



Original Paper

Comparative morphobiometry of *×Butyagrus nabonnandii* (Arecaceae) and its parents, *Syagrus romanzoffiana* and *Butia odorata*, in natural vegetation of Rio Grande do Sul, Brazil

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Abstract

The worldwide cultivation of palm trees has sparked the interest of researchers and the population in general due to their economic, ecosystemic, food, and landscape potential in their areas of occurrence. Among the species of this family in Rio Grande do Sul (RS), Brazil, *×Butyagrus nabonnandii* and its parents, *Syagrus romanzoffiana* and *Butia odorata*, stand out. Until recently, *×B. nabonnandii* was considered sterile due to the lack of records on seed germination. However, our group recently demonstrated the germination of the hybrids' seeds from three natural populations in RS, indicating that it is fertile. The present study assessed the vegetative and reproductive morphology and biometry of *×B. nabonnandii* and its parents in four natural populations in RS. The hybrid had characteristics common to both parents, in addition to unique ones. The comparative morphological characterization of individuals in natural environments and their parents is necessary to understand patterns of phenotypic variability and distribution of genetic diversity between and within populations and support programs aiming to recover, maintain, and sustainably use these resources.

Key words: comparative morphometry, intergeneric hybrid, mule palm, palm trees.

Resumo

O cultivo mundial de palmeiras tem despertado o interesse de pesquisadores e da população no geral, devido ao seu potencial econômico, ecossistêmico, alimentar e paisagístico que desempenham nas áreas de ocorrência. Dentre os *taxa* dessa família, no Rio Grande do Sul (RS), Brasil, destacam-se *×Butyagrus nabonnandii* e seus progenitores, *Syagrus romanzoffiana* e *Butia odorata*. Tradicionalmente, *×B. nabonnandii* era considerado estéril pela falta de registros de germinação de suas sementes. Entretanto, nosso grupo demonstrou recentemente a germinação de sementes do híbrido originadas de três populações naturais do RS. O presente trabalho avaliou e aferiu a morfologia vegetativa e reprodutiva de *×B. nabonnandii*, comparando-as com seus progenitores em quatro populações naturais do RS. O híbrido apresentou características comuns a ambos os genitores, além de características exclusivas. A caracterização morfológica comparativa de indivíduos estabelecidos em ambientes naturais e seus progenitores é necessária para compreender padrões de variabilidade fenotípica e distribuição da diversidade genética inter e intrapopulacional, com o intuito de subsidiar medidas de recuperação, manutenção e uso sustentável desses recursos.

Palavras-chave: morfometria comparativa, híbrido intergênero, palmeira mula, palmeiras.

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Introduction

Arecaceae is the family of palm trees, comprising approximately 2,600 species distributed in 181 genera, inhabiting ecosystems of the tropical and temperate regions of the planet (Baker & Dransfield 2016; Lorenzi *et al.* 2010; Stevens 2017). This family presents high genetic diversity and is notable in its range of occurrence due to its shape, size, ecological, economic, and nutritional characteristics (Noblick 2010; Muscarella *et al.* 2020).

Dransfield *et al.* (2008) and others highlighted the growing worldwide interest in palm cultivation. The diversity of genera, species, and hybrids available to nurseries, collectors, and farmers has increased, particularly in the last twenty years, due to their potential in landscaping and as fruit and seed food resources (Elias *et al.* 2018; Noblick 2010).

Among the Arecaceae in Rio Grande do Sul, stand out *Syagrus romanzoffiana* (Cham.) Glassm., *Butia odorata* (Barb.Rodr.) Noblick and their natural hybrid, *×Butyagrus nabonnandii* (Prosch.) Vorste (Noblick 2010; Soares *et al.* 2014a). These *taxa* constitute a very peculiar plant group in landscaping and recovery of anthropized areas and ecosystem value (Fior *et al.* 2013; Noblick 2010; Soares *et al.* 2014b).

×Butyagrus nabonnandii is a palm tree originating from the natural cross between *S. romanzoffiana* and *B. odorata*, occurring in Rio Grande do Sul, Uruguay, and Argentina, where their parents usually grow syntopically. (Glassman 1971; Noblick 2010; Soares *et al.* 2014a). The fruits of these palms are edible and consumed by wildlife and the inhabitants of the region (Noblick 2010). It became popularly known as the mule palm due to the lack of records on seed germination (Glassman 1971; Noblick 2010; Soares *et al.* 2014a). However, Rosa *et al.* 2023 recently showed that this hybrid is fertile since its seeds germinate.

In the literature, vegetative and reproductive characteristics of *×B. nabonnandii* were described mostly from cultivated or herborized specimens, without comparing them to their parents (Glasman 1971; Noblick 2010, 2012, 2017; Noblick & Sant' Anna-Santos 2021; Soares *et al.* 2014a).

Comparative morpho-biometry of naturally occurring *×B. nabonnandii* and its parents will help identify these palm trees, especially in fieldwork as shown for other palms (Sant' Anna-Santos 2021; Santos *et al.* 2021). Moreover, the recognition

of the characteristics of *×B. nabonnandii* will be important for projects of sustainable use of its resources, seedlings' preservation and propagation by nurseries and landscapers, and management and conservation programs, thus preventing the predatory extraction of palm trees (Rosa *et al.* 2021).

