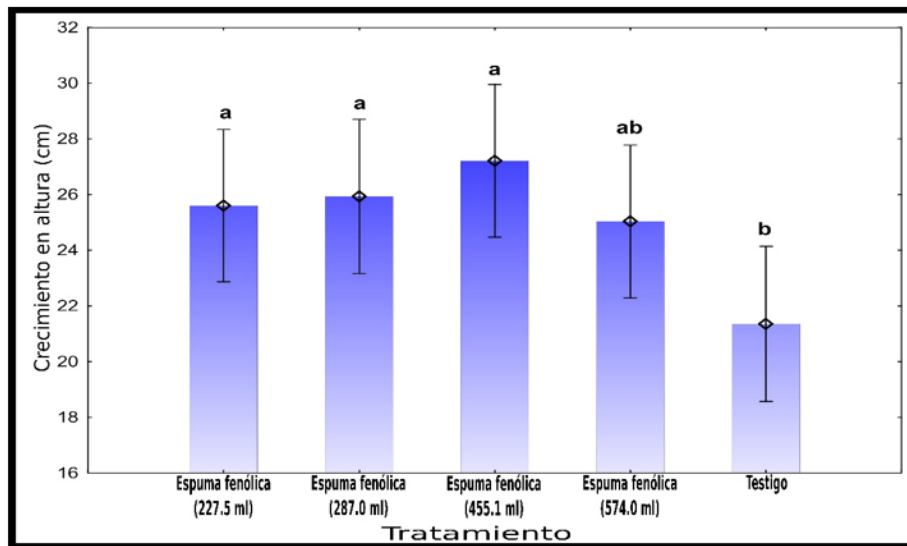


Figure 6. - Height growth in *P. leiophylla* plants with different hydrated phenolic foam treatments.

* Bars with different letters indicate significant differences ($P \leq 0.05$)

CONCLUSIONS

Applying hydrated phenolic foam at the time of transplanting significantly increases survival and height in *P. leiophylla*.

In *P. teocote*, no significant differences were observed in survival and diameter and height growth.



The study suggests that the application of hydrated phenolic foam at the time of transplant increase survival.

REFERENCES

- ABDALLAH, A.M., 2019. The effect of hydrogel particle size on water retention properties and availability under water stress. *International Soil and Water Conservation Research* [en línea], vol. 7, no. 3, ISSN 2095-6339. DOI <https://doi.org/10.1016/j.iswcr.2019.05.001>. Disponible en: <https://www.sciencedirect.com/science/article/pii/S2095633918301114>.
- BEZERRA NETO, E., SANTOS, R., PESSOA, P., ANDRADE, P., OLIVEIRA, S. y MENDONÇA, I., 2010. Tratamento de espuma fenólica para produção de mudas de alface. *Revista Brasileira de Ciências Agrárias*, vol. 5, no. 3, DOI 10.5039/agraria.v5i3a728. <https://www.redalyc.org/pdf/1190/119016971022.pdf>
- BURNEY, O., ALDRETE, A., REYES, R.A., SA, R. y MEXAL, J.G., 2015. México Addressing challenges to reforestation., vol. 113, no. July, DOI <https://doi.org/10.5849/jof.14-007>.
- BUSCH, J. y FERRETTI-GALLON, K., 2017. What Drives Deforestation and What Stops It? A Meta-Analysis. *Review of Environmental Economics and Policy*, vol. 11, no. 1, ISSN 1750-6816. DOI 10.1093/reep/rew013. <https://www.journals.uchicago.edu/doi/abs/10.1093/reep/rew013>
- CHANG, I., LEE, M., TRAN, A.T.P., LEE, S., KWON, Y.-M., IM, J. y CHO, G.-C., 2020. Review on biopolymer-based soil treatment (BPST) technology in geotechnical engineering practices. *Transportation Geotechnics* [en línea], vol. 24, ISSN 2214-3912. DOI <https://doi.org/10.1016/j.trgeo.2020.100385>. Disponible en: <https://www.sciencedirect.com/science/article/pii/S2214391220302737>.



FAO, 2018. *The State of the World's Forests 2018 Forest pathways to sustainable development* [en línea]. 1st. Rome, Italy: FAO. [consulta: 31 enero 2023]. ISBN 9789251305614. Disponible en: <https://www.fao.org/3/ca0188en/ca0188en.pdf>.

FONSECA-GONZALEZ, JUANA; DE LOS SANTOS-POSADAS, H. MANUEL; RODRIGUEZ-ORTEGA, ALEJANDRO and RODRIGUEZ-LAGUNA, RODRIGO. 2014. Efecto del daño por fuego y descortezadores sobre la mortalidad de *Pinus patula* Schl. et Cham en Hidalgo, México. *Agrociencia* [online], vol.48, n.1 [cited 2023-12-26], pp.103-113. ISSN 2521-9766. Available from: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-31952014000100007&lng=en&nrm=iso.

