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RESEARCH ARTICLE

Potential bamboo species for cultivation in the southern plateau of Atlantic Forest, Brazil

G. E Pereira[1] . K. L. Santos[1*] . M. P. Guerra[2] . D. C. Ortiz[1] . L. R. Tapanotti[2]

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Abstract: In the Atlantic Forest, several native bamboo species have a history of use by local populations, being a source of Non-Timber Forest Products (NTFPs). Later, with the colonization process, the introduction of Asian species increased the diversity of bamboo in use. However, in the Santa Catarina State plateau region, bamboo exploration is still incipient, and in this sense, this study is part of an initiative that aims to generate information for the development of Bamboo productive chain in southern Brazil. This study aimed primarily to identify bamboo species, native and exotic, with potential for cultivation with emphasis on the establishment of diversified production systems. As a first research strategy, seven species were studied in three experimental areas in order to evaluate their adaptability to the conditions of the plateau region of the Santa Catarina State. The second strategy sought to identify bamboo species already in use by family farmers in this region. Based on the results the transition phase of clumps to a mature and harvested state of evaluated bamboo species in this study can take more than three years. In addition, the maintainers interviewed pointed out eight exploited bamboo species, among them *Bambusa tuldoides*, and two native species from Brazil *Chusquea sellowii* and *Guadua chacoensis*. We suggest that the management of bamboo, even native ones, should be done based on environment context and technical strategies, to establish diversified systems balanced with environmental services.

Keywords: diversification, bamboo uses, diversified systems, ethnobotanical approaches

*Corresponding Authors

[1] Federal University of Santa Catarina,
Rodovia Ulysses Gaboardi, 3000,
Curitibanos, Santa Catarina, Brazil
✉ karine.santos@ufsc.br

[2.] Federal University of Santa Catarina,
Rodovia Admar Gonzaga, 1346,
Itacorubi, Florianópolis, Santa Catarina, Brazil

Introduction

Bamboos belong to the *Poaceae* family, Bambusoideae subfamily, which encompasses around 1,700 species in 120 genera, with a wide geographical distribution in the world (Clark *et al*., 2015; Chalopin *et al*., 2021). Brazil holds 232 estimated species, the majority endemic (Drumond & Wiedman 2017, Felisberto *et al*., 2017, Vorontsova *et al*., 2016). Considering the Neotropical woody bamboos, Brazil holds the largest number, 168 species in 17 genera (Ruiz-Sanchez *et al*., 2021).

Bamboos have important economic, ecological and cultural functions around the world, especially in the Eastern region of the planet, being one of the most versatile plants. Some bamboo species are woody, have good culm quality and high economic value (Lobovikov *et al*., 2012). They have been used for many proposals as crafts, pulp, paper, panels, boards, veneer, flooring, roofing, fabrics, oil, gas, charcoal, fuel, absorbent, store and sequester carbon, restore degraded lands and even for food (bamboo shoot) (Lobovikov *et al*., 2007). This group of plants

This group of plants can be found in a wide range of soil and ecological conditions, from tropical to temperate zones, and from the sea level and up to 5,000 meters (Greco and Cromberg, 2011, Sharma *et al*., 2018).

Bamboos cultivation provides environmental services associated with high performance in nutrient cycling, reducing erosion, supply of organic matter to the soil, high availability of aerial and underground biomass to the systems, reducing pressure to deforest native forests, fixing expressive amounts of carbon, among others (Greco and Cromberg, 2011, Nath *et al*., 2015). The bamboo's ecological aspects such as its ability to grow on degraded lands, fast growth, dense root system, and simple maintenance, prove it as a powerful ally for the restoration of degraded areas (Sharma *et al*., 2018). Some bamboo species can be used in the restoration of abandoned shifting agricultural lands with special respect to soil nutrient enrichment, soil erosion control and biodiversity conservation (Arunachalam and Arunachalam, 2002, Mishra *et al*., 2014). Consequently, to recognize bamboos advantages and weaving them into mechanisms for sustainability, mitigation, adaptation, and rural development appear suitable to face climate change and other bottlenecks, especially in rural areas (Lobovikov *et al*., 2012).

