Scientific Research Publishing

American Journal of Plant Sciences, 2020, 11, 1031-1048
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Description of Flower Biology of Under-Exploited Species, *Zingiber barbatum* (Wall.) from Myanmar

Musavvara Kh. Shukurova[1], Daisy Myint[1], Syed Abdullah Gilani[2], Kazuo N. Watanabe[3]

[1]Graduate School of Life & Environmental Sciences, University of Tsukuba, Tsukuba, Japan
[2]Department of Biological Sciences and Chemistry, University of Nizwa, Nizwa, Sultanate of Oman
[3]Tsukuba-Plant Innovation Research Center, University of Tsukuba, Tsukuba, Japan
Email: musavvara@gmail.com

How to cite this paper: Shukurova, M.Kh., Myint, D., Gilani, S.A. and Watanabe, K.N. (2020) Description of Flower Biology of Under-Exploited Species, *Zingiber barbatum* (Wall.) from Myanmar. *American Journal of Plant Sciences*, **11**, 1031-1048.
https://doi.org/10.4236/ajps.2020.117074

Received: April 27, 2020
Accepted: July 14, 2020
Published: July 17, 2020

Abstract

Characterization of the reproductive morphology in genus *Zingiber* is still relevant on classical taxonomic studies because most of the species are phenotypically similar and difficult to distinguish in the absence of the flowering stage. Reports mainly derived based on the herbarium collections are insufficient for the detailed morphological review. *Zingiber barbatum* (Wall.) belongs to the genus *Zingiber* and has been neglected for a long time. Existed intraspecific morphological and genetic variations also intricate the description of this species. The objective of this study was to characterize the reproductive morphology of under-exploited *Z. barbatum* species. The study was done based on the traditional description of morphology and habit of inflorescence and flowers, with a recording of minimum quantitative and qualitative parameters and phenological observation regarding inflorescence life span and duration of blossom. Assessment of reproductive morphology displayed phenotypic variations regarding inflorescences habit during the growth stage and morphological features of the flower. Perhaps, an existed variation was driven by eco-geographical factors resulting in reproductive isolation due to which genetic divergence might occur. The taxonomic affiliation of *Z. barbatum* based on inflorescence habit has been confirmed. This is the first comprehensive report regarding flower biology on *Z. barbatum*.

Keywords

Wild Ginger, Inflorescence Habit, Flower Morphology, Phenotypic Variation, Taxonomy, *Zingiber barbatum*, Genus *Zingiber*

1. Introduction

Zingiber barbatum Wall. is an aromatic, medicinal and endemic species for Myanmar [1]. The biology of *Z. barbatum* is poorly known. The species is characterized as a geophyte, flowering plant, varying in height and size, with horizontal tuberous rhizomes. It is a perennial but grows as an annual with a forced dormancy period. The plant goes dormancy and loses all the vegetative aboveground parts with the onset of winter when the habitat temperature decreases below 15˚C to 10˚C in the night. The plant grows wild in hilly areas from 75 m up to 1050 m altitudes of the Dipterocarp and Shorea forests, and prefers light, but moderate shade and high humid environment; the major pollinators are bees and moths [2]. Nowadays, the local population keeps *Z. barbatum* as a backyard plantation and grows it in small places near fences or levees, more for personal consumption as a medicinal plant, than for commercial production or food.

Z. barbatum is one of the most troublesome taxa due to the very variable morphological features and Myanmar considered as a center of its diversification [3]. Genetic diversity studies based on morphological and molecular markers revealed high intraspecific genetic variability among *Z. barbatum* genotypes [4]. *Z. barbatum* is well known by its vernacular names "Pwe-au" or "Meik-thalin" in Myanmar [3]. However, there is still ambiguity that occurs in the description of *Z. barbatum* due to the lack of comprehensive investigations. The specific epithet "Meik-tha-lin" is also used as a common name for *Z. montanum* by the local population of Myanmar [5], bringing confusion on characterizing these two different taxa. Therefore, the inflorescence habit and flower morphology remain the most common parameters used to discriminate *Zingiber* taxa at the first stage of the taxonomic description. Although the general morphology of *Z. barbatum* has been described by Wicaksana [6], the description of the flower morphology was not included in the study through the absence of flowers.

Z. barbatum belongs to the section *Cryptanthium* Horan. of the monophyletic genus *Zingiber* [7] and characterized by inflorescence consisting of spike on a short procumbent peduncle [8]. Taxonomically, *Zingiber* classified into four sections based on the inflorescence habit [8] [9] [10]. The fusion of two sterile stamens into a labellum and presence of single anther with a horn-like appendage embracing the upper part of the style [11] are the distinguishing features of the flowers in *Zingiber*. The complexity of characterizing *Zingiber* flowers lies in the fact that flowers are delicate and ephemeral, and liable to rot if exsiccate in the bracts; thus the herbaria specimens have a little value for study of flower morphology [12].

The objective of this study was to characterize the reproductive morphology of under-exploited *Z. barbatum* species with the focus on the inflorescence architecture and phenotypic features of the flower. This a first comprehensive study on the characterization of flower biology of *Z. barbatum* from Myanmar, which complements a cycle of previous studies done in the Gene Research Center of the University of Tsukuba (Tsukuba, Japan) (GRC UT) on the assessment of existed genetic diversity in *Z. barbatum*.

2. Material and Methods

2.1. Plant Materials

Two accessions of *Z. barbatum* with identification code number ZO113 and ZO223, from the collection of the GRC UT (Tsukuba, Japan) were used for the morphological descriptive characterization of the inflorescence and flowers. The rhizome of ZO113 accession was obtained from Yezin Agricultural University (YAU) of the Nay Pyi Taw region and the rhizome of ZO223 accession was obtained from Kyauk Pa Daung township of the Mandalay region of Myanmar. The plant material (rhizomes) were obtained during filed exploration of plant genetic resources in Myanmar under a Grand-in-Aid for Overseas Scientific Research of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan [13] [14]. The obtained plant material was transferred to Japan via Standard Material Transfer Agreement (SMTA) for the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) of the United Nations (UN) Food and Agriculture Organization (FAO). The collected materials were recorded as an accession with an appropriate identification code number and maintained as a living collection in the greenhouse of the GRC UT.

