



# Are the Alien Species of Melastomataceae and Bombacoideae a Potential Risk for Brazilian Cerrado?

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## Abstract

The cultivation of species in urban areas for landscaping or consumption has increased in cities surrounded by Cerrado, putting in risk the local flora. Thus, the objective of this paper was to describe seed germination and seedling emergence of five urban cultivated species of Melastomataceae and Bombacoideae and compare them with Cerrado native species to evaluate if they offer any risk to local vegetation. The seeds were collected in the urban area of Uberlândia, within the Brazilian Cerrado. We calculated germination and emergence measurements and compared them to literature data. Seeds of *Bombax ceiba* and *Pachira aquatica* had a germination and emergence pattern similar to other Bombacoideae. *Tibouchina pulchra* and *Tibouchina granulosa* also had a similar pattern to other Melastomataceae, with low germinability. In contrast, seed germination of *Heterotis rotundifolia*, an invasive African species, was similar to *Clidemia hirta*, also known as invasive, including the higher spreading of germination through time, a common character of invasive plants. Seed germination of *H. rotundifolia* was more similar to Cerrado species with dormant seeds, showing high germinability and germination spread through time. These features added to its fast-growing due to its decumbent herbaceous habit that forms dense mats could offer risks to local species. Thus, it is being recommended that its populations be monitored.

## Subject Areas

Ecology

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## Keywords

Bombacoideae, Cerrado, Dormancy, Melastomataceae, Malvaceae, Seedling Emergence, Seed Germination, Urban Ecology

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## 1. Introduction

The broad cultivation of non-local species in urban areas or their introduction in natural vegetation, regardless of their origin, may offer a potential risk to local species in many aspects, as affecting the niches and interaction networks [1] [2] [3]. They are commonly called invasive or alien species. In this context, the biology of alien species received attention in recent studies [3]. Some seed germination features have been related to the invasive ability in many alien species and were evaluated in some places in Europe [4], but there are no similar studies, as far as we know, regarding Neotropical plants.

Studies in the last two decades about seed germination patterns of Cerrado species [5] may allow some initial comparisons. Some differences in seed ecology between alien or invasive and local or native species were identified focusing on germinability, different light conditions for germination, stratification requirements, dormancy strategies, seedling growth or vigour and other traits [6] [7] [8] [9] [10].

Tropical Malvaceae-Bombacoideae and Melastomataceae trees are widely cultivated around the world and some species of these groups present an invasive potential. Melastomataceae is a highly diverse worldwide family, with ca. 4500 species according to Clausen & Renner [11], and some species show a high invasion potential around the world. The most famous invasive species are *Clidemia hirta* D. Don [12] and *Miconia calvescens* DC. [13], but the list is increasing with *Heterotis rotundifolia* (Sm.) Jacq.-Fél., which has been considered invasive in many countries [14]. Recently, species from the Atlantic Forest as *Tibouchina granulosa* (Desr.) Cogn. and *T. pulchra* Cogn. [15] are being widely cultivated in urban areas of the Cerrado domain and also show some invasive potential. *Tibouchina granulosa* and *T. pulchra* are not viewed as alien or invasive species, but their cultivation may represent threats to local species. They usually occur as native species in the Atlantic Forest, but their habit and exuberant flowering has stimulated their cultivation in Brazilian urban areas [16].

Special attention should be given to *Heterotis rotundifolia*, originated in African savannas [17], which occurs from forests to open areas, roadsides and disturbed areas, because it is a fast-growing species, and due to its decumbent herbaceous habit that forms dense mats, it could displace natural vegetation [18] [19]. Although it has viable seeds, this species has vegetative growth and reproduction and, for this reason, it was included in the Global Compendium of Weeds [14], and was listed as invasive and a weed species around the world [19] [20] [21] [22]. *H. rotundifolia* in Brazil was introduced in urban areas for culti-

vation, mainly for its dense mats and attractive flowers. Its present distribution in Brazil is sub-estimated due to the low number of surveys in urban areas, especially for non-arboreal plants, but it occurs in the states of Minas Gerais and Amazonas [23].

In Bombacoideae (Malvaceae), some species also have a strong potential for cultivation in urban areas, especially due to their flowering and human seed consumption. Two of these species are cosmopolitan trees and cultivated around the world, *Bombax ceiba*, originated from Asia, and *Pachira glabra*, which has an uncertain origin. Robyns [24] suggests that *P. glabra* has its origin in the Tropical American Forests, with occasional and non-natural occurrence in disturbed and human altered areas of Cerrado. *Pachira glabra* is an alien in Cerrado areas, but it is commonly cultivated in urban areas inside the Cerrado Biome [25].

This paper wants to describe the seed germination or seedling emergence pattern of five species of Bombacoideae and Melastomataceae commonly cultivated in urban areas surrounded by Cerrado, comparing them to local species from the same family and local flora.

## 2. Material and Methods

### 2.1. Species Selected and Seed Collection

Seeds of *Heterotis rotundifolia*, *Tibouchina granulosa*, *T. pulchra* (Melastomataceae), *Bombax ceiba* and *Pachira glabra* (Bombacoideae-Malvaceae) were collected in urban areas of Uberlândia (48° 18'W and 18° 59'S), Minas Gerais State, Brazil as described in Table 1. The region is included in the Cerrado domain, the Neotropical savanna of Brazil [26]. The climate of this region is characterized as Aw Megathermic, according to the updated classification of Köppen-Geiger [27], a tropical wet climate with a dry winter (April to September) and a wet summer (October to March) [28]. The voucher specimens were included in the *Herbarium Uberlandense* (HUFU).

Mature fruits were collected directly from the mother plants and mixed for the analysis. The capsular fruits were kept in paper bags until seed dispersion. All dried seeds were kept in paper bags and stored in plastic pots with silica gel at room temperature ( $\pm 25^\circ\text{C}$ ) until sowing. Additionally, for *Pachira glabra*, we

**Table 1.** Seed collection details for species of bombacoideae and melastomataceae cultivated in an urban cerrado biome area from Brazil.

Species	NIS	DSC	DS	RN	SNR	TSNS
<i>Heterotis rotundifolia</i>	7	04/03/2007	10	10	50	500
<i>Tibouchina granulosa</i>	2	03/19/2007	19	10	50	500
<i>Tibouchina pulchra</i>	1	06/23/2007	75	10	100	1000
<i>Bombax ceiba</i>	1	09/24/2013	78	2	32	64
<i>Pachira glabra</i>	5	09/2003	30	4	25	100

Legend: NIS: number of individuals sampled, DSC: date of seed collection, DS: days stored before sowing, RN: replicate number, SNR: seed number by replicate, TSNS: total seed number sampled.

collected seeds on the soil, since the species shows large seeds with barochory. These seeds were collected on the same dates as the seeds collected directly from the trees to test the hypothesis if both seed groups have differences in the germination. We suspected that soil seeds show low physiological quality. See details of each collection in **Table 1**.

We collected seeds from only one tree of *T. pulchra* and *B. ceiba* since the species occurs in low density in the city with a low number of fruiting individuals. Only five alien species, segregated in two families (Melastomataceae and Bombacoideae), were included because other alien species from these two families do not occur in the city. We included only Melastomataceae and Bombacoideae alien species since we had sufficient data for comparative studies. In parallel we conducted specific studies to describe the seed germination patterns in these families.