Therefore, this study aimed to analyze comparatively the vegetative and reproductive morphology between *×B. nabonnandii* and its parents (*B. odorata* and *S. romanzoffiana*), in four natural populations in Rio Grande do Sul, Brazil.

Material and Methods

Data collection and analysis

Collections for the morphometric analysis of vegetative and reproductive structures using adult and fertile plants occurred between January 2021 and December 2022. Fourteen excursions were carried out in four natural populations of *S. romanzoffiana*, *B. odorata*, and *×B. nabonnandii*, totaling 18 individuals accessed in the Pampa Biome, Rio Grande do Sul, Brazil, distributed in the municipalities of Cachoeira do Sul (30°02'21"S, 52°53'38"W), Manoel Viana (29°35'21"S, 55°28'58"W), Porto Alegre (30°01'58"S, 51°13'48"W) and Venâncio Aires (29°31'26"S, 52°09'25"W; 29°33'05"S, 52°10'05"W; 29°37'08"S, 52°11'40"W). In Venâncio Aires, due to the occurrence of a larger number of individuals, three locations were collected: one hybrid group and its parents in the urban area and two groups in the rural area (Fig. 1).

In the field, wild specimens were photographed and measured (plant height - stem and leaves included, stem height, and diameter). Additionally, leaves, inflorescences, and infructescences were collected for comparative morphometry. The images were obtained using a Sony a3000 ILCE digital camera with an 18–55 mm lens and a 25 mm sensor.

Herbarium specimen vouchers were prepared following the techniques of Peixoto & Maia (2013). One voucher for each specimen was deposited in Bruno Edgar Irgang Herbarium (HBEI, acronym according to Thiers, continuously updated) from the Department of Biological and Forest Sciences of the Federal University of Pampa (Unipampa), São Gabriel Campus, Rio Grande do Sul, Brazil. The voucher numbers of hybrids are HBEI1641 (Cachoeira do Sul), HBEI1642

(Manoel Viana), HBEI1640 (Porto Alegre), and HBEI1638 (Venâncio Aires). The vouchers of *B. odorata* are HBEI1651 (Cachoeira do Sul), HBEI1632 (Manoel Viana), HBEI1653 (Porto Alegre), and HBEI1647 (Venâncio Aires). The vouchers of *S. romanzoffiana* are HBEI1650 (Cachoeira do Sul), HBEI1645 (Manoel Viana), HBEI1654 (Porto Alegre), and HBEI1648 (Venâncio Aires).

Morphometry

To evaluate vegetative and reproductive morphometry, fertile adult palm trees of *S. romanzoffiana*, *B. odorata*, and $\times B. nabonnandii$ with inflorescences, infructescences, and fully developed leaves were selected. The terminology

used for morphometric measurement and evaluation follows Dransfield *et al.* (2008), Glassman (1971), Noblick (2010, 2017), Soares *et al.* (2014a), Soares *et al.* (2014b) and Sant'Anna-Santos (2021).

For the morphometry of fruits, pyrenes, and seeds, we followed Brazil (2009) and Fior *et al.* (2018). The data used for the statistical analysis was obtained from a set of 18 naturally occurring individuals from four populations. Fruits were manually collected from the plants, and 20 were selected from each specimen per municipality, totaling 360 fruits evaluated. In this analysis, the variables tested were: equatorial fruit length (EFL), polar fruit length (PFL), equatorial pyrene length (EPL), polar pyrene length (PPL), equatorial seed

