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Review Article

Forest Management

Sustainable Management of *Eremanthus erythropappus* in Minas Gerais, Brazil – A Review

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ABSTRACT

We reviewed key studies published so far regarding *Eremanthus erythropappus* (DC.) MacLeish (*Candeia*), in order to approach the sustainable management of this species. The objective of this study was to discuss what is already known by the scientific community, presenting the current scenario and outlining the main challenges that still need to be addressed. *Candeia* is a tree species found in some Brazilian states, being used in the production of fence posts, and essential oils. It aids in the preservation and restoration of natural areas when properly managed, promoting social development through the creation of jobs and economic growth, due to the current high demand and market value for its products. Due to the high value of its timber, there is a strong anthropic pressure on this species, and it has consequently been exploited in an unsustainable manner. However, already published research suggests that well-managed stands of *Eremanthus erythropappus* can be economically feasible.

Keywords: sustainability, forest management, alpha-bisabolol.

1. INTRODUCTION

Eremanthus erythropappus (DC.) MacLeish (*Candeia*) is a tree species, found in some Brazilian states, used by local inhabitants to produce fence posts, and essential oils. *Candeia* stands occur mainly in the southern region of the state of Minas Gerais, forming huge mosaics called "*candeais*". When submitted to forest management, its cultivation presents characteristics that satisfy the three pillars of sustainability, encouraging the conservation and restoration of natural areas, and promoting social development through job creation and economic growth, due to its products currently having high demand and market value.

The first studies with *Eremanthus erythropappus* were conducted in 2000 by the Laboratory for Studies and Projects in Forest Management at the Federal University of Lavras (LEMAF/UFLA). These projects sought to facilitate the sustainable management of *Eremanthus erythropappus* in native stands, and to establish production systems in commercial plantations. However, there still is significant demand for research to make it a viable commercial option for farmers and entrepreneurs who wish to involve in this business.

Since then, studies have been carried out regarding technology of the *Candeia*'s wood, genetic, management and other related areas. According to Donadelli (2012), this species is only exploited and produced in Brazil. This explains the development of research that focuses on the sustainable management of this species, with the aim of strengthening the economic forest sector in the country.

Only five companies are directly involved in the extraction of alpha-bisabolol (Donadelli, 2012) – the *Candeia*'s essential oil extracted from this wood. Most of the essential oil produced is exported and is used by cosmetics and pharmaceutical industries in European countries (Santos et al., 2008). Essential oil factories pay rural producers who deliver the wood directly to them, from $330.00 to $370.00 for one stacked cubic meter of wood. This same companies sell the essential oil at a price ranging from US$ 50.00 to US$ 55.00 per kg of oil.

The first studies demonstrated that sustainable management of *Eremanthus erythropappus* is thecnically viable. Such research encouraged the creation of the Administrative Act IEF nº 01 of January 5th, 2007, which regulates and presents standards for managing native stands in the state of Minas Gerais. However, in 2012, this ordinance was repealed with the justification that some assumptions for the management of this species needed to be improved.

The management of *Eremanthus erythropappus* in Minas Gerais, the only state that has specific standards for this species, is being regulated by a term of reference in accordance with art.18, chapter V, of the joint resolution SEMA/IEF (Secretary of State for Environment and Development / State Forest Institute) nº 1804, from January 11th, 2013. Every work on native stands of *Eremanthus erythropappus* carried out until now meets the requirements of the first ordinance of 2007. This justifies and confirms the importance of this study to guide sustainable management for *Eremanthus erythropappus*. The key studies published so far about *Eremanthus erythropappus* were reviewed to prepare this study. The objective was to discuss what is already known by the scientific community, showing the current scenario and to present the main issues that still need to be better understood.

2. THE GENUS *EREMANTHUS*

Eremanthus erythropappus belongs to the genus *Eremanthus*, family of Asteraceae. Species belonging to this genus are saplings, trees, rarely shrubs, with alternating leaves, sessile to petiole, with whole limbo, discolored, and without revolute margin or leaf sheaths. The floral heads are often aggregated in a secondary receptacle forming a second order inflorescence. The fruits are persistent to a lapsed pappus with two to five series of stramineous bristles (MacLeish, 1987; Loeuille, 2011).

The genus *Eremanthus* includes 22 species (Scolforo et al., 2012a). They are species endemic to the Cerrado (Brazilian Savanna) and rupestrian fields in the Brazilian Central Plateau, and only two of them (*E. mattogrossensis* and *E. rondoniensis*) are also found in Bolivia. Among the 22 listed species, *Eremanthus erythropappus* (DC.) MacLeish is the focus of this study, since it is sold for the production of fence posts and extraction of essential oil. The majority of research and studies already published are related to this species.

3. *EREMANTHUS ERYTHROPAPPUS* (DC.) MACLEISH

Eremanthus erythropappus is a tree species with diverse uses. Its wood is widely used for fence posts due to its durability, as well as for extraction of essential oil, whose active principle is alpha-bisabolol (or α-bisabolol). Such active principle iswidely used to manufacture medicines and cosmetics. Among the products based on α-bisabolol which have a high market demand, we can cite: creams, sunscreen, lotions, and medications, products for baby and adult skincare, among others (Scolforo et al., 2012b).

