J. Bamboo Rattan (2022) 21(3):138-145
https://doi.org/10.55899/09734449/jbr021305 www.jbronline.org
RESEARCH ARTICLE

Novel aerial sampling method to detect flowering *Bambusa vulgaris* (Schrad. ex J.C. Wendl.) in Trinidad and Tobago, West Indies

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Received: 18 November 2022/Accepted: 24 January 2023
Published online 2 June 2023

Abstract: Little to no records of *Bambusa vulgaris* (Schrad. ex J.C. Wendl.) flowering events have been published for Trinidad and Tobago, West Indies. This paper aims to document past flowering events on these islands and to record environmental conditions surrounding an individual flowering event in north-west Trinidad. A novel systematic sampling approach using aerial surveys was adopted. An unmanned drone was used to establish a 500 m radial transect at the first flowering clump and this method was continued until no more flowering bamboo clumps/clusters were identified. Additional aerial surveys and site visits along major roads were also conducted to search for flowering clumps/clusters on both islands. Much research is still warranted (using similar methodologies and guidelines) to record environmental cues associated with *B. vulgaris* flowering on the islands as the present study was only able to provide a baseline for future studies.

Keywords: Caribbean islands, environmental conditions, Poaceae, sporadic synchronized flowering

Introduction

Common bamboo (*Bambusa vulgaris* Schrad. ex Wendl.) occurs throughout the tropics and subtropics. In the islands of Trinidad and Tobago, West Indies, the species' predominant mode of dispersal is via water; hence, within the last 100 years bamboo clumps (patches) became naturalized along riverbanks (Canavan *et al.* 2017). Bamboo is frequently used and is in high demand in the agricultural, construction and cultural sectors. Consequently, new clumps are quickly and easily established along the periphery of rural communities, forest edges, wastelands, and general open areas, preferably on lowlands.

Bambusa vulgaris does not depend on flowering to reproduce (Canavan *et al.,* 2019; Koshy and Pushpangadan, 1997; Zheng *et al.,* 2020). This may be due to the high number of seed predators or the enormous energy cost required for inflorescence production, which subsequently leads to death. The unfruitfulness of *B. vulgaris* may be due to stress (induced by environmental conditions), the presence of natural pollinators, a high rate of pollen sterility, and floral self-incompatibility, possibly due to the inhibition of pollen tubes in the stigmatic papillae (Barbosa *et al.,* 2006; Koshy and Jee, 2001). Little is known about the flowering time of *Bambusa vulgaris* however, clumps are known to live for over 150 years, flower sporadically, then die (Janzen, 1976; Zheng *et al.,* 2020). Zheng *et al.,* (2020) hypothesized that in bamboo, conspecific individuals with the same genotype, derived from the same fertilized egg or 'ramet', share a unique flowering cycle. Therefore, *B. vulgar*is clumps from the same ramet are expected to flower every 150 years (Zheng *et al.* 2020).

Bambusa vulgaris does not practise caryopsis (the production of fruit-dry one-seeded grains), yet many animals visit culms when in flower. In other parts of the globe with seed-bearing bamboo species

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e.g., *Bambusa arnhemica, B. bambos*, and *Melocanna baccifera*, insects, rodents, birds, and other animals satiate themselves with bamboo grains. To increase seedling survival, these bamboo species practise mass synchronized flowering. The premise of this biological process is to overwhelm seed/seedling predators with a surplus of grains, allowing plants to survive long enough to defend themselves with tough fibres containing bioactive chemicals such as tannins, cyanide acid, and other toxins (Barbosa *et al.,* 2006; Haque and Bradbury, 2002; Putra and Kencana, 2009).

Records of bamboo flowering on the islands are sparse. A flowering bamboo clump in Tobago was reported by Jaggernauth (2001), who also mentioned a hunter who observed a similar occurrence of flowering in 1971. Much of what is known about local flowering events of *B. vulgaris* has been via word of mouth. Anecdotal records indicate a combined massive synchronized and sporadic partial flowering event in Talparo, central Trinidad, in the mid to late 1980s where bamboo clusters alongside the local river were all in flower, together with sporadic flowering clusters in the area (N. Leotaud, personal communication January 12, 2022: unreferenced).