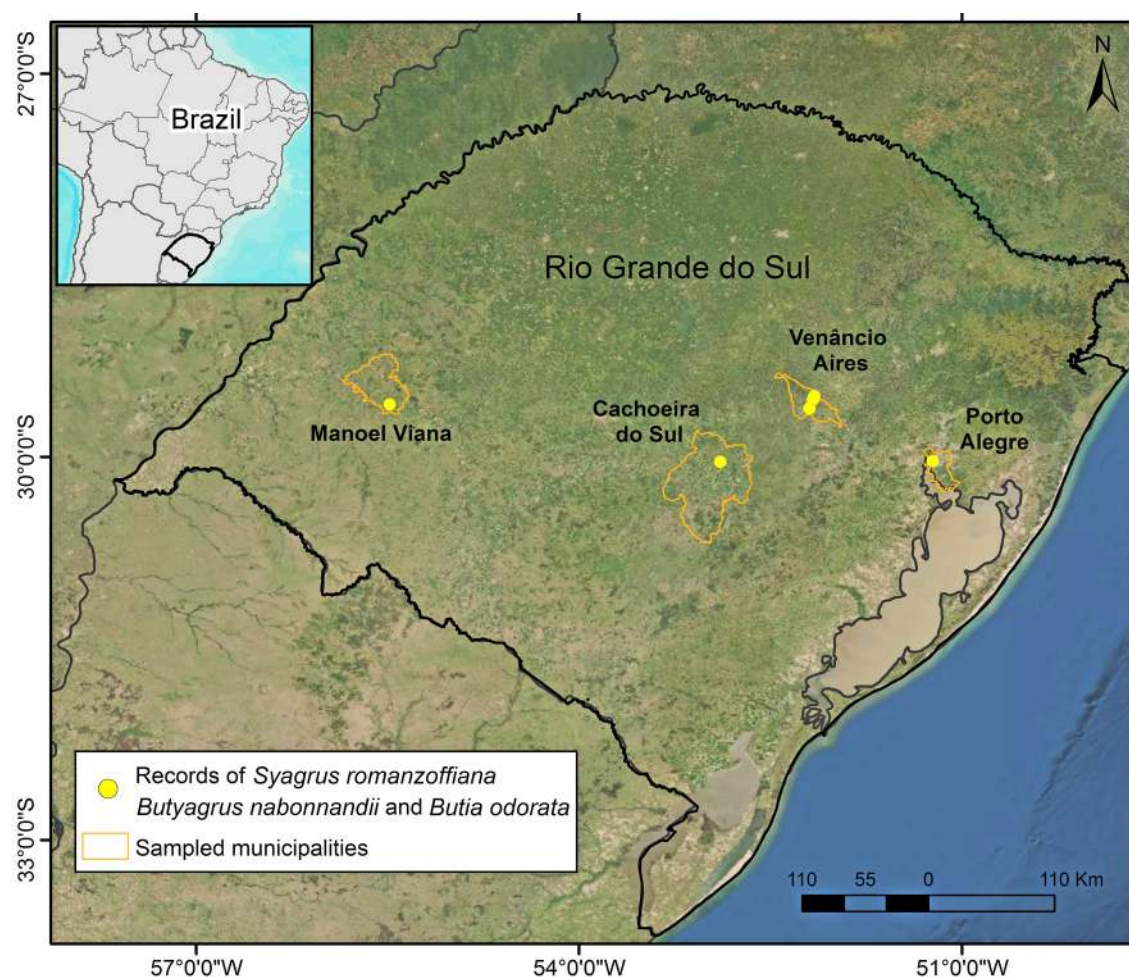


Figure 1 – Collection sites of the naturally occurring $\times B. nabonnandii$, *S. romanzoffiana* and *B. odorata*. Each yellow dot on the map indicates the place of natural occurrence and collection of plant material of the hybrid and its parents in the municipalities of Cachoeira do Sul, Manoel Viana, Porto Alegre and Venâncio Aires, in Rio Grande do Sul, Brazil.

length (ESL), polar seed length (PSL), fruit wet mass (FWM), mesocarp wet mass (MWM), pyrene wet mass (PWM), and seed wet mass (SWM).

The wet mass of fruits, mesocarp, pyrene and seeds was determined with an analytical digital scale (CHJ model MH-200) with a resolution of 0.01 g (Lima & Ferreira 2017; Muscarella *et al.* 2020). The polar and equatorial lengths of the fruits, pyrenes, and seeds were measured using a stainless steel digital caliper (MTX) with a resolution of 0.01 cm. Measurements of the tree and stem heights, as well as the diameter at breast height (DBH), were made using a flexible measuring tape and a 20 cm culm. The methodology of Schwartz (2010) for estimating the number of flowers per inflorescence was followed.

The pyrenes of 20 fruits per specimen were separated by depulping the mesocarp. Then, the pyrenes were dried in the shade for ten days to facilitate seed release. Afterward, the seeds were extracted from the pyrenes by manual fractionation

with a hammer or sawing with a 12-inch fine-blade in a size 3 bench vise, according to Brazil (2009).

The values of each variable were submitted to bidirectional analysis of variance (2-way ANOVA) for multiple comparisons of quantitative data. Prism GraphPad (version 6.0, GraphPad Software Inc, San Diego, California) was used for the analysis, with the results presented as mean $\pm$ standard error of the mean (SEM) and considered significant when $p < 0.05$.

Results and Discussion

The results of the morphological evaluation are detailed in Table 1, where it is possible to identify similarities and dissimilarities of vegetative and reproductive characteristics between the hybrid and its parents, as well as the characteristics of the hybrid. These data are consistent with the methodological models described in (Glassman 1971; Noblick 2010, 2012, 2017; Soares *et al.* 2014a; Engels *et al.* 2021).

Table 1 – Comparative qualitative characteristics of adult reproductive plants of $\times$ *Butyagrus nabonnandii*, *Syagrus romanzoffiana* and *Butia odorata*.