Candeia's habits of distribuition varies since forest comunity to open fields (cerrado, rupestrian fields and fields of altitude), forming nearly pure stands. In mixed forests, trees of *Candeia* may be found if clearings had been opened, once it is a heliophylous species and sunlight benefits its germinationby (Scolforo et al., 2012b). The tree may have three to four flowers per floral head, which are grouped in a hemispheric syncephalia. The abaxial glandular surface area of the trichomes is branched in a profusion formation, which explains the whitish aspect of the leaves to the naked eye, due to light reflection. Anatomically, *Candeia*'s leaves show typically xeromorphic structures, which contribute to leaves' mechanical and chemical protection and to adaptation to the natural environment. The association of non-glandular and glandular trichomes occurs on both sides of the *Candeia*'s leaf, providing protection to the tree against environmental abiotic and biotic factors, besides playing an important role to retain the essential oil (Dutra et al., 2010).

Flowering occurs from July to September, when the dry and cold period of the year takes place. Its fructification and dispersion occurs in the period when temperature is rising, from August to September and extends to October and November, when the rainy season starts. According to Scolforo et al. (2012b), *Candeia* has ability to grow in shallow and low fertility soils, and predominantly in high altitude fields, ranging between 400 and 2,200 m. These characteristics make *Candeia* be an interesting alternative of cultivation, where agricultural or forest species hardly would grow.

Eremanthus erythropappus was classified as belonging to pioneer and early secondary species, being one of the first tree species in the invasion of fields (Carvalho, 1994). Scolforo et al. (2004) classified it as a species from ecotone areas with transition from semi-deciduous forests to open fields (cerrado), or also in high altitude fields. Despite presenting high seed production, the dispersal syndrome is anemochorous with a high rate of natural regeneration, which is characteristic of pioneer species, and its life cycle is long. *Eremanthus erythropappus* has a fast deleopment in open fields, forming nearly pure forest stands. Inside the forest, this happens after disturbance, because the species requires the presence of sunlight for its development (Scolforo et al., 2012b). Ecophysiological results obtained by Pedralli (1997) showed that the photoblastic of *Eremanthus erythropappus* is positive.

4. ENVIRONMENT OF OCCURRENCE OF *EREMANTHUS ERYTHROPAPPUS*

Eremanthus erythropappus is distributed throughout the south-eastern area of the Central Plateau, and is quite common in colonies in the middle of the secondary forest in coastal strips and in the Cerrado (Brazilian savanna), in rocky fields of the interior plateau of the center-west (Goias and Federal District) and also in southeastern (states of Minas Gerais, Espirito Santo, Rio de Janeiro and São Paulo) Brazil (Macleish, 1987; Loeuille et al., 2012). According to Gomide et al. (2012), the species of the genus *Eremanthus* occur predominantly in the State of Minas Gerais (Figure 1).

Eremanthus erythropappus naturally occurs in regions classified by Köppen as humid mesothermal tropical climate - Cwb, with mild summers. The annual average temperature varies between 18 and 20 °C and the average annual rainfall is between 1,400 and 1,550 mm. The months of the highest rainfall level are: November, December, January and February, and the lowest rainfall occurs in June, July and August (Scolforo et al., 2012b).

Eremanthus erythropappus may occur in the following soils: Cambisol alic (Ca), Cambisol dystrophic (Cd), Dark Red Latosol dystrophic (DRLd) and Typic Haplustox dystrophic (THd), Dusky Latosol dystrophic (DLd), Dark Red Latosol alic (DRLa), Litholic alic (La) and Red Yellow Podzolic dystrophic (RYPd), with an average pH of 5.1 (Scolforo et al., 2012b).

Chemical and physical soil characteristics in *Eremanthus erythropappus* remnants present the following average values (Scolforo et al., 2012b): average organic

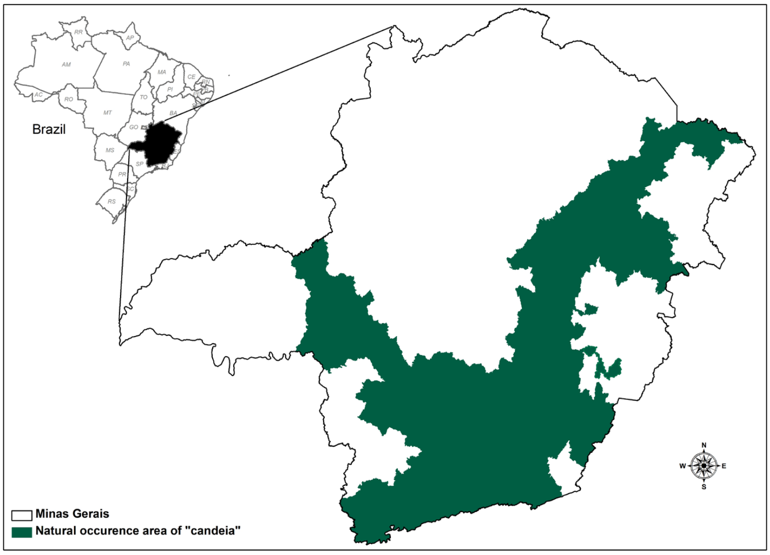

Figure 1. Distribution map of the *Eremanthus* genus in the state of MG.

