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Effect of sectioning, drying, and shading on the propagation of *Opuntia cochenillifera* (L.) Mill. cladodes

Efecto del seccionamiento, secado y sombreado en la multiplicación de cladodios de *Opuntia cochenillifera* (L.) Mill.

Efeito da divisão, secagem e sombreamento na multiplicação de cladódios de Opuntia cochenillifera (L.) Mill.

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Abstract

Opuntia cochenillifera (L.) Mill. has a forage potential in arid areas. Because pastures are insufficient to meet livestock's nutritional demands during the dry season, this research aimed to evaluate the effects of sectioning (S), drying (D), and shading (Sh) of cladodes on the propagation of *Opuntia cochenillifera* (L.) Mill. The S factors (whole cladode and apical, middle, and basal sections), D (pre-drying at room temperature on mesh under shade for 14 days), and Sh (with and without shading under 80 % density raffia mesh), resulted in a combination of 16 treatments, arranged in a split-plot treatment design and a completely randomized experimental design. Percentages of living, rooted, and sprouted cladodes, number of shoots per cladode, and number and length of roots were evaluated 35 days after establishment. An analysis of variance and a means test were applied to determine differences among treatments. An increase in the percentage of rooted cladodes was obtained with the middle, apical, and basal fractions compared to the whole cladode, regardless of the drying process. Prior shading was counterproductive for cladode survival; high environmental humidity, combined with their water content, may have favored the appearance of secondary rots. In general, considering most of the variables evaluated, cladode sectioning without drying emerged as the best technique for asexual propagation of the species, due to the yield of vegetative material and its practicality.

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Resumen

La *Opuntia cochenillifera* (L.) Mill. tiene potencial forrajero en zonas áridas. Debido a que en la época seca los pastizales no son suficientes para satisfacer la demanda alimenticia del ganado, en esta investigación se planteó el objetivo de evaluar el efecto del seccionamiento (S), secado (Se) y sombreado (So) de los cladodios en la multiplicación de *Opuntia cochenillifera* (L.) Mill. Los factores S (cladodio entero y secciones apical, media y basal), Se (secado previo a temperatura ambiente sobre malla y bajo sombra durante 14 días) y So (con y sin sombreado bajo malla rafia al 80 %) resultaron en una combinación de 16 tratamientos, dispuestos en un diseño de tratamiento de parcelas divididas y un diseño experimental totalmente al azar. Se evaluaron porcentajes de cladodios vivos, enraizados y brotados, número de brotes por cladodio y número y longitud de raíces a los 35 días del establecimiento. Se utilizó un análisis de varianza y prueba de medias para determinar diferencias entre tratamientos. Se obtuvo un incremento en el porcentaje de cladodios enraizados con la fracción medial, fracción apical y fracción basal, en comparación con el cladodio entero, independientemente del secado. El sombreado previo fue contraproducente para la sobrevivencia de los cladodios; la alta humedad ambiental, aunado al contenido hídrico de los mismos pudo favorecer la aparición de pudriciones secundarias. En general, considerando la mayoría de las variables evaluadas el seccionamiento del cladodio, sin secado se perfiló como la mejor técnica para propagar asexualmente la especie, debido al rendimiento del material vegetativo, así como por su practicidad.

Palabras clave: nopal, cladodio, propagación, forraje.

Resumo

A *Opuntia cochenillifera* (L.) Mill tem potencial como forragem em áreas áridas. Devido ao déficit de sementes, foi testado um método de propagação assexuada através dos seguintes fatores de estudo: sombreamento (com e sem sombreamento com tela de ráfia de 80 %), seccionamento (cladódio inteiro e seções apical, média e basal) e pré-secagem (à temperatura ambiente sobre tela e à sombra por 14 dias), resultando em uma combinação de 16 tratamentos, dispostos em um delineamento experimental de parcelas divididas e blocos aleatórios. As porcentagens de cladódios vivos, enraizados e brotados, o número de brotos por cladódios e o número e comprimento das raízes foram avaliados 35 dias após o estabelecimento. Análise de variância e testes de média foram aplicados para determinar as diferenças entre os tratamentos. Um aumento na porcentagem de cladódios enraizados foi obtido com a fração medial, fração apical e fração basal, em comparação com o cladódio inteiro, independentemente da secagem. O sombreamento prévio foi contraproducente para a sobrevivência dos cladódios; a alta umidade ambiental, combinada com o teor de água dos cladódios, pode ter favorecido o aparecimento de podridão secundária. Em geral, considerando as variáveis avaliadas, o corte dos cladódios sem secagem emergiu como a melhor técnica para propagação assexuada da espécie, devido ao rendimento do material vegetativo e sua praticidade.