The flowering of *B. vulgaris* in different environmental conditions is intriguing because this species practises monocarpic flowering (i.e., flowering once and then dying) (Janzen, 1976). This is rare in the plant kingdom (Zheng *et al.,* 2020). Among the hundreds of known bamboos, certain species do not always die after flowering, although their chances of a full recovery after flowering are minimal. They rarely flower but when they do it can be a spectacle, with browning of foliage and development of tall, feathery, grass-like flowers (Arneaud, 2022).As little to no records of *Bambusa vulgaris* (Schrad. ex Wendl.) flowering events have been published for Trinidad and Tobago, this paper aims to document past *B. vulgaris* flowering events in the country and to record the environmental conditions surrounding an individual flowering event in Chaguaramas, north-west Trinidad.

Materials and Methods

Study locations and data collection design

Observations of *Bambusa vulgaris* Schrad. ex Wendl) were made in January 2022 on the islands of Trinidad 10°32'11.1" N, 61°18'43.0" W (4,768 km^2) and Tobago 11°15'0.00" N, 60°40'1.20"W (300 km^2) (Fig. 1A). Situated at the foot of the Caribbean archipelago, south-east of Grenada, Trinidad is a continental land-bridge island off the north-east coast of Venezuela (Weber *et al.,* 2001). Rainfall on the islands varies between 2500–3500 mm per annum with a rainy season between July to December, and a dry season between January to June. Both islands share a minimum and maximum annual temperature of 26–31^{o}C (TTMS, 2022).

This study was conducted in three phases: phase one was an initial anecdotal survey of past *Bambusa vulgaris* flowering events based on herbarium records, published information and known sightings over the years; phase two recorded environmental conditions surrounding a flowering bamboo clump in the Bamboo Cathedral, Chaguaramas, Trinidad; whereas phase three involved detailed aerial surveys and site visits along several major roadways in Trinidad and Tobago.

Past *B. vulgaris* flowering events in Trinidad and Tobago

Experts in various environmental-related disciplines were consulted and anecdotal information was limited to physical sightings. A strategic (systematic) literature search was then conducted by searching various data-bases and results were limited to only peer-reviewed documents.

Environmental conditions

The present study surveyed numerous sites along forest reserves in the Northern Range (Trinidad), the Main Ridge Forest Reserve (Tobago), and surrounding foot-hill areas for flowering bamboo clumps. Additionally, sporadic surveys were made throughout the islands.

The following environmental observations were recorded; canopy coverage, temperature, slope, elevation, soil type, soil moisture, evidence of fire, wind description, proximity to Nearest Housing Settlement (NHS), and associated fauna. Whenever possible, world Climatic data (for 1970-2000) were recorded using WorldClim version 2.1 at a spatial resolution of ~1 km^2. (Fick and Hijmans, 2017) Additionally, floral material was vouchered and stored for future comparisons.

Aerial surveys and site visits

Two DJI Mavic Air 2 UAV drones were deployed at the initial *B. vulgaris* clump (Bamboo Cathedral, Chaguaramas) to the height of 100 m. A 500 m radial -transect was then established at the centre of the