Characteristic	$\times$ <i>Butyagrus nabonnandii</i>	<i>Syagrus romanzoffiana</i>	<i>Butia odorata</i>
Habit	Solitary	Solitary	Solitary
Stem shape	Cylindrical and upright	Cylindrical and upright	Cylindrical and upright
Leaf sheath persistence in the stem	Semipersistent, some basal portions scatter throughout the stem	Caducous, leaving ringed scars throughout the stem	Persistent throughout most of the stem
Leaf type and arrangement in the rachis	Pinnate, slightly arched, shiny dark green; pinnae (sub) opposite, somewhat straight	Pinnate, slightly arched, giving the leaf a feathery appearance, shiny dark green; the pinnae are inserted in divergent planes on the rachis	Pinnate; not feathery; grayish-green; pinnae inserted approximately in the same planes forming a “V” on the rachis
Leaf arrangement on the stem	Contemporary, arranged in a crown at the top of the stem	Contemporary, arranged in a crown at the top of the stem	Contemporary, spirally arranged in a crown at the top of the stem
Pseudopetiole margins	Fibrous, with flexible fibers and slightly dented near the base, becoming smooth near the apex	Fibrous, with soft fibers near the base, becoming smooth near the apex	Fibrous near the base, becoming thick or finely dentate near the apex
Pinnae grouping	The first four pinnae are grouped at the base of the rachis	The first four pinnae are grouped at the base of the rachis	The first four pinnae are grouped at the base of the rachis

Characteristic	<i>×Butyagrus nabonnandii</i>	<i>Syagrus romanzoffiana</i>	<i>Butia odorata</i>
Ramenta (persistent scales)	Present on the abaxial surface in the basal portion of the pinnae; brown, scale-like	Absent	Present on the abaxial surface in the basal portion of the pinnae; brown, scale-like
Pinnae tips	Slightly acuminate, with asymmetrical apex	Slightly acuminate, with asymmetrical apex	Acuminate, with symmetrical apex
Peduncular bract texture, notch, and shape	Canoe-shaped, woody, glabrous, with outer longitudinal grooves (varying from shallow to deeply grooved), ending in a beak-shaped expanded tip	Canoe-shaped, woody, glabrous with outer longitudinal grooves (varying from shallow to deeply grooved), ending in a beak-shaped expanded tip	Canoe-shaped, woody, glabrous, smooth, ending in an expanded tip shaped like a small beak.
Inflorescence type and color	Panicle, yellow-orange	Panicle, pastel yellow	Panicle, varying from pastel yellow to pinkish red
Flowers	Staminate and pistillate, organized in triads from the base up to the middle of the rachillae; usually only with staminate flowers at the terminal portion of the rachillae	Staminate and pistillate, organized in triads from the base up to the middle of the rachillae; usually only with staminate flowers at the terminal portion of the rachillae	Staminate and pistillate, organized in triads from the base up to the middle of the rachillae; usually only with staminate flowers at the terminal portion of the rachillae
Fruits	In infructescence; ovoid to globose, yellow with or without brownish streaks at the apex; fleshy drupe with sweet, fibrous, and slightly mucilaginous mesocarp; containing a pyrene	In infructescence; ovoid to slightly globose, yellow; fleshy drupe with sweet, fibrous, and mucilaginous mesocarp; containing a pyrene	In infructescence; globose, ranging from yellow, orange, orange-reddish to purple; a fleshy succulent drupe, usually sweet; containing a pyrene
Form, texture, and position of pores in pyrene	Ovoid; stony/woody; with three pores, arranged symmetrically to slightly asymmetrically in the basal region; sometimes with three protrusions in the apical region	Ovoid; stony/woody; with three symmetrically arranged pores in the basal region; with traces of three apical protrusions	Globose and smooth. Stony/woody, with three pores in the equatorial region
Shape and number of endocarp cavities	Regular, symmetrical or vestigial, unilocular	Irregular, asymmetrical, and unilocular	Regular, symmetrical, uni to trilocular
Seed presence and shape	Present or absent, cordiform	Present, gibbous to uncinate	Present, cordiform
Seed infestation	Larvae of Coleopteran insects	Larvae of Coleopteran insects	Larvae of Coleopteran insects
Germination	Present, late, and heterogeneous among the populations studied	Present, late, and uniform	Present, late, and uniform
Phenology	Flowering and fruiting year around, with greater productivity from October to March	Flowering and fruiting year around, with greater productivity from October to March	Flowering and fruiting from October to March

Several characteristics are shared between $\times B. nabonnandii$ and both parents, such as habit and size (Fig. 2a-c), leaf type, and arrangement of the first four pinnae at the base of the rachis (Fig. 2d-f). Reproductively, the three taxa share panicle inflorescences (Fig. 2g-i), staminate and pistillate flowers in triads (Fig. 2j-l), infructescences with drupe fruits (Fig. 3a-c), edible fruits and the presence of a pyrene (Fig. 3d-f), the presence of a peduncular bract (Fig. 3g-i), and stony or woody texture of the endocarp (Fig. 4j-i). Notably, seeds (Fig. 4j-i) may be infested by coleopteran larvae and germinate slowly or late.

$\times Butyagrus nabonnandii$ exhibits similarities to *S. romanzoffiana* in terms of the margins of non-armed pseudopetioles, which are formed by lightly thickened fibers (Fig. 2d-e), and the position of germinal pores in the endocarp. In $\times B. nabonnandii$, three pores are present, either symmetrically or asymmetrically located in the basal region (Fig. 4a), whereas in *S. romanzoffiana*, three pores are symmetrically positioned in the basal region (Fig. 4b). Additionally, both species feature three apical protruding projections in their endocarps (Fig. 4d-e), although the protrusions in *S. romanzoffiana* are less pronounced compared to those in $\times B. nabonnandii$.