Most of the native Brazilian bamboo occur in forest ecosystems, especially in the Amazon and Atlantic Forest Biomes (Felisberto *et al*., 2017). Although its worldwide importance, data about its resources, production, and trade, especially in southern Brazil, remain scarce (Felisberto *et al*., 2017, Vorontsova *et al*., 2016). However, in 2011, it was established the national Brazilian Bamboo Policy in order to encourage its sustainable management and the cultivation. Among different strategies, this has been guidelines to incentive research and technological development about bamboo focused on sustainable management, cultivation, environmental services, and applications.

The State of Santa Catarina, located in the domain of Atlantic Forest biome/Brazil, has bamboo plantations already installed throughout the State. On the coast region, the most common cultivated species is *Bambusa vulgaris* Schrad, while some species of the genus *Phyllostachys* that show resistance to the frosts (Brand *et al*., 2020) have been cultivated in the Plateau Region of Santa Catarina, a suitable region for research and planting temperate and subtropical bamboo species.

Considering the previous information, we launched a project to identify and evaluate suitable bamboo species to conditions in southern Brazil, aiming at fostering the bamboo productive chain in the southern plateau of Atlantic Forest. In such context, this study aimed to assess the i) adaptability of seven bamboo species established in a germplasm collection, ii) investigate the species already used by local farmers in the Plateau Region of Santa Catarina; and iii) based on these results, suggest strategies to integrate bamboo species as option to diversified production systems in farmlands.

Materials and methods

The study was carried out in three experimental areas of the Federal University of Santa Catarina (UFSC), located in the Curitibanos county, Plateau Region of Santa Catarina, Southern Brazil (fig. 1). This region is located in the Mata Atlântica Biome, specifically in the Mixed Ombrophilous Forest (MOF). Its climate is classified as Cfb (Wrege *et al*., 2011), with an average annual temperature of 14ºC, an average altitude of 1,000 meters m.a.s.l., and an average annual precipitation ranging from 1,600 to 1,900 mm (Alvares *et al*., 2014).

Evaluation of potential species

The valuation plots started to be established in 2016 at different areas maintained by UFSC. The soils were classified according to the Brazilian System of Soil Classification (Santos *et al*. 2018) and USA Soil Taxonomy, as described;

i) Agriculture Experimental Area (AEA): The predominant soil is characterized as Haplic Cambisol/ Inceptisol (27º16"26'S and 50º30"13'W)

ii) Forest Experimental Area (FEA): The soil classified as Dystrophic Red-Yellow Latosol/Oxisol (27º19"07' S and 50º 42" 36' W)

iii) Agroforestry System (AF): this area presents Humic Cambisol/Inceptisol (27º17"13'S and 50º31"59' W)