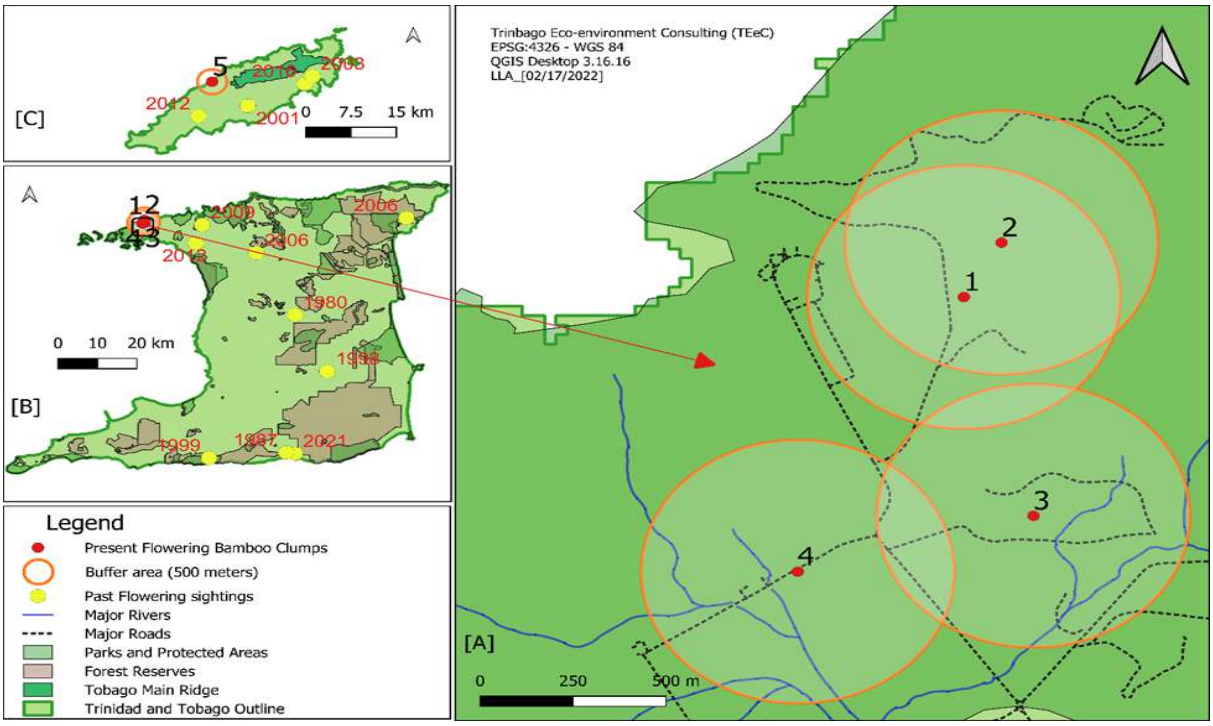

Fig. 1. Flowering *Bambusa vulgaris* Schrad. (common bamboo) clumps in Trinidad and Tobago, W.I. (A) Present flowering *B. vulgaris* locations within the Bamboo Cathedral, Tucker Valley, Chaguaramas, Trinidad; (B) Past *B. vulgaris* flowering locations in Trinidad; (C) Past *B. vulgaris* flowering locations in Tobago

flowering clump, and the drones were programmed to fly systematically within each quarter of the radial transect. Flights were recorded with the manufacturer's magnification capabilities (4×), and were subsequently reviewed on a computer to validate sightings. Once a flowering clump was identified, the method was repeated within the 500 meters radius until no more flowering clumps were seen. Wherever flowering clumps were accessible, site visits were conducted to observe general environmental conditions.

To spot flowering clumps, careful visual inspections were made along some major roads in Trinidad and Tobago (Table 1). Wherever a large area of *B. vulgaris* was spotted, drones were deployed and 500 m radial quadrants were established.

Table 1. Transect lines (major roads) used to search for *Bambusa vulgaris* Schrad. flowering events in Trinidad and Tobago, West Indies

No.	Name of major road	*Approx. Length (kilometres)	General location
1	Tucker Valley Road	8.5	North-west Trinidad
2	Charlotteville – L'Anse Fourmi Road	9.7	North-east Tobago
3	Northside Road	4.5	Central Tobago
4	Caura Royal Road	6.5	North-west Trinidad
5	Acono Road	5.0	North-west Trinidad
6	Aripo Road	8.4	North-east Trinidad
7	Tabaquite Road	12.5	Central Trinidad
8	Talparo Road	10.0	Central Trinidad
9	Naparima Mayaro Road	20.5	South-west Trinidad
10	Guayaguayare Mayaro Road	19.5	South-east Trinidad

Results

Past *B. vulgaris* flowering events in Trinidad and Tobago

The literature review did not find any peer-reviewed papers that recorded *B. vulgaris* flowering in Trinidad and Tobago. Only one observation of *B. vulgaris* flowering was recorded in a local newspaper (Jaggernauth, 2001). The National Herbarium of Trinidad and Tobago collected ten flowering voucher specimens from 1818 to 2022 (Table. 1). Thirteen past flowering occurrences between the 1980s and 2016 were reported from various experts/consultants (Figs. 1 B and C).

