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RESEARCH

# Flowering and fruiting phenology of herbs, climbers, shrubs, and trees in the deciduous dipterocarp forest of Northern Thailand

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**Background:** The flowering and fruiting periods play an important role in biological processes. The deciduous dipterocarp forest is an important forest type in Thailand, however the phenological studies are still limited, particularly in different plant life forms. Thus, the present study focused on the flowering and fruiting phenology of herbs, climbers, shrubs, and trees in the deciduous dipterocarp forest at Lampang province of Northern Thailand. Field visits were made to record plant life forms and observe reproductive phenological events at monthly intervals from November 2018 to October 2019 and September to December 2020.

**Results:** The phenological observations were based on 126 species of 45 families and 102 genera. Flowering and fruiting periods showed similar patterns in herbaceous plants, climbers, and shrubs. Most of these species produced flowers and fruits from the end of the rainy season (October) to the winter season (November–January). Whereas most of flowering and fruiting trees were found from the summer season (March–April) to the beginning of the rainy season (May–June). Most of the dry-fruited species occurred during the dry period (winter and summer seasons), while the majority of fleshy-fruited species dominated in the wet period (rainy season). The statistical analysis supported the phenological patterns of flowering and fruiting in the present study. There were significant negative correlations between the number of flowering and fruiting species and temperature. The number of flowering and fruiting species is significantly impacted by the interaction between seasons and plant life forms.

**Conclusions:** Plant life form seems to be the important factor that affects the different phenological patterns in the studied plants. The abiotic and biotic factors play major roles in reproductive phenology. However, long-term study and in-depth phenological observations are necessary for better understanding.

**Keywords:** deciduous dipterocarp forest, flowering, fruiting, Lampang, phenology, Thailand

## Introduction

Phenology is a study of the periodicity of recurring biological phenomena in plants such as leaf drop, leaf flushing, flowering, fruiting, etc. These phenological events are dealing with the relationship between climatic factors and periodic phenomena, for example the response of living organisms to seasonal and climatic changes in the environment (Kachenchart et al. 2008; Nakar and Jadeja 2015). The timing of flowering and fruiting plays an important role in biological processes from organismal to ecological scales (Mohandass et al. 2016). Their patterns ultimately determine the reproductive success in plants (Carvalho and Sartori 2015). The studies on phenology of different plant species have been undertaken from different parts of the world (Mosissa 2019). However, there are only a few phenological studies in Asia, despite this continent has a variety of forest types and climates (Mohandass et al. 2016).

In Southeast Asia, the studies on the flowering and fruiting phenology of trees have tended to focus on the equatorial rain forests (e.g., Corlett 1990; Lord Medway 1972; van Schaik 1986), while the attempts to describe these phenomena in the drier tropical climates, where there are exhibited strongly seasonal of the dry and rainy seasons, are still limited. Therefore, studies on phenology are urgently needed for this region, especially for the dry tropical forests where are considered as the most threatened of the major tropical ecosystems (Janzen 1988).

The dry forests are the majority of forest types in Thailand. One of the most important drier forest types is the deciduous dipterocarp forest (dry dipterocarp forest). It is commonly found in the northern, northeastern, and central parts of the country. Currently, there are restricted data on the phenology of deciduous forests in Thailand (Khemnark 1978). The previous studies on phenological observations in this forest type of country concentrate on tree species (Elliott et al. 1994; Khemnark 1978; Sukwong et al. 1975). There are only a few studies that provide phenological information on all plant species in the deciduous forests of Thailand (Kachenchart et al. 2008; Inuthai 2021). Unfortunately, the results of those phenological studies represent the combination data of whole community, so some specific information about each plant life form might disappear.

Phenological patterns vary at different levels of analysis (Boyle and Bronstein 2012). Different life forms such as herbs, shrubs, trees, and climbers are correlated with different patterns of flowering and fruiting phenology (Croat 1975; Nakar and Jadeja 2015). Each plant life form demonstrates a particular association with particular climatic conditions (Ramírez and Briceño 2011). The phenological data differ depending on whether only trees and shrubs, only herbaceous plants, or one or more populations are studied (Carvalho and Sartori 2015). Thus, each species may have its own phenological strategy, that might remain undetected if only the whole community is considered (Boyle and Bronstein 2012; Medeiros et al. 2007).

Phenology of trees has been studied extensively around the world (Anderson et al. 2005; Bhat 1992; Handayani 2016; Kurten et al. 2018; Mishra et al. 2006; Mosissa 2019; Singh and Kushwaha 2006; Yap 1982), while phenology of herbs, shrubs, and climbers is not well studied, with few exceptions (Croat 1975; Morellato and Leitão-Filho 1996; Nakar and Jadeja 2015). This confirms that the study on phenology of each plant life form, particularly in the deciduous forests of Thailand, is greatly needed.

