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Scientific Note

Baru tree ideotypes for production systems[1]

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ABSTRACT

The *Dipteryx alata* domestication is still in its early stages, characterized by instability in fruit production, absence of proper management practices, and lack of selected cultivars. This study aimed to define *D. alata* ideotypes for two cultivation systems, based on the perception and preferences of wild harvesters and farmers, as well as on documented phenotypic variability. A questionnaire was administered to wild harvesters and producers of the Goiás state, Brazil (n = 62 valid respondents), and the data were analyzed using descriptive statistics. The results revealed a strong preference for trees with open canopies (80.7 %), large and rounded fruits (87.1 %), and large nuts (61.3 %). The first ideotype, tailored for pure or intercropped systems, is characterized by a short-to-intermediate stature and a compact canopy architecture. The second, designed for silvopastoral systems, features an intermediate-to-tall stature and open canopy architecture. The proposed ideotypes integrate productive and morpho-agronomic attributes, providing a preliminary conceptual and quantitative framework for plant breeding and contributing to the sustainable use and conservation of natural baru populations in the Brazilian Savanna.

KEYWORDS: *Dipteryx alata*, Brazilian Savanna, plant breeding.

RESUMO

Ideótipos de baruzeiro para sistemas de produção

A domesticação de *Dipteryx alata* ainda se encontra em estágio inicial, caracterizada pela instabilidade na produção de frutos, ausência de práticas de manejo adequadas e falta de cultivares selecionadas. Objetivou-se definir ideótipos de *D. alata* para dois sistemas de cultivo, com base na percepção e preferências de coletores e agricultores silvestres e na variabilidade fenotípica documentada. Um questionário foi aplicado a extrativistas e produtores do Estado de Goiás, Brasil (n = 62 respondentes válidos), e as respostas foram analisadas por meio de estatística descritiva. Os resultados revelaram forte preferência por árvores com copas abertas (80,7 %), frutos grandes e arredondados (87,1 %) e castanhas grandes (61,3 %). O primeiro ideótipo, voltado a plantios puros ou consorciados, caracteriza-se por porte baixo a intermediário e arquitetura de copa compacta. O segundo, destinado a sistemas silvipastoris, apresenta porte intermediário a elevado e arquitetura de copa aberta. Os ideótipos propostos integram atributos produtivos e morfoagronômicos, fornecendo uma estrutura conceitual e quantitativa preliminar para o melhoramento genético e contribuindo para o uso sustentável e a conservação de populações naturais de baru no Cerrado.

PALAVRAS-CHAVE: *Dipteryx alata*, Cerrado, melhoramento genético.

The baru tree (*Dipteryx alata* Vogel - Fabaceae) is a native species of the Cerrado (Brazilian Savanna) which plays a crucial role both ecologically and socioeconomically. Ecologically, it is considered a keystone species of the Cerrado, as its fruits ripen during the dry season, providing food for several species of local fauna as well as livestock (Sano et al. 2004, 2016). From a socioeconomic perspective, the sustainable extractivism of baru, the fruit of the baru tree, generates income for traditional communities and family farmers, strengthening local economies and promoting environmental conservation (Burgos & Mertens 2024).

The baru nut has a high nutritional value, as it is rich in proteins, fibers, antioxidants, and healthy fats (Santos et al. 2021), making it an ally of food security and human health. Fruit maturation occurs between July and September, and each plant

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may produce up to 5,000 fruits (Sano et al. 2016). However, this production is extremely unstable between years, and it is common for larger fruits to occur in years of lower production and vice versa (Oliveira & Sigrist 2008).

An essential step for domestication and genetic breeding of the baru tree is to identify ideotypes, meaning ideal plant models capable of maximizing efficiency and productivity under specific cultivation contexts (Donald 1968).

Unlike selection based solely on observation of higher yield, the ideotype approach starts from the prior definition of desirable attributes that, taken together, guide the genetic improvement process (Rasmusson 1987). The ideotype concept enables incorporating approaches focused on morphology, physiology, or biochemistry into the ideal model. Therefore, it is necessary to clearly define the focus used to establish the ideotype intended for cultivation, enabling the selection of specific traits for each superior type to be obtained (Price et al. 2022, Carbajal-Friedrich & Burgess 2024).