matter of 2.2 dag.kg^{-1}; calcium content is from medium to low (0.3 mg.dm^{-3}); magnesium content ranges from low to very low (0.1 cmolc.dm^{-3}); potassium content presents significant variation of availability in the areas, with values around 40.7 mg.dm^{-3}; phosphorus presents low values (1.4 mg.dm^{-3}) and average aluminum values are around 1.2 (cmolc.dm^{-3}). The index of base saturation is, on average, 9.7% and the aluminum saturation rate is 67.6%. Regarding physical soil characteristics, the grain size distribution indicates a medium texture, with 68.7% sand, 20.8% clay and 11.2% silt.

5. TREE MEASUREMENT ISSUES AND *EREMANTHUS ERYTHROPAPPUS* YIELD

The wood of *Eremanthus erythropappus* can be harvested from native areas or commercial plantations. In each case it has specific tree measure patterns, which directly affect productivity and consequently, profitability. The reference values presented here for *Eremanthus erythropappus* are averages taken from Scolforo et al. (2012a), therefore they may vary according to site conditions.

In native populations of *Eremanthus erythropappus*, the average diameter at breast height (DBH) of thinner trees is 7.6 cm and approximately 32.0 cm for larger trees. The total height (Ht) for these two categories is, on average, 6.5 m and 11.0 m, respectively. The average diameter for this population is 20.0 cm and the average height is 9.0 m. The total average volume of the tree with bark is 0.2159 m^3, which may vary from 0.0171 to 0.5905 m^3. Thinner plants presented an average volume of 0.0176 m^3 and larger ones presented an average of 0.5093 m^3. The average bark volume percentage in relation to total volume of each tree is 17.60%. Stacking of the wood of *Eremanthus erythropappus* is a common practice during sale. In this case, an average stacking factor of 2.46 stacked cubic meter.m^{-3} is used. This value is significant given the great irregularity of the trunk, which generates a lot of empty space when the wood is arranged in a 1 m^3 stack.

Average basic density of wood can vary by region, being 630 and 640 kg.m^{-3}, respectively in the cities of Delfim Moreira and Aiuruoca, and 680 kg.m^{-3} for the municipality of Ouro Preto, all in the State of Minas Gerais (Scolforo et al., 2012c). Pérez et al. (2004) found an average basic density of 670 kg.m^{-3} per tree in the municipality of Baependi, MG. The tree dry weight is 142.37 kg.m^{-3}, ranging from 11 to 413 kg.m^{-3}.

The average yield of essential oil for wood with bark is 10.96 kg.m^{-3}, ranging from 8.57 to 14.47 kg.m^{-3}. The production of the oil reaches an average of 11.78 L.m^{-3} of wood, ranging from 9.21 to 15.55 L.m^{-3}. The ratio of weight of oil by weight of wood is of 1.68% on average, from which 88.49% of the oil is pure alpha-bisabolol.

Studies of *Eremanthus erythropappus* plantations are still in progress and the few experimental areas are still being monitored, what requires simulations of scenarios for estimating wood and oil productions. Taking values presented by Scolforo et al. (2012c), such as 1,600 plants per hectare, trees with an average diameter of 12.5 cm, average volume of 0.0589 m^3, average density of 610 $kg.m^{-3}$, and dry matter mass of 35.94 kg, we obtained an oil yield of 943.24 kg per hectare in planted stands.

The first work on modeling of *Eremanthus erythropappus* was performed by Scolforo et al. (2004) in native fragments in the Aiuruoca region, Minas Gerais. The recommended equation to estimate total volume (m^3) over bark was $Ln(V) = -12,0214 + 2,0244.Ln(CAP) + 0,8229.Ln(H)$, with R^2=97.63% and Syx=±0.0527 m^3. To estimate the total dry weight (kg) the equation used was $Ln(PS) = -4,6265 + 2,0706.Ln(CAP) + 0,4124.Ln(H)$ with R^2=97.06% and Syx=±42.59 kg; while for the oil weight in kg, the equation

$$Ln(PO) = -10,1097 + 2,2872.Ln(CAP) + 0,4354.Ln(H)$$

with R^2=91.86% and S_{yx}=±1.07 kg is recommended. In all cases, the Schumacher-Hall mathematical model presented accurate estimates for the dependent variables.

Camolesi et al. (2010) proposed equations by regions, covering different vegetation locations where *Eremanthus erythropappus* is found in Minas Gerais. In this study we evaluated various mathematical models with the Spurr's model $Y = \beta_0 + \beta_1.(DAP^2.H) + e_i)$ providing the most precise equations. We found that, to estimate the total volume of wood with and without bark, an equation with regional applicability can be used. On the other hand, a specific equation for the stand location should be used to estimate the number of fence posts per tree.