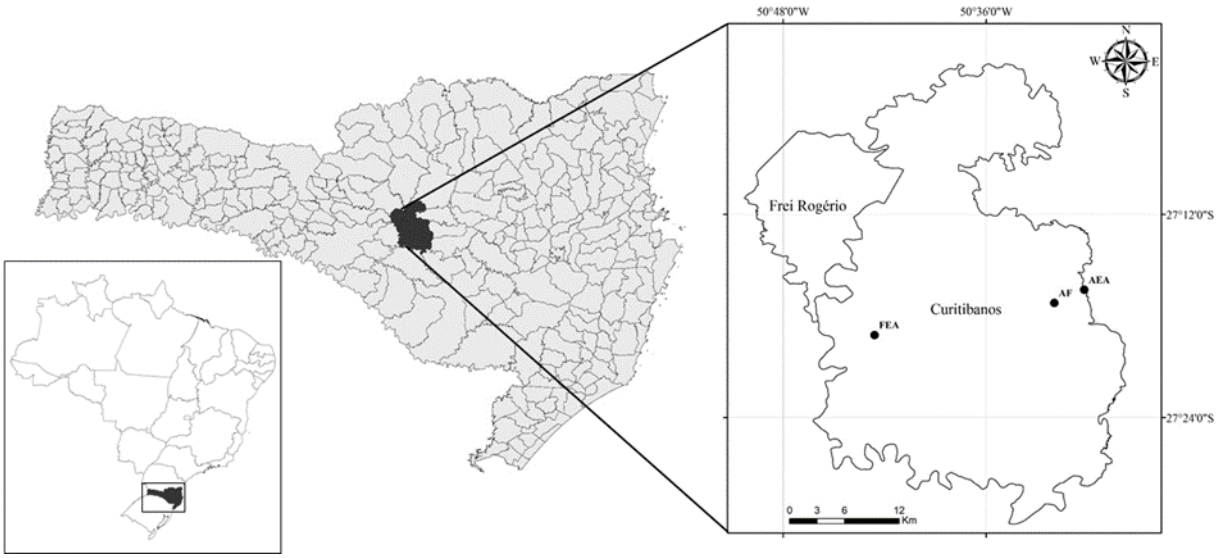

Fig 1. Map highlighting Curitibanos and Frei Rogério counties in the Plateau Region of Santa Catarina State, South Brazil, in detail the location of the studied areas. (AEA) Agriculture Experimental Area; (FEA) Forest Experimental Area, and (AF) Agroforestry System.

The plots' soil had its acidity previously corrected by lime, the planting stocks were planted under a spacing of 5 x 5 meters, and they received an organic compound as fertilization every six months after planting. The species evaluated were selected based on indications from professionals who already working in bamboo research in other areas of Santa Catarina state. Spreading bamboo species *Phyllostachys nigra* was established before this study, and then the measurements of the number of culms, diameter, and height of straws were measured in a plot of 2 x 2m. The species, number of seedlings per species and study areas are displayed in table 1.

The weed control was performed by mowing the spontaneous vegetation between cultivated lines every month during summer and every two months during winter. In the first six months, the spontaneous vegetation closest to the seedlings (in a ratio up to 2 m) was removed manually. Annually, the plants were pruned from the base up to 2 m of height, removing branches and leaves. This action was conducted during winter, after the seedlings´ sprouting.

After the pruning, the bamboo plants were measured, every year, in terms of the number, diameter and height of the culms. The diameter was measured at breast height (DBH) (1.30 m) using a pachymeter, and the height was measured with a clinometer. When the culm did not reach 1.3 m height, the diameter was measured at the highest point. As detailed in table 1, for one plot previously established, with spreading bamboo species, it was considered only the sprouting in an area of 2 x 2 m. The descriptive statistics for the variables studied (survival rate (%), number, diameter, and height of culms) were performed by software R.

Identification of bamboo species in use by farmers

Qualitative and quantitative ethnobotanical approaches were employed to describe the use and management of bamboo species by small farmers in the counties of Curitibanos and Frei Rogério, in the Plateau Region Santa Catarina State, Brazil. Semi-structured interviews were conducted to obtain information about the knowledge and potential use of the species and associated management procedures.

In compliance with the regulations related to studies with human beings, the work was submitted for authorization by the CEPSH (Human Research Ethics Committee) having a Certificate of Presentation for Ethical Appreciation number 54149316.6.0000.0121.

Table 1. Bamboo species, number of seedlings (NS) per species and studied area of vegetative evaluation in Curitibanos County, Santa Catarina State, South Brazil.

Species	NS	Area*
Bambusa oldhamii Munro	79	AEA; FEA; AF
Bambusa tuldoides Munro	5	AEA; FEA
Bambusa multiplex (Lour.) Raeusch. ex Schult.f.	1	FEA
Dendrocalamus strictus (Roxb.) Nees	1	FEA
Dendrocalamus asper (Schut. f.) Backer	14	FEA; AF
Dendrocalamus latiflorus Munro	21	FEA; AF
Phyllostachys nigra var. *henonis* (Mitford) Rendle**	2	AF

*Experimental areas: (AEA) Agriculture Experimental Area; (FEA) Forest Experimental Area, and (AF) Agroforestry System. **Spreading bamboo species.