The study was conducted from July to November of 2019. In total, the collection of GRC UT includes 25 accessions of *Z. barbatum*. Since the moment the accessions have been introduced into the collection, only two accessions (ZO113 and ZO223) had bloomed for the first time in 2019. Therefore, only these two accessions were used to conduct the current study.

2.2. Characterization of the Acquisition Areas

The YAU (Yezin Agricultural University) lies between 19˚49'59"N latitude and 96˚16'30"E longitudes at 213 m elevation above sea level and located in Zeyar Thiri Township of Nay Pyi Taw region of Myanmar. The township Kyauk Pa Daung located in the foothills of Mt. Popa, the Myingyan District of the Mandalay Region of Myanmar. The township lies between 20˚49'59.99"N latitudes and 95˚07'60.00"E longitudes with the elevation of 380 m above sea level. Most of the area is forest mountain and climate type are tropical savanna. The average maximum temperature of both the acquisition areas is 37.8˚C and the average rainfall is 762 mm. **Figure 1** indicates the approximate location of the acquisition area of the plant material was obtained.

2.3. Observation, Description and Illustration of Inflorescence and Flowers

The detailed description along with color photographs of *Z. barbatum* inflorescences with flowers provided for better visualization and easy identification. The data includes summary records of the morphological characterization and phenological observation regarding the inflorescences and flowers. Screening of inflorescence habit for a general description of some morphological features and

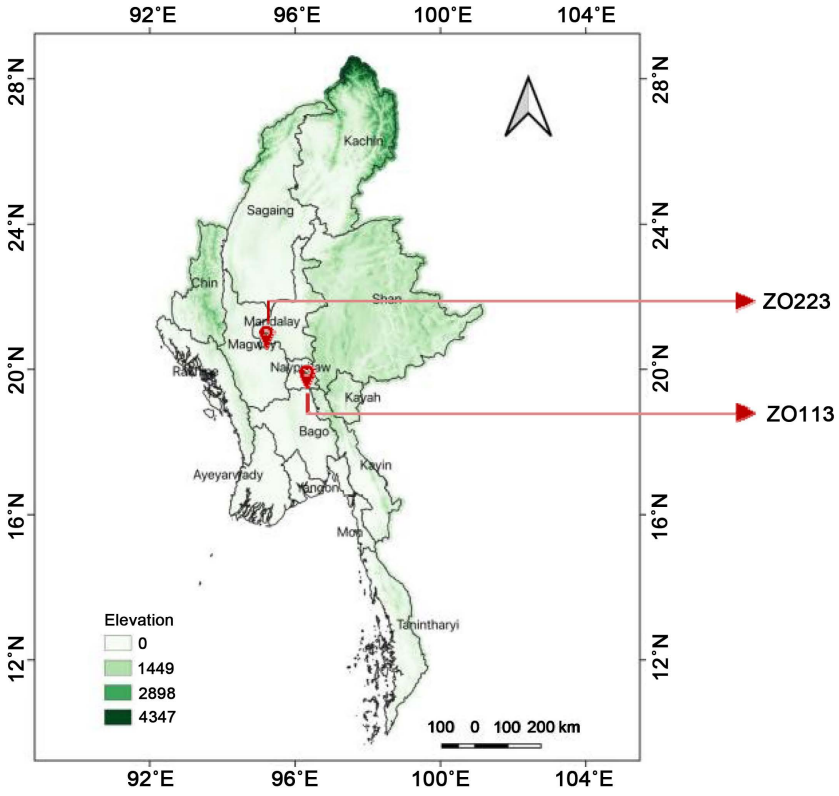

Figure 1. Map of Myanmar indicating the collection sites of *Z. barbatum* accessions. Accession ZO113 was collected in Yezin of Nay Pyi Taw region (former Mandalay region) at elevation 213 m a.s.l; and accession ZO223 was collected near Kyauk Pa Daung township of Mandalay region at elevation 595 m a.s.l.

detection of variation during phenological growth was made based on minimum quantitative and qualitative characterization.

Seven parameters had chosen for quantitative description, *i.e.* plant height, inflorescence length, peduncle length, spike length, peduncle width, spike width and the number of inflorescences per accession.

Qualitative characterization comprised a description of the form and habit of inflorescence and peduncle, the shape, color, and pubescence of the spike bracts and sheathing bracts of the peduncle. Observation and measurement were done every three days since the inflorescences emerged until they have undergone withering. The measuring was stopped when the last three measurements showed similar parameters on respective days.

Flower morphology was described based on observation and dissection of the flower and its related parts. Phenology of flower was screened and recorded every day, started from the first bloomed flower until the last one. The parameters recorded during flower phenology were the number of flowers per spike and duration of flower span per accession.

2.4. Data Analysis

The study does not include statistical analysis due to the absence of replication

per flowering plant. The study has been conducted based on general observation and everyday measurement of quantitative parameters and recording the observed changes in qualitative characteristics and phenology.

3. Results

The two accessions of *Z. barbatum*, ZO113 and ZO223, formed inflorescences and flowered from the beginning of July up to begin of September of 2019. The accession ZO223 (Figure 2) produced one and accession ZO113 produced two inflorescences respectively (Figure 3). The plant height and inflorescence length and width measurement showed the growth of both the plant itself and the inflorescence continued throughout the entire flowering period (Table S1). The summary of comparative morphological characteristics of similarities and/or differences in *Z. barbatum* based on quantitative and qualitative assessment has shown in Table S2.