Therefore, the present study attempts to fill in the knowledge gaps and increase the phenological information of plants in the dry forest of Thailand. The specific objective is to investigate the flowering and fruiting phenology of herbs, climbers, shrubs, and trees in the deciduous dipterocarp forest at Lampang province, Northern Thailand.

## Materials and Methods

### Site area

The present study was conducted in the tropical deciduous forest of Thammasat University, Lampang Campus, Lampang province, Northern Thailand (18°19′1.6″ N Latitude, 99°23′52.2″ E Longitude; elevation, 257–267 m above sea level). The study area covers about 45,000 $m^2$. The natural vegetation is the deciduous dipterocarp forest and dominated by *Dipterocarpus obtusifolius* Teijsm. ex Miq., *Dipterocarpus tuberculatus* Roxb., *Cratoxylum cochinchinense* (Lour.) Blume, *Diospyros ehretioides* Wall. ex G. Don, *Garcinia nigrolineata* Planch. ex T. Anderson, and *Anacardium occidentale* L. (Inuthai 2022). A forest's structure comprises three crown layers as follows the top, middle, and shrub canopies (above 12 m, 6–12 m, and less than 6 m high), respectively. The forest understory is composed of a variety of tree saplings, herbaceous plants, and climbers (Inuthai 2022). The topology of the study site is flat, with loamy sand soil bearing a pH ranging from 5.6–7.5. The climate is characterized by three strong seasons: hot-dry summer (February–April); rainy (May–October); and cool-dry winter (November–January). Rainfall and temperature data for the study area were collected from Northern Meteorological Center, Meteorological Department (Lampang Agromet 2020). Mean monthly rainfall and temperature patterns during the study period are given in Figure 1.

### Data collection

Field visits were made at monthly intervals from November 2018 to October 2019 and September to December 2020. The survey was carried out by walking through the entire study area to collect all the reproductive plant species and record their phenological phenomena. Plant life forms were observed and classified as follows: herbaceous plants (including terrestrial orchids), climbers, shrubs, and trees. All plant specimens were identified using the taxonomic literature, e.g., Flora of Thailand, Thai Forest Bulletin, Flora of China, Handbook, including the appropriate taxonomic websites (e.g., Balslev and Chantaranothai 2018; eFloras 2022; Koyama et al. 2016; Pooma et al. 2017; Puff et al. 2021; Thaithong et al. 2018; Utteridge and Bramley 2014). International Plant Names Index (IPNI 2023), World Flora Online Plant List (2021), and Tem Smitinand's Thai Plant Names, Revised Edition (Pooma and Suddee 2014) were used for scientific names and author abbreviations. The phenological data were recorded through surveys by docu-

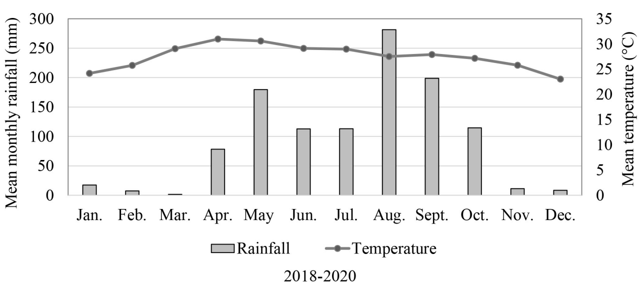


Fig. 1 Mean monthly rainfall and temperature during the study period (2018–2020) in Lampang province, Northern Thailand.

menting its period of flowering and fruiting. Binocular observations were made to check the overlapping of events. Graphs of flowering and fruiting activities were performed for each plant life form, together with a graph of combination data of all plant species. Fruit types recorded were either fleshy or dry, then a graph was generated for showing the result. The voucher specimens were organized following the procedure defined by Bridson and Forman (1998) and have been deposited in the Biotechnology Laboratory of Thammasat University, Lampang Campus, Thailand.

### Statistical analysis

Spearman's rank correlation coefficient ($r_s$) between the meteorological factors (rainfall and temperature) and the number of flowering and fruiting species were calculated. The one-way analysis of variance (ANOVA) was conducted to determine whether there was a difference in the number of flowering and fruiting species by seasons and by plant life forms. The pairwise comparisons were performed with the Scheffe post hoc test. The two-way ANOVA was operated to analyze the effect of seasons and plant life forms on the number of flowering and fruiting species. The chi-square test was used to test the relationship between fruit types and periods. All the tests were executed by using the software IBM SPSS statistics v.28.0.1.1 (IBM Co., Armonk, NY, USA).