Similar to other native fruit species of the Cerrado, *D. alata* exhibits a wide phenotypic variability to be explored (Mota et al. 2020). However, there is no empirically grounded definition of ideotypes for *D. alata* adapted to production systems, particularly integrating stakeholder preferences with documented phenotypic variability. In this context, and focusing on the use of the species as a non-timber forest resource, the present study has three main objectives: to present and review information from the literature on the morpho-agronomic variation of the species; assess the perception of extractivist communities and producers, regarding the ideal phenotypic traits of the plant; and propose two ideotypes for the genetic improvement of the species, targeting two types of cultivation systems which are considered promising for the baru production.

The ideotype construction followed a two-step framework: identifying phenotypic variability ranges from the literature, and prioritizing traits based on stakeholder preference frequencies, thereby allowing to define ideotypes constrained by biologically observed limits. Phenotypic variation comprised biometric values reported in the literature and obtained through experimental assessments, particularly for traits such as tree growth form, fruit size, and seed shape. These characteristics can support decision-making in breeding programs when integrated with the traits preferred by stakeholders involved in the baru production chain.

Phenotypic variability in the baru tree is expressed in significant differences in height, canopy shape, and fruit and seed characteristics. Studies indicate that the tree height can range from 5 to 25 m (Sano et al. 2016), with trunk diameters reaching up to 70 cm. The canopy is dense and rounded, with a diameter of approximately 6 to 11 m (Sano et al. 2016), depending on environmental and genetic conditions. In addition, the tree architecture is characterized by a smooth trunk that is slightly fissured, especially in young individuals, becoming rougher and more fissured with age (Almeida et al. 1998).

Baru fruits show a wide morphological and biometric variability, which has been documented in different regions of the Cerrado. Whole fruit mass ranges from 9 to 73 g (Sano et al. 1999, Corrêa et al. 2000, Corrêa et al. 2008, Mota et al. 2020), whereas fruit length varies between 3.6 and 7.0 cm (Corrêa et al. 2000, Mota et al. 2020). Despite the tendency toward wide variation ranges, fruits with average values of 3.9 cm in width and 2.9 cm in thickness are commonly reported (Silva et al. 1994, Corrêa et al. 2000, Corrêa et al. 2008, Zuffo et al. 2014), with a predominance of oval and slightly flattened fruits (Mota et al. 2020).

In turn, mean values of 1.22 g for mass, 2.5 cm for length, 1.0 cm for width, and 0.8 cm for thickness have been estimated for seeds, indicating elongated seeds with an oval cross-section. According to Mota et al. (2020), most of the variation in seed traits occurs among individuals; however, some provenances (subpopulations) show higher mean values for fruit and seed characteristics, making them targets for germplasm collection.

Importantly, positive correlations between fruit and seed traits have been reported for *D. alata*. Mota et al. (2020) demonstrated significant positive phenotypic correlations between fruit mass and seed mass ($r = 0.710$) and fruit length and seed length ($r = 0.813$), indicating that larger fruits tend to yield larger and heavier seeds. Consistent with these findings, Amorim (2026) used image-based phenotyping of baru fruits from the Universidade Federal de Goiás (UFG) germplasm collection and also observed positive correlations between fruit and seed width ($r = 0.48$), mass ($r = 0.64$), and length ($r = 0.73$). Similar associations were reported by

Corrêa et al. (2008) and Zuffo et al. (2014), who identified fruit fresh mass as the variable with the greatest potential for improving seed yield in baru. These correlations are particularly relevant for breeding programs, as they suggest that indirect selection for fruit size can result in simultaneous gains in seed yield. Furthermore, the woody endocarp of baru represents a major bottleneck in the productive chain, as it makes mechanical processing costly and inefficient (Magalhães 2019, Burgos & Mertens 2024). Therefore, traits such as endocarp thickness and its ease of cracking are also important targets to be considered in defining ideotypes for the species.