## 2.2. Seed Experiments

For seed germination experiments of Melastomataceae species, the seeds were sown over filter paper inside Emanuelli chambers, a plastic germination container [29]; see photos and details in Mendes-Rodrigues & Oliveira [30] filled with distilled water (ca. 20 mL). For Bombacoideae species, the seeds were sown on 50 - 60 mL of fine vermiculite (expansion volume of 0.1 m<sup>3</sup>), inside transparent germination boxes, moistened, as necessary, with distilled water. The replicates from all species were distributed randomly and kept in a seed germination chamber (Model MDG2000, Seedburo Company, USA) under continuous white fluorescent light at temperatures of 25°C.

For the seedling emergence, seeds of Bombacoideae species were sown ca. 1 cm below surface in multicelled polystyrene germination trays filled with a commercial substrate (Plantmax<sup>®</sup>, Eucatex Mineral Ltda, São Paulo, Brazil). They were maintained in a greenhouse, in an experimental field in Uberlândia, and moistened when necessary.

The number of seeds germinated was observed daily and the protrusion of any part of the embryo was used as germination criterion. The number of seedlings emerged was also observed daily and the appearance of any part of the seedling above the soil surface was used as emergence criterion. All replicates of each species were treated as a sample to process the descriptive analysis. The original experiments were installed in a conventional experimental design, because they belonged to a larger study for each family germination pattern characterization. The germination and emergence were observed up to two months after the last event (germination or emergence) in all replicates as the criteria to stop the evaluation of the experiment.

For each sample, germinability or emergence, mean germination or emergence time, time of the first and last seed germination or seedling emergence, coefficient of variation of germination or emergence time, uncertainty and synchrony were calculated [31]. Further details on the applications of these germi-

nation measurements can be found in Ranal & Santana [31] and Ranal *et al.* [32].

### 2.3. Cerrado Species Comparisons

For this purpose, the data obtained for the species here analysed were compared with other Cerrado species and see species list in **Table 1** and **Table 2**, including Melastomataceae and Bombacoideae. The majority of species included in the comparison were studied by [33]-[41]. The data were not estimated but obtained directly from the authors, and the seed germination measurements were recalculated as a single sample (all replicates were summed), without considering the original experimental design. When studies involved seed preparation treatments, we used only the control treatment (seeds moistened only with water, without dormancy breaking or additional treatment) and when they involved different individuals, fruit characters or seed types from the same plant, these data were grouped in a single sample. That was necessary due to differences in populations, individuals or seed classification according to the physiological qualities involved in each study. Working with the original replicates could lead to an error of analysis, since when comparing the species among themselves we would be comparing replicates with different sources of variation (e.g. replicates originated from individuals versus replicates originated from different types of fruit).

Independently of the experimental design, all studies included here were based on the same germination measurements and without time censoring (no experiment was interrupted and all necessary time for seed germination was allowed), making it possible to compare the studies. Besides, we also included only daily evaluated experiments. This criterion of paper selection minimizes the effects of experimental conditions making it possible to compare the species. Some studies were conducted in Uberlândia, in the same or similar conditions that we used in our seed germination experiments (same temperature, light conditions and same chamber model) or in the seedling emergence experiments (same greenhouse and environmental conditions). For seed germination comparisons, 36 species of 18 families of the Cerrado Biome were included. For seedling emergence, comparisons were made with 47 species of 20 families as described in **Table 2**. Details for each species, sampling and experimental design can be observed in the original papers listed in **Table 1** and **Table 2**. In the present paper, data were used only for descriptive and comparative purposes, without statistical inferences.

As exploratory analysis, we performed Principal Component Analyses (PCA) to compare and group the alien (or cultivated) species with the native Cerrado species. In this analysis, we used germinability, germination or emergence time of the first seed or seedling, mean germination or emergence time, germination or emergence time of the last seed or seedling, coefficient of variation of the germination or emergence time, uncertainty of germination or emergence and synchrony of germination or emergence. The PCA was performed separately for

**Table 2.** Seed germination measurements for some species of malvaceae and melastomataceae cultivated in an urban area inside Cerrado, the Brazilian neotropical savanna, compared with native species from Cerrado.

Species – Population number (P)	Code	Family	seeds	G (%)	GTFS (day)	MGT (day)	GTLS (day)	CVGT (%)	UG (bit)	ZG	Data Source and cultivated classification
<i>Acacia polyphylla</i> DC.	Acp	Mimosaceae	96	90.63	1	3.80	15	58.75	2.70	0.1804	Ranal <i>et al.</i> 2010
<i>Aegiphylia sellowiana</i> Cham.	Aes	Lamiaceae	120	12.50	147	170.73	203	16.00	2.11	0.2095	Ranal <i>et al.</i> 2010
<i>Alibertia sessilis</i> K. Schum.	Als	Rubiaceae	140	95.71	9	13.28	44	33.56	3.10	0.1447	Ranal <i>et al.</i> 2010
<i>Anadenanthera colubrina</i> (Vell.) Brenan	Anc	Fabaceae	100	94.00	1	4.07	15	45.42	1.93	0.3352	Ranal <i>et al.</i> 2010
<i>Anadenanthera peregrina</i> Speg.	Anp	Fabaceae	100	98.00	1	4.50	7	25.18	1.90	0.3697	Ranal <i>et al.</i> 2010
<i>Ananas ananassoides</i> (Baker) L.B.Sm.	Ana	Bromeliaceae	100	96.00	14	17.61	21	11.78	2.91	0.1316	Anastácio & Santana 2010
<i>Astronium fraxinifolium</i> Schott	Asf	Anacardiaceae	150	97.33	2	3.23	12	40.46	1.76	0.3185	Ranal <i>et al.</i> 2010
<i>Bombax ceiba</i> L.	Bc	Malvaceae	64	93.75	3	4.82	9	22.45	1.93	0.3090	this study, cultivated
<i>Bowdichia virgilioides</i> Kunth	Bv	Fabaceae	400	73.00	2	6.88	26	50.48	3.26	0.1367	Ribeiro-Oliveira & Ranal 2013
<i>Cariniana estrellensis</i> (Raddi) Kuntze	Ce	Lecythidaceae	100	88.00	9	16.42	42	34.09	3.80	0.0729	Ranal <i>et al.</i> 2010
<i>Cecropia pachystachya</i> Trécul-P1	Cp1	Cecropiaceae	100	94.00	6	7.19	11	15.43	1.61	0.4473	Ranal <i>et al.</i> 2010
<i>Cecropia pachystachya</i> -P2	Cp2	Cecropiaceae	400	90.25	4	7.29	18	20.35	1.99	0.3531	Ribeiro-Oliveira & Ranal 2016
<i>Ceiba speciosa</i> (A.St.-Hil., A. Juss. & Cambess.) Ravenna-P1	Cs1	Malvaceae	400	82.25	2	7.60	38	80.81	3.48	0.1207	Ribeiro-Oliveira & Ranal 2016
<i>Ceiba speciosa</i> -P2	Cs2	Malvaceae	250	78.40	2	6.76	17	32.65	3.05	0.1373	Ranal <i>et al.</i> 2010
<i>Clidemia hirta</i> D. Don-P1	Cl1	Melastomataceae	500	95.40	8	21.34	87	48.42	4.84	0.0447	Mendes-Rodrigues <i>et al.</i> 2008
<i>Clidemia hirta</i> D. Don-P2	Cl2	Melastomataceae	500	92.20	8	15.38	80	35.01	3.89	0.0832	Mendes-Rodrigues <i>et al.</i> 2008
<i>Dorstenia cayapia</i> Vell.	Dc	Moraceae	100	51.00	13	20.04	41	36.85	3.50	0.0902	Luz <i>et al.</i> 2010
<i>Enterolobium contortisiliquum</i> Kuntze-P1	Ec1	Mimosaceae	400	98.75	3	4.90	9	17.48	1.78	0.3582	Ribeiro-Oliveira & Ranal 2016
<i>Enterolobium contortisiliquum</i> -P2	Ec2	Mimosaceae	100	5.00	10	44.40	102	79.21	1.92	0.1000	Ranal <i>et al.</i> 2010
<i>Eriotheca gracilipes</i> (K. Schum.) A. Robyns	Eg	Malvaceae	100	96.00	7	31.64	77	55.17	5.09	0.0281	Mendes-Rodrigues <i>et al.</i> 2011 a
<i>Eriotheca pubescens</i> Schott & Endl.-P1	Ep1	Malvaceae	100	98.00	5	11.91	36	55.02	3.95	0.0690	Mendes-Rodrigues <i>et al.</i> 2011 a
<i>Eriotheca pubescens</i> -P2	Ep2	Malvaceae	100	79.00	4	11.58	54	93.37	3.89	0.0798	Mendes-Rodrigues <i>et al.</i> 2011 a
<i>Guazuma ulmifolia</i> Lam.-P1	Gu1	Malvaceae	350	38.29	3	159.37	424	76.87	6.58	0.0042	Ranal <i>et al.</i> 2010
<i>Guazuma ulmifolia</i> -P2	Gu2	Malvaceae	400	93.00	1	3.52	26	86.52	2.20	0.3341	Ribeiro-Oliveira & Ranal 2016
<i>Handroanthus serratifolius</i> (Vahl) S. O. Grose	Hs	Bignoniaceae	100	98.00	5	8.30	34	41.94	2.78	0.1780	Ranal <i>et al.</i> 2010

