Macaúba: Multi-criteria spatial assessment of alternative oil crop production systems in Brazil

AUTHORS

Sai Anurag Nandagiri [1],
Ricardo Vargas-Carpintero [1,2],
Thomas Hilger [2]

[1] University of Hohenheim, Dept. Biobased Resources in the Bioeconomy, Germany
[2] University of Hohenheim, Inst. of Agric. Sci. in the Tropics, Acrocomia Hub, Germany

I. INTRODUCTION

The **macaúba palm (*Acrocomia aculeata*)** is increasingly recognized as a **promising alternative oil crop in Brazil** due to its ecological adaptability, **high oil yields**, and potential to generate co-products such as **proteins and fibers for the bioeconomy**. Unlike conventional tropical oil crops like African oil palm (*Elaeis guineensis*), macaúba can be established on degraded pasturelands in **Brazil's Cerrado biome**, offering opportunities for **ecological restoration** and **rural development** while reducing deforestation pressure on tropical forests**.**

Advances in domestication have led to the transition of this palm **from wild use to initial cultivation** in Brazil, driven mainly by biofuel sector (Motoike & Hilger 2024; Vargas-Carpintero et al., 2021, 2022). More than 4,000 ha have already been planted, with expansion plans targeting up to 400,000 ha by 2030, mainly on degraded land and under different production systems (e.g. agroforestry and plantations).

Aim: This study presents a proof of concept combining an **integrated multi-criteria decision analysis (MCDA)** framework (Vargas-Carpintero, 2025) with **spatial datasets** to conduct an **ex-ante** assessment of macauba crop production systems in three municipalities of the **State of Minas Gerais** (Brazil) (Fig 2)**.** Each municipality hosts a distinct **macaúba cultivation and value chain initiatives**, thus shaping distinct **typology configurations** for macaúba in these regions.

II. METHODS

1. Spatial Datasets

Spatial datasets were selected and organized into three **MCDA** pillars (Hill et al., 2005) (Fig 3):

II. **Biophysical-environmental feasibility criteria** combines a **macaúba bio-physical suitability map (Walter et al. 2021)** with **pasture-degradation layer**, after masking **protected areas** to ensure legal compliance while avoiding conflicts with biodiversity-conservation priorities.

III. **Techno-economic viability criteria** is represented by an **infrastructure proximity index** based on distances to warehouses, urban-centers, and highways.

IV. **Socio-institutional desirability criteria** is captured through a **community rural density index** as proxy for rural labor and social presence. .

Land-use and **land-cover data** are used to distinguish pasture and crop systems and assess where macaúba can be integrated via **agroforestry systems (silvopastoral or agrosilvicultural)** or **plantation configurations (monocropping).**

1. Composite Implementability index and Production System Typology

From these layers, a **composite implementability index** and a **production system typology map** were developed (Fig 3), classifying map cells as potential areas for **plantation** or **agroforestry systems** (**community/commercial silvopastoral**, or **agrosilviculture** with **coffee**, **soybean**, or **other-annual-crops)**.

III. RESULTS

The **production system typology maps** illustrate following findings (Fig 4):

I. **Montes Claros:** The results suggest a **hybrid pattern**, where both **plantation systems** and **community silvopastoral** arrangements are feasible. This reflects a territorial configuration in which macaúba can be integrated into existing cattle-based landscapes while also supporting more organized production nodes.

II. **João Pinheiro:** The municipality shows **large, contiguous areas** that are well suited to **plantation-oriented** macaúba models, particularly in landscapes already associated with degraded pasture. This makes it a strong candidate for a more **industrial** and **spatially-concentrated production structure.**

III. **Patos de Minas:** The municipality presents a more **diversified mosaic**, where **agroforestry** and **community silvopastora**l typologies appear most consistent with current land-use patterns. Here, macaúba seems better aligned with **mixed agricultural settings** and **multi-use rural landscapes**.

IV. CONCLUSIONS

The study shows that **macaúba expansion and value chain development** in **Brazil** should be guided by **typology-aware spatial analysis** rather than climate suitability or investment opportunity alone.

1. Territorial Alignment

I. **Montes Claros (Company A: Acelen):** Strong match for industrial scale with ~1,200 km² of plantation-suitable land. However, the 1,450 km² of community silvopastoral land highlights a need to integrate smallholders rather than focus solely on monoculture plantations.

II. **João Pinheiro (Company B: S.Oleum):** Clear match for large, contiguous commercial agroforestry. Widespread degraded pastures and low community rural density favor corporate investments, although this limits local countervailing power.