## Results

The present study revealed 126 species of vascular plants belonging to 45 families and 102 genera (Table 1). Most of them were collected from 2018 to 2019. Only five species were added to the database based on the collection in 2020. Species-rich families were Fabaceae (26 species), Malvaceae (11 species), Convolvulaceae (8 species), Lamiaceae and Apocynaceae (7 species each). Among 126 taxa, 38 species were herbaceous plants (30.16%), 32 species were climbers (25.40%), 39 species were shrubs (30.95%), and 17 species were trees (13.49%).

The phenological record of individual species was presented in Table 1. From observation of the present study, the results showed that flowering and fruiting periods seemed to have quite a similar pattern in herbaceous plants, climbers, and shrubs (Figs. 2-4). Flower formation of those three life forms showed a peak during the end of the rainy season to the beginning of the winter season (October–November). They included 26, 16, and 17 species of herbs, climbers, and shrubs, respectively. However, climbers and shrubs also showed another small flowering peak in the rainy season (June). The lowest flowering periods of herbaceous plants, climbers, and shrubs were found in the summer season to the beginning of the rainy season (March–May). Whereas tree species showed the opposite trend. The highest number of flowering trees was recorded with six species during the summer season (March–April) and the beginning of the rainy season (May) (Fig. 5). The peak periods for fruiting phenology were observed in the rainy season (October and June) for herbaceous plants (26 species) and trees (8 species), and presented in the winter season (January and November–December) for climbers (16 species) and shrubs (18 species). The lowest fruiting periods were recorded in the summer season for herbaceous plants, in the rainy season for climbers and trees, and from the summer to rainy seasons for shrubs.

The diagram in Figure 6 demonstrated the trend of flowering and fruiting periods of all plant life forms throughout the year. The results showed that flowering and fruiting periods pointed to the peaks in the winter season (November and December, respectively). Then, the number of flowering and fruiting species steadily declined in the summer season and reached the lowest amounts in April and May, respectively. Afterward, the number of flowering and fruiting species gradually increased again in the rainy season.

The highest of flowering and fruiting of the whole species occurred in the winter season. They contained 59 species of flowering in November and 57 species of fruiting in December. Whilst the lowest flowering and fruiting periods happened at the end of the summer season and the beginning of the rainy season, based on 21 species in April and 17 species in May, respectively. Interestingly, the highest and lowest numbers of fruiting were observed in a month after the highest and lowest flowering.

The results of the statistical study revealed that there was no statistically significant relationship between the number of flowering and fruiting species and rainfall. While there were strong negative correlations between temperature and the number of flowering ($r_s$ = −0.774, $p$ = 0.003), and fruiting species ($r_s$ = −0.947, $p < 0.001$) (Table 2).

The number of flowering and fruiting species was compared between the winter, summer, and rainy seasons using a one-way ANOVA. The number of flowering species varied significantly by seasons at the 0.05 level, $F_{(2, 9)}$ = 4.664, $p$ = 0.041 (Table 3). Scheffe's post hoc test for multiple comparisons indicated that the mean numbers of flowering species were significantly different between the winter and summer seasons ($p$ = 0.05; 95% confidence interval [CI] = 0.03, 47.97) (Table 4). However, there were no statistically significant differences in the mean numbers of flowering species between the winter and rainy seasons ($p$ = 0.106), or between the rainy and summer seasons ($p$ = 0.645) (Table 4). Moreover, there was a significant difference in the number of fruiting species among seasons at the 0.05 level, $F_{(2, 9)}$ = 6.585, $p$ = 0.017 (Table 3). According to Scheffe's post hoc analysis, there were significant differences in the mean numbers of fruiting species between the winter and summer seasons ($p$ = 0.033; 95% CI = 2.32,