## Continued

<i>Heterotis rotundifolia</i> (Sm.) Jacq.-Fél.	Hr	Melastomataceae	500	95.40	8	77.85	219	43.44	6.36	0.0148	this study, cultivated
<i>Jacaranda cuspidifolia</i> Mart.	Jc	Bignoniaceae	400	22.25	5	10.79	34	49.70	3.44	0.1004	Ranal <i>et al.</i> 2010
<i>Kielmeyera coriacea</i> Mart. & Zucc.	Kc	Clusiaceae	672	80.80	1	4.31	23	53.69	2.79	0.1800	Santana <i>et al.</i> 2010
<i>Lafoensia pacari</i> A.St.-Hil.	Lp	Lythraceae	400	97.00	6	10.42	21	19.43	2.84	0.1857	Ribeiro-Oliveira & Ranal 2016
<i>Lithraea molleoides</i> (Vell.) Engl.	Lm	Anacardiaceae	200	87.50	6	88.72	217	50.95	6.51	0.0069	Ranal <i>et al.</i> 2010
<i>Luehea divaricata</i> Mart.	Ld	Malvaceae	210	47.14	4	22.71	82	73.51	4.81	0.0350	Ranal <i>et al.</i> 2010
<i>Matayba guianensis</i> Aubl.	Mg	Sapindaceae	90	86.67	2	4.37	9	37.25	2.45	0.2125	Ranal <i>et al.</i> 2010
<i>Miconia albicans</i> (Sw.) Triana	Ma	Melastomataceae	350	75.71	6	14.57	72	52.82	4.31	0.0565	Ranal <i>et al.</i> 2010
<i>Miconia ferruginata</i> DC.	Mfe	Melastomataceae	2300	17.00	7	12.30	45	47.38	3.52	0.1291	Mendes-Rodrigues <i>et al.</i> 2010
<i>Microlicia fasciculata</i> Mart. ex Naud.	Mfa	Melastomataceae	3750	14.43	6	10.52	16	21.04	2.98	0.1480	Ranal <i>et al.</i> 2016
<i>Ormosia arborea</i> Harms	Oa	Fabaceae	200	96.00	8	25.69	86	60.76	5.02	0.0345	Ranal <i>et al.</i> 2010
<i>Pachira glabra</i> Pasq. – soil collected seeds	Pg.soil	Malvaceae	100	74.00	2	4.31	10	34.75	2.20	0.2703	this study, cultivated
<i>Pachira glabra</i> – tree collected seeds	Pg.tree	Malvaceae	100	98.00	4	6.73	18	35.52	2.89	0.1500	this study, cultivated
<i>Piptadenia gonoacantha</i> J. F. Macbr.	Pg	Mimosaceae	200	92.50	1	4.91	24	72.80	3.29	0.1360	Ranal <i>et al.</i> 2010
<i>Plathymenia reticulata</i> Benth.	Pr	Mimosaceae	250	58.80	2	16.24	169	151.12	4.04	0.0855	Ranal <i>et al.</i> 2010
<i>Pseudobombax longiflorum</i> (Mart. & Zucc.) A.Robyns	Pl	Malvaceae	100	99.00	4	12.17	20	29.83	3.64	0.0874	Mendes-Rodrigues <i>et al.</i> 2011 b
<i>Pseudobombax tomentosum</i> (Mart. & Zucc.) A. Robyns	Pt	Malvaceae	100	95.00	7	11.54	18	21.34	3.11	0.1386	Mendes-Rodrigues <i>et al.</i> 2011 b
<i>Schefflera morototoni</i> (Aubl.) Maguire, Steyererm. & Frodin Frodi -P1	Sm1	Araliaceae	400	86.25	9	55.08	178	39.44	5.33	0.0339	Ribeiro-Oliveira & Ranal 2016
<i>Schefflera morototoni</i> -P2	Sm2	Araliaceae	200	48.50	38	49.60	72	12.98	4.29	0.0554	Anastácio <i>et al.</i> 2010
<i>Tapirira guianensis</i> Aubl.	Tag	Anacardiaceae	150	100.00	1	2.03	3	10.53	0.30	0.9099	Ranal <i>et al.</i> 2010
<i>Tibouchina granulosa</i> (Desr.) Cogn.	Tig	Melastomataceae	500	6.00	5	9.83	23	42.65	3.04	0.1034	this study, cultivated
<i>Tibouchina pulchra</i> Cogn.	Tip	Melastomataceae	1000	13.90	9	13.77	45	56.04	3.90	0.0989	this study, cultivated
<i>Trema micrantha</i> (L.) Blume	Tm	Ulmaceae	250	24.40	36	231.89	512	39.50	4.31	0.0459	Ranal <i>et al.</i> 2010
<i>Virola sebifera</i> Aubl.	Vs	Myristicaceae	100	96.00	16	24.03	44	23.30	3.99	0.0651	Ranal <i>et al.</i> 2010

Legend: G: Germinability, GTFS: germination time of the first seed, MGT: mean germination time, GTLS germination time of the last seed, CVGT coefficient of variation of the germination time, UG uncertainty of germination, ZG: synchronization index of germination. The code refers to first and/or second letter from species name, followed by population number if more than one.

germination and emergence. The analyses were performed in R using the vegan and graphics packages [42]. All other data were presented in a descriptive approach since the data show some limitations and any inference was proposed.