For interview responses (species and uses) the rarefaction curve was calculated by Estimates version 9.1 (Colwell, 2013) and descriptive statistics was measured (number of citations).

Result and discussions

Species adaptation in the germplasm collection

A wide range of adaptive responses was observed in the evaluated species. For instance, *D. strictus* did not sprout during the evaluation time, and over the three years of monitoring did not show a performance to guarantee its recommendation for cultivation in this region.

Only the species that presented sprouts at any time during the evaluation; also demonstrating their behavior over the years (Table 2). There was a tendency of decreasing the survival rate over the years for most of the species, which could indicate an adaptability issue for these species in this region. In general, there was an increasing number of culms over the years, this trend was quite clear for *B. oldhamii*, *D. asper*, and *D. latiflorus*. For *P. nigra* var. *henonis*.

Following a similar trend, the performance on height and diameter also increased over the years for most of the species. The tallest species was *Phyllostachy*, reaching up to a mean of 2.92 m, followed by *B. oldhamii*, with 2.48 m and *D. asper*, with a mean height of 2.27 m. Regarding diameter, *P. nigra* showed an average diameter of 1.59 cm, followed by *B. oldhamii*, with an average diameter of 1.42 cm, and then *D. asper*, with 1.12 cm of average diameter (Table 2).

According to literature the bamboo species, those with the greatest potential for cultivation in Brazil are *D. latiflorus* and *D. asper*, as well as species of the genus *Phyllostachys, Dendrocalamus* and *Bambusa* (Greco and Cromberg, 2011, Miranda *et al*., 2017). However, as mentioned the survival rate for the species cultivated in the Plateau Region of Santa Catarina indicates an adaptability concern for these species in this region, at least in the first years of evaluation.

Indeed, *B. oldhamii* is a species that stands out in terms of culms density and size, and low mortality rate, as observed by Sanquetta *et al*., (2015) and Sanquetta *et al*. (2017). Although, our mean data suggest that more evaluation time is needed for the full establishment of the *B. oldhamii* in the region, possibly due to local climatic conditions that may have delayed the development. For example, the agro-meteorology group at the UFSC Campus registered 37 frost episodes from 2017 to 2019.

Table 2. Performance of bamboo species, year of evaluation, survival rate, number of culms (NC), height and diameter at breast height (DBH) in Curitibanos County, Santa Catarina State, South Brazil.

Bamboo species	Year	Survival Rate (%)	NC	Height (m)	DHB (cm)
B. oldhamii	2017	43.0	2	1.18	0.72
	2018	24.1	5	2.61	1.76
	2019	24.1	12	3.64	1.79
Mean	-	30.4	6	2.48	1.42
Standard deviation		11.0	5.1	1.2	0.6
B. tuldoides	2017	83.3	5	1.70	0.84
	2018	60.0	9	2.24	0.92
	2019	60.0	8	2.15	1.36
Mean	-	67.8	7	2.03	1.04
Standard deviation		13.5	2.0	0.3	0.3
B. multiplex	2017	100.0	2	0.90	0.40
	2018	100.0	3	1.30	0.67
	2019	100.0	5	1.82	0.68
Mean	-	100.0	3	1.34	0.58
Standard deviation		0.0	1.5	0.5	0.2
D. asper	2017	64.3	2	1.60	0.52
	2018	71.4	2	1.57	1.17
	2019	57.1	11	3.65	1.68
Mean	-	64.3	5	2.27	1.12
Standard deviation		7.1	5.0	1.2	0.6
D. latiflorus	2017	39.1	2	0.85	0.55
	2018	34.8	3	1.59	1.12
	2019	45. 5	8	2.54	1.48
Mean	-	39.8	4	1.66	1.05
Standard deviation		5.4	3.2	0.9	0.5
Phyllostachys sp	2017	25.0	9	2.62	1.32
	2018	25.0	6	3.10	1.26
	2019	13.0	4	3.03	2.18
Mean	-	21.0	6	2.92	1.59
Standard deviation		6.9	2.3	0.3	0.5