Butia odorata and $\times B. nabonnandii$ both exhibit slightly arched leaves and possess abaxial ramenta or cataphiles in the basal portion of the pinnae (Fig. 4g,i). In *B. odorata*, pinnae are inserted at V-shaped angles on each side of the rachis (Fig. 4i). Furthermore, both species share a symmetrical endocarp cavity containing a cordiform seed and a prominent operculum (Fig. 4j-l).

$\times Butyagrus nabonnandii$ presents intermediate characteristics between its parents, such as the pinnae inserted on each side in the rachis, somewhat straight and slightly arched in the canopy. Additionally, it displays semi-persistent sheath bases scattered along the stem (Fig. 4m). In contrast, *S. romanzoffiana* shows a ringed stem with scars from the caducous sheaths (Fig. 4n), while *B. odorata* presents persistent sheaths throughout the stem (Fig. 4o).

The results of the comparative reproductive morphometry between $\times B. nabonnandii$ and both parent species are detailed in Tables 2-4. These data are consistent with the methodological models described by other authors (Engels *et al.* 2021; Glassman 1971; Noblick 2010, 2012, 2017; Soares *et al.* 2014a; Sant'Anna-Santos 2021). For more information on the parents, see Lorenzi *et al.* (2010), Soares *et al.* (2014a), Noblick (2017).

$\times Butyagrus nabonnandii$ exhibited statistically significant similarities to *S. romanzoffiana* ($p < 0.05$) concerning leaf and peduncular bract length (Tab. 2); inflorescence length and number of rachillae (Tab. 3); equatorial fruit length, equatorial and polar pyrene length, number of cavities in the endocarps, and wet mass of the seeds (Tab. 4). Furthermore, *B. nabonnandii* also demonstrated statistically significant ($p < 0.05$) similarities with *B. odorata* in terms of plant and stem height, diameter at breast height (Tab. 2); and fruit wet mass (Tab. 4). Additionally, all three species displayed similarities ($p < 0.05$) in rachillae length, length and width of the pistillate and staminate flowers, number of stamens, petals, and sepals (Tab. 3); polar fruit length, number of pyrenes and wet mass and number of pores of pyrenes (Tab. 4).

In comparison to *B. odorata*, $\times B. nabonnandii$ exhibited significant differences ($p < 0.05$) in various characteristics, including leaf length and peduncular bract length (Tab. 2); inflorescence length and number of rachillae (Tab. 3); equatorial fruit length, equatorial and polar length of the pyrene, number of cavities in the endocarps and wet mass and number of seeds (Tab. 4). Other significant differences ($p < 0.05$) were observed between *B. nabonnandii* and *S. romanzoffiana* regarding plant and stem height, diameter at breast height (Tab. 2), and fruit wet mass (Tab. 4).

The results of this work confirm that $\times B. nabonnandii$ has a natural occurrence in the state of Rio Grande do Sul, where, generally, its progenitors grow close to each other (Elliott *et al.* 2017; Glassman 1971; Noblick 2010; Soares *et al.* 2014a). They were located in the municipalities of Venâncio Aires, Cachoeira do Sul, Manoel Viana, and Porto Alegre, as previously disclosed in our methods, data also confirmed by Rosa *et al.* (2023).

The sampling data from the four studied areas, summarized in Tables 1 (qualitative characteristics) and 2 to 4 (quantitative characteristics), reveal considerable variations concerning the comparative morphometry between the hybrid and its parents. Among the evaluated characteristics, notable variations were observed in plant height, stem texture, pinnae insertion in the rachis, presence of ramenta, fruit size and quantity, amount of fibers and mucilage in the mesocarp, pyrene shape, pore arrangement in the endocarp, and presence of apical projections in the pyrene. Variations in wet mass, size, and quantity of fruits in Arecaceae specimens may result from the actions of environmental and



Figure 2 – a-l. Plant, leaf, inflorescence and rachillae – a-c. the three palm taxa – a. $\times B. nabonnandii$; b. *S. romanzoffiana*; c. *B. odorata*; d-f. leaves – d. $\times B. nabonnandii$ leaf; e. *S. romanzoffiana* leaf; f. *B. odorata* leaf (the orange arrows indicate the arrangement of the first four pinnae); g-i. inflorescences – g. $\times B. nabonnandii$ inflorescence; h. *S. romanzoffiana* inflorescence; i. *B. odorata* inflorescence; j-l. Rachillae – j. $\times B. nabonnandii$ rachillae; k. *S. romanzoffiana* rachillae; l. *B. odorata* rachillae.