Overall, studies on the phenotypic characterization of baru fruits and seeds reveal a wide diversity in size and shape, including plants with desirable traits for food exploitation, such as those bearing larger fruits and seeds (Silva et al. 1994, Corrêa et al. 2000, Corrêa et al. 2008, Zuffo et al. 2014, Mota et al. 2020). An advantage for this type of exploitation is the fact that the Universidade Federal de Goiás maintains an *in vivo* germplasm collection of baru trees, established under an experimental design, which ensures robust estimation of quantitative and molecular genetic parameters (Guimarães et al. 2019a, Mota et al. 2020). The genetic characterization of this germplasm collection accelerates the selection of superior plants within genetic breeding programs and enables the prospection of natural populations that may enrich the genetic diversity conserved *ex situ* (Diniz-Filho et al. 2012, Guimarães et al. 2019b).

In order to capture the ideal phenotypic traits of baru plants from the perspective of those who work directly with the species, a questionnaire was applied to extractivists and producers in the Goiás state, between May and July 2024, using a Google Forms survey, prepared in accordance with the ethical principles established for research involving human subjects (Certificate of Presentation for Ethical Review nº 78493924.9.0000.5083). The sampling followed a non-probabilistic network approach, which limits extrapolation but is adequate for an exploratory ideotype definition. This instrument assessed the participants' perceptions regarding the following aspects of the plant: forms of baru use (extractivism, small- or large-scale cultivation); most viable production systems (exclusive planting or intercropping with annual, perennial, or pasture species); propagation systems (seeds or cloning); ideal plant size; preferred fruit and nut size and shape; and space for additional comments and suggestions regarding the species use, production systems, and ideal morphological traits. The obtained responses were analyzed using descriptive statistics. Although this approach limits identifying latent patterns, it is considered adequate, given the exploratory nature of the study and the sample size. Future studies with larger and stratified samples could apply multivariate or preference-ranking analyses to identify patterns across stakeholder profiles. Based on this framework, and on the distinct forms of baru use identified among respondents, two cultivation models were considered for ideotype definition: an ideotype for forest-based cultivation systems and an ideotype for integrated crop-livestock-forest systems.

Of the total 64 responses, 96.9 % declared agreement with the Informed Consent Form, confirming their participation in the study. Valid responses corresponded to 62 participants, mainly from Goiânia (11.3 %), Brasília (9.7 %), Ceres and Mineiros (4.8 % each), as well as from other municipalities in the states of Goiás, Minas Gerais, Mato Grosso do Sul, Bahia, Paraná, and Tocantins, reflecting the territorial coverage of the consulted network.

The analysis of the exploitation mode of the species revealed that the majority of respondents (64.4 %) use the baru tree through extractivism, followed by 30.6 % who practice small-scale cultivation, and only 3.2 % who cultivate the species on a large scale. These results confirm that the baru production chain is still strongly dependent on extractivism, a reality already highlighted in previous analyses of the use and commercialization of products from the Cerrado's sociobiodiversity (Magalhães 2019). On the other hand, the mention of small-scale cultivation suggests openness to adopting baru in cultivated systems.

Intercropping with pastures stood out as the production system considered most viable (33.9 %), followed by intercropping with annual crops (27.4 %) and perennial crops (16.1 %). Only 9.7 % of the participants indicated exclusive planting as their preferred alternative, whereas other specific forms of intercropping (e.g., agroforestry systems, ecological restoration, and species mixtures) were mentioned less frequently.

Most participants (79 %) expressed a preference for using seeds as the propagation system, reflecting the predominance of traditional,

more economical, and accessible methods for managing native species. The baru tree is known to exhibit high seed germination and survival rates, and sexual propagation is widely practiced for seedling production (Sano et al. 2004, 2006). In contrast, 21 % opted for cloning, a method which is still not widely adopted. However, it has mainly shown advances through grafting techniques, which appear to be the most viable approach for the vegetative propagation of this species, ensuring a greater genetic uniformity and potential for genetic improvement and domestication (Silva Neto 2019, Lima et al. 2023).

The preference for low-stature individuals with open canopies (48.4 %), followed by tall individuals with open canopies (32.3 %), indicates a demand for plants that combine productivity with ease of management, since open canopies favor light penetration and facilitate fruit harvesting. This result is consistent with the variability in stature already reported for *D. alata* (Corrêa et al. 2008, Ferreira et al. 2018).