D. asper is an important species in Brazil, being also used to produce edible shoots (Felisberto *et al*., 2017). In the evaluated conditions *D. asper* presented enhanced adaptability to the local conditions due to a possible cold resistance, which was not observed in a previous study (Sanquetta *et al*., 2017). Concerning the successional growth of culms, an increase in diameter and height is naturally expected to happen over the years. It was shown in *D. asper* and *Gigantochloa levis* (Blanco) Merr. gains in diameter and height along the planting in Philippines (Fernandez *et al*., 2003). The authors observed a transition from the juvenile phase of clumps toward a mature and harvestable state by the fourth year.

Species from the genus *Phyllostachys* are being used, mainly in the municipality of Frei Rogerio; this fact is mainly due to Japanese colonization, which had a great influence on the introduction of such species. The genus *Phyllostachys* has been cultivated, essentially, for presenting resistance to frosts (Brand *et al*., 2019, Brand *et al*., 2020), and because farmers use these species for food purposes, and more recently to supply the industry in the region for the manufacture of toothpicks and barbecue sticks (Brand *et al*., 2019). In addition, the species *P. reticulata* and *P. nigra* are being studied as alternative of raw material for the manufacture of briquettes and domestic charcoal and have shown satisfactory results for energy generation (Brand *et al*., 2019, Brand *et al*., 2020).

Interviews with the farmers

Nine informants were interviewed, all males, with ages ranging from 45 to 90 years old. They have direct relations with agriculture, working on a myriad of agricultural activities, from fruit to livestock.

As expected, bamboo showed to be important for informants, with an average of 7.4 species mentioned per interview applied. Most informants reported that they have bamboo on their properties due to the need for materials that help in the management of vegetables and small constructions.

The main use mentioned was furniture manufacturing with 05 citations, followed by construction, handcrafts, household utensils, food, and tutoring with 03 citations each and finally; soil recovery and landscaping with 01 citation each (Table 03). All informants have been using bamboo as a source of complementary income, and only one of them uses bamboo as the main source of income, in this case especially for furniture manufacturing.

Informants emphasized the species *Phyllostachys edulis, Phyllostachys reticulata* and *P. nigra* var. henonis, which had the highest number of citations, and, according to them, these species are very versatile. Only two bamboo species native from Brazil were cited, *Chusquea sellowii* Rupr. and *Guadua chacoensis*.

Besides the uses cited by farmers, *P. edulis* and *P. nigra* can be also used for construction, furniture and laminates (Grecco and Cromberg, 2011). *P. reticulata* is a spreading bamboo species originally from China, being also widely cultivated in Brazil. The most common uses are for construction, furniture and laminates (Grecco and Cromberg, 2011). According to farmers interviewed, locally the main use of this species is by structural support in construction activities.

B. tuldoides is also native from southern China, and widely cultivated in Santa Catarina State. This species has been used in paper manufacture, construction, fences and as an anchor in the cultivation of vegetables (Grecco and Cromberg, 2011).

The native species *Chusquea sellowii,* also called Cará, is endemic in the South and Southeast regions of Brazil and mostly distributed on the altitude conditions (Shirasuna *et al*., 2015). *Chusquea* is a peculiar genus since it presents solid stems and branching with multiple buds. This species also reveals ornamental potential value (Filgueiras and Viana, 2017).

The taquaruçu (*Guadua chacoensis*), also known as Chacoensis, naturally occurs in Brazil, Paraguay, Argentina and Bolivia. It is commonly cultivated due to the habit, color and internodes. The stems are 10-20 m high with a diameter of 10-13 cm. These are usually erect with hollow internodes and white pubescence close to the nodes and spinning branches (Greco and Cromberg, 2011, Filgueiras and Viana, 2017).