**Table 1** List of species, family, life form, flowering period, fruiting period, and fruit type of plants in the deciduous dipterocarp forest at Lampang province, Northern Thailand

| No. | Scientific name | Family | Life form | Flowering period | Fruiting period | Fruit type |
|---|---|---|---|---|---|---|
| 1 | *Aeschynomene americana* L. | Fabaceae | Shrub | Nov–Dec | Nov–Jan | Dry |
| 2 | *Alternanthera sessilis* (L.) R. Br. ex DC. | Amaranthaceae | Herb | Nov–Dec | - | - |
| 3 | *Alysicarpus vaginalis* (L.) DC. | Fabaceae | Herb | Oct | Oct | Dry |
| 4 | *Amphineurion marginatum* (Roxb.) D. J. Middleton | Apocynaceae | Climber | Jun | - | - |
| 5 | *Anacardium occidentale* L. | Anacardiaceae | Tree | Nov–Jun | Mar–Jun | Dry |
| 6 | *Andrographis paniculata* (Burm. f.) Wall. ex Nees | Acanthaceae | Herb | Nov–Jan | Nov–Jan | Dry |
| 7 | *Antidesma ghaesembilla* Gaertn. | Phyllanthaceae | Shrub | Jul | - | - |
| 8 | *Argyreia osyrensis* (Roth) Choisy | Convolvulaceae | Shrub | Nov | Apr | Fleshy |
| 9 | *Aristolochia tagala* Cham. | Aristolochiaceae | Climber | Sep–Nov | Nov–Feb | Dry |
| 10 | *Asystasia gangetica* (L.) T. Anderson | Acanthaceae | Herb | Oct–Feb | Oct–Feb | Dry |
| 11 | *Barleria cristata* L. | Acanthaceae | Shrub | Nov | Nov | Dry |
| 12 | *Bidens pilosa* L. | Asteraceae | Herb | Jan–Dec | Jan–Dec | Dry |
| 13 | *Biophytum umbraculum* Welw. | Oxalidaceae | Herb | Oct–Nov | Oct–Dec | Dry |
| 14 | *Brucea javanica* (L.) Merr. | Simaroubaceae | Shrub | Mar–Oct | Mar–Nov | Fleshy |
| 15 | *Butea monosperma* (Lam.) Taub. | Fabaceae | Tree | Feb–Mar | Feb–Mar | Dry |
| 16 | *Caesalpinia furfuracea* (Prain) Hattink | Fabaceae | Climber | Sep–Oct | Oct–Mar | Dry |
| 17 | *Calopogonium mucunoides* Desv. | Fabaceae | Climber | Oct | - | - |
| 18 | *Capparis sepiaria* L. | Capparaceae | Climber | Apr–May | - | - |
| 19 | *Capparis zeylanica* L. | Capparaceae | Climber | Mar–Apr | Apr–Aug | Fleshy |
| 20 | *Casearia grewiifolia* Vent. | Salicaceae | Tree | Jul | Jun–Sep | Fleshy |
| 21 | *Catunaregam spathulifolia* Tirveng. | Rubiaceae | Tree | - | Nov–Jan | Fleshy |
| 22 | *Centrosema pubescens* Benth. | Fabaceae | Climber | Oct–Jan | Oct–Feb | Dry |
| 23 | *Chamaecrista pumila* (Lam.) K. Larsen | Fabaceae | Herb | Oct | Oct | Dry |
| 24 | *Chromolaena odorata* (L.) R. M. King & H. Rob. | Asteraceae | Herb | Nov–Mar | Dec–Mar | Dry |
| 25 | *Clausena excavata* Burm. f. | Rutaceae | Shrub | Mar–Jun | Jun–Sep | Fleshy |
| 26 | *Cleome rutidosperma* DC. | Cleomaceae | Herb | Aug–Oct | Aug–Oct | Dry |
| 27 | *Clerodendrum paniculatum* L. | Lamiaceae | Shrub | Sep | Oct–Nov | Fleshy |
| 28 | *Clitoria macrophylla* Wall. ex Benth. | Fabaceae | Climber | Sep | - | - |
| 29 | *Commelina benghalensis* L. | Commelinaceae | Herb | Dec–Jan | - | - |
| 30 | *Corchorus aestuans* L. | Malvaceae | Herb | Oct–Jan | Oct–Jan | Dry |
| 31 | *Cratoxylum cochinchinense* (Lour.) Blume | Hypericaceae | Tree | Apr–Sep | Jan–Dec | Dry |
| 32 | *Cratoxylum formosum* (Jacq.) Benth. & Hook. f. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein | Hypericaceae | Tree | May | Jun–Jul | Dry |
| 33 | *Crotalaria alata* Buch.-Ham. Ex D. Don | Fabaceae | Shrub | Oct–Jan | Oct–Jan | Dry |
| 34 | *Crotalaria incana* L. | Fabaceae | Herb | Nov–Jan | Dec–Jan | Dry |
| 35 | *Desmodium triflorum* (L.) DC. | Fabaceae | Herb | Sep–Nov | Sep–Nov | Dry |
| 36 | *Desmodium velutinum* (Willd.) DC. subsp. *velutinum* | Fabaceae | Shrub | Nov–Dec | Nov–Jan | Dry |
| 37 | *Dillenia aurea* Sm. | Dilleniaceae | Tree | Apr–Jun | Apr–May | Fleshy |
| 38 | *Dillenia obovata* (Blume) Hoogland | Dilleniaceae | Tree | Feb–Mar | Apr | Fleshy |
| 39 | *Diospyros ehretioides* Wall. ex G. Don | Ebenaceae | Tree | Mar–Apr | Jan–Dec | Fleshy |
| 40 | *Dipterocarpus obtusifolius* Teijsm. ex Miq. | Dipterocarpaceae | Tree | Oct–Dec | Oct–Mar | Dry |
| 41 | *Dipterocarpus tuberculatus* Roxb. | Dipterocarpaceae | Tree | - | - | - |
| 42 | *Dunbaria bella* Prian | Fabaceae | Climber | Nov–Feb | Nov–Feb | Dry |
| 43 | *Dunbaria punctata* (Wight & Arn.) Benth. | Fabaceae | Climber | Oct–Nov | Oct–Dec | Dry |
| 44 | *Ellipanthus tomentosus* Kurz | Connaraceae | Tree | Mar | - | - |
| 45 | *Erythroxylum cuneatum* (Miq.) Kurz | Erythroxylaceae | Shrub | Jul–Sep, Dec | Jul–Sep, Dec | Fleshy |
| 46 | *Eulophia graminea* Lindl. | Orchidaceae | Herb | Jan–Mar | Mar | Dry |
| 47 | *Euphorbia heterophylla* L. | Euphorbiaceae | Herb | Sep | Sep | Dry |
| 48 | *Euphorbia hirta* L. | Euphorbiaceae | Herb | May–Feb | May–Feb | Dry |
| 49 | *Eurycoma longifolia* Jack | Simaroubaceae | Shrub | Feb–Jun | May–Jul | Fleshy |
| 50 | *Evolvulus alsinoides* var. *decumbens* (R. Br.) Ooststr. | Convolvulaceae | Herb | Sep–Oct | - | - |
| 51 | *Evolvulus nummularius* (L.) L. | Convolvulaceae | Herb | Aug–Jan | Aug–Feb | Dry |
| 52 | *Flemingia stricta* Roxb. ex W. T. Aiton | Fabaceae | Shrub | Oct–Mar | Nov–Jan | Dry |
| 53 | *Garcinia nigrolineata* Planch. ex T. Anderson | Clusiaceae | Tree | - | Feb–Jun | Fleshy |
| 54 | *Geodorum recurvum* (Roxb.) Alston | Orchidaceae | Herb | Jul | - | - |