Environmental conditions surrounding an individual B. vulgaris flowering event

In early January 2022, a flowering *B. vulgaris* clump was noticed along an off-road hiking/cycling trail in the Bamboo Cathedral in Tucker Valley, Chaguaramas, north-west Trinidad (Wayne Butcher, January 02, 2022: unreferenced), and was located one week later. The Bamboo Cathedral (Shepherd, Hoskisson, and Downie, 2016 (Table 1) is located in the foothills of a semi-evergreen seasonal forest, which is representative of an open forest that is strongly affected by the dry season (Helmer *et al*, 2012).

Aerial surveys and site visits

Four flowering *B. vulgaris* clumps were identified within the vicinity of the initial clump (Fig. 1 A), whereas only one flowering clump was observed in Tobago (Fig. 1 C). Additionally, we were unable to identify any flowering clumps/clusters throughout the various studied areas in Trinidad (Table 1) inclusive of Caura Royal Road, Acono Road, Aripo Road, Tabaquite Road, Northside Road, Naparima–Mayaro Road, and Guayaguayare–Mayaro Road.

Dominant tree species surrounding the observed *B. vulgaris* clump were: royal palm (*Roystonea oleracea* [Arecaceae]), saman (*Samanea saman* [Fabaceae]), *Casearia* sp. [Salicaceae], Rubber (*Castilla elastica* [Moraceae]), mahoe (*Sterculia pruriens* [Malvaceae]), cooperhoop (*Brownea coccinea* [Fabaceae]) and guatecare (*Eschweilera subglandulosa* [Lecythidaceae]). Some general environmental observations of the observed *B. vulgaris* clump are provided in Table 3.

Table 2. Voucher specimens of flowering *Bambusa vulgaris* Schrad. collected from 1818–2022 from the National Herbarium of Trinidad and Tobago, West Indies

No	Date	Locality	Region	TRIN #	Collector	Collector #
1	Jun* (1857)	Tucker Valley	Diego Martin$^{NW\ (Tri)}$	148		s.n.
2	r.i.	Caroni, Caledonia	San Juan–Laventille$^{NW\ (Tri)}$	10940	R. Williams	s.n.
3	-	-	-	1676	Preston	s.n.
4	Feb (1861)	-	-	3376	r.i.	840
	1895	r.i.	-	5789	r.i.	s.n.
5	-	-	-	3171	-	s.n.
6	-	-	-	1681	-	s.n.
7	Apr (1978)	Cumaca, Valencia	Sangre Grandre$^{NE\ (Tri)}$	22005	M. Kalloo	1044
8	Feb (1991)	Plymouth Rd, Mt. Pelier	St George$^{C\ (Tob)}$	31914	G. Douglas	s.n.
9	Feb (2003)	Blue Basin Gardens	Diego Martin$^{NW\ (Tri)}$	40417	H. Boos	s.n.
10	Jan (2022)	Bamboo Catheral	Diego Martin $^{NW\ (Tri)}$	22427	L. Arneaud	1

TRIN # Trinidad number; - no data; * wet season; NW north-west; NE north-east; C Central; Tri Trinidad; Tob Tobago; s.n. without a personal collection number; r.i.—record indistinguishable

Table 3. General environmental observations surrounding a flowering *Bambusa vulgaris* Schrad. clump along a hiking/off-road cycling trail in the Bamboo Cathedral, Chaguaramas, Diego Martin, north-west Trinidad in early January 2022 (dry season)

Environmental observations* of flowering *Bambusa vulgaris*							
Abiotic characteristics							
Canopy coverage	open	no other plant species grew over *B. vulgaris*.					
Temperature	≈ 31.5°C	normal temperature for the dry season.					
Elevation	20 m	flowering clump was situated at the base of the hill.					
Slope	5–10 %	*B. vulgaris* clump was situated in a generally flat area.					
Soil type	sandy loam	coarse to loamy with high leaf litter content.					
Soil moisture	dry	surface soil was dry to the touch; however, the clump was located close to a watercourse (approx. 15–20 m) and may acquire moisture deeper within the soil.					
Wind description	light breeze	culms gently swayed side to side.					
Fires	none	no signs of recent fire events.					
Climatic and Bioclimatic variables**							
min. temperature	21.4 °C	BIO 1	26.16	BIO9	25.80	BIO17	169
max. temperature	29.2 °C	BIO2	7.28	BIO10	26.63	BIO18	586
avg. temperature	25.4 °C	BIO3	79.35	BIO11	25.33	BIO19	351
solar radiation	17170 kJ m^{-2} day^{-1}	BIO4	58.94	BIO12	1876		
precipitation	89 mm	BIO5	30.50	BIO13	251.00		
elevation	38 m	BIO6	21.30	BIO14	46.00		
WVP	2.52 kPa	BIO7	9.10	BIO15	47.96		
wind speed	4 m s^{-1}	BIO8	26.45	BIO16	699		

