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Director: DrC. Marta Bonilla Vichot
Email: mbon@upr.edu.cu

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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*

Abraham Palacios Romero[1], Rodrigo Rodríguez Laguna[2], Ramón Razo Zárate[2], Edith Jiménez Muñoz[3]*

[1] Tecnológico de Monterrey. Mexico

[2] Institute of Agricultural Sciences, Autonomous University of the State of Hidalgo. Mexico.

[3] Apan Higher School, Autonomous University of the State of Hidalgo. Mexico.

*Corresponding author: abraham.palacios@tec.mx

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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 km ^{2} 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 Cuautepec 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.

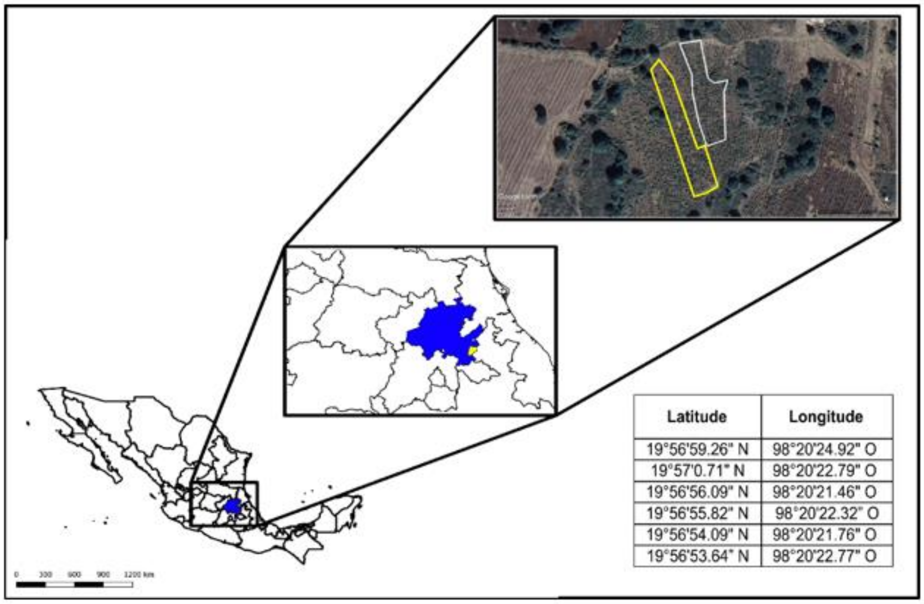

Figure 1. *- Geographic location of the study area. The P. leiophylla plantation is shown in yellow line and the P. teocote plantation in white*

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 cm^3 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).