Concerning the height-diameter relationship for *Eremanthus erythropappus* in planted stands, Araújo et al. (2012b) recommends using the Henricksen $(H = \beta_0 + \beta_1.Ln(DAP) + e_i)$, Stofells $(Ln(H) = \beta_0 + \beta_1.Ln(DAP) + e_i)$, Assman $(H = \beta_0 + \beta_1.(1/DAP) + e_i)$, Trorey $(H = \beta_0 + \beta_1.DAP + \beta_2.DAP^2 + e_i)$, and Curtis $(Ln(H) = \beta_0 + \beta_1.(1/DAP) + e_i)$ models. The choice of model should be made depending on the spacing of planting and the age of the stand, with the grouping of equations for different spacings or ages not being recommended.

The only work done to define plot size and shape for *Eremanthus erythropappus* was carried out by Oliveira et al. (2011). In commercial plantations with such species, these authors analyzed the best plot size and shape to estimate the variables circumference at breast height (CBH), total height (HT), and total volume (TV). They found that the optimum plot size for plantations is 60 plants in a rectangular shape plot, 2 rows with 30 plants. In addition, the Hatheway method was the most proper to estimate the optimal size in order to minimize the error in the estimation of the variables. In native populations of *Eremanthus erythropappus* the use of rectangular plots and area of 1,000 m^2 is recommended, with systematic sampling.

We found no study in the literature that recommends an ideal sampling method for evaluating natural regeneration of *Eremanthus erythropappus* in managed areas. This is important for quantification of regeneration of the species with cost minimization and greater precision when estimating the number of plants per hectare. According to Silva et al. (2008), studies with natural regeneration in wild areas should adopt sampling procedures to ensure the representativeness of the area, in which the systematic structure is the most appropriate.

6. THE ECONOMIC POTENTIAL OF *EREMANTHUS ERYTHROPAPPUS*

Many degraded sites can be found in the State of Minas Gerais, mainly in areas with predominance of Cambisols (Scolforo et al., 2012b). These soil types hinder the development of forest species with potential for cultivation for the purpose of environmental restoration or forest production (Scolforo et al., 2012b). *Eremanthus erythropappus* is one of the few species that can be recommended for cultivation in these areas, as it occurs naturally in sandy and stony soils.

The majority of the works already carried out on *Eremanthus erythropappus* highlight the economic potential of this species as a justification for creating commercial plantations (Barreira et al., 2006; Camolesi et al., 2010; Galdino et al., 2006; Melo et al., 2012; Oliveira et al., 2011; Paes et al., 2010; Pérez et al., 2004; Santos et al., 2009; Scolforo et al., 2004; Silva et al., 2005; Silva et al., 2007a; Silva et al., 2007b; Souza et al., 2007; Vieira et al., 2012), strengthening the desire to establish a commercial production system of plantations, or management of the native woodlands in rural properties located mainly on the Mantiqueira Mountains and Espinhaço in the State of Minas Gerais .

The wood of *Eremanthus erythropappus* can be used for fence posts or for the extraction of essential oil to produce alpha-bisabolol for different industrial applications (Pérez et al., 2004). According to Pedralli (1997), α-bisabolol holds antiphlogistic, antifungal and dermatological properties, which gives the species high economic potential. Both in managed plantation and in native areas, oil extraction is the most economically attractive option, achieving high prices on domestic and international markets.

In commercial plantations, the gross income from the sale of timber for the extraction of essential oil can reach US$ 25,692.00 ha^{-1}, in a ten-years stand with 98.82 stacked cubic meter ha^{-1} of average (Scolforo et al., 2012d). The farmer grows *Candeia* in hilly areas with shallow and infertile soils, in conditions that would be adverse for wood production with other species. Thus, it is not reasonable to compare the production of wood of *Eremanthus erythropappus* from plantations with other highly productive forest species, such as those of the genus *Eucalyptus*. In addition, the results obtained from established field experiments are still new and studies about the silviculture, nutrition, tree improvement, cloning and other important issues are essential to provide significant improvements in productivity. These studies will provide information for a possible comparison with the productivity of species of the genus *Eucalyptus*, which have received tens of million dollars of investments over the last decades in Brazil (Scolforo et al., 2012d).

When a farmer opts for managing *Eremanthus erythropappus* in native areas, the most significant costs are associated with timber harvesting and transport, representing 67% of the total costs (Oliveira et al., 2010). To ensure higher profit, farmers should sell their timber directly to companies that extract the essential oil, without intermediaries for the transactions (Oliveira et al., 2009).