Table 3. Bamboo species in use by farmers in the Plateau Region of Santa Catarina State, South Brazil, followed by scientific name and the number of citations.

Common Name	Scientific Name	Numb. of citations
Mossô	*Phyllostachys edulis (Carrière) J. Houz.*	7
Madake	*Phyllostachys reticulata (Rupr.) K.Koch*	6
Hachiku	*Phyllostachys nigra* var. henonis	5
Quadrado	*Chimonobambusa quadrangularis* (Franceschi) Makino	3
Taquara	*Bambusa tuldoides*	2
Bambu Negro	*Phyllostachys nigra* (Lodd. ex Lindl.) Munro	2
Cará	*Chusquea sellowii*	1
Taquaruçu	*Guadua chacoensis (Rojas Acosta) Londoño & P.M. Peterson*	1

*Species identification was carried out with bibliographic support and technical consulting from the Catarinense Association of Bambu, BambuSC.

The time for which the bamboo species have been cultivated by the interviewees ranged from three to 30 years. Regarding cultivation management, informants did not mention any specific difficulties, and according to them bamboos take some time to establish in the field, but after a period of four to six years, the plants develop well.

In the present study the evaluation of seven species of bamboos in the plateau region of Santa Catarina State, South Brazil, showed that in addition to all the listed characteristics, other factors especially temperature, should be considered for the implementation of bamboo cultivation in the region. The mortality of plants highlights the frost sensitivity for some of the evaluated species, and even the surviving plants demonstrate reasonable time for their establishment. Alternatively, plants grown in canopy-covered systems, or close to areas more protected by forest vegetation, can perform better, suggesting that the establishment of bamboo cultivation should preferably be carried out in integrated production systems, such as Agroforestry Systems.

Another relevant aspect refers to the records of biological invasions by bamboo are widespread in the ecological literature, and its consequences vary from the addition of new species to drastic disruptions on the community structure (Larpkern *et al.*, 2011). Generally, these overabundant species, even native species, are opportunists that respond positively to changes in the original community, which is a common feature of human-modified landscapes (Lima *et al*., 2012). Consequently, high human disturbance can cause a shift in the dominance structure of forest ecosystems, and may result in a concomitant reduction in species abundance, richness, and diversity (Larpkern *et al*., 2011). Thus, the management of bamboos, even native ones, such as the *Guadua* species, should be done based on environment context and technical strategies by controlling their distribution in natural and agricultural areas.

An important factor for strengthening bamboo cultivation in the Santa Catarina plateau was an initiative by a local producer to donate seedlings to friends and neighbors. This specific producer was repeatedly mentioned during the interviews, as being considered a "guardian". Recently, the strengthening of the use of bamboo in the region is gradually being linked to the actions of private companies in the forestry sector, which have been using bamboo for production of matchsticks and sticks for culinary use.

Currently, in Brazil, bamboo has been part of the investment of some companies, which have promoted commercial plantations and research, aiming at their uses. In general, gradually, the increase in the bamboo market in Brazil has been observed, which highlights the importance of studies related to productive performance, ecological adaptability and use of bamboo species in the diverse Brazilian eco-systems.

Conclusions

Based on the results of the present work we suggest that the transition from the juvenile phase of clumps to a mature and harvested state of bamboo species evaluated on this study can take more than three years in the plateau of Santa Catarina State, South Brazil.

In addition, the informant's answers demonstrate the plasticity of uses of this group, which have been used as a source of complementary income as well. Three species (*P.edulis*, *P. reticulata* and *P. nigra* var. henonis) were mentioned in more than 55% of the interviews, with an emphasis on the species *P. edulis* with the highest number of citations, showing its potential as a promising species in the composition of productive systems.

Considering the vegetative performance and data from the interviews, factors as climate characteristics should be considered in future studies for the implementation of bamboo cultivation in the region, alternatively, we suggest the establishment of bamboo cultivation research preferably in integrated production systems, such as Agroforestry Systems, to prevent frost damage.

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