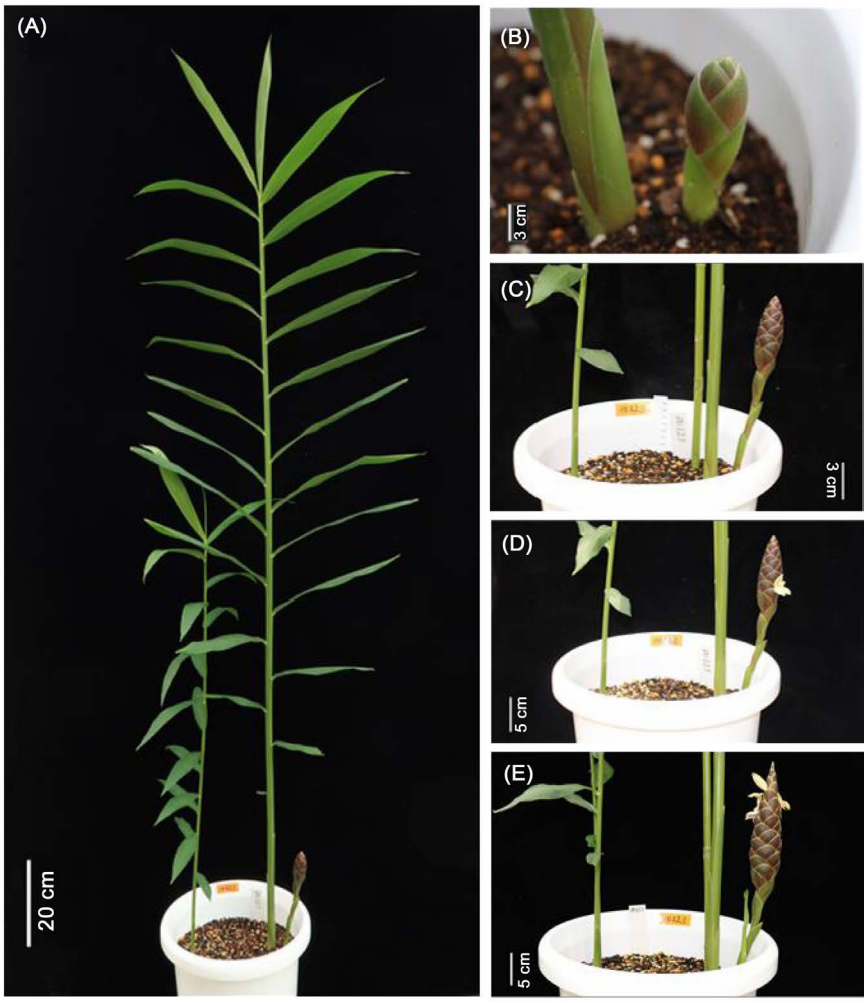

Figure 2. *Z. barbatum* (accession ZO223) inflorescence at a different stage of growth and flowering. (A) Plant habit with inflorescence; (B) Emerged inflorescence (5 days old); (C) Inflorescence of 24 days old; (D) Inflorescence with flowers at the stage of blossom began (35 days old); (E) Inflorescence almost at the stage of blossom end (48 days old).

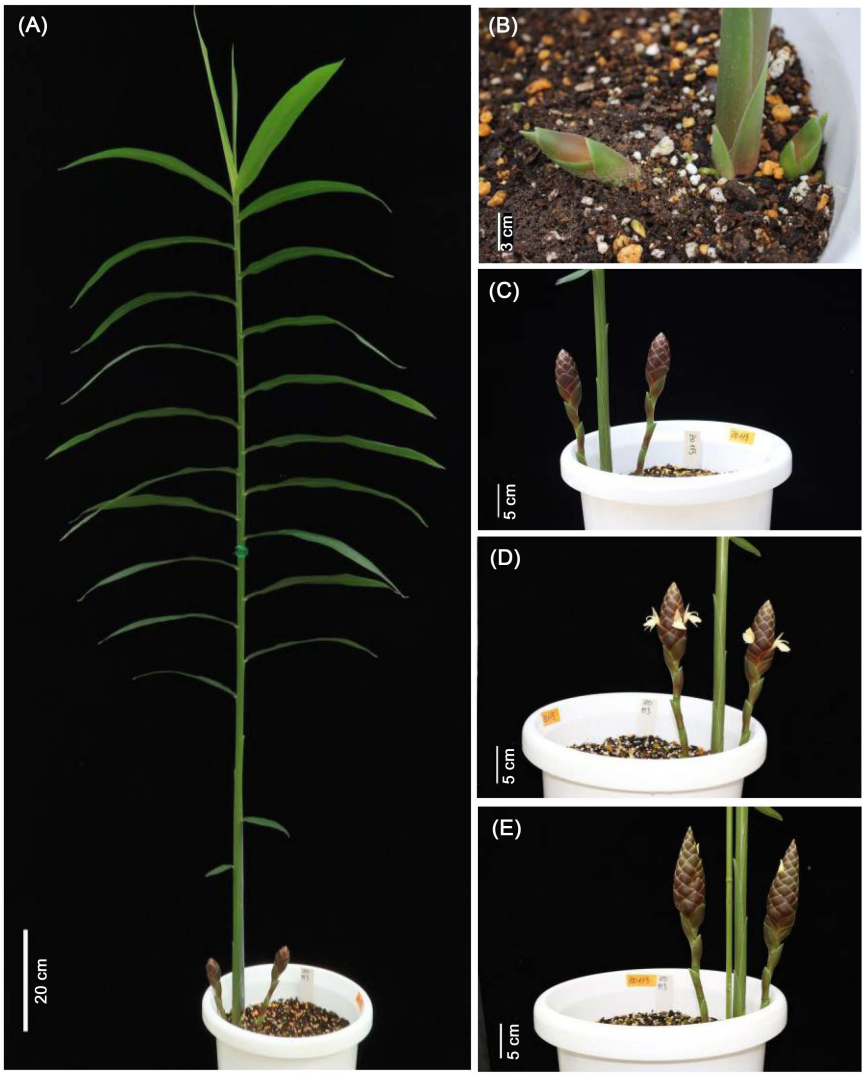

Figure 3. *Z. barbatum* (accession ZO123) inflorescence at a different stage of growth and flowering. (A) Plant habit with inflorescence; (B) Emerged inflorescences (3 - 5 days old); (C) Inflorescences of 26 - 28 days old; (D) Inflorescences with flowers at the stage of blossom began (35 - 37 days old); (E) Inflorescence almost at the stage of blossom end (55 - 57-days old).

3.1. Qualitative Description

Though two accessions belong to *Z. barbatum*, some differences had been observed regarding the shape of inflorescences at the stage of emergence and during growth, which were visually easy to detect. The emerged inflorescence of ZO223 had an elliptic shape on a short peduncle (scape) with obtuse apex (**Figure 2(B)**), while emerged inflorescences of ZO113 had conical shape with acuminate apex without peduncle (**Figure 3(B)**).