Regarding fruit characteristics, the vast majority of respondents (87.1 %) preferred large and rounded fruits. There was a preference for a rounded shape for the nuts (56.5 %), when compared with an elongated shape (43.5 %), as well as for a higher proportion of large nuts (61.3 %), over medium (37.1 %) and small nuts (1.6 %).

Overall, the perceptions expressed by the participants reinforce that the baru ideotype should be understood as a dynamic model, adjustable to cultivation conditions and different end uses (Clement 2001). These findings also underscore the importance of integrating local and traditional knowledge into breeding approaches, reinforcing the value of participatory approaches in expanding social participation and democratizing the development of solutions for native species.

The consolidation of these preferences demonstrates the importance of developing selected plant materials which not only improve productivity, but are also adapted to management practices and the most viable cultivation systems. Thus, the results of the questionnaire provided a practical framework for defining the ideotypes proposed for *D. alata*. The ideotype attributes were established by integrating the phenotypic variability reported in the literature with the preferences expressed by extractivists and producers (Table 1). The commercial plantation ideotype emphasizes ease of management, harvesting efficiency, and fruit production, whereas the silvopastoral ideotype additionally prioritizes shade provision and compatibility with integrated livestock systems.

One ideotype for forest-based cultivation system is proposed for exclusive cultivation of the baru tree or for integration into agroforestry systems intercropped with perennial species such as cashew, mangaba, pequi, and medium-rotation timber crops. Short-cycle crops could be used in the inter-

Table 1. Attribute vectors and operational ranges proposed for *Dipteryx alata* ideotypes intended for commercial plantation and silvopastoral systems. Trait values were defined by integrating phenotypic variability documented in the literature with the preferences expressed by extractivists and producers surveyed in this study.

Trait	Reported phenotypic variability	Stakeholder preference (%)
Plant height (m)	5-25	48.4 (short stature with open canopy)
Canopy architecture	Canopy diameter: 6-11 m	80.7 (open canopy)
Fruit mass (g)	9.75-72.97	87.1 (large fruits)
Fruit length (cm)	3.6-7.0	87.1 (large fruits)
Seed size (cm)	Length: 1.56-3.31	61.3 (large nuts)
Seed shape	Rounded to elongated	56.5 (rounded nuts)
Propagation system	Sexual or clonal	79.0 (seed propagation)
Trait	Commercial plantation ideotype	Silvopastoral ideotype
Plant height (m)	3-5	5-10
Canopy architecture	Broad, compact, and open canopy	Open and well-distributed canopy
Fruit mass (g)	≥ 40	≥ 40
Fruit length (cm)	≈ 7.0	≈ 7.0
Seed size (cm)	Large seeds (> 3.0)	Large seeds (> 3.0)
Seed shape	Rounded	Rounded
Propagation system	Seed propagation	Seed propagation

Source: Prepared by the authors based on Mota et al. (2020), Mota (2017), and stakeholder preferences assessed in the present study.

rows, or even between baru trees, during orchard establishment, such as common bean, cassava, maize, or guariroba. The proposed ideotype should prioritize early-maturing plants of low to medium stature, with height ranging from 3 to 5 m, and a broad and rounded canopy. This allows for higher planting density and facilitates management and harvesting in agroforestry systems. The feasibility of selecting for reduced plant height is supported by quantitative genetic studies. Cândido (2021) reported moderate heritability estimates for plant height (0.277 at the progeny level and 0.421 at the individual level), together with sufficient genetic variation to enable selection gains.

Fruits of this ideotype are expected to be large and rounded, with mean values of 7 cm in length, 4.5 cm in width, and 3.5 cm in thickness. Seeds are expected to measure approximately 2.5 cm in length, 1.0 cm in width, and 0.8 cm in thickness. The forest-based cultivation ideotype is defined by plant height between 3 and 5 m, canopy diameter ≥ 5 m, fruit mass ≥ 40 g, fruit length ≈ 7 cm, and seed mass ≥ 1.5 g. As a threshold selection criterion, candidate genotypes should simultaneously meet height below 5 m, fruit mass above 40 g, and early bearing, allowing their direct use as selection targets in genetic improvement programs.