Wood from managed native areas can be sold by up to US$ 350.stacked cubic $meter^{-1}$ when the essential oil is delivered to the factory by the farmers. The stacked wood at the roadside is sold at US$ 230.00 stacked cubic $meter^{-1}$ and standing timber at US$ 100.00 (stacked cubic $meter)^{-1}$ (Oliveira et al., 2012). On the other hand, an area with average production volume of $45m^3.ha^{-1}$ and stacking factor of 2.67, for a cutting cycle of 15 years and wood delivered to the manufacturer, at a price of US$ 350.stacked cubic $meter^{-1}$, can provide a net profit of US$ 15,387.62 ha^{-1}. According Oliveira et al. (2010), management for the extraction of essential oil is economically feasible, even under high interest rates, or low wood prices.

7. MANAGEMENT OF NATIVE STANDS OF *EREMANTHUS ERYTHROPAPPUS*

Historically, *Eremanthus erythropappus* has been locally and unsustainably exploited, without applying management criteria to minimize harmful impacts (Araújo et al., 2012a; Silva et al., 2008). Such exploitation was due to the technological properties of the wood of *Eremanthus erythropappus*, which guaranteed high economic outcomes (Oliveira et al., 2012).

Donadelli (2012) cite that the scenario of illegal exploitation of *Eremanthus erythropappus* presented a lack of control by governmental regulations on the extraction chain of the essential oil. The solution to control the chain would be the proposal and implementation of a sustainable forest management plan, based on knowledge about the species' ecology (Souza et al., 2007).

To prevent the illegal exploitation of *Eremanthus erythropappus*, which had become totally unregulated and environmentally damaging, it was necessary to investigate the ecological and silvicultural aspects of this species, looking for sustainable management practices (Scolforo et al., 2012a). From the studies recommended by LEMAF/UFLA and with the need to regulate extraction activities, the ordinance Nº 01 January 5, 2007 was issued. This presented guidelines to draft and implement a management plan for sustainable *Eremanthus erythropappus* production in the State of Minas Gerais (Minas Gerais, 2007).

The first study that aimed to define a model for managing *Eremanthus erythropappus* in native areas was performed by Pérez et al. (2004). Considering a selective logging system, a management system based on essential oil weight, growth rate, vegetation structure and a balanced forest concept was proposed. On that occasion, it was found that the removal of up to 60% of the total basal area would not compromise forest structure.

Scolforo et al. (2008) suggested, in addition to the selective logging system, other sylvicultural systems to be applied with *Eremanthus erythropappus*: a selection system by group, a cutting system in bands and a seed-tree system. The conception of these systems allowed *Eremanthus erythropappus* to be sustainably managed. The main requirements that must be adhered to when implementing these management systems are: Mapping of native populations of *Eremanthus erythropappus*; measuring the wood stock; and defining an extraction system that minimizes its impacts and emphasizes the care of the remaining forest stand, with the objective of enabling natural regeneration. These requirements, as well as the detailed recommendations regarding how to develop the management plan, are presented in Scolforo et al. (2012e).

In all cases, management should only be carried out in areas where the species is predominant, where at least 70% of individuals are *Eremanthus erythropappus* (Minas Gerais, 2007).

Management with the seed-tree system is the most widely applied method due to its sylvicultural practicality and, to some extent, for allowing the removal of a greater number of *Eremanthus erythropappus* trees per hectare for the extraction of essential oil. As outlined in ordinance Nº 01 of January 5, 2007, in this system, up to 70% of the *Eremanthus erythropappus* individuals can be exploited. However, some requirements must be met, such as leaving at least 100 seed-trees per hectare. In addition, seed-trees must be separated, on average, by 10 m from each other. The application of this system allows the soil cover to be quickly and safely reestablished, because regeneration is intense (11,275 plants ha^{-1}), due to opening gaps, in addition to reducing the cost of conducting the regeneration (Scolforo et al., 2012e).

Concomitant to the preparation and implementation of management plans for *Eremanthus erythropappus*, managed areas were monitored by LEMAF/UFLA (Laboratory for Studies and Projects in Forest Management / Federal University of Lavras) in partnership with the Forest Institute, the agency for forestry regulation in the State of Minas Gerais (IEF). According to Araújo et al. (2012a), by the end of 2009, approximately 130 management plans had been monitored, following the standards outlined in the ordinance cited above and supervised by the IEF. This represents a total managed area of 1,108 hectares and extracted wood volume from native areas of around 30,521.89 m^3. The management plans encompass 35 municipalities from southern and central regions of the State of Minas Gerais .

The monitoring of these areas has allowed us to infer that management, when performed in accordance with the requirements of the legislation, contributes to the conservation of original flora and fauna in the area, besides reducing illegal logging. This occurs because the legislation requires cares of the area after the intervention, such as transplanting epiphytes and compiling annual reports on the monitoring of the area (Scolforo et al., 2008).

Araújo et al. (2012a) demonstrated that managing *Eremanthus erythropappus* in native areas is sustainable only when performed in accordance with the promulgated legislation, generating income, environmental conservation and social improvements for the rural producers who wish to management of areas of *Candeia*. These areas often present low fertility Cambisol soils at high altitude, and that this species dominates these areas with a minimum frequency of 70%. In areas where *Eremanthus erythropappus* density is less than 70%, natural regeneration will not flourish because, under these conditions, the presence of tree species other than *Eremanthus erythropappus* reduces the incidence of sunlight in the understory.