Along with growth and development, the size and shape of the inflorescences (spike) undergone several changes. The shape of spikes had changed gradually by increasing their width and length, along with peduncles' growth and lengthening. This tendency was to keep going on despite flowering, resulted signifi-

cantly changing the shape of the spike from the moment of appearance. The spike shape of ZO223 had changed gradually from wide-elliptic to ovate-oblong with the obtuse-acute apex at the stage of blossom begun, and to the fusiform with acuminate apex at the final stage of blossom (**Figures 2(C)-(E)**). The same tendency was observed in ZO113, the shape of spike had changed gradually from a conical to the ovate-oblong with obtuse-acute apex at the stage of blossom begun, and to the wide fusiform with an acute apex at the final stage of blossom (**Figures 3(C)-(E)**).

The spike dense and carries helically arranged bracts (**Figures 2(C)-(E)** and **Figures 3(C)-(E)**). Mature bracts broadly ovate with papery margin, apices obtuse or obtuse-acute, protuberant, dark red color, enclosing single flower per bract.

The lowermost 2 - 4 bracts are sterile and do not produce flowers. The rigid peduncle is erect, consists of internodes, covered by sheathing bracts. The sheathing bracts ovate, with acute apices, protuberant, light green at apices and reddish close to a bottom. The bracts and sheathing bracts have pubescence of c. 1.0 - 2.0 mm, soft and velvety in appearance, but reduced during growth.

The senescence of inflorescences started by changing the color of bracts from dark red to dim brownish-red followed to change color in the middle of bracts to light dull brownish, and to light red at the edges, then to orange-red and ended by drying (**Figure S1**).

The drying of the inflorescence began from the top to the bottom and was accompanied in parallel by drying of the sheathing bracts from the bottom to up. The observed senescence was identical in both accessions.

3.2. Quantitative Description

The total inflorescence length was 30.0 cm for ZO223 and ranged between 35.0 - 37.0 cm among two inflorescences of ZO113. The peduncles' length ranged from 13.0 to15.0 cm and the peduncles' width ranged from 9.0 to 9.4 mm between two accessions. The spikes length ranged from 15.0 to 22.0 cm and the width of the spikes were 34.4 mm for ZO223 and 38.1-38.6 mm for ZO133 respectively. The detailed score of quantitative measurement by days has shown in **Table S1**.

The span time of inflorescence senescence was different between the two examined accessions. The senescence of inflorescence in ZO223 began 15 days after completion of flowering and ended in 25 days, while ZO113 had prolonged time of senescing. The senescence began 21 days after completion of flowering and extended up to 49 days.

3.3. Flower Phenology and Description

The flowering began at the end of July, after 28 - 34 days of the inflorescences formed and lasted up to 19 - 22 days (**Table S3**). In total, ZO223 formed 40 flowers, and ZO133 formed 47 - 48 flowers during the entire of the flowering period. The life span of flowers was very short; they begin to appear from bracts early in the morning, at 4:00 AM and are already fading by the evening. Flowers

fully opened after 4 - 6 hours from the moment of appearance. In inflorescence, they bloomed sequentially from the bottom to up and one to three flowers are opened simultaneously, rarely four.

Z. barbatum flowers of pale to light-yellow (Figure 4(A), Figure 4(B), Figure 4(D)); floral tube c. 0.3 cm in diameter, slender, externally and internally white and glabrous. Calyx light-yellow, glabrous, membranous, apex shortly serrated, tubular, unilaterally split. Flower length ranged from 4.7 to 5.0 cm between two examined accessions (Figure 4(C)). Corolla lobes are subequal in length, lanceolate, pale-yellow, longitudinally striped. Dorsal lobe facing the inflorescence axis, slightly concaves in the hood. Dorsal lobe c. 2.5 × 1.5 cm; lateral lobes c. 2.5 × 1.0 cm wide. The stamen, belonging to the inner circle of the androecium, placed at the base of the corolla. The two other sterile members of the androecium

Figure 4. *Z. barbatum* flowers and its dissected parts in comparison. (A) Close up view of flower of accession ZO223; (B) Close up view of flower of accession ZO113; (C) General view of flowers in comparison, flower of accession ZO223 (left, slightly bigger) and flower of accession ZO113 (right); (D) Dissected parts of flowers, upper line accession ZO223, lower line, accession ZO113: 1, labellum with two lateral staminodes; 2, dorsal corolla lobes; 3, two lateral corolla lobes; 4, stamens; (E) Anthers of flowers in comparison (front side), upper line accession ZO223, lower line, accession ZO113; (F) Stigma.

have fused into petal-shaped staminodes, called labellum and are placed opposite to the stamen. The base of the labellum is tubularly folded and attached to the corolla tube. The labellum is soft-velvety in appearance, light-yellow. The central labellum lobe 2.8 × 2.2 cm, obcordate, apex emarginate, margins slightly undulate-reflexing; the lateral staminodes 1.5 × 0.6 cm, ovate-lanceolate, apex acute (ZO223) or acuminate (ZO113), connate to the labellum by basal 1/2 - 1/3 (**Figure 4(D)**). It should be noted, the central labellum lobe of ZO113 was bifurcated on the middle (**Figure 4(B)** and **Figure 4(D)**); with pinky dots at the base of labellum (**Figure 5**). The stamen c. 1.5 - 1.7 cm long (with not anther crest straightened), light yellow; carries 2 single-nested anthers. Another light-yellow, c. 1.6 cm long (excluding anther crest), thecae cylindrical, parallel, dehiscence longitudinal, anther crest light-yellow, hooded, wrapped around style, leaving the stigma free (**Figure 4(C)** and **Figure 4(F)**). Style is white, glabrous, and filiform. The stigma of c. 0.15 × 0.1 cm, is white in color, slightly wider than the style, tubular, downwards facing, with ciliate ostiole (**Figure 4(C)** and **Figure 4(F)** and **Figure 5**). Seeds have not been observed during the study.

4. Discussion

Myanmar is situated in Indo-Burma biodiversity hotspot and possesses various types of ecosystems (evergreen rainforests, montane forest, mixed deciduous, savanna and alps) due to climate, topography, and wide latitudinal range from tropical to subtropical [15] [16]. Myanmar is also known as a country with a strong cultural heritage possessing more than a hundred ethnic groups with their own dialects and traditions [5]. The traditional agricultural approach perhaps is one of the factors affecting the distribution and diversification of the *Z. barbatum* species in Myanmar.