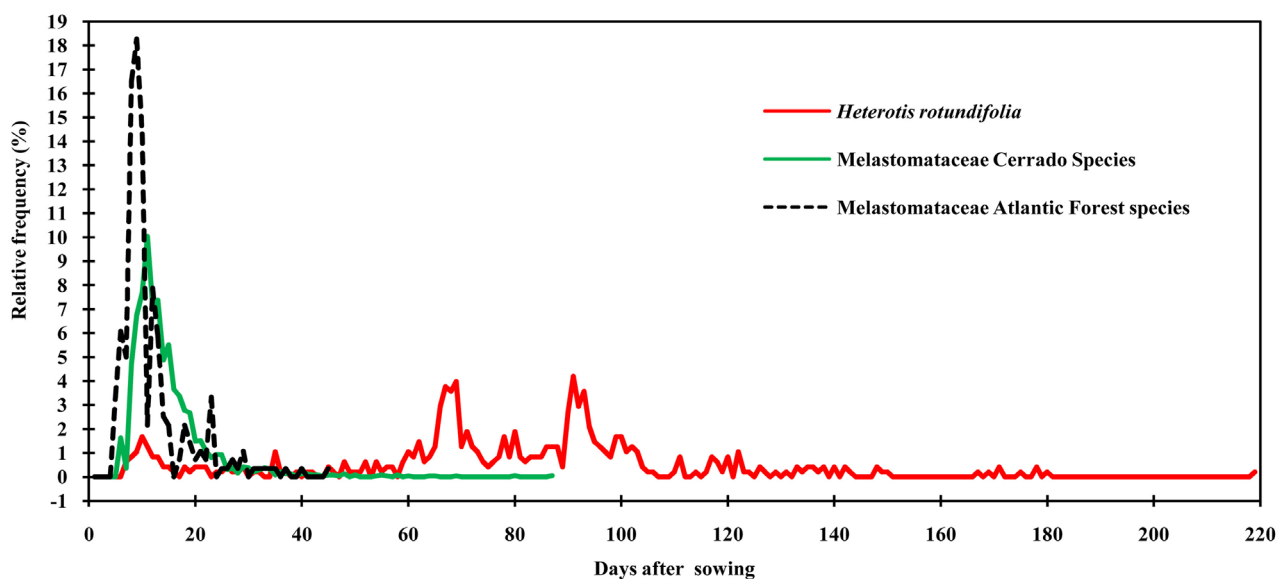
### 3. Results

#### 3.1. Alien Species

The time for the first germination among the seven alien Melastomataceae species ranged from 5 to 9 days, and the time for the last germination for the same species ranged from 16 to 219 days as **Table 2** demonstrate.

Among the Melastomataceae, seeds of *Heterotis rotundifolia* showed high germinability (95.4%), and the highest values for mean germination time (77.85 days), for the last seed germination (219 days) and uncertainty (6.36 bits), and the lowest value for synchrony (0.0148) in relation to the species compared, characterizing its germination process as slow and asynchronous as described in **Table 2**. Seed germination was spread from 8 to 219 days, with few peaks of low relative frequency per day (below 4.5%, **Figure 1**), evidencing strong spreading of germination through time, when compared with the other Melastomataceae. The seed germination of *H. rotundifolia* was concentrated between 60 and 100 days as illustrated in **Figure 1**. Seeds of this species showed similar germinability and coefficient of variation of germination time to seeds of *Clidemia hirta*, but with more spreading through time, higher uncertainty and lower synchrony as illustrated in **Figure 2(a)** and **Figure 3(a)**. In relation to synchrony and when compared to other Cerrado species, seeds of *H. rotundifolia* were the second most asynchronous, only behind *Guazuma ulmifolia* seeds as illustrated in **Figure 3(a)**.

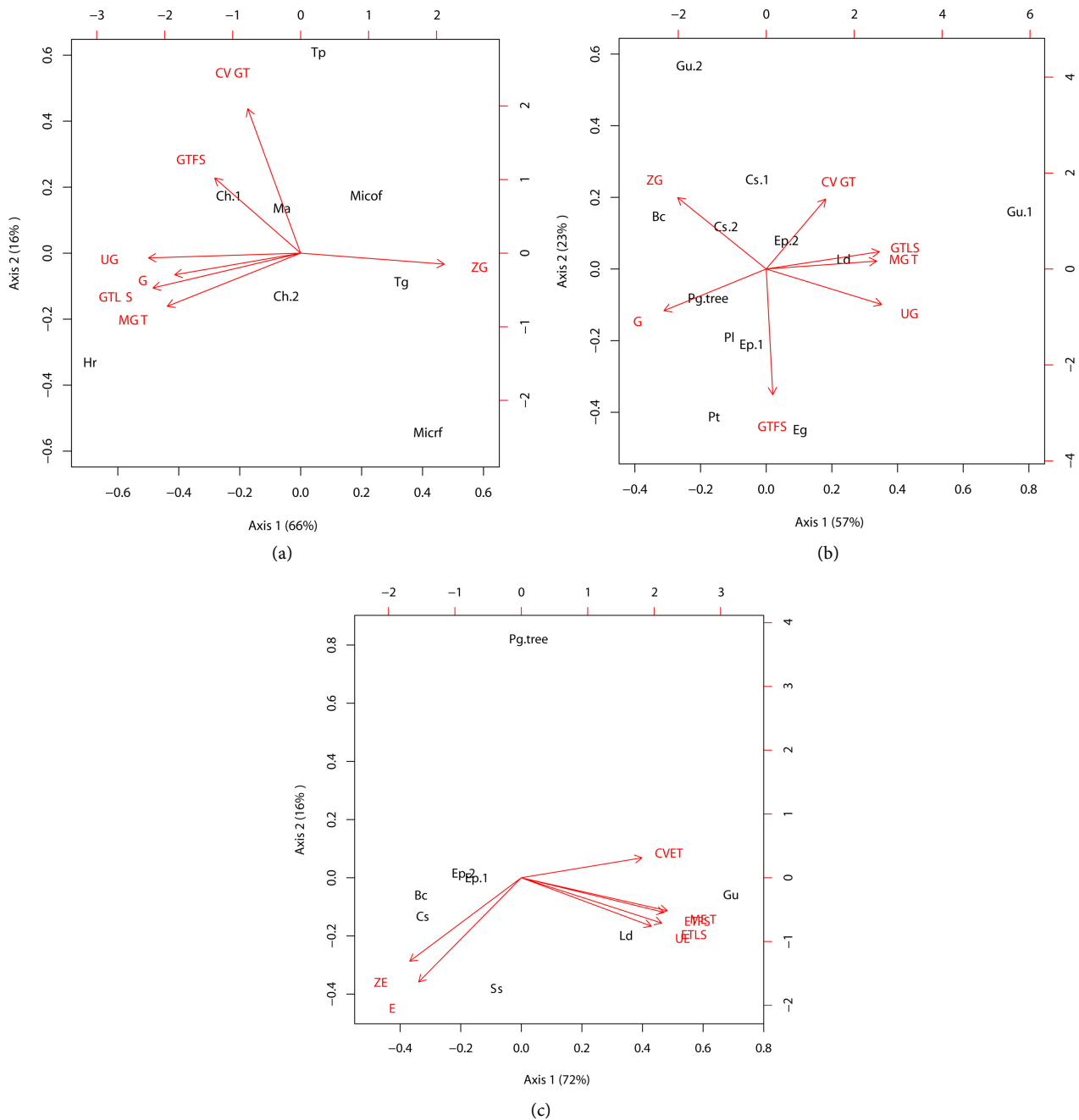
*Tibouchina granulosa* and *T. pulchra* seeds showed low germinability (lower 14%) and similar germination time (initial, final and mean) in relation to seeds of other Melastomataceae Cerrado species as illustrated in **Figure 2(a)** and **Figure 3(a)**, except *Heterotis rotundifolia*. Seeds of *T. pulchra* had the highest