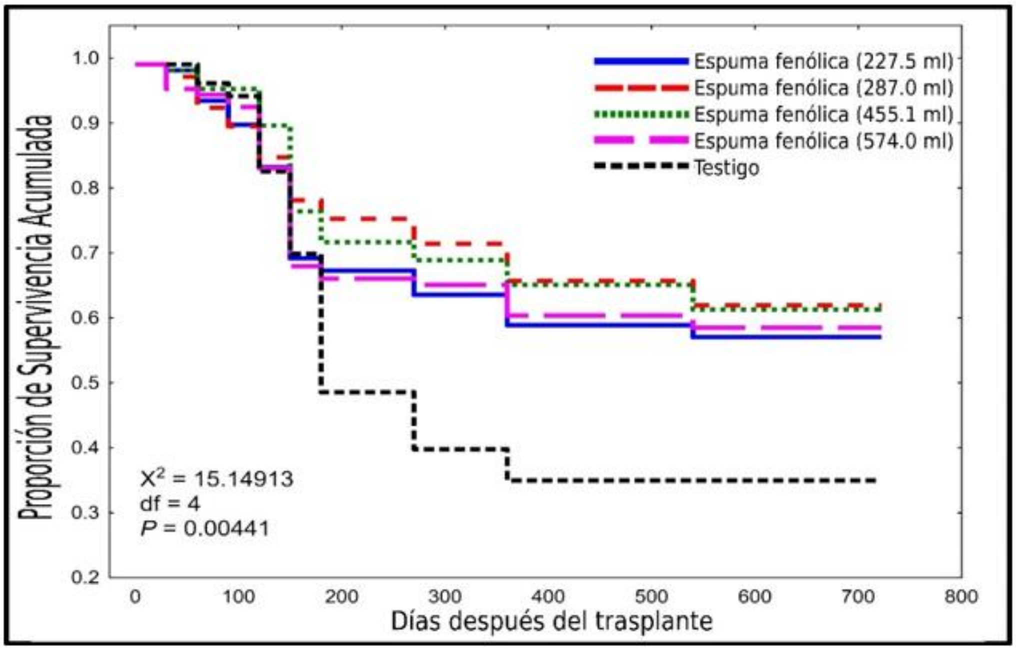

Figure 2. *- Survival of P. leiophylla plants with different hydrated phenolic foam treatments*

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).

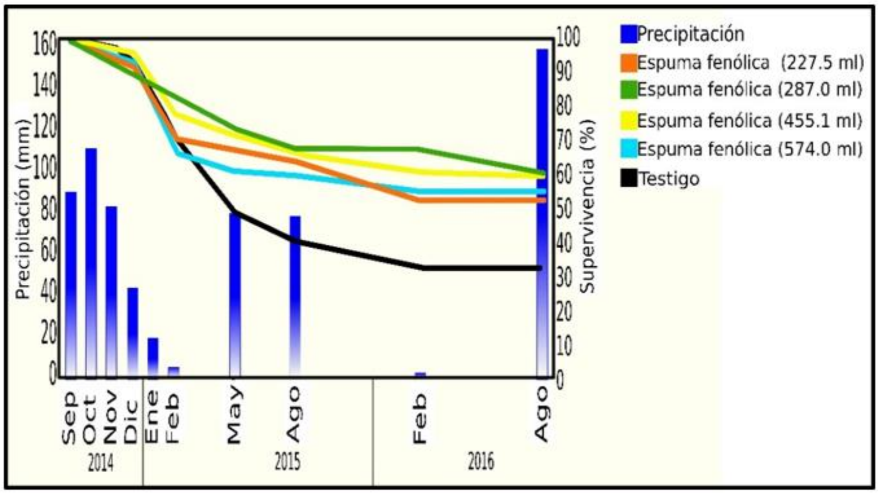

Figure 3. *- Survival of P. leiophylla plants with different hydrated phenolic foam treatments in relation to precipitation*

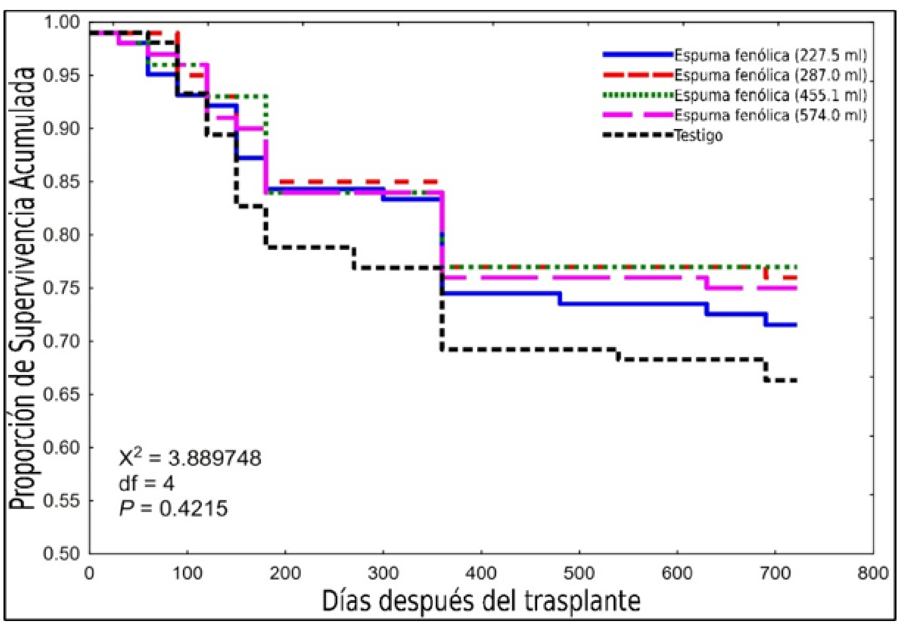

Figure 4. *- Survival of P. teocote plants with different hydrated phenolic foam treatments*

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).