The lower-stature baru tree ideotype is more suitable for fruit exploitation in single-crop or intercropped planting systems. This ideotype should be considered a dynamic stage of plant stature, as trees tend to grow and further develop with age. This characteristic may involve genetic and/or environmental components, and further investigation is needed to identify the relative contribution of genetic *versus* environmental factors in determining canopy shape and plant stature in baru trees.

It should also be noted that plants whose first bifurcation occurs close to the ground tend to develop more open canopies. The presence of herbivorous animals, especially cattle, tends to prune the lower part of the canopy up to the height they can reach. Like most Cerrado plant species, the baru tree does not tolerate light restriction imposed by competition among tree species very well, which reduces canopy diameter in such cases

It should be emphasized that the traditional propagation system for the baru tree is by seeds, which results in trees with taller and slender canopies on average. Studies on vegetative propagation, combined with formative pruning and the definition of appropriate spacing for each type of exploitation, are necessary to enable fruit production in plants with reduced stature. Another important factor is production precocity: the earlier fruit production begins the slower the tree tends to develop its arboreal architecture, which is desirable for fruit-oriented systems. The opposite is also true in situations where timber production is prioritized over fruit production; in such cases, taller plants with straighter boles are preferred, provided that they achieve a diameter compatible with the intended exploitation, usually under higher planting densities.

The ideotype for integrated crop-livestock-forest system is aimed at integrating the baru tree with pastures, configuring systems that combine livestock production and fruit exploitation. In this case, medium- to tall-stature trees, with height ranging from 5 to 10 m and open, well-distributed canopies are desirable. The canopy provides shade and thermal comfort for cattle. Moreover, more open canopies are recommended in silvopastoral systems because they provide shade without excessively impairing pasture growth (Poudel et al. 2024).

Although the initial growth of the baru tree is not extremely rapid, variation among plants indicates that some individuals have the potential for more vigorous growth (Zuffo et al. 2014, Andrade et al. 2020). This implies that the existence of diversity in plant stature provides a basis for selecting medium to tall trees suitable for silvopastoral management.

Fruit production in this ideotype should be abundant, especially during the dry season, providing an additional food source for cattle and potential for seed commercialization. Fruits should be large and rounded, with measurements close to 7 cm in length, 4.5 cm in width, and 3.5 cm in thickness. Seeds should be larger and rounded, measuring approximately 2.5 cm in length, 1.0 cm in width, and 0.8 cm in thickness.

The silvopastoral ideotype is defined by plant height between 5 and 10 m, open and well-distributed canopy architecture, and fruit and seed characteristics equivalent to those of the forest-based ideotype.

These quantified intervals transform the ideotype descriptions from purely conceptual models into operationally usable technical references for breeding programs. These characteristics fall within the ranges reported in studies on baru and are considered to represent larger-sized fruits and seeds (Zuffo et al. 2014, Mota 2017, Mota et al. 2020).

The ideotypes presented herein represent an initial framework that integrates local knowledge with the currently available phenotypic information. By defining desirable target traits for contrasting production systems, they provide a valuable contribution to pre-breeding activities, supporting the development of improved baru cultivars. The proposed ideotypes can be applied in specific planting situations to meet local needs or to guide decision-making in breeding programs for the species. In addition, the forest-based cultivation ideotype may also be used to enrich extractivist homegardens.

However, the ideotypes proposed in this study should be interpreted as preliminary conceptual models. The characteristics should be regarded as desirable targets for future selection and validation rather than as already proven traits to maximize productivity under all cultivation conditions (Corrêa et al. 2000, Corrêa et al. 2008, Mota et al. 2020).

Genetic improvement methods such as recurrent selection and early selection may accelerate establishing more homogeneous plantings which meet both carpological and architectural requirements for the economic use of the baru tree. Validation of the proposed ideotypes will require additional studies on genetic parameters, heritability, genetic correlations among traits, fruit yield stability, canopy architecture, and adaptation to environmental conditions. In this context, future studies should advance the integration of phenotypic, genetic, and productive data across environments, aiming to consolidate efficient strategies for selecting and domesticating the species.

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