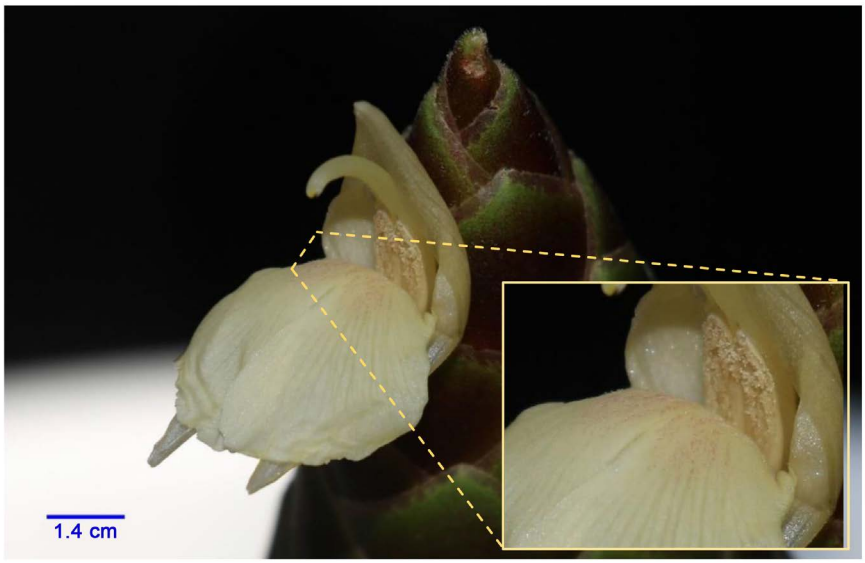

Figure 5. Photograph demonstrates the presence of pinky dots in the base of central labellum lobe of *Z. barbatum* flower, accession ZO113.

Z. barbatum for the first time was described by Wallich in Plantae Asiaticae Rariores [17]. According to Wallich [17], the species was abundantly found in Rangoon (current Yangon of Myanmar) in the hills along the Irrawaddy River near Prome (current Pyay city).

The detailed revision of the available literature confirmed scarcity of information regarding *Z. barbatum*, especially on flower biology for comparison with the current study. *Z. barbatum* produced flowers in radical inflorescences on erect peduncle and confirms the former studies of taxonomic affiliation of *Z. barbatum* to the *Zingiber* section *Cryptanthium* Horan. [8] [9]. According to Wallich [17], inflorescences are forming from the creeping roots near the stem or from the base of the stem and are barely elevated above the ground surface. Our study confirms that inflorescences arise directly from a rhizome near the stem; however, they were formed on a long enough erect peduncle, which also corresponds to the description of the inflorescence habit of *Z. barbatum* reported by Theilade [18]. According to Theilade [18], *Z. barbatum* produces inflorescence on the erect peduncle of 2.0 - 6.0 cm length, while according to Aung [3], *Z. barbatum* belonging to Type A, produces inflorescence on the erect peduncle of approximately 3.0 cm length.

There was not observed notable differences among quantitative parameters assessed regard to inflorescences and flowers among two accessions, except the time span that inflorescences undergo senescence, while the qualitative parameters showed some variation regarding the shape of inflorescences at the stage of appearance and the shape of the labellum (bifurcation of the central labellum lobe in ZO113) between two examined accessions. The reported distinguishing feature of *Z. barbatum* inflorescence, corresponding to its etymology ("barbatum"—having long, weak hair), is the presence of high pubescence [3] [17]. However, we did not observe the high pubescence of inflorescence among two examined accessions; on the contrary, the observed pubescence decreased in the process of inflorescence growth.

We observed a notable change in the visual shape of inflorescences (spikes) among two accessions during growth. The comparative assessment of the observed phenotypic variation regarding the shape of the spike during growth revealed similarity corresponding with the description of the spike given for both *Z. barbatum* (spike shape at the stage of blossom begun, current study) and *Z. montanum* (spike shape at the last stage of blossom, current study) [3]. We assume it might be the variation of the morphological traits among *Z. barbatum* species or it might be a completely different species (e.g. *Z. montanum* and/or its variation) which the local people of Myanmar are not able to distinguish easily due to the phenotypic similarity of plants and utilized similar vernacular name, of what was reported by Wicaksana [6]. The comprehensive investigations are required to elucidate this confusion, such as the whole genome sequencing or the sequences of highly conserved genes and intergenic spacers of organellar DNA.

From another side, the observed differences regarding the shape of inflores-

cence and shape of labellum can be either genetically determined feature, when the activity and position of the shoot apical meristem (SAM) is determining a degree of the inflorescence architecture [19], or as a result of phenotypic plasticity, when due to various environmental condition the variation of the same traits among the species of the same taxa could be inducing [20]. The visual reduction of indumentum (pubescence) also could be the result of phenotypic plasticity or/and as the consequence of the terminated trichomes metabolic activity, after which they die, may either persist or be shed [20] [21].

Z. barbatum has zygomorphous, bisexual, ephemeral, epigynous flowers, with a light fragrance, with the presence of a horn-like anther crest embracing the upper part of the style and leaving the stigma free. The observed life span of flowers was less than one day. Also, Wallich [17] reported the plants introduced into Calcutta Garden blossom freely during the cold and rainy season. We observed flowers mainly during August when the average daily temperature was above +30˚C and the average humidity above 80%. The result of study corresponds with those reported by Aung [3] for *Z. barbatum* Type A when the flowers and fruits were observed in July-September. Although the plants were kept in a greenhouse, we observed about 5 - 6 days gap in flowering in ZO113 accession (**Table S3**). According to Ravindran *et al.* [22] rarity of flowering in *Zingiber* is influenced by photoperiodic and climatic factors. Thus, the observed trend probably was triggered by temperature differences on those days, when the average daily temperature ranged between +21˚C ... + 28˚C, and the weather was mostly cloudy and cool.

We did not observe the formation of seeds in *Z. barbatum*. The absence of seeds could be due to the high pollen sterility of many *Zingiber* species resulting in hence no sexual reproduction [22] influenced by a single or the complex of factors. The dominant xenogamy, entomophily and different types of breeding systems have been reported for *Zingiberaceae* [23] [24] [25] [26]. The heterostyly with a gametophytically controlled self-incompatibility system has been reported for *Z. officinale* [27] and a partial self-incompatibility reported for *Z. densissimum* [28]. Given the above, it can be assumed that several factors have been influenced by the absence of seeds in *Z. barbatum* in our study:

1) The "failed" xenogamy due to absence of pollinators when the plants are grown in a greenhouse.