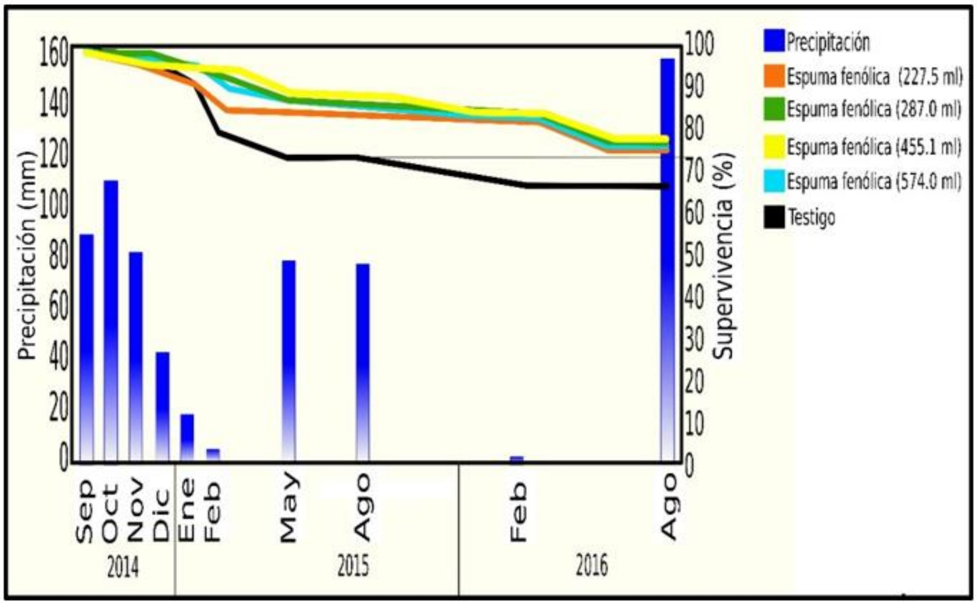

Figure 5. *- Survival of P. teocote plants with different hydrated phenolic foam treatments in relation to precipitation*

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

Variable	Variance analysis		
	Mean squares		Pr>F
	Treatment (4)[z]	Error (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*

Variance analysis			
Variable	Mean squares		Pr>F
	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.

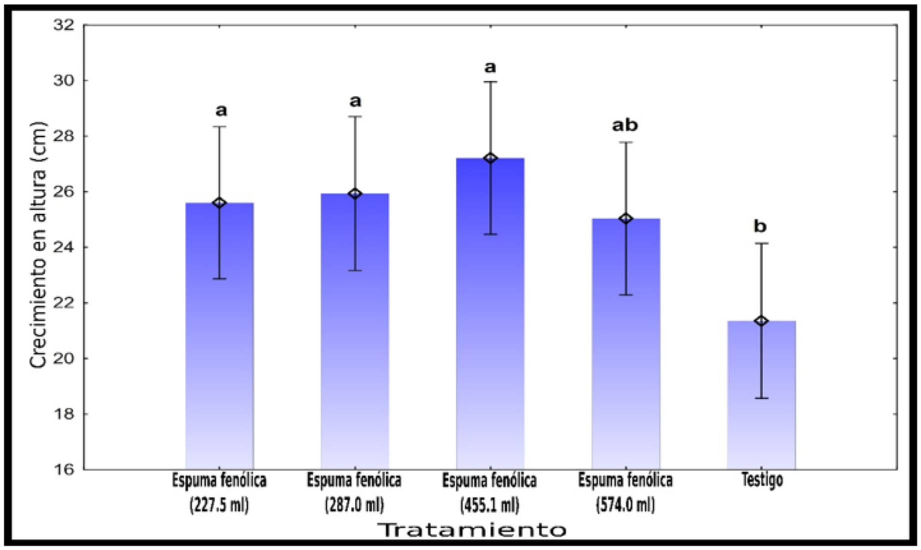

Figure 6. *- Height growth in P. leiophylla plants with different hydrated phenolic foam treatments.*

* Bars with different letters indicate significant differences (P≤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.

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***Conflict of interests*:**

The authors declare not to have any interest conflicts.

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The authors have participated in the writing of the work and analysis of the documents.

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