Biotic characteristics		
NHS	< 0.5 km	Tucker Valley Escape Cottage Retreat, Tucker Valley Road, Chaguaramas
AFS	mammal (non-volant)	Tufted Capuchin monkey (*Sapajus apella* [Primates: Cebidae]) interacting/ feeding on invertebrates/ inflorescences.
	mammal (avifauna)	Little Hermits (*Phaethornis longuemareus* [Apodiformes: Trochilidae]); White-lined Tanagers (*Tachyphonus rufus* [Passeriformes: Thraupidae]); Bananaquits (*Coereba flaveola* [Passeriformes: Thraupidae]); and House Wrens (*Troglodytes aedon* [Passeriformes: Troglodytidae]) observed interacting/feeding on inflorescences.
	Invertebrates	very loud buzzing sounds were heard, particularly, during the early morning and late evening periods. Bee and wasp species observed included, but were not limited to: *Apis* sp.; *Trigona* sp.; *Peponapis* sp.; *Xylocopa* sp.; *Augochlora* sp.; *Coelioxys* sp.; *Trypoxylon* sp.; *Amisega* sp.; *Polistes* sp.; and *Pepsis* sp.). Additionally, numerous flies and bugs were seen interacting with inflorescences.

AFS—Association with Faunal Species; .NHS—Nearest Housing Settlement
WVP — water vapor pressure; BIO1 = Annual Mean Temperature; BIO2 = Mean Diurnal Range; BIO3 = Isothermality; BIO4 = Temperature Seasonality (standard deviation ×100); BIO5 = Max Temperature of Warmest Month; BIO6 = Min Temperature of Coldest Month; BIO7 = Temperature Annual Range; BIO8 = Mean Temperature of Wettest Quarter; BIO9 = Mean Temperature of Driest Quarter; BIO10 = Mean Temperature of Warmest Quarter; BIO11 = Mean Temperature of Coldest Quarter; BIO12 = Annual Precipitation; BIO13 = Precipitation of Wettest Month; BIO14 = Precipitation of Driest Month; BIO15 = Precipitation Seasonality; BIO16 = Precipitation of Wettest Quarter; BIO17 = Precipitation of Driest Quarter; BIO18 = Precipitation of Warmest Quarter; BIO19 = Precipitation of Coldest Quarter.

Note: *observations based from four site visits
**according to world Climatic data v 2.1 for 1970-2000 (spatial resolution of ~1 km^2) see Arneaud (2022) for images of *B. vulgaris* clump with inflorescences

Discussions

Few flowering clumps were recorded in the past, possibly due to the absence of persons knowledgeable in the reproductive anatomy and morphology of B. vulgaris at the place and time of flowering; hence, smaller sporadic flowering periods may have gone undetected, especially those further away from housing settlements. Indeed, causal factors of B. vulgaris flowering have been subject to debate. Theories include rejuvenation, periodic ageing, mutation, individual variation, pathology, free radicals, external cause, nutrition, and growth cycle (Zheng et al., 2020). Zheng et al., (2020) noted that some investigators point out that the periodic flowering of bamboo is a result of an endogenous mechanism relatively immune to conditions of the environment, whereas others hypothesize interacting exogenous and endogenous cues to *B. vulgaris* flowering, which develops flowering waves and other patterns of flowering. We cannot speculate whether the five flowering clumps identified in Chaguaramas (north -west Trinidad) and the one flowering clump in Parlatuvier (north Tobago) were derived from the same ramet or parent plant, but it is possible. We, therefore, present our aerial survey techniques and results as a baseline study for future research in Trinidad and Tobago.