8. NATURAL REGENERATION OF *EREMANTHUS ERYTHROPAPPUS*

Little is known about the natural regeneration of *Eremanthus erythropappus*, especially in areas subject to management. Until now, only one study evaluating the regeneration intensity in these locations was performed (Araújo et al., 2012a). These authors aimed to evaluate the natural regeneration intensity in areas subjected to management with seed-tree systems at different ages.

According to Dalanesi et al. (2004), *Candeia* tends to be more abundant in Litholic alic soil. However, Araújo et al. (2012a) found that forest management conducted in this soil type resulted in lower intensity regeneration. The ideal conditions for forest management are achieved in Cambisol soils. These results show that more studies should be conducted to understand the development of the species along time, since changes to environmental conditions influence its metabolism (Souza et al., 2003).

Sunlight availability can be highlighted among the most relevant factors for the *Candeia's* development; such as a heliophylous species, *Eremanthus erythropappus* requires direct sunlight for development. Scolforo et al. (2012e) recommends that, after the management of *candeais*, soil scarification should be performed. The soil layer should achieve depth of 5 to 10 cm, in circles of 60 cm of diameter, 2.5 m apart from each other, throughout the managed area, avoiding thus the suppression of other plant species. This practice allows direct contact between seed and soil, stimulating germination and expansion of its natural regeneration once exposure to light.

Another characteristic of the natural regeneration of *Eremanthus erythropappus* in managed areas is the strong spatial dependence between individuals, indicating a distribution tipically aggregate. Due to this pattern of distribution, Pérez et al. (2004) recommend managements comprising a thinning during regeneration, so that an average density of 1 plant per 4 m^2 be achived, reducing thus competition and stimulating the development of remaining trees.

Araújo et al. (2012a) found a spatial continuity of the number of regenerated plants in managed areas. These authors observed a spatial aggregate pattern, besides noting that natural regeneration tends to form aggregates in areas of arboreal vegetation free of *Eremanthus erythropappus*. In areas where *Eremanthus erythropappus* competes with other species, regeneration levels fall due to shading. This reinforces that management of *Eremanthus erythropappus* should be performed only in areas where it is dominant (Araújo et al., 2012a).

This aggregation pattern was first detected by Silva et al. (2008) by using Ripley's K function. Silva et al. evaluated the regeneration pattern of *Candeia* and its spatial distribution in an area subject to forest management with seed-tree system. These authors also detected a aggregated pattern, which allows formation of mosaics across the vegetation, with presence of large stands of *Candeia*.

9. THE COMMERCIAL CULTIVATION OF *EREMANTHUS ERYTHROPAPPUS*

Given the expressive reduction of native areas of *Eremanthus erythropappus*, plantations is the alternative to produce *Candeia* (Oliveira et al., 2011). The experience acquired with plantations is more recent than that from native areas. The existing plantations are experimental areas whose growth and yield are still under monitoring. *Candeia* plantations have been expanded and showed promise. As cited, once *Candeia* grows in low nutritional soils, it has been implanted even in degraded areas, i.e. land unsuitable for agricultural crops (Altoé et al., 2012).

Initial studies indicate spacing of 1.5 × 2.0 m provides good growth rates (Silva et al., 2012b). According to Silva et al., spacings denser than the one cited may decrease the growth rate so that it becomes unfeasible technically. Overall, in the stands of *Eremanthus erythropappus*, the maximum revenue, with lower risk, is reached at 12 years old when it is planted with spacing of 1.5 × 3.0 m (Silva et al., 2014). Wider spacing is recommended in more productive sites, likewise smaller spacing are better in lower quality sites.

In general, Scolforo et al. (2008) recommend spacing of 2.5 × 2.5 m under conditions both of mechanized or manual planting. To maximize production, Scolforo et al. (2012a) recommend fertilizing the soil at a dosage of 100 to 150 g of NPK, with a formulation in proportion 8:28:16 by pit. Planting can be carried out with seedlings measuring from 25 to 35 cm of heigth, followed by ant control, clearing and pruning when growth rates fall. As mentioned by Scolforo et al. (2012d), under these planting conditions (2.5 × 2.5 m), gross profit may reaches US$ 25,692.00 ha^{-1}, with a maximum volume of 43.05 m^3 ha^{-1} at ten years old.

Regardless the spacing, pruning is required in order to stimulate production of straight stems, especially if the timber is destined to production of fence posts. The first pruning should be performed twelve months after planting and should not exceed 50% of the total height of the plant (Scolforo et al., 2012d). A second pruning should be performed between 1 and 2 years old, depending on objectives of the final product. When the goal is timber production for oil extraction, pruning is unrequired because it tends to reduce essential oil yields in relation to dried wood weight (Altoé et al. 2012).

Another alternative is to plant *Eremanthus erythropappus* in agro-forestry systems. Silva et al. (2012a) showed that the more profitable conditions for this type of system are attained with a spacing of 10 m × 2 m, intercropped with corn between lines. Under these conditions the average profit can reach US$ 3,699.8 ha^{-1} at ten years old.