**Figure 1.** Relative frequency of seed germination of some Melastomataceae species as a function of time. The seeds of *Tibouchina granulosa* and *Tibouchina pulchra* (Atlantic Forest species) and *Heterotis rotundifolia* species were collected in urban areas of Uberlândia surrounded by Cerrado, the Neotropical savanna of Brazil.





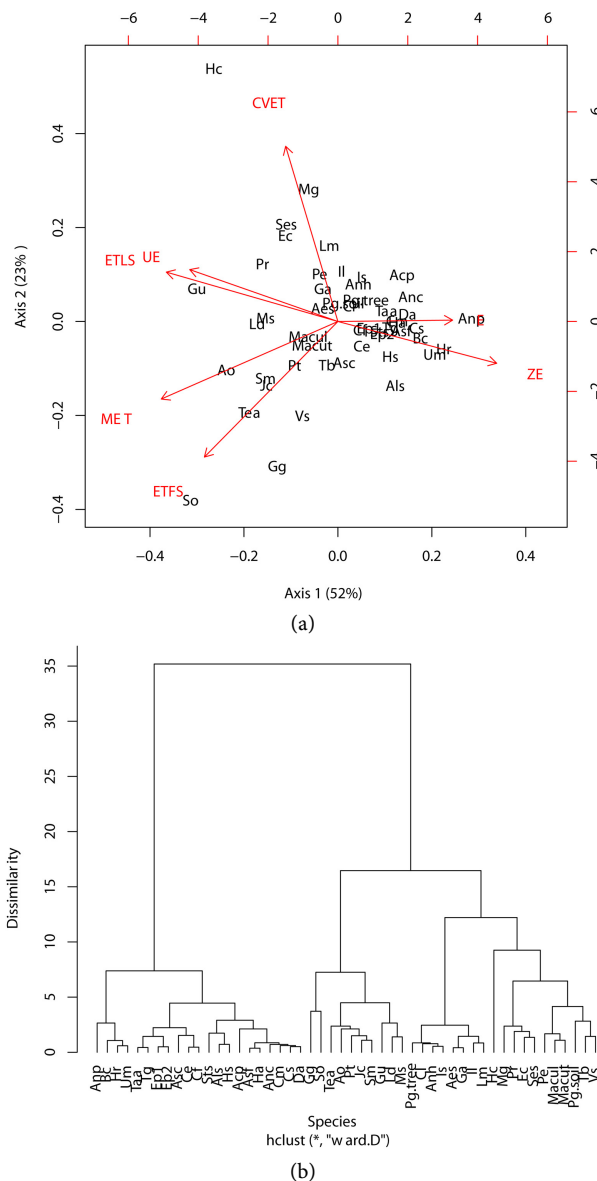


**Figure 3.** Principal Component Analyses (PCA) for some cultivated Bombacoideae-Malvaceae and Melastomataceae in the Cerrado Biome, compared with local species: (a) PCA based on seed germination measurements for Melastomataceae; (b) PCA based on seed germination measurements for Bombacoideae. (c) PCA based on seed emergence measurements for Bombacoideae. The cultivated species are Bc: *Bombax ceiba*, Hr: *Heterotis rotundifolia*, Pa: *Pachira aquatica*, Tig: *Tibouchina granulosa* and Tip: *Tibouchina pulchra*. See species code name and measurements details in [Table 2](#).

spreading of germination around the mean time (coefficient of variation of the germination time of 56.04%) in relation to the other Melastomataceae as described in [Table 2](#).

*Bombax ceiba* and *Pachira glabra* showed high germinability and percentage of seedling emergence, and similar synchrony in relation to the other Bomba-

coideae species (Malvaceae) from Cerrado as illustrated in **Figure 2**, **Figure 3(a)** and **Figure 3(b)**. No clear difference in the germination or emergence processes were observed among alien or local species of this group or in relation of the local flora as illustrated in **Figure 3(b)**, **Figure 3(c)**; **Figure 4(a)** and **Figure 4(b)**. Low physiological quality of *Pachira glabra* seeds collected from the soil was observed during the emergence process, with only 5% of seedling emergence, which was slower and more asynchronous when compared to seeds collected directly from the trees as described in **Table 2** and **Table 3**.



**Figure 4.** Principal Component Analyses (PCA) and clustering based on seed emergence measurements for some cultivated Bombacoideae-Malvaceae and Melastomataceae in the Cerrado Biome compared to local species flora: (a) PCA; (b) Clustering; The cultivated species are Bc: *Bombax ceiba*, Hr: *Heterotis rotundifolia*, Pa: *Pachira aquatica*, Tig: *Tibouchina granulosa* and Tip *Tibouchina pulchra*. See species code name and measurements details in **Table 2** & **Table 3**.

**Table 3.** Seedling emergence measurements for species of malvaceae and melastomataceae cultivated in an urban area inside cerrado, the Brazilian neotropical savanna, compared with native species from cerrado.