Palavras-chave: figo-da-Índia, cladódio, propagação, forragem.

Introduction

Livestock remains the main source of income for rural communities in arid zones and is a critical component of resilient production systems and an indicator of wealth. However, this sector faces numerous challenges, including food availability and climate change. Grasslands in semi-arid regions are vital for livestock production systems, although their contribution to animal feed is declining. This situation has increased interest in the use of CAM species as forage due to their high efficiency in the use of water and ability to be cultivated on abandoned lands with marginal soils (Niechayev *et al.,* 2019). In addition, CAM species offer additional benefits, as they are ideal for reforestation and ecological restoration in areas affected by desertification and climate change (Owen *et al.,* 2015). In this context, the prickly pear cactus (*Opuntia* spp.) emerges as a promising solution; it is not only drought-resistant but also converts biomass more efficiently than C3 and C4 plants. In fact, it generates three times more biomass per unit of water than C4 plants and five times more than C3 plants. It is estimated that 900,000 hectares of prickly pear are cultivated for forage worldwide (Reynolds and Arias Jiménez, 2003). In Venezuela, the prickly pear of the genus *Opuntia* is one of the cacti with the greatest presence in semi-arid regions (Gallardo *et al.,* 2016). It has been observed that the species *Opuntia cochenillifera* (L.) Mill., which lacks spines, has a high preference and palatability by cattle; it stands out for its high nutritional value, with a crude protein content of 6.2 % and a digestibility of 78 %. Its adaptability to various environmental conditions makes it a sustainable option for livestock production systems, especially in arid and semi-arid regions (Vázquez Mendoza *et al.,* 2019). However, the problem lies in the insufficient availability of propagules for their massive propagation. This underscores the design of strategies to develop livestock production systems based on prickly pear, favoring the human population and reducing pressure on natural grasslands. In this sense, propagation techniques are essential for the mass propagation and establishment of plantations of this species.

It has been established that reducing the size of the cutting of the cladode does not reduce its potential for rhizogenesis and caulogenesis. This fragmentation represents a substantial gain in material and time, especially for large, cultivated areas of *O. ficus-indica* (Stambouli-Essassi *et al.,* 2015). While Mondragón *et al.,* (2003) suggest that the size of the cladode does not affect its ability to form roots and shoots, Homrani *et al.,* (2016) indicate a positive correlation with its number. Another factor evaluated in asexual or vegetative propagation is the pre-drying of cladodes, as it reduces water loss and the incidence of rot, favoring rooting (Mulas and Dessena, 2019). Therefore, the objective of this study was to evaluate the effect of the factors of pre-drying, sectioning, and shading of the cladodes, as well as their interactions, on the propagation of *Opuntia cochenillifera* (L.) Mill., to provide an alternative forage source in arid and semi-arid regions.

Materials and methods

Experiment location

The trial was carried out at the "El Mamonal" farm, located on the Falcón-Zulia highway, Miranda municipality, Zulia state, Piñero sector, coordinates 10º39´57.3"N and 71º21´47.2"W, belonging to a Tropical Dry Forest ecosystem, with an average temperature of 28.7°C and average annual rainfall of 300 mm. Rainfall is distributed irregularly, presenting a bimodal behavior. This means that there are two rainfall peaks, one in May and one in October, while the months of December to March and July to August are the driest periods (Ferrer-Paris *et al.*, 2015).

Plant material

Cladodes of *Opuntia cochenillifera* (L.) Mill. (Cactaceae) were used, selected from plants approximately 1 to 2 years old and in good phytosanitary condition, from a population of 800 prickly pear cacti established in cultivation at the production facility. The cladodes measured approximately 28 cm in length and 11 cm in diameter.

Planting substrate

The cladodes were planted in 20 kg bags with a substrate mixture composed of two parts topsoil and one part of previously washed cow manure (2:1 ratio). In each bag, the cladodes were positioned vertically, respecting their natural polarity, and buried to a depth of up to two-thirds (2/3) of their length (Figure 1).