10. PRODUCTION OF SEEDS AND SEEDLINGS OF *EREMANTHUS ERYTHROPAPPUS*

So far, there are no provenances, progenies or clones of *Eremanthus erythropappus* tested that can be recommended for planting in specific environments or regions. Therefore, seeds from local sources are normally used originated from seed trees with good phenotypic characteristics (Scolforo et al., 2008). If the seed tree is not eventually well selected, seeds will have low germination percentage (Feitosa et al., 2009), as previously shown by Velten & Garcia (2005).

For seed production, Davide et al. (2012) recommends that *Candeia's* populations be selected from the regions most favorable for its natural occurrence with wide genetic variability. In populations with more than 500 trees, seeds should be collected from 15 to 25 trees approximately 50 to 100 m far away from each other. Davide et al. also emphasize that the seed trees should be vigorous and present good health, with a small canopy, cylindrical trunk, good natural pruning and high seed productivity. Seed collection should be performed at the beginning of seed dispersion, before completing its natural drying and occurrences of wind dispersion. For *Eremanthus erythropappus*, this period occurs from August to October and may extend to November. Davide et al. (2012) highlight the importance of avoiding seed collection during or immediately after the occurrence of rain, once it may accelerate the seed deterioration process.

The production of seedlings of *Eremanthus erythropappus* is exclusively seminal. For this reason, it is necessary to process the seeds, separating empty seeds from the fertile ones. According to Tonetti et al. (2006), the large number of empty or infertile seeds is responsible for a low rate of germination. After seed selection by means of a blower, Davide et al., (2012) noted that the average rate of germination increases from 11 to 73%, taking into account different origins. Alternatively, seeds also can be selected by means of screens, centrifugation or liquid immersion. In all cases, the seeds are separated due to differences in density (Davide & Melo, 2012).

After collecting and selecting fertile seeds, one option is to produce seedlings via direct sowing in containers, because this does not require sowing, and reduces pest incidence and costs. According to Davide & Melo (2012), the most proper containers are plastic bags or tubes. This last provides the advantages of preventing the winding of roots, and reduce the quantity of substrate. In addition, tubes are reusable, its use benefits the work ergonomics, besides being cheaper than plastic bag.

To use of plastic bags for seedling production, the substrate may be composed by 3 parts, being: sifted soil, manure, and carbonized rice husk. At every 1,000 liters of substrate, 5 kg of superphosphate and 120 g of potassium chloride should be added. When using tubes, 2 parts of sifted soil, 5 parts of carbonized rice husk, and 3 parts of vermiculite of average particle size are recommended, with the same proportion of fertilizer used in the plastic bag (Davide & Melo, 2012). Other substrate compositions are also presented by Davide & Melo. On the other hand, Melo et al. (2014) obtained a bad response of cow manure, in which the seedlings had a low growth rate.

The seedling production cycle can take 120 to 150 days, depending on climatic conditions, with individuals reaching 25 to 40 cm of height and 4 to 6 mm in diameter at the base. At 30 to 45 days, it is necessary to thin the seedlings of the containers, leaving only one seedling in order to reduce competition and stimulate their growth. With respect to the nutritional conditions in the nursery, Venturin et al. (2005) point the lack of phosphorus and nitrogen as limiting factor for the seedlings' rate of growth. According to these authors, seedlings of *Eremanthus erythropappus* present lower nutrient requirement for calcium, potassium and zinc.

Silva et al. (2005) found that inoculation with arbuscular mycorrhiza is also an important factor which can increase the seedling growth. The period of rustification of the seedlings occurs approximately between 4 and 6 months of age, within 15 to 25 days, and after this period, it can be planted.

Seminal seedling production is normally not the best option, due to the development of more heterogeneous plants caused by genetic variability. Asexual propagation by grafting, micro-propagation, cutting and mini-cutting are alternative techniques, despite little is known about these methods for *Eremanthus erythropappus*. There are few studies that characterize the seeds and that seek to understand the biochemical and physiological effects in events of imbibition and germination (Davide et al., 2008).

Melo et al. (2012) proposed a methodology for the vegetative propagation of adult individuals of *Eremanthus erythropappus*. This methodology aids future research by improving to understand the behavior of the variables of this tree species. We found that coppice and exposure of roots is an effective technique to rescue selected seed trees. Additionally, cuttings produced from sprouts of harvested stems presented excellent rooting when they were inserted in plant beds in a heated vegetation house. These results contribute significantly to the genetic techniques applied to *Eremanthus erythropappus.*

11. GENETIC ASPECTS OF *EREMANTHUS ERYTHROPAPPUS*

Little is known about the genetic aspects, spatial distribution of genotypes and reproduction system of *Eremanthus erythropappus* (Carvalho et al., 2012). Further research is essential to generate knowledge and propose methods for selecting good matrices, in addition to designing strategies for conservation and genetic improvement of the species. The implementation of a genetic improvement program would ensure the formation of forest stands with individuals reaching maximum productivity levels.