Species-Population Number (P)	Cod	Family	seeds	E (%)	ETFS (day)	MET (day)	ETLS (day)	CVET (%)	UE (bit)	ZE	Data Source and cultivated classification
<i>Acacia polyphylla</i> DC.	Acp	Mimosaceae	112	62.50	4	6.17	21	45.50	2.69	0.1797	Ranal <i>et al.</i> 2010
<i>Aegiphylla sellowiana</i> Cham.	Aes	Lamiaceae	120	86.67	22	31.94	69	26.93	4.24	0.0558	Ranal <i>et al.</i> 2010
<i>Alibertia sessilis</i> K. Schum.	Als	Rubiaceae	140	95.71	24	26.34	33	7.78	2.63	0.1923	Ranal <i>et al.</i> 2010
<i>Anacardium humile</i> A.St.-Hil.	Anh	Anacardiaceae	50	96.00	11	19.27	38	34.33	3.72	0.0601	Carvalho <i>et al.</i> 2005
<i>Anadenanthera colubrina</i> (Vell.) Brenan	Anc	Fabaceae	128	90.63	3	7.53	24	32.05	2.78	0.1732	Ranal <i>et al.</i> 2010
<i>Anadenanthera peregrina</i> Speg.	Anp	Fabaceae	200	97.50	3	4.06	10	38.95	1.85	0.3671	Ranal <i>et al.</i> 2010
<i>Aspidosperma cylindrocarpum</i> Müll. Arg.	Asc	Apocynaceae	92	95.65	29	43.22	70	17.03	3.55	0.1455	Ranal <i>et al.</i> 2010
<i>Astronium fraxinifolium</i> Schott	Asf	Anacardiaceae	90	87.78	9	12.30	22	18.24	2.83	0.1532	Ranal <i>et al.</i> 2010
<i>Bombax ceiba</i> L.	Bc	Malvaceae	64	78.13	7	9.54	15	18.85	2.45	0.2098	this study, cultivated
<i>Cariniana estrellensis</i> (Raddi) Kuntze	Ce	Lecythidaceae	100	91.00	16	30.69	39	11.85	3.47	0.0960	Ranal <i>et al.</i> 2010
<i>Casearia mariquitensis</i> Kunth	Cm	Flacourtiaceae	200	95.00	9	14.67	38	22.43	3.05	0.1707	Ranal <i>et al.</i> 2010
<i>Cedrela fissilis</i> Vell.	Cf	Meliaceae	250	96.40	16	24.91	47	16.47	3.68	0.0972	Ranal <i>et al.</i> 2010
<i>Ceiba speciosa</i> (A.St.-Hil., A. Juss. & Cambess.) Ravenna	Cs	Malvaceae	250	95.60	6	9.48	17	19.49	2.72	0.1811	Ranal <i>et al.</i> 2010
<i>Copaifera langsdorffii</i> Desf.	Cl	Caesalpiniaceae	100	95.00	18	27.01	56	30.71	3.74	0.0943	Ranal <i>et al.</i> 2010
<i>Dipteryx alata</i> Vogel	Da	Fabaceae	72	100.00	8	10.85	19	26.47	2.91	0.1616	Ranal <i>et al.</i> 2010
<i>Enterolobium contortisiliquum</i> Kuntze	Ec	Mimosaceae	108	11.11	12	41.92	93	63.79	3.42	0.0152	Ranal <i>et al.</i> 2010
<i>Eriotheca pubescens</i> Schott & Endl.-P1	Ep1	Malvaceae	45	70.33	13	16.24	23	16.72	3.06	0.1212	Mendes-Rodrigues <i>et al.</i> 2011 a
<i>Eriotheca pubescens</i> Schott & Endl.-P2	Ep2	Malvaceae	260	70.77	13	18.91	32	16.49	3.43	0.1107	Mendes-Rodrigues <i>et al.</i> 2011 a
<i>Genipa americana</i> L.	Ga	Rubiaceae	200	84.50	17	28.50	71	31.04	4.41	0.0548	Ranal <i>et al.</i> 2010
<i>Guarea guidonia</i> (L.) Sleumer	Gg	Meliaceae	200	3.00	70	81.83	99	14.30	1.92	0.1333	Ranal <i>et al.</i> 2010
<i>Guazuma ulmifolia</i> Lam.	Gu	Malvaceae	350	19.43	32	88.87	175	45.50	5.21	0.0176	Ranal <i>et al.</i> 2010
<i>Handroanthus avellanadae</i> (Lorentz ex Griseb.) Mattos	Ha	Bignoniaceae	128	80.47	10	12.71	22	23.78	2.91	0.1574	Ranal <i>et al.</i> 2010
<i>Handroanthus roseo-albus</i> (Ridl.) Mattos	Hr	Bignoniaceae	200	96.00	8	9.49	19	20.09	2.13	0.2816	Ranal <i>et al.</i> 2010
<i>Handroanthus serratifolius</i> (Vahl) S.O.Grose	Hs	Bignoniaceae	128	96.09	18	21.09	35	12.82	2.87	0.1554	Ranal <i>et al.</i> 2010
<i>Hymenaea courbaril</i> L.	Hc	Bignoniaceae	72	65.28	7	48.68	284	126.33	4.58	0.0315	Ranal <i>et al.</i> 2010
<i>Inga laurina</i> (Sw.) Willd.	Il	Mimosaceae	144	97.22	11	20.77	53	35.83	4.30	0.0553	Ranal <i>et al.</i> 2010
<i>Inga sessilis</i> (Vell.) Mart.	Is	Mimosaceae	144	99.31	11	16.23	52	37.77	3.70	0.0906	Ranal <i>et al.</i> 2010
<i>Jacaranda cuspidifolia</i> Mart.	Jc	Bignoniaceae	400	85.75	48	74.31	101	14.49	4.60	0.0572	Ranal <i>et al.</i> 2010
<i>Lithraea molleoides</i> (Vell.) Engl.	Lm	Anacardiaceae	200	82.00	8	21.00	48	44.84	4.71	0.0434	Ranal <i>et al.</i> 2010
<i>Luehea divaricata</i> Mart.	Ld	Malvaceae	500	53.00	29	62.47	105	22.71	5.19	0.0323	Ranal <i>et al.</i> 2010
<i>Machaerium aculeatum</i> (Vell.) Stelfeld	Macul	Fabaceae	200	53.50	30	41.16	100	24.11	3.79	0.1049	Ranal <i>et al.</i> 2010

## Continued

<i>Machaerium acutifolium</i> Vogel	Macut	Fabaceae	100	51.00	28	39.80	60	17.34	3.95	0.0565	Ranal <i>et al.</i> 2010
<i>Matayba guianensis</i> Aubl.	Mg	Sapindaceae	96	21.88	11	25.71	97	86.89	3.37	0.0857	Ranal <i>et al.</i> 2010
<i>Myracrodruon urundeuva</i> Allemão	Um	Anacardiaceae	150	90.00	8	10.28	16	14.14	2.32	0.2498	Ranal <i>et al.</i> 2010
<i>Myrsine umbellata</i> Mart.	Ms	Myrsinaceae	200	25.00	17	68.76	92	24.62	4.51	0.0318	Ranal <i>et al.</i> 2010
<i>Ormosia arborea</i> Harms	Oa	Fabaceae	200	89.00	57	80.42	145	21.30	5.24	0.0279	Ranal <i>et al.</i> 2010
<i>Paquiria glabra</i> Pasq.-soil	Pg.soil	Malvaceae	100	5.00	12	17.00	24	30.84	2.32	0.0000	this study, cultivated
<i>Paquiria glabra</i> Pasq.-tree	Pg.tree	Malvaceae	100	84.00	10	19.05	30	26.37	3.69	0.0843	this study, cultivated
<i>Plathymentia reticulata</i> Benth.	Pr	Mimosaceae	200	34.50	22	47.06	143	46.94	4.45	0.0465	Ranal <i>et al.</i> 2010
<i>Platypodium elegans</i> Vogel	Pe	Fabaceae	100	48.00	17	27.25	70	44.61	3.79	0.0700	Ranal <i>et al.</i> 2010
<i>Pouteria torta</i> Radlk.	Pt	Sapotaceae	35	100.00	40	61.63	99	19.29	3.93	0.0555	Ranal <i>et al.</i> 2010
<i>Schefflera morototoni</i> (Aubl.) Maguire, Steyerl. & Frodin	Sm	Araliaceae	160	55.63	43	68.64	87	13.49	4.52	0.0403	Anastácio <i>et al.</i> 2010
<i>Senna silvestris</i> (Vell.) H. S. Irwin & Barneby	Ses	Caesalpiniaceae	100	31.00	10	35.97	89	60.26	4.41	0.0237	Ranal <i>et al.</i> 2010
<i>Sterculia striata</i> A.St.-Hil. & Naudin	Sts	Malvaceae	50	92.00	18	29.20	80	29.45	2.79	0.2164	Ranal <i>et al.</i> 2010
<i>Syagrus oleracea</i> Becc.	So	Arecaceae	100	47.00	100	117.40	144	8.92	4.00	0.0620	Ranal <i>et al.</i> 2010
<i>Tabebuia aurea</i> (Silva Manso) S. Moore	Taa	Bignoniaceae	72	97.22	9	13.63	25	24.26	3.21	0.1139	Ranal <i>et al.</i> 2010
<i>Tapirira guianensis</i> Aubl.	Tg	Anacardiaceae	96	100.00	10	15.83	25	15.97	3.23	0.1224	Ranal <i>et al.</i> 2010
<i>Terminalia argentea</i> Mart.	Tea	Combretaceae	100	37.00	61	73.14	110	14.52	3.82	0.0571	Ranal <i>et al.</i> 2010
<i>Terminalia brasiliensis</i> (Cambess. ex A. St.-Hil.) Eichler	Tb	Combretaceae	200	6.50	28	35.00	45	15.91	2.93	0.0897	Ranal <i>et al.</i> 2010
<i>Virola sebifera</i> Aubl.	Vs	Myristicaceae	70	15.71	46	57.73	66	10.25	2.66	0.0909	Ranal <i>et al.</i> 2010