Based on our investigations, it is essential to consider a more reliable method in the future, such as red, green and blue orthomosaic imagery, which can identify and quantify individual flowering events throughout the islands. However, this will require

high-definition aerial photography and training models to pinpoint individual flowering clumps. Training models must be capable of providing a good fit for topographic, edaphic and climatic environmental variables influencing *B. vulgaris* distribution.

Information about the environmental conditions surrounding *B. vulgaris* flowering events from the present study can be used as a baseline for future studies as little to no information is presently available. A growing number of scholars have reached consensus about the cause of bamboo flowering, agreeing that environmental conditions are critical in modulating flowering, whereas internal genetic factors and flowering are root causes that are usually experienced when bamboo grows to its physiological maturity (Putra and Kencana, 2009). A range of external aspects, including human disturbance and climate may play a role in stopping, delaying, or advancing bamboo flowering events to some degree (Putra and Kencana, 2009). For instance, applying exogenous hormones may either advance or delay bamboo flowering time. Nevertheless, research is inconclusive regarding any specific key element inducing the initiation of bamboo flowering. Accordingly, Zheng *et al.,* (2020) hypothesis that endogenous hormones, which to some extent signal molecules, can be one of the primary factors that trigger flowering. Nonetheless, Zheng *et al.,* (2020) emphasize the need to investigate this hypothesis further. Understanding the complete life cycle of *B. vulgaris* can only be achieved by recording successive flowering events accurately over generations (Zheng *et al.,* 2020), a task that scientists cannot achieve during their lifetimes, hence the need for standardized experimental designs, accurate methods and consistent data collection.

Reproductive materials (flowering bud and infertile inflorescences) were stored in a Thermo Forma refrigerator (-80^{o} C) at the Biotechnology Lab, Department of Sciences and Technology, UWI, St. Augustine. These materials are intended to be use for future physiological and molecular comparisons of *B. vulgaris* flowering plants in the region.

None of the bamboo clumps outside Tucker Valley (Trinidad) and Parlatuvier (Tobago) were seen flowering during the study period. This may indicate that these bamboo stands had not yet crossed their 150 year mark or have not been exposed to favourable conditions that may initiate reproduction. This poses an ecological problem because *B. vulgaris* has displaced many native trees throughout the islands, particularly along the foothills of the Northern Range (Trinidad), and the Main Ridge (Tobago) (Helmer *et al.,* 2012). Ecological managers should pay close attention to future massive, synchronized flowering events and death of *B. vulgaris* clusters. They should take the opportunity to record environmental conditions surrounding these events and to restore portions of these degraded hillsides. This would foster the reintroduction of indigenous flora and fauna that once thrived in these forests many years ago, prior to the naturalization of *B. vulgaris*.

Conclusion

Bambusa vulgaris has been instrumental in the development of human life, particularly in countries such as Trinidad and Tobago, which has rich bamboo resources. Globally, the flowering and consequent death of whole bamboo forests causes significant environmental concerns and economic losses. For this reason, understanding local bamboo flowering in detail is essential, but at present, little to no records of *B. vulgaris* flowering are documented for Trinidad and Tobago. This paper sought to record past *B. vulgaris* flowering events in Trinidad and Tobago and to provide detailed environmental conditions surrounding an individual flowering event in Chaguaramas, north-west Trinidad. Few flowering clumps were observed in the past, possibly due to the absence of those knowledgeable about the species' reproductive anatomy. Information from the present study, such as aerial survey techniques and findings can be used as a baseline for future studies as little to no information exists in the literature.

Acknowledgements

This project would not have been successful without the assistance of Shane Manchouck who played an integral part in data collection. We thank Caleb Lewis, Azaria Lewis, Pristine Lewis, and Ferladai Lewis for assistance in the field. Special thanks go out to all naturalists, enthusiasts, hunters, farmers, consultants, and experts who provided anecdotal information on past flowering events, and Francisco Morales from the National Herbarium of Trinidad and Tobago for providing records of voucher specimens. Lastly, thanks to Sheeba Sreenivasan for proofreading the manuscript.

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