2) Due to heterostyly of flowers which may be a contributing factor of sterility. According to our observation, *Z. barbatum* flowers belong to longistylous morphotype in which anthers are situated below the slender longer style that protrudes out of the flower parts, and hence the pollen grains cannot reach the stigma.

3) Due to self-incompatibility, when the growth of the pollen tube can be enzymatically inhibited in the style to prevent inbreeding [29].

4) Since *Z. barbatum* flowers are monoclinous, a dichogamy (protandry or protogyny) can be another reason influenced the absence of seeds. The protandry as one type of the breeding system has been reported in *Zingiberaceae* [25],

however, if more than two flowers of an individual asynchronously bloom, the geitonogamy can occur [30].

Elucidation of the above-mentioned trend requires further detailed studies on pollination ecology, palynology, and mechanism of a breeding system that will allow better understand of the reproductive biology of *Z. barbatum* species.

The study allows concluding that phenotypic variation exists among *Z. barbatum* species. Two *Z. barbatum* accessions showed phenotypic variation that can be differentiated by the inflorescence shape and morphological feature of the central labellum lobe. The study confirmed the taxonomic affiliation of *Z. barbatum* at the intraspecific level based on the inflorescence habit. The conventional taxonomic description based on inflorescence habit and flower morphology accepted as a useful method primarily identify taxa and elucidate an occurred ambiguity at the intraspecific level. However, we think that a comprehensive investigation of reproductive biology (flower biology, pollen ecology, palynology, breeding system) joint with molecular biology is required to understand existed variability among *Z. barbatum* species. The eco-geographical factors, artificial selection, and/or traditional agricultural approaches probably influenced the reproductive isolation of *Z. barbatum* leading its diversification and variability. The study will be useful in different areas of biology as taxonomy, botany, plant systematics, biodiversity and conservation purposes since this species is found in the wild and up to now only in Myanmar.

Conflicts of Interest

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

References

[1] Govaerts, R. (2004) World Checklist of Monocotyledons Database in ACCESS: 1-54382. The Board of Trustees of the Royal Botanic Gardens, Kew. https://wcsp.science.kew.org/acceptedRef.do?name_id=273224

[2] Htwe, Y.M. and Cuevas, V.C. (2015) Ecological Factors Affecting Distribution Pattern and Reproduction Mode of *Zingiber barbatum* Wall., in Mt. Popa, Central Myanmar. 1-29. https://www.researchgate.net/publication/303881265

[3] Aung, M.M. (2016) Taxonomic Study of the Genus *Zingiber* Mill. (Zingiberaceae) in Myanmar. Ph.D. Thesis, Kochi University, Japan.

[4] Wicaksana, N., Gilani, S.A., Ahmad, D., Kikuchi, A. and Watanabe, K.N. (2011) Morphological and Molecular Characterization of Underutilized Medicinal Wild Ginger (*Zingiber barbatum* Wall.) from Myanmar. *Plant Genetic Resources*, **9**, 531-542. https://doi.org/10.1017/S1479262111000840

[5] Awale, S., Linn, T.Z., Than, M.M., Swe, T., Saiki, I. and Kadota, S. (2006) The Healing Art of Traditional Medicines in Myanmar. *Journal of Traditional Medicine*, **23**, 47-68.

[6] Wicaksana, N. (2012) Characterization and Diversity Assessment of *Zingiber* Species with Special Reference to Underutilized Medicinal *Z. barbatum* Species from Myanmar. Ph.D. Thesis, University of Tsukuba, Japan.

[7] Kress, W.J., Prince, L.M. and Williams, K.J. (2002) The Phylogeny and a New Classification of the Gingers (Zingiberaceae): Evidence from Molecular Data. *American Journal of Botany*, **89**, 1682-1696. https://doi.org/10.3732/ajb.89.10.1682

[8] Theerakulpisut, P., Triboun, P., Mahakham, W., Maensiri, D., Khampila, J. and Chantaranothai, P. (2012) Phylogeny of the Genus *Zingiber* (Zingiberaceae) Based on Nuclear ITS Sequence Data. *Kew Bulletin*, **67**, 389-395. https://doi.org/10.1007/s12225-012-9368-2

[9] Triboun, P., Larsen, K. and Chantaranothai, P. (2014) A Key to the Genus *Zingiber* (Zingiberaceae) in Thailand with Descriptions of 10 New Taxa. *Thai Journal of Botany*, **6**, 53-77.

[10] Newman, M.F. (2015) A New Species of *Zingiber* (Zingiberaceae) from Lao P.D.R. *Gardens' Bulletin Singapore*, **67**, 123-127.

[11] Sabu, M., Sreejith, P.E., Joe, A. and Pradeep, A.K. (2013) *Zingiber neotruncatum* (Zingiberaceae): A New Distributional Record for India. *Rheedea*, **23**, 46-49.

[12] Theilade, I. and Mood, J. (1997) Five New Species of *Zingiber* (Zingiberaceae) from Borneo. *Nordic Journal of Botany*, **17**, 337-347. https://doi.org/10.1111/j.1756-1051.1997.tb00325.x

[13] Watanabe, K., Tun, Y.T. and Kawase, M. (2007) Field Survey and Collection of Traditionally Grown Crops in Northern Areas of Myanmar, 2006. *Plant Genetic Resource Search and Introduction Survey Report*, **26**, 161-175.

[14] Kawase, M., Wunna and Watanabe, K. (2011) Second Field Survey Collecting Traditionally Grown Crops in Northern Areas of Myanmar, 2009. *Plant Genetic Resource Search and Introduction Survey Report*, **27**, 83-98.

[15] Tanaka, N. (2005) Plant Inventory Research: Contributions to the Flora of Myanmar. *Acta Phytotaxonomica et Geobotanica*, **56**, 21-26.