According to Melo et al. (2012), the maximum potential productivity of a planting area with *Eremanthus erythropappus* can be achieved using seedlings with improved genetic material. The occurrence of differences in the behavior of seedlings from seeds of different populations is common. To achieve better growth levels, it is important to use genotypes more adapted to a specific environment. This practice provides the best strategies for conservation and forest management (Barreira et al., 2005).

Studies have shown that populations of *Eremanthus erythropappus* present sufficient genetic variability and should be used in breeding programs and conservation. Estopa et al. (2006) argue that a higher rate of genetic diversity is influenced by altitude gradients and is greater within populations than between them. According to Mori et al. (2009), higher levels of alpha-bisabolol are related to higher altitudes, therefore it is an important condition that influences on the content and quality of the essential oil (Galdino et al., 2006). Barreira et al. (2006) showed that forest management promotes positive changes in the species' genetic quality, besides increasing the genetic diversity and favoring reproduction between a larger number of individuals.

In general, the few studies approaching the genetic characteristics of *Eremanthus erythropappus* are limited. The high genetic diversity, as well the demographic characteristics of very dense populations, suggest us that the species' genetic quality should be carefully evaluated as a potential support for sustainable forest management (Carvalho et al., 2012).

12. OTHER POTENTIAL USES OF *EREMANTHUS ERYTHROPAPPUS*

As has already been mentioned, the main use of the wood of *Eremanthus erythropappus* is essential oil for cosmetics and pharmaceutical industries. According to Ribeiro et al. (2010), this use is justified by the therapeutic effects of species of the genus *Eremanthus*. However, the essential oil of *Eremanthus erythropappus* is used to other ends.

The essential oil is the main characteristic responsible for the high wood durability of the wood of *Eremanthus erythropappus*, however, when subjected to partial or total extraction, the wood has resistance reduced, mainly when attacked by the fungus *Gloeophyllum trabeum* (Oliveira et al., 2005). Thus, the essential oil could be used for wood treatment. Paes et al. (2010) showed that the essential oil is also resistant to the attack by the xylophagous termite *Nasutitermes corniger* Motsch. However, the high cost of the essential oil makes the wood treatment a possibly viable option, despite more detailed economic studies are required in this sense.

Available studies also reveal little information regarding the technological aspects of the wood of *Eremanthus erythropappus* (Mori et al., 2010). The few studies that investigate the anatomical characteristics and physical and chemical properties of the wood of *Eremanthus erythropappus*, makes it difficult to recommend its wood for specific purposes. After oil extraction, the wood wasted could be reused to produce wood-cement panels or articulated panels, being a viable commercial option (Santos et al., 2008). This option should be chosen when the wood residues are mixed with residues from other species (Santos et al., 2012). Another option for the timber residuals after oil extraction is production of wood panels (Santos et al., 2009).

The possibility of honey production can also be considered, since *Eremanthus erythropappus* presents 77.25% pollen viability, with the bees *Apis mellifera* and *Trigona* sp. being the most frequent pollinator (Vieira et al., 2012). Another possibility for using *Eremanthus erythropappus* essential oil is in biological control agent, since alpha-bisabolol inhibits the growth of phytopathogens, such as *Rhizoctonia solani*, *Alternaria* sp. and *Alternaria carthami* (Hillen et al., 2012). Salustiano et al. (2006) also pointed out the possibility of using the extracts and the Candeia's oil as an antimicrobial agent. The ethanolic extract presents anti-conceptive, anti-inflammatory and anti-ulcerogenic effects, suggesting potential for therapeutic use in zootechnical laboratories. Further studies are required for examining possible application in human medicine (Silvério et al., 2008).

Research as Magalhães et al. (2008) and Rosumek (2008) show the interaction of *Eremanthus erythropappus* with fungi and ants, respectively. Such studies highlight the importance of *Eremanthus erythropappus* not only for production point of view, but also due to its ecological relevance. Assessing how *Eremanthus erythropappus* interacts with other species enables us to better understand the environments where it occurs (Dias et al., 2002; Fujaco et al., 2010).

13. CONCLUSIONS

To manage *Eremanthus erythropappus*, the main requirement is the presence of indivudals of the species in the stand. After timber harvesting, soil scarification benefits seed germination and the natural regeneration must be thinned in order to stimulate the remaining species' rate of growth.

The management of *Eremanthus erythropappus* in natural forests, where would be unfeasible for cultivation of other forest or agricultural species, contributes to production and income gains, besides preserving and conserving the species in the region. Once the species is distributed in transition areas between Atlantic Forest and Cerrado, it contributes to maintain the connectivity between these biomes.

Managing *Eremanthus erythropappus* inhibits its unsustainable exploitation and offers development for mainly small and medium farmers in the region where the species is found. Several surveys present the advantages of its cultivation and also cite the importance of generating more technical and scientific knowledge.

The establishment of *Eremanthus erythropappus* plantations can be seen as the next challenge, since that is the option to meet the demand for wood and alpha-bisabolol on the national and international markets, as well as minimizing the use of the few remaining forest fragments.

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