Legend: E: Emergence rate, ETFS: emergence time of the first seed, MET: mean emergence time, ETLS emergence time of the last seed, CVET coefficient of variation of the emergence time: UE uncertainty of emergence, ZE: synchronization index of emergence. The code refers to first and/or second letter from species name, followed by population number if more than one.

### 3.2. Cerrado Species

For the seed germination process of Cerrado species, germinability ranged from 5%, for *Enterolobium contortisiliquum* Kuntze—Population 2, to 100% for *Tapirira guianensis* Aubl. The germination time for the first seed ranged from 1 day in seven species to 147 days for *Aegiphylia sellowianna* Cham., while the germination time for the last seed ranged from 3 days for *Tapirira guianensis* to 512 days for *Trema micrantha* (L.) Blume. The mean germination time ranged from 2.03 days for *Tapirira guianensis* to 231.89 days for *Trema micrantha*, and the coefficient of variation of germination time ranged from 10.53% for *Trema micrantha* to 151.12% for *Plathymentia reticulata* Benth. The uncertainty of germination ranged from 0.30 bits for *Tapirira guianensis* to 6.58 bits for *Guazuma ulmifolia* Lam.—Population 1, and the synchrony of germination ranged from 0.0042 for *Guazuma ulmifolia*-Population 1 to 0.9099 for *Tapirira guianensis* as described in **Table 2**.

For seedling emergence percentage the values ranged from 3% for *Guarea guidonia* (L.) Sleumer to 100% in three species (*Diteryx alata* Vogel, *Pouteria torta* Radk., *Tapirira guianensis* Aubl.). The emergence time for the first seedling

ranged from 3 days for *Anadenanthera colubrina* (Vell.) Brenan and *A. peregrina* Speg. to 100 days for *Syagrus oleracea* Becc., while the emergence time for the last seedling varied from 10 days for *Anadenanthera peregrina* to 284 days for *Hymenaea courbaril* L. The mean emergence time ranged from 4.06 days for *Anadenanthera peregrina* to 117.40 days for *Syagrus oleracea*, with the coefficient of variation of emergence time ranging from 7.78% for *Alibertia sessilis* (Vell.) K. Schum. to 126.33% for *Hymenaea courbaril*. The uncertainty of emergence ranged from 1.85 bits for *Anadenanthera peregrina* to 5.24 bits for *Ormosia arborea* Harms, and the synchrony of emergence ranged from 0.0152 for *Enterolobium contortisiliquum* to 0.3671 for *Anadenanthera peregrina* as described in **Table 3**.

### 3.3. Comparison between Alien and Native Cerrado Species

Comparing Melastomataceae with other Cerrado species, seeds of *Heterotis rotundifolia* were similar to *Guazuma ulmifolia*, *Lithraea molleoides* and *Schefflera morototoni*, which formed a clear group with a high mean germination time and seed germination spread through time as illustrated in **Figure 2**. When *Heterotis rotundifolia* was compared with other Melastomataceae, it was similar to *Clidemia hirta* with high germinability and asynchronous seed germination, but the latter species has shorter seed germination time as illustrated in **Figure 3(a)**. *Tibouchina granulosa* and *T. pulchra* formed a group with the other Cerrado Melastomataceae, with similar seed germination measurements as illustrated in **Figure 3(a)**.

*Bombax ceiba* and *Pachira glabra* were similar to other Cerrado Bombacoideae species (*Ceiba speciosa*, *Eriotheca* spp. and *Pseudobombax* spp.), but with a different pattern in relation to species of other tribes of Cerrado Malvaceae for the germination and emergence processes as illustrated in **Figures 2-4**. The non-Bombacoideae species of Malvaceae showed a lower germinability and percentage of emergence compared to Bombacoideae, with higher spread of germination in time in relation to Bombacoideae species, probably related to dormancy. When compared to Cerrado native species, the alien Bombacoideae did not show any marked difference as illustrated in **Figures 2-4**.

## 4. Discussion

The alien Bombacoideae species showed similar seed germination and seedling emergence pattern in relation to native Cerrado species of the same family, with high germinability and percentage of emergence, low germination or emergence time and synchronous processes [5] [37] [38]. Low germinability and percentage of emergence, with high germination or emergence time and asynchronous germination observed for seeds (or seedlings) of other Malvaceae tribes are associated with seed dormancy [5] [39]. It is very important to observe some attributes of seeds during the germination or emergence process to consider dormancy, that is, the quantity activated that is expressed by embryo protrusion

or seedling emergence through time. This is the velocity of the process, which is measured by means of distribution over time. Dormancy can also be measured by synchrony. Dormant seeds, in general, show low velocity of embryo protrusion or seedling emergence and asynchrony, spreading the process through time. In reality, more important than the mean germination/emergence time is the amplitude between the first and last event, as was demonstrated for diaspores of *Lithraea molleoides* (Vell.) Eng. [43]. The total seeds germinated or seedlings emerged frequently are more associated with viability than with dormancy.

For Melastomataceae, we found some differences. The seed germination pattern of *Heterotis rotundifolia* was similar to *Clidemia hirta*. The latter is considered an invasive species [12], with high germinability, slow and asynchronous seed germination [44]. Seeds of both species are probably dormant, but the type of dormancy is unknown. The dormancy types and metabolism in Melastomataceae are poorly known, although some studies have showed multiple dormancy [36], physiological dormancy [45] and water impermeability in seed coat [46]. The spreading of the germination through time, typical of seeds of several Melastomataceae, permits the inclusion of these seeds in the category of relative dormancy as proposed by Labouriau [47], but the type of dormancy is unclear because the spreading of the germination through time can be due to physical, morphological, physiological or combination of these causes. Dormancy is also present in other invasive species [6] [8] [9], reinforcing the risk related to the cultivation of *Heterotis rotundifolia* near natural areas.