Figure 1. Establishment of the cladodes in bags.

Cultural practices

The cladodes were irrigated twice a week, in the afternoon, with a total contribution of 400 cc per bag. The irrigation frequency was every three days, adjusted according to atmospheric conditions to ensure that the substrate was maintained at field capacity. Weed control was performed manually.

Study factors and levels

Three factors at different levels were studied: Sectioning of the cladodes: whole cladode and apical, middle, and basal sections; each section measured approximately 9 cm. The sections were made with sharp blades, disinfecting them at the beginning with 0.5 % sodium hypochlorite for 10 minutes. There was no application of healing agents in the cut area, considering the good healing observed in previous trials.

Drying of the cladodes: without drying and with drying.

Both whole and sectioned cladodes were left to dry at room temperature on mesh and under shade for 14 days.

Shading of the cladodes: without shade and with shade.

The cladodes established in shade had a roofed area covered with 80 % density raffia mesh. The cladodes without shade were placed in the field under full sun exposure. In both cases, two rows of eight bags were placed randomly within each row.

Treatments

From the combination of the levels of study, 16 treatments were generated. The experimental unit consisted of a bag where four cladodes (whole, apical, middle, and basal) were established, with two replications per treatment, for a total of 32 experimental units.

Experimental design

The treatment design used was Split Plots 2x4x2, whose combinations were established in a completely randomized experimental design. The shading factor was located in the main plot, and the sectioning and drying factors were in the secondary plots.

Statistical processing and analysis

An analysis of variance was performed, and for the effects that were significant, Tukey's means test was applied, using the InfoStat software under the Windows platform.

Results and discussion

The following results were obtained based on the effects of sectioning and drying the cladodes under full sun exposure, since the cladodes placed in the shade were not viable, resulting in one hundred percent mortality.

Drying under shade was carried out from February 1st to 15th, 2025 (14 days), where a relative humidity of 18 % corresponding to the dry season prevailed; however, there was a generalized rot in the *Opuntia* cladodes, possibly associated with the environmental conditions during shading (under Polyshade mesh) and exacerbated by the weekly 2-mm irrigation depth, prevailing a microclimate of high humidity and limited ventilation, which caused the proliferation of fungal and bacterial pathogens.

It has been reported that shade has a positive influence on the growth and biomass production of the prickly pear cactus. Compared to full sun conditions, shading up to 50 % benefits plant establishment, leaf area, and biomass production. However, higher shading (75 %) has a negative effect on plant survival due to microbial rot and a lower reduction in dry biomass (Dev *et al.,* 2018). This suggests that shading levels should be measured with greater precision in future trials.

Percentage of rooted cladodes (PRC)

The analysis of variance showed significant differences ($P<0.05$) only for the effect of sectioning on the PRC variable. Drying as a single effect and its interaction with sectioning were not significant ($P>0.05$).

Regarding sectioning, the highest PRC was achieved in the middle and apical sections, both reaching 100 % rooted cladodes. These did not differ statistically from the basal section (93.51 %) but did show significant differences compared to the whole cladodes (62.50 %), which exhibited the lowest PRC, as shown in Figure 2.

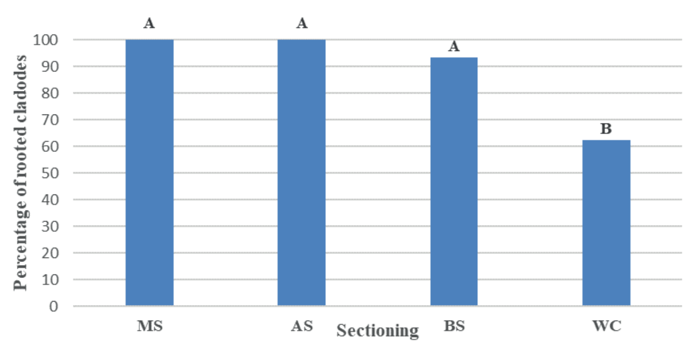

Figure 2. Effect of sectioning on the variable percentage of cladodes rooted in *Opuntia cochenillifera* (L.) Mill. MS: Middle section; AS: Apical section; BS: Basal section; WC: Whole cladode. Equal letters do not present statistically significant differences ($P>0.05$).