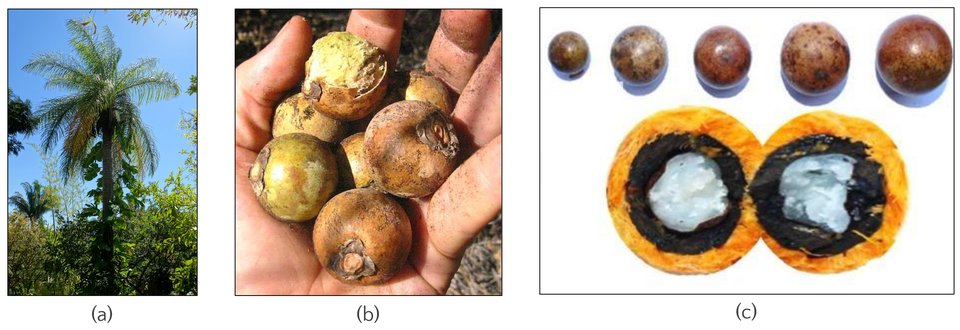
III. **Patos de Minas (Company C: INOCAS):** Ideal match for cooperative, smallholder-led networks due to high community rural density. However, substantial land-use share reflected documented urbanization-driven Cerrado conversion (N. M. de Oliveira et al., 2014). This indicates that INOCAS's operational scope is concentrated in a subset of the municipality rather than distributed across its full extent.

2. Future Outlook

I. **AHP Weighting:** The equal weighting of MCDA components is a good starting point but does not reflect differentiated decision-making priorities across typologies. Analytic Hierarchy Process (AHP) weighting, based on expert elicitation, is the most immediate methodological improvement (Herzberg et al., 2019).

II. **Data Integration:** Future models should incorporate tenure data, cooperative registers, socio-economic vulnerability indices of farmers, and institutional networks that allow for the interpretation of centralisation or decentralisation of production systems in these municipalities further improving socio-institutional resolution.

III. The final output provides a **transferable template** that can be scaled across all 5,568 Brazilian municipalities to optimize other novel or underutilized crops.



(a) (b) (c)

Fig 1: (a) Macaúba palm (b) Macaúba fruit (c) Composition of fruit layers (Vargas-Carpintero et al., 2021)

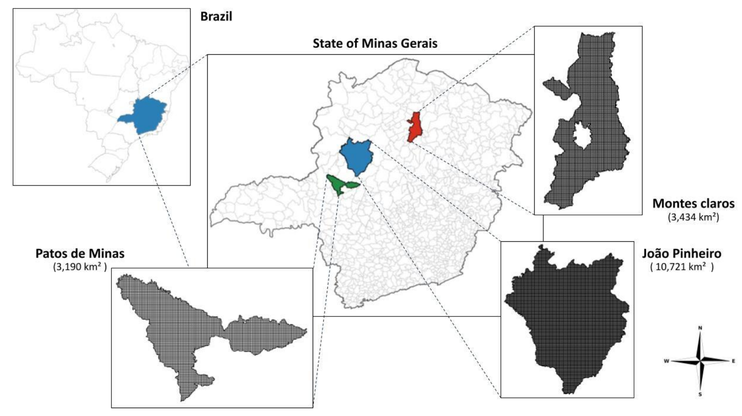


Fig 2: Geographical locations of the three municipalities in Minas Gerais state of Brazil

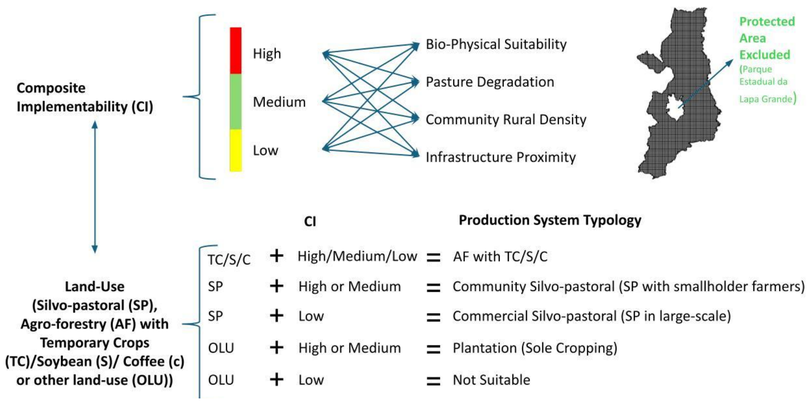


Fig 3: Schematic representation of composite implementability and production system typology