The germination process for Melastomataceae species usually starts in less than 30 days and is associated with dormancy in many species [41] [44] because more important than this limit, as was proposed by Baskin and Baskin [48] to consider seeds non-dormant, is the behaviour of the germination process through time. The spreading of the germination through time, that is, the broad range between the first and last germination or emergence is the most important reference point to consider dormancy and it is valid for species of other families. For example, seeds of *Luehea divaricata*, *Ormosia arborea* and *Virola sebifera* with dormancy, had a mean germination time of 24.1, 25.7 and 24 days, respectively, but with a range of the germination process from 4 to 104, 8 to 86, and 16 to 44 days, respectively [5]. The same species had a mean emergence time of 62.8, 80.4 and 57.7 days and a range of the emergence process from 29 to 105, 57 to 145 and 46 to 66 days, respectively. During this time, they reached 48.1%, 96% and 96% of germinability and 53, 89 and 15.7 of emergence. Seedlings of *Copaifera langsdorffii* and *Genipa americana* reached 95% and 84.5% of emergence with mean a emergence time of 27 and 28.7 days, ranging from 18 to 56 and 17 to 71 days [5]. All of them had the mean germination or emergence time lower than 30 days and relative dormancy due to the spreading of germination or emergence through time. Seeds of *Luehea divaricata* have relative dormancy caused by physiological dormancy, of *Ormosia arborea* have physical and mechanical dormancy, of *Virola sebifera* have physiological dormancy, and those of *Copaifera langsdorffii* have physical, chemical and physiological dormancy (see

the relative frequency of germination or emergence in Ranal *et al.* [5] and more information for *C. langsdorffii* in Pereira *et al.* [49]. It is also important to consider that the low mean germination time of some species is associated with time censoring of the experiment, a particular decision of the researcher but, in these cases, the time measurements are underestimated. Another point is that for some species with dormant seeds that show a broad range between the first and last germination and very low synchrony, as is the case of *Enterolobium contortisiliquum*, *Guazuma ulmifolia*, *Hymenaea courbaril* [5], *Lithraea molleoides* [43], *Senna sylvestris* and *Trema micrantha* [5], the mean germination time does not have the same importance or utility as for those that germinate very closely, even if this occurs after a long time. The relative frequency of germination or emergence and the survival analysis seems to be more appropriate for these species as pointed out by Berger *et al.* [43]. The last point is that seeds of some species could take a long time for the first germination, but most of them could germinate synchronously a long time after they were sowed. The seeds were dormant and this condition could be broken at the same time, weeks or months after sowing.

Regardless of the question of criterion, seeds of the Melastomataceae species, for example, specifically for Cerrado, show mean germination time values below 30 days [36] [41] [44] [45] [50] [51] [52], reinforcing the importance of the high mean germination time and germination time of the last seed values found here for *H. rotundifolia* seeds.

The spreading of germination through time is associated with dormancy and this character permits soil seed bank formation for Melastomataceae, as was observed for *Clidemia hirta*, *Miconia chartaceae*, *Miconia ferruginata*, *Microlicia fasciculata* [36] [41] [44] [45] [53] [54] and *Miconia ferruginata* (MA Ranal, personal observation). Seeds of *Clidemia hirta* when unearthed, show a faster and synchronic germination process than seeds stored in paper bags in laboratory conditions [44], and these results represent irrefutable evidence of its ability to survive in soil and form soil seed banks. Thus, this behaviour is an important signal that seeds of *Heterotis rotundifolia* can persist in seed banks, and in favourable situations can compete with the natural vegetation, although this character needs to be investigated. Seeds of *Miconia albicans* established in grasslands have slow and asynchronous germination, and this fact could increase seedling survival in grasslands, a more unpredictable environment compared to woodlands [52].

Another important factor for the establishment of invasive species is that a larger introduction is more important to survival than small and frequent insertions [10]. *Heterotis rotundifolia* could incorporate the two processes with multiple insertions, one of them by means of the relative dormancy of its seeds that spread the germination through time, which represents the small and frequent insertions, and a second type represented by large introductions due to the high germinability of the seeds present in the soil seed banks, when exposed to ideal conditions for germination. It was observed for *Leucaena leucocephala* (Lam.)



de Wit, another invasive species of the Cerrado region, that it also has its invasive capacity related to seed bank formation due to dormancy and high seed production [9].

The low germinability of *Tibouchina pulchra* and *T. granulosa* seeds is comparable to seeds of *Miconia ferruginata* [44] and *Microlicia fasciculata* [41]. *Miconia ferruginata* presents high embryoless seed percentages [44], a fact that could be present in the seeds of the two *Tibouchina* species. Studies have demonstrated that germinability of 27.84% and 23.92%, respectively for seeds of *Tibouchina pulchra* and *T. granulosa* [55] is related to the absence of embryos in their seeds, a common character in Melastomataceae [56].

For *Tibouchina pulchra* and *T. granulosa*, low germinability could also represent reproductive inadequacies for local conditions, for example, soil quality. The urban area that was studied here has a high plant and animal diversity, and probably has no deficiency in pollination services. As the seed quality and germination pattern in some Cerrado Melastomataceae could be also related to aluminium presence [41] [44], the presence of this element in Cerrado soils could be a disadvantage to non-Cerrado species as *Tibouchina pulchra* and *T. granulosa*. *Heterotis rotundifolia* might not be affected by this element taking into account its origin in African savannas, with possibly similar soil conditions. The last important point for some invasive species is that a low germination percentage has been found and that is compensated with other features as seedling vigour [6].

*Heterotis rotundifolia* represents high potential risks to local species, especially because of the high germinability and spreading of germination through time with a not yet known dormancy mechanism. Allied to these factors, this species shows fast growth and vegetative propagation [18] [19]. Thus, special attention is necessary in monitoring the spread of this species and the possible impacts in the local species of Cerrado.

Other seed germination characters have also been related to the success of alien species. We have the examples of *Clausena excavata* Burm., which germinates in broad light conditions [7], *Impatiens glandulifera* Royle, which requires a short period of time for seed stratification [6], and alien *Impatiens* species, which have a more successful local adaptation rate compared to local *Impatiens* species [8].

Besides this information, seed germination characters are not generally related to the capacity of invasion, except high germination rates [57], probably because of the low number of comparative studies for other metrics related to seed germination. Another point is the absence of studies that compare seed germination patterns of species when they are in their native area and when they are alien. Unfortunately, we do not know the seed germination measurements for the alien species studied here in their natural habitat.

Our data could present some limitations due to the low number of trees evaluated, statistical inference and low number of species and families studied, but they represent the first data for some species, regardless of being in natural

or alien areas. These descriptive data could improve information to plan future experimental investigations.

## 5. Conclusions

In conclusion, our data show two possible different patterns. Bombacoideae alien species studied here show the same seed pattern of local species, without a distinctive factor in seed germination or seedling emergence. On the other hand, Melastomataceae shows one species with a distinct pattern, *Heterotis rotundifolia*, which could offer risks to local flora. This species had a similar behaviour of other dormant species of the Cerrado flora.

Although we did not evaluate the entire process of the introduction of alien or cultivated species, the analyses of seed germination and seedling emergence measurements, as the spreading of germination in time, could offer information that is related to the success of invasive species.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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