According to Stambouli-Essassi *et al.,* (2015), sectioning of cladodes, even in small portions such as halves, quarters, and tenths, has proven to be an effective strategy for vegetative propagation of *Opuntia ficus-indica*. This technique does not reduce the potential of cladodes for rhizogenesis. According to these authors, sectioning can lead to 100 % rooting in the cuttings of right cladodes, with a higher number of roots (80) developing in specific portions such as the right basal tenth. The highest percentage of secondary cladodes (70 % and 74 %) was initiated in the right apical cuttings, and the longest roots (13 and 14 cm) were initiated in the two basal tenths, both left and right. This method represents a considerable advantage in terms of material and time optimization, which is especially beneficial for the establishment of large prickly pear plantations.

Likewise, Mulas and Dessena (2019) evaluated the feasibility of the propagation of *Opuntia ficus-indica* using cladode fragments; they concluded that the effect of sectioning combined with a pre-drying process is a beneficial methodology for the propagation of the prickly pear cactus. In contrast to the results obtained in this research, Mulas and Dessena (2019) showed that cladode fragments that were subjected to 96 hours of drying not only managed to root, but crucially, showed an increase in their initial fresh weight after rooting. This weight increase is a key indicator of successful and vigorous plant establishment, suggesting that this approach allows for a higher number of viable and well-developed individuals to be obtained from the same amount of mother material, thus optimizing the rate of plant propagation.

Number of roots per cladode (NRC)

The analysis of variance did not detect significant differences (P>0.05) for any of the effects evaluated (drying and sectioning), nor for their interaction. The overall average was 8.94 ± 4.07 roots.cladode^{-1}. Figure 3 shows a rooted cladode, showing the approximate number of roots obtained.

Figure 3. Cladode with root formation

The previous results are comparable to those obtained by Mulas and Dessena (2019), who, while evaluating the propagation of *Opuntia ficus-indica* from cladode fragments, observed that the average number of roots per cladode did not vary significantly among the different drying treatments.

The values recorded for the number of roots per cutting ranged from 1.87 for the 96-hour drying treatment to 2.01 for the 120-hour drying treatment. Although the proportion of rooted cuttings was higher with 96 hours of drying (92.6 %) compared to 72 hours (85.7 %) and 120 hours (83.9 %), the number of individual roots per cutting did not show a direct dependence on these drying times.

Root formation in *Opuntia* species, such as prickly pear (*Opuntia ficus-indica*) and *O. robusta*, is markedly influenced by the planting method. According to Snyman (2006), when the cladode was placed flat on the ground, both species developed a greater number of roots. This phenomenon is due to an increase in the contact of the areoles, which are the structures from which the roots sprout, with the substrate. Variations in the shape and size of cladodes between *O. ficus-indica* and *O. robusta* explain the differences in the number of areoles that come into contact with the soil and, consequently, in root development. Despite these morphological differences, most of the areoles in contact with the ground in both species managed to form roots after three weeks, regardless of the planting method used.

Root length (RL)

For RL per cladode, the analysis of variance detected significant differences (P<0.05) due to the effect of sectioning and drying. The interaction of both factors was not significant (P>0.05).

In reference to sectioning, the middle fraction (7.63 cm) differed from that of the whole cladode (3.98 cm). The apical and basal fractions had a similar behavior to the other fractions, as shown in Figure 4.

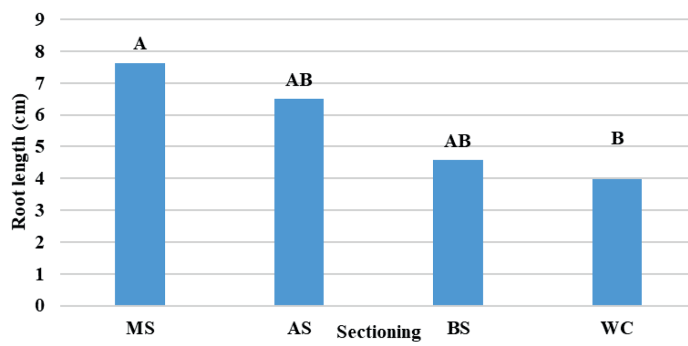

Figure 4. Effect of sectioning on the variable root length in *Opuntia cochenillifera* (L.) Mill. MS: Cladode in middle section; AS: Cladode in apical section; BS: Cladode in basal section; WC: Whole cladode. Equal letters do not present statistically significant differences (P>0.05)

Similarly, significant differences (P<0.05) were observed due to the effect of drying, as shown in Figure 5. The cladodes that were not dried obtained a mean of 6.80 cm, while those subjected to the procedure reached 4.53 cm, a 66.61% lower response (P<0.05). This fact strengthens the results obtained for the percentage of cladodes rooted, which suggests that drying under shade does not have a determining effect on root production.