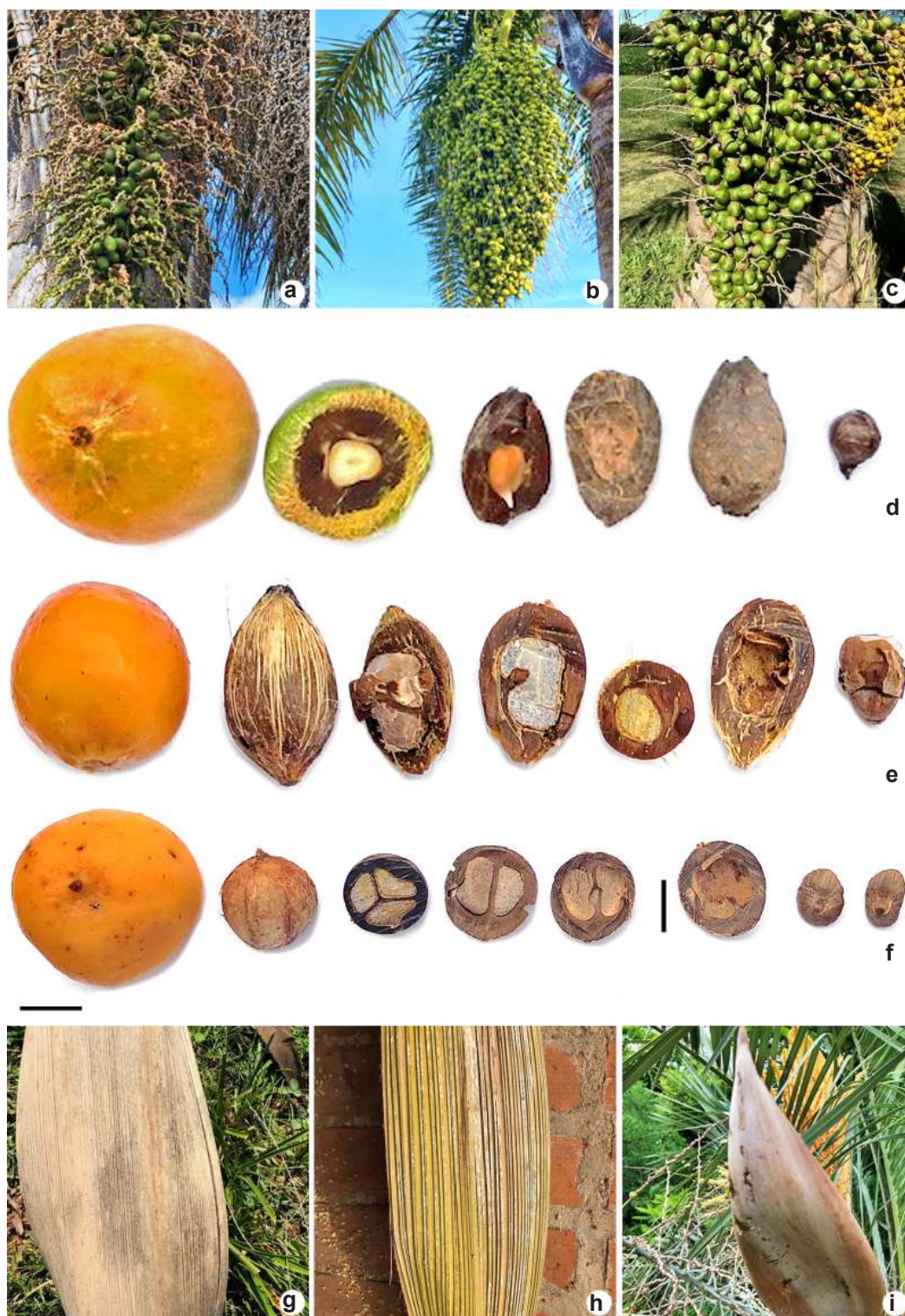


Figure 3 – a-i. Fruit and bract – a-c. infructescences – a. *B. nabonnandii* infructescence; b. *S. romanzoffiana* infructescence; c. *B. odorata* infructescence; d. from left to right: whole fruit, sectioned fruit, seeded and seedless endocarps, pyrene, and seed of *B. nabonnandii*; e. from left to right: whole fruit, pyrene, seeded and seedless endocarps, and seed of *S. romanzoffiana*; f. from left to right: whole fruit, pyrene, seeded and seedless endocarps showing the locules and seeds of *B. odorata*; g-i. bracts – g. *B. nabonnandii* bract; h. *S. romanzoffiana* bract; i. *B. odorata* bract.



Figure 4 – a-o. Comparative vegetative traits among $\times B. nabonnandii$, *S. romanzoffiana* and *B. odorata* – a-c. the red arrows indicate the endocarp basal pores – a. $\times B. nabonnandii$; b. *S. romanzoffiana*; c. *B. odorata*; d-f. the yellow arrows indicate the apical endocarp projections (no apical projections were found on the endocarp of *B. odorata*); d. $\times B. nabonnandii$; e. *S. romanzoffiana*; f. *B. odorata*; g-i. pinnae and ramenta (the orange arrows indicate ramenta. *S. romanzoffiana* has no ramenta); g. $\times B. nabonnandii$ pinnae with ramenta; h. *S. romanzoffiana* pinnae without ramenta; i. *B. odorata* pinnae with ramenta; j-l. endocarps and seeds (the white arrows point to endocarps, “se” stands for seeds); j. $\times B. nabonnandii$ endocarp with one seed; k. *S. romanzoffiana* endocarp with one seed; l. *B. odorata* endocarp with two seeds; m-o. stem morphometry – m. $\times B. nabonnandii$ stem; n. *S. romanzoffiana* stem; o. *B. odorata* stem.