[16] Ding, H.B., Yang, B., Zhou, S.S., Maw, M.B., Maung, K.W. and Tan, Y.H. (2019) New Contributions to the Flora of Myanmar I. *Plant Diversity*, **41**, 135-152. https://doi.org/10.1016/j.pld.2019.05.002

[17] Wallich, N. (1830) Plantae Asiaticae Rariores, or, Descriptions and Figures of a Select Number of Unpublished East Indian Plants. Treuttel and Würtz, London. https://doi.org/10.5962/bhl.title.468

[18] Theilade, I. (1999) A Synopsis of the Genus *Zingiber* (Zingiberaceae) in Thailand. *Nordic Journal of Botany*, **19**, 389-410. https://doi.org/10.1111/j.1756-1051.1999.tb01220.x

[19] Benlloch, R., Berbel, A., Ali, L., Gohari, G., Millán, T. and Madueño, F. (2015) Genetic Control of Inflorescence Architecture in Legumes. *Frontiers in Plant Science*, **6**, 543. https://doi.org/10.3389/fpls.2015.00543

[20] Thompson, J.D. (1991) Phenotypic Plasticity as a Component of Evolutionary Change. *Trends in Ecology & Evolution*, **6**, 246-249. https://doi.org/10.1016/0169-5347(91)90070-E

[21] Johnson, H.B. (1975) Plant Pubescence: An Ecological Perspective. *The Botanical Review*, **41**, 233-258. https://doi.org/10.1007/BF02860838

[22] Ravindran, P.N., Nirmal Babu, K. and Shiva, K.N. (2005) Botany and Crop Improvement of Ginger. In: Ravindran, P.N. and Nirmal, B.K., Eds., *Ginger*: *The Genus Zingiber*, CRC Press, New York, 15-85.

[23] Sakai, S., Kato, M. and Inoue, T. (1999) Three Pollination Guilds and Variation in Floral Characteristics of Bornean Gingers (Zingiberaceae and Costaceae). *American Journal of Botany*, **86**, 646-658. https://doi.org/10.2307/2656573

[24] Li, Q.-J., Kress, W.J., Xu, Z.-F., Xia, Y.-M., Zhang, L., Deng, X.-B., *et al.* (2002) Mating System and Stigmatic Behavior During Flowering of *Alpinia kwangsiensis* (Zingiberaceae). *Plant Systematics and Evolution*, **232**, 123-132. https://doi.org/10.1007/s006060200031

[25] Jatoi, S.A., Kikuchi, A. and Watanabe, K.N. (2007) Genetic Diversity, Cytology, and Systematic and Phylogenetic Studies in Zingiberaceae. *Genes, Genome and Genomics*, **1**, 56-62.

[26] Specht, C.D., Yockteng, R., Almeida, A.M., Kirchoff, B.K. and Kress, W.J. (2012) Homoplasy, Pollination, and Emerging Complexity during the Evolution of Floral Development in the Tropical Gingers (Zingiberales). *The Botanical Review*, **78**, 440-462. https://doi.org/10.1007/s12229-012-9111-6

[27] Dhamayanthi, K.P.M., Sasikumar, B. and Remashree, A.B. (2003) Reproductive Biology and Incompatibility Studies in Ginger (*Zingiber officinale* Rosc.). *Phytomorphology*, **53**, 123-131.

[28] Fan, Y.-L., Kress, W.J. and Li, Q.-J. (2015) A New Secondary Pollen Presentation Mechanism from a Wild Ginger (*Zingiber densissimum*) and Its Functional Roles in Pollination Process. *PLoS ONE*, **10**, e0143812. https://doi.org/10.1371/journal.pone.0143812

[29] De Nettancourt, D. (2001) The Basic Features of Self-Incompatibility. In: *Incompatibility and Incongruity in Wild and Cultivated Plants*, Springer-Verlag, Berlin, 1-24. https://doi.org/10.1007/978-3-662-04502-2_1

[30] Gao, J.-Y., Zhang, L., Deng, X.-B., Ren, P.-Y., Kong, J.-J. and Li, Q.-J. (2004) The Floral Biology of *Curcumorpha longiflora* (Zingeberaceae): A Ginger with Two-Day Flowers. *American Journal of Botany*, **91**, 289-293. https://doi.org/10.3732/ajb.91.2.289

Supplementary Materials

Table S1. The detailed score of quantitative measurement by days.

Attributes	Date of observation (day-month), 2019														
	10-Jul	13-Jul	16-Jul	19-Jul	22-Jul	25-Jul	28-Jul	31-Jul	3-Aug	6-Aug	9-Aug	12-Aug	15-Aug	18-Aug	21-Aug
Plant height (cm)															
ZO223	155.6	156.8	157.0	158.7	160.0	162.0	168.6	170.3	176.4	180.0	181.5	185.0	185.5	185.5	185.5
ZO113	162.0	165.3	167.6	172.7	176.5	179.2	180.0	182.3	183.8	185.0	187.4	189.5	189.5	189.5	189.5
Inflorescence length (cm)															
ZO223	2.0	10.3	17.0	20.0	21.4	22.0	23.5	24.5	24.5	26.8	28.0	28.5	30.0	30.0	30.0
ZO113_1 inf.	1.5	7.9	12.8	15.0	18.0	18.5	19.5	21.5	22.0	23.5	24.0	25.9	31.5	37.0	37.0
ZO113_2 inf.	1.0	5.2	8.0	11.0	13.0	14.0	16.0	18.0	19.6	21.5	21.5	24.2	29.6	35.0	35.0
Peduncle length (cm)															
ZO223	1.0	5.3	11.5	12.8	13.5	14.0	14.3	14.5	14.5	14.5	14.5	14.5	15.0	15.0	15.0
ZO113_1 inf.	0.0	4.1	8.5	9.2	11.0	12.1	13.0	12.5	13.0	14.5	14.5	14.5	14.5	15.0	15.0
ZO113_2 inf.	0.0	1.9	3.8	6.0	7.5	8.2	10.0	10.0	10.4	11.0	13.0	13.0	13.0	13.0	13.0
Spike length (cm)															
ZO223	1.0	5.0	5.5	7.0	7.0	8.0	8.5	10.0	10.0	12.3	13.5	14.0	15.0	15.0	15.0
ZO113_1 inf.	1.5	3.8	4.3	5.8	6.0	6.4	6.5	9.0	9.0	9.0	9.5	10.9	17.0	22.0	22.0
ZO113_2 inf.	1.0	3.3	4.2	5.0	5.5	5.8	6.0	8.0	9.2	10.5	8.5	11.7	16.6	22.0	22.0
Spike width (mm)															
ZO223	8.0	22.0	25.0	26.5	27.2	28.0	28.3	31.3	31.3	31.3	31.3	31.3	32.6	34.4	34.4
ZO113_1 inf.	6.0	19.0	22.0	22.7	26.0	29.3	30.2	31.1	31.1	31.1	31.1	31.1	34.6	38.6	38.6
ZO113_2 inf.	4.0	10.0	14.0	20.9	24.2	27.5	26.8	29.3	29.3	29.3	29.3	29.3	33.7	38.1	38.1
Peduncle width (mm)															
ZO223	5.0	5.0	5.0	8.3	8.6	9.0	9.1	6.8	6.8	8.5	8.5	9.0	9.0	9.4	9.4
ZO113_1 inf.	0.0	4.0	4.0	8.4	8.6	8.6	8.8	9.0	8.9	8.9	8.9	8.9	9.0	9.0	9.0
ZO113_2 inf.	0.0	4.0	4.0	7.9	7.9	8.0	8.2	8.8	8.8	8.8	8.8	8.8	9.0	9.2	9.2