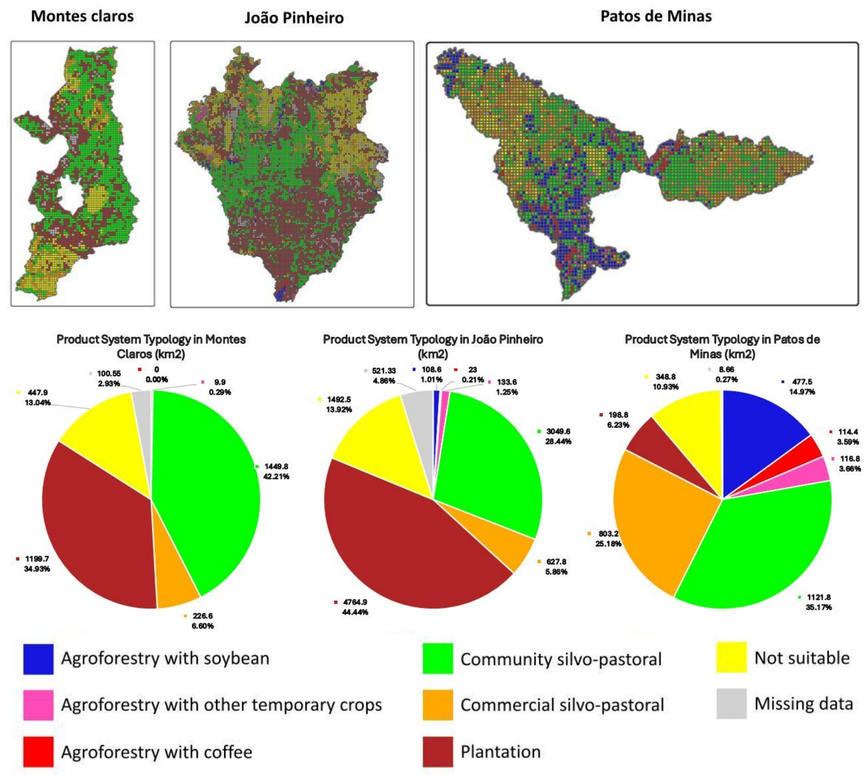


Fig 4: Production system typology distribution in the three municipalities

References:

1. Motoike, S., & Hilger, T. (Eds). (2024). Macaúba: do plantio à colheita. Oficina de Textos. ISBN: 8579754003.
2. Vargas-Carpintero, R., Hilger, T., Mössinger, J., Souza, R. F., Barroso Armas J.C., Lewandowski, I. (2021). Acrocomia spp.: neglected crop, ballyhooed multipurpose palm or fit for the bioeconomy? A review. Agronomy for Sustainable Development, 41(6). https://doi.org/10.1007/s13593-021-00729-5.
3. Vargas-Carpintero, R. (2025). Development of an integrated multi-criteria framework to assess the implementation potential of biobased value chains and webs with a territorial approach. Industrial Crops and Products, 223, 120104. https://doi.org/10.1016/j.indcrop.2024.120104.
4. Hill, M. J., Braaten, R., Veitch, S. M., Lees, B. G., & Sharma, S. (2005). Multi-criteria decision analysis in spatial decision support: The ASSESS analytic hierarchy process and the role of quantitative methods and spatially explicit analysis. Environmental Modelling & Software, 20(7), 955–976. https://doi.org/10.1016/j.envsoft.2004.04.014.
5. Oliveira, N. M. de, Sousa, C. H. E. de, Barbosa, G. R., & Pereira, S. G. (2014). Fragmentos de Cerrado no município de Patos de Minas: Mapeamento das áreas entre os anos 2005-2012. Perquirere, 1(11), 275–288.
6. Herzberg, R., Pham, T. G., Kappas, M., Wyss, D., & Tran, C. T. M. (2019). Multi-Criteria Decision Analysis for the Land Evaluation of Potential Agricultural Land Use Types in a Hilly Area of Central Vietnam. Land, 8(6). https://doi.org/10.3390/land8060090.
7. Walter, Arnaldo, Joaquim Seabra, Jansle Rocha, Marjorie Guarenghi, Nathália Vieira, Desirèe Dalmane, and João L. Santos. 2021. "SAFmaps - Macaw Palm." 2. doi:10.17632/5498jdrm87.2.

ACRO ALLIANCE

https://www.acroalliance.info/

CONTACT

Sai Anurag Nandagiri

saianuragrameshkumar.nandagiri@uni-hohenheim.de