Table 2 – Stem, leaf and peduncular bract biometrics.

Stem biometrics	× <i>B. nabonnandii</i>	<i>S. romanzoffiana</i>	<i>B. odorata</i>
Stem Height (m)	2.52 ± 1.22	6.34 ± 1.51	3.45 ± 0.56
DBH (m)	0.51 ± 0.07	0.41 ± 0.04	0.58 ± 0.03
Plant Height	3.91 ± 1.31	7.37 ± 1.31	4.25 ± 1.39
Leaf Biometrics	× <i>B. nabonnandii</i>	<i>S. romanzoffiana</i>	<i>B. odorata</i>
Total length of leaves (m)	4.45 ± 0.40	4.90 ± 0.65	2.65 ± 0.38
Petiole length (m)	1.27 ± 0.21	1.31 ± 0.35	0.92 ± 0.23
Sheath Length (cm)	72.81 ± 2.57	41.27 ± 4.65	37.23 ± 3.21
Median portion of sheath (cm)	26.93 ± 4.73	47.32 ± 5.11	15 ± 2.78
Rachis length (m)	3.05 ± 0.43	3.87 ± 0.51	1.88 ± 0.32
Median rachis' midrib circumference (cm)	3.52 ± 1.07	4.01 ± 1.37	1.75 ± 1.11
Total number of pinnae	259 ± 29.28	443.2 ± 12.09	131 ± 13.45
Median pinna length (cm)	82.5 ± 10.11	90.4 ± 14.79	61 ± 8.79
Median pinna width (cm)	2.66 ± 0.47	3.89 ± 0.51	3.19 ± 0.53
Biometry of the Peduncular Bract	× <i>B. nabonnandii</i>	<i>S. romanzoffiana</i>	<i>B. odorata</i>
Length (m)	1.81 ± 0.10	2.11 ± 0.21	1.12 ± 0.13
Apex (cm)	13.38 ± 5.08	8.39 ± 3.14	13.23 ± 4.35
Outer perimeter (cm)	24.72 ± 7.06	33.08 ± 7.74	22.54 ± 5.36

Table 3 – Inflorescence biometrics.

Inflorescence Biometrics	× <i>B. nabonnandii</i>	<i>S. romanzoffiana</i>	<i>B. odorata</i>
Total length (cm)	156.5 ± 5.56	168.5 ± 11.79	114.3 ± 6.43
No. of basal rachillae	49.5 ± 20.43	41.23 ± 9.47	18.32 ± 4.76
No. of median rachillae	87.75 ± 8.65	116.4 ± 18.79	125.6 ± 27.4
No. of apical rachillae	81.3 ± 26.52	78.1 ± 21.03	19.4 ± 7.38
Total number of rachillae	219.5 ± 29.14	234.2 ± 21.04	162.4 ± 21.3
Length of basal rachillae (cm)	58.75 ± 7.45	63.21 ± 6.51	56.32 ± 5.34
Length of median rachillae (cm)	47.5 ± 10.84	45.12 ± 5.32	43.21 ± 9.89
Length of apical rachillae (cm)	28.5 ± 17.13	35.17 ± 4.76	20.1 ± 11.38
No. of female flowers	16,245 ± 6,960	17,610 ± 1,239	3,097 ± 1,151
No. of male flowers	51,584 ± 18,485	58,210 ± 1,439	22,128 ± 9,147
Female flower length (mm)	6.82 ± 0.73	5.13 ± 0.95	5.43 ± 0.54
Female flower width (mm)	5.65 ± 0.66	5.43 ± 0.54	4.98 ± 0.35
Male flower length (mm)	10.31 ± 0.75	11.09 ± 0.35	9.69 ± 0.58
Male flower width (mm)	13.13 ± 4.73	12.43 ± 0.27	11.32 ± 3.88
No. of stamens	6	6	6
No. of male petals	3	3	3
No. of female petals	3	3	3