Abbreviation: inf., Inflorescence.

Table S2. Comparative morphological characteristics of similarities and/or differences in *Z. barbatum* based on quantitative and qualitative assessment.

Attributes	**ZO113**	**ZO223**	***Z. barbatum***	***Z. barbatum***
Literature source for description	This study, 2019	This study, 2019	Wallich, 1830	Theilade, 1999
Distribution (township/region/country)	Ye Zin, Nay Pyi Taw	Kyauk Pa Daung , Mandalay	Prome, Burma	Chiang Mai, Thailand
Elevation (m)	104	595	Not reported	100 - 150
Number of inflorescences per accession	2	1	Not reported	Not reported

Continued

Plant total height (cm)	185.5	189.5	121.9 - 152.4	0.6 - 1.0
Inflorescence features	Radical, on erect, rigid peduncle, dense, ovate-oblong, apex acute	Radical, on erect, rigid peduncle, dense, elongated ovate-oblong, apex acuminate	Radical, on thick and rigid, short peduncle, ovate, apex acute	Radical, on erect peduncle, ovate to conical, apex acute
Total inflorescence length (cm)	35.0 - 37.0	30	Not reported	Not reported
Peduncle length (cm)	13.0 - 15.0	15	5	2.0 - 6.0
Peduncle width (mm)	9.0 - 9.2	9.4	n/a	n/a
Spike length (cm)	22	15	5.0 - 7.5	5.0 - 10.0 (12.0)
Spike width (mm)	38.1 - 38.6	34.4	n/a	3.0 - 4.0
Bract features	Imbricated, broadly ovate, with papery margin, apex obtuse-acute, protuberant, velvety-villous, dark red	Imbricated, broadly ovate, with papery margin, apex obtuse, protuberant, velvety-villous, dark red	Imbricated, broadly ovate, convex, ventricose, apex cuspidate, hairy at all part, dull dark reddish or greenish	Ovate to cuspidate, upper ones narrower and more pointed, villous
Flowering month	August	August	August-February (in Calcutta Garden)	Not reported
Duration of flowering (days)	21 - 22	19	Not reported	Not reported
Number of flowers per spike	47 - 48	40	Not reported	Not reported
Flower features	Pale-yellow, zygomorphous, monoclinous, ephemeral, epigynous, with light fragrance, longistylous		BIG in size, white to pale pink	White
Calyx features	Glabrous, membranous, apex shortly serrated		Two-dentate	White in colour
Corolla features	Lobes subequal in length, lanceolate, pale-yellow, longitudinally striped, slightly concave in hood		Lobes lanceolate, dorsal lobe ascended, rostrate-acuminate, apex concave	White, dorsal lobe larger than lateral lobes
Labellum features	Pale-yellow with pinky tinge in the bottom of mid-lobe, soft-velvety, mid-lobe obcordate, margin slightly undulate-reflexing, mid-lobe bifurcated in the middle, lateral staminode ovate-lanceolate, apex acute	Light-yellow, soft-velvety, mid-lobe obcordate, margin slightly undulate-reflexing, lateral staminode ovate-lanceolate, apex acute	Labellum ovate, apex emarginate, notched bellow convex	Labellum white with a yellow tinge inside; midlobe obovate, emarginate; side lobes small
Stamen and carpel features	Another c. 1.6 cm long, light yellow, thecae cylindrical, parallel, dehiscence longitudinal, anther crest hooded, wrapped around style; style white, glabrous, filiform; stigma white, scarcely wider than style, tubular, downwards-facing, ostiole ciliate		Another large, subsessile, with anther crest protruded over curved lip, elevated above anther; style clavate, apex curved, slightly protuberate; stigma convex, ciliate	Not reported
Capsule (fruit/seed)	Not observed		Capsule obovate, tufted, glabrous, cherry-size; seeds, black, aril big, white	Not reported

Table S3. Recorded number of flowers per respective day of blooming.

Date of observation (day-month), 2019	ZO223	ZO113, 1st inf.	ZO113, 2nd inf.
	Number of flowers bloomed		
31-Jul	1	0	0
1-Aug	2	0	0
2-Aug	2	0	0
3-Aug	2	0	0
4-Aug	2	0	0
5-Aug	2	1	0
6-Aug	4	2	1
7-Aug	3	4	3
8-Aug	2	2	2
9-Aug	3	3	3
10-Aug	1	1	2
11-Aug	3	3	3
12-Aug	3	3	3
13-Aug	3	2	2
14-Aug	1	2	2
15-Aug	2	1	1
16-Aug	3	2	2
17-Aug	0	1	2
18-Aug	1	3	3
19-Aug	end	1	2
20-Aug		2	2
21-Aug		0	0
22-Aug		0	0
23-Aug		0	0
24-Aug		0	0
25-Aug		0	0
26-Aug		1	0
27-Aug		4	3
28-Aug		2	3
29-Aug		3	3
30-Aug		1	2
31-Aug		3	2
1-Sep		1	1
2-Sep		end	end
Number of total flowers per inflorescence	40	48	47
Duration of flowering (days)	19	22	21

Abbreviation: inf., Inflorescence.

(A)

(B)

Figure S1. Senescing of *Z. barbatum* inflorescence. (A) Inflorescence is gradually changing the color to orange-red; (B) Dried inflorescence.