GAO, Y., GHILARDI, A., PANEQUE-GALVEZ, J., SKUTSCH, M. y MAS, J.F., 2016. Validation of MODIS Vegetation Continuous Fields for monitoring deforestation and forest degradation: two cases in Mexico. *Geocarto International*, vol. 31, no. 9, ISSN 10106049. DOI 10.1080/10106049.2015.1110205. <https://link.springer.com/book/10.1007/978-3-662-04101-7>

GARDZIELLA, A., PILATO, L.A. y KNOP, A., 2015. *Phenolic Resins: Chemistry, Applications, Standarization, Safety and Ecology*. 2nd. New York: Springer. vol. 2. ISBN 9788578110796. <https://link.springer.com/book/10.1007/978-3-662-04101-7>

GERNANDT, D.S. y PÉREZ-DE LA ROSA, J.A., 2014. Biodiversidad de Pinophyta (coníferas) en México. *Revista Mexicana de Biodiversidad* [en línea], vol. 85, ISSN 1870-3453. DOI <https://doi.org/10.7550/rmb.32195>. Disponible en: <https://www.sciencedirect.com/science/article/pii/S1870345314706840>.

HARTMANN, H., BASTOS, A., DAS, A.J., ESQUIVEL-MUELBERT, A., HAMMOND, W.M., MARTÍNEZ-VILALTA, J., MCDOWELL, N.G., POWERS, J.S., PUGH, T.A.M., RUTHROF, K.X. y ALLEN, C.D., 2022. Climate Change Risks to Global Forest Health: Emergence of Unexpected Events of Elevated Tree Mortality Worldwide. *Annual Review of Plant Biology* [en línea], vol. 73, no. 1, ISSN 1543-5008. DOI 10.1146/annurev-



arplant-102820-012804. Disponible en: <https://doi.org/10.1146/annurev-arplant-102820-012804>.

HERNÁNDEZ RAMOS, J., MAGAÑA, J.J.G., FLORES, H.J.M., GARCÍACUEVAS, X., REYES, T.S., LÓPEZ, C.F. y RAMOS, A.H., 2013. Guía de densidad para manejo de bosques naturales de *Pinus teocote* Schlecht. et Cham. en Hidalgo. *Revista Mexicana de Ciencias Forestales*, vol. 4, no. 19, DOI <https://doi.org/10.29298/rmcf.v4i19.379>.

INAFED, 2010. Enciclopedia de los municipios y delegaciones de México. [en línea]. [consulta: 1 enero 2015]. Disponible en: <http://www.inafed.gob.mx/work/enciclopedia/EMM13hidalgo/municipios/13024a.html>.

LIANG, B., LI, X., HU, L., BO, C., ZHOU, J. y ZHOU, Y., 2016. Foaming resol resin modified with polyhydroxylated cardanol and its application to phenolic foams. *Industrial Crops and Products*, vol. 80, ISSN 09266690. DOI 10.1016/j.indcrop.2015.11.087. <https://www.sciencedirect.com/science/article/abs/pii/S0926669015305884>

MULLER DA SILVA, P.H., KAGER, D., DE MORAES GONÇALVES, J.L. y GONÇALVES, A.N., 2012. Produção de mudas clonais de eucalipto em espuma fenólica: crescimento inicial e mortalidade. *CERNE*, vol. 18, no. 4, DOI 10.1590/S0104-77602012000400014.

PALACIOS ROMERO, A., RODRÍGUEZ LAGUNA, R., PRIETO GARCÍA, F., MEZA RANGEL, J., RAZO ZÁRATE, R. y HERNÁNDEZ FLORES, M. de la L., 2015. Supervivencia de *Pinus leiophylla* Schiede ex Schltdl. et Cham. en campo mediante la aplicación de espuma fenólica hidratada. *Revista Mexicana de Ciencias Forestales*, vol. 6, no. 32, DOI 10.29298/rmcf.v6i32.100. https://www.scielo.org.mx/scielo.php?pid=S2007-11322015000600083&script=sci_abstract



PALACIOS-ROMERO, A., RODRÍGUEZ-LAGUNA, R., RAZO ZÁRATE, R., MEZA-RANGEL, J., PRIETO-GARCÍA, F. y HERNÁNDEZ FLORES, M. de la L., 2017. Espuma fenólica de célula abierta hidratada como medio para mitigar estrés hídrico en plántulas de *Pinus leiophylla*. *Madera y Bosques* [en línea], vol. 23, no. 2, ISSN 2448-7597. DOI 10.21829/myb.2017.232512. Disponible en: <http://myb.ojs.inacol.mx/index.php/myb/article/view/512>.

PAULUS, D., MEDEIROS, S.L.P., SANTOS, O.S., RIFFEL, C., FABBRIN, E.G. y PAULUS, E., 2005. Substratos na produção hidropônica de mudas de hortelã. *Horticultura Brasileira*, vol. 23, no. 1, ISSN 0102-0536. DOI 10.1590/S0102-05362005000100010. <https://www.scielo.br/j/hb/a/3b6GskHknwkCrXVgq4kRFFB/>

PEREIRA PADRON, A.C., 2014. Utilización de imágenes digitales para medición del diámetro de frutos de mandarina (*Citrus reticulata*) en crecimiento. *Ciencia y Tecnología*, vol. 6, no. 1, DOI 10.18779/cyt.v6i1.173. <https://dialnet.unirioja.es/servlet/articulo?codigo=4737493>

WINKLER, K., FUCHS, R., ROUNSEVELL, M. y HEROLD, M., 2021. Global land use changes are four times greater than previously estimated. *Nature Communications* [en línea], vol. 12, no. 1, ISSN 2041-1723. DOI 10.1038/s41467-021-22702-2. Disponible en: <https://doi.org/10.1038/s41467-021-22702-2>.

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