Table 4 – Fruit, pyrene and seed biometrics

Fruit, pyrene and seed biometrics	$\times B. nabonnandii$	<i>S. romanzoffiana</i>	<i>B. odorata</i>
Equatorial and polar fruit length (mm)	$23.1 \pm 5.63 \times 24.1 \pm 3.7$	$18.4 \pm 2.42 \times 22.5 \pm 2$	$26.6 \pm 3.2 \times 23.3 \pm 3$
Fruit wet mass (g)	9.8 ± 4.74	2.92 ± 3.02	14.52 ± 3.51
No. of pyrenes	1	1	1
Equatorial and polar length of pyrene (mm)	$13.7 \pm 0.7 \times 21.2 \pm 1.5$	$12.1 \pm 0.2 \times 22 \pm 0.2$	$14.2 \pm 0.34 \times 17.9 \pm 0.6$
Wet mass of pyrene (g)	2.40 ± 0.55	1.79 ± 0.40	2.32 ± 0.45
No. of Pores of Pyrene	3	3	3
No. of endocarp cavities	1	1	1–3
equatorial and polar seed length (mm)	$7.3 \pm 0.02 \times 10.8 \pm 0.1$	$7 \pm 0.03 \times 10.6 \pm 0.2$	$9.5 \pm 0.03 \times 11.9 \pm 0.04$
Seed wet mass (g)	0.27 ± 0.01	0.26 ± 0.02	0.44 ± 0.06
No. of seeds	0–1	1	1–3

anthropogenic factors associated with genetic variability (Mhanhmad *et al.* 2011; Noblick & Sant’Anna-Santos 2021). Even leaf morphology and anatomy, considered stable for *Syagrus* (Noblick 2017) and *Butia* species (Sant’Anna-Santos *et al.* 2015, 2018), may vary according to the population studied and different environmental conditions. These studies agree with several authors (*e.g.*, Lorenzi *et al.* 2010; Noblick 2010; Soares *et al.* 2014a) on the high morphological diversity for *B. odorata*, while *S. romanzoffiana* is more stable. These data also call attention to the importance of an extensive sampling encompassing these individuals’ maximum distribution.

$\times Butyagrus nabonnandii$ share with its parent species the following characteristics: solitary habit, upright cylindrical stem, pinnate leaves, presence of peduncular bracts, paniculate inflorescence, staminate and pistillate flowers in triads along the rachillae, edible drupaceous fruit with fleshy and fibrous mesocarp, a single pyrene per fruit with thick and stony endocarp, presence of seeds (usually). This similarity in the vegetative and reproductive characteristics is in line with studies by Engels *et al.* (2021), Heiden & Sant’Anna-Santos (2023), Glassman (1971), Noblick (2010), and Soares *et al.* (2014a).

Our results agree with Rosa *et al.* (2023), who pointed out that $\times B. nabonnandii$ shares with *S. romanzoffiana* the presence of mucilage in the fruit mesocarp, ovoid shape, basal position of the germinal pores, apical projections in the pyrene, and the unilocular endocarp with a seed. Regarding

the similarity with *B. odorata*, our data indicate the presence of ramenta on the abaxial surface next to the midrib, arrangement of the pinnae in the rachis, and ovoid to cordiform shape of the seed with prominent operculum.

Our results reveal striking and novel characteristics unique to the hybrid, such as the texture of the stem, marked by semi-persistent sheaths scattered throughout its length, and the basal germinal pores in the pyrene that vary from symmetric to asymmetric. However, Noblick (2010) and Soares *et al.* (2014a) reported a smooth texture for the $\times B. nabonnandii$ stem, evidencing the variability of this character. Recently, Rosa *et al.* 2023 suggested that the hybrid is closer to *B. odorata* concerning the size of the palm tree and the presence of ramenta on the abaxial surface of the pinnae. However, based on the morphological data alone, it is impossible to determine the direction of the cross, thus preventing precise identification of the hybrid’s paternity or maternity. Future studies using molecular and anatomical analysis are needed to address the parentage in these palm trees more accurately.

The comparative vegetative and reproductive morphometry study identified similar characteristics between the $\times B. nabonnandii$ and its parents, and helped recognize its unique characters. Moreover, these data will aid visual identification of this hybrid, especially in natural environments. A comparative study of the leaf anatomy of *Butia* by Sant’Anna-Santos *et al.* (2015) provided valuable characteristics for differentiating *Butia capitata* and *B. odorata*.

The results reveal striking and unprecedented characteristics of the hybrid, such as the semi-persistent sheaths sparsely scattered along the stem, the basal germinal pores in the pyrene ranging from symmetrical to asymmetrical, and the presence of three apical projections.

The morphological studies of these palms are complex due to intra and interpopulation phenotypic variability, indicating the need for further anatomical and molecular studies to enhance the understanding of the biology of this plant group. Such studies would facilitate the development of management programs, conservation *in situ* and *ex situ*, and using these palms as economic, landscape, and environmental resources.

In addition to providing novel descriptions for the three palm taxa in four localities in Rio Grande do Sul (Brazil), this study opens avenues for further investigation and research projects. For example: 1) Can the statistically significant trends observed in this study, such as variation in fruit size, presence or absence of seeds, and germination, serve as characteristic variables for each municipality? 2) How significant are these results for developing new programs to manage, conserve, and sustainably use these palm trees as food, landscaping, and economic resources? 3) Can future molecular biology and leaf anatomy studies allow us to detect inter- and intrapopulation phenotypic variations? 4) To what extent can genetic variations be utilized to infer the genetic diversity within individuals and populations, or to estimate speciation events and effects of human activities on environmental changes?

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Data availability statement

In accordance with Open Science communication practices, the authors inform that there is no data sharing of this manuscript.

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