The above is explained by the cells' need for water to support their metabolic processes, such as sustaining cell multiplication and elongation, leading to the production of tissues responsible for root growth (Khanna, 2024).

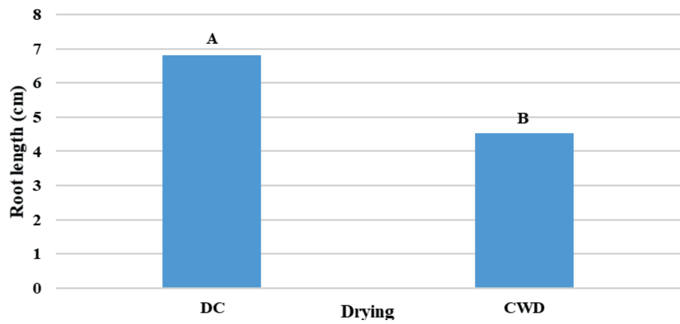

Figure 5. Effect of drying on the variable root length in *Opuntia cochenillifera* (L.) Mill. DC: Dry cladodes; CWD: Cladodes without drying. Equal letters do not present statistically significant differences (P>0.05).

The sectioning of *Opuntia ficus-indica* cladodes has a significant influence on the root length. According to the observations of Stambouli-Essassi *et al.,* (2015), whole cladodes transplanted in spring produce the longest roots, reaching 17 cm, while cladode halves under the same conditions develop 13 cm roots. In the case of the cladodes sectioned into quarters, the right portions, both basal and apical portions, generated longer roots (9 cm and 8.8 cm, respectively) compared to the left portions (6.8 cm and 7.8 cm). The basal tenths of the cladode, especially those on the right side, produced the longest roots, reaching 14 cm, while the middle portions showed the shortest roots (between 5 and 6 cm). These findings suggest that reducing the size of the cladode does not necessarily decrease its rhizogenesis potential, and that planting polarity influences root development.

Stambouli-Essassi *et al.,* (2015) also concluded that right-side cladode portions, planted vertically and with their normal polarity, demonstrated the best results in aptitude for rhizogenesis and secondary cladode initiation, compared to left-side portions planted horizontally.

Percentage of sprouted cladodes (PSC)

Like the PRC variable, the analysis of variance showed only significant effects (P<0.05) for the sectioning factor on the PSC variable. In contrast, drying and the interaction of drying and sectioning were not significant (P>0.05).

The highest PSC was obtained by the whole cladode (100 %), being statistically different (P<0.05) from the middle section (62.50 %), and the lowest PSC value. The basal (87.50 %) and apical (81.25 %) sections had a similar behavior among themselves and with the rest of the levels studied (Figure 6).

These results are similar to those obtained by Stambouli-Essassi *et al.,* (2015) who determined differences in sprouting percentages according to the type of sectioning; the whole cladodes reached 100 % sprouting, while those sectioned in two halves showed 90 % for the apical segments and 60 % sprouting for the basal segments; the cladodes sectioned into four parts presented the lowest percentages (20-30 %). These findings suggested that excessive sectioning of the cladode compromises sprouting capacity, possibly due to the reduction of nutrient reserves and available water, as well as an increased risk of dehydration and susceptibility to pathogens.

Number of shoots per cladode (NSC)

The analysis of variance detected significant differences (P<0.01) due to the effect of the sectioning factor on the variable NSC.

The highest number of shoots corresponded to the whole cladode with 3.13 shoots.cladode^{-1}, which differed (P<0.05) from those corresponding to the basal and middle sections, which obtained 1.63 and 1.06 shoots.cladode^{-1}, respectively, in the NSC of the apical section, a similar behavior is observed to the rest of the levels studied, whose level produced 1.94 shoots.cladode^{-1} (Figure 7). Figure 8 shows a whole cladode with cauline shoots.

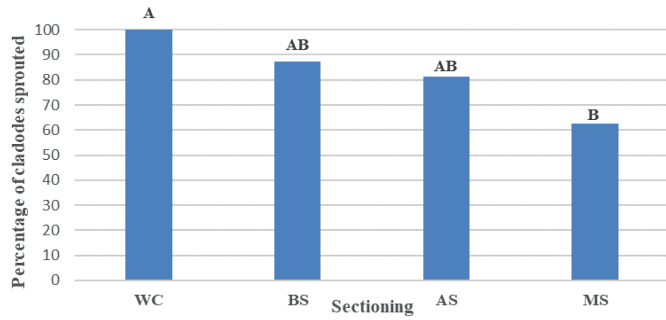

Figure 6. Effect of sectioning on the variable percentage of cladodes sprouted in *Opuntia cochenillifera* (L.) Mill. WC: Whole cladode; BS: Cladode in basal section; AS: Cladode in apical section; MS: Cladode in middle section; Equal letters do not present statistically significant differences (P>0.05).

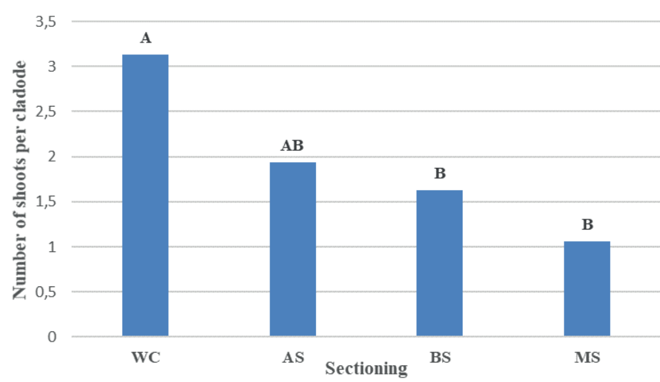

Figure 7. Effect of sectioning on the variable number of shoots per cladode in *Opuntia cochenillifera* (L.) Mill. WC: Whole cladode; BS: Cladode in basal section; AS: Cladode in apical section; MS: Cladode in middle section; Equal letters do not present statistically significant differences (P>0.05).

In the research conducted by Mateus-Arango (2018), the sectioning of the cladodes of *Opuntia ficus-indica* proved to be an effective strategy to increase the average number of shoots; thus, complete cladodes generated an average of 1.83 shoots; those divided into two parts produced 3.25 shoots, and those sectioned into four parts reached an average of 4.75 shoots. This upward trend suggested that cladode fragmentation enhances the activation of a greater number of latent buds, resulting in higher proliferation of shoots per sectioned unit. The results of Mateus-Arango (2018) are different from those obtained in this research, where the fragmentation of the cladodes caused a decrease in the sprouting percentage.

Khalafalla *et al.,* (2007) evaluating the *in vitro* micropropagation of *Opuntia ficus-indica*, highlighted the high shoot multiplication rate obtained, reporting a generation of 26.5 ± 1.74 shoots per explant in a period of 90 days, using an MS medium enriched with 5 mg.L^{-1} benzyladenine. This result underlines the potential of tissue culture techniques for the mass production of plant material, as they allow for

Figure 8. Whole cladode with cauline shoots.

obtaining a large number of shoots from an initial fragment. In relation to the previous results, it is convenient to point out that this efficiency was achieved in a highly controlled laboratory environment, inherent to micropropagation, differing from the conventional propagation conditions under which this research was carried out; however, it could represent an excellent alternative for the propagation of the evaluated species.

Conclusions

Cladode sectioning proved to be the most effective technique for rooting and thus for the mass propagation of *O. cochenillifera* (L.) Mill. However, the use of whole cladodes allows for an increase in the number of shoots, which is a factor to consider depending on the objectives of propagation.

Pre-drying had an impact on the obtaining of cladodes with longer root lengths, which can be beneficial for their survival; however, as it did not have a significant impact on the other variables studied, its application should continue to be evaluated, since it implies an additional expenditure of time and resources.

Shading using 80 % density raffia mesh proved to be counterproductive due to the high incidence of pathogens; therefore, reducing this percentage is suggested to allow for greater direct solar radiation. Consequently, the implementation of meshes with lower shade density (30 – 50 %) is recommended, as well as evaluating other aeration and temperature conditions.

With the results obtained, a mass propagation method of *O. cochenillifera* (L.) Mill. was established to ensure forage availability during dry seasons, providing a foundation for the sustainability of livestock production systems in arid and semi-arid environments.

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