**Table 1** Continued

| No. | Scientific name | Family | Life form | Flowering period | Fruiting period | Fruit type |
|---|---|---|---|---|---|---|
| 55 | *Harrisonia perforata* (Blanco) Merr. | Rutaceae | Shrub | Mar–Jun | Jun–Oct | Fleshy |
| 56 | *Helicteres lanceolata* A. DC. var. *gagnepainiana* (Craib) Phengklai | Malvaceae | Shrub | Jul–Sep | - | - |
| 57 | *Helicteres lanceolata* A. DC. var. *lanceolata* | Malvaceae | Shrub | Jul–Oct | - | - |
| 58 | *Holarrhena pubescens* Wall. ex G. Don | Apocynaceae | Shrub | Mar, Jun | - | - |
| 59 | *Hoya kerrii* Craib | Apocynaceae | Climber | May–Jul | Jul–Aug | Dry |
| 60 | *Hyptis brevipes* Poit. | Lamiaceae | Shrub | Nov–Dec | Jan | Dry |
| 61 | *Hyptis suaveolens* (L.) Poit. | Lamiaceae | Shrub | Sep–Feb | Oct–Feb | Dry |
| 62 | *Ichnocarpus frutescens* (L.) W. T. Aiton | Apocynaceae | Climber | Oct–Dec | Jan | Dry |
| 63 | *Indigofera cassioides* Rottler ex DC. | Fabaceae | Shrub | Jan–Feb | Jan–Feb | Dry |
| 64 | *Indigofera hirsuta* L. | Fabaceae | Shrub | Sep–Jan | Sep–Jan | Dry |
| 65 | *Ipomoea obscura* (L.) Ker Gawl. | Convolvulaceae | Climber | Jan–Dec | Dec–May | Dry |
| 66 | *Ipomoea pes-tigridis* L. | Convolvulaceae | Climber | Aug–Oct | Sep–Oct | Dry |
| 67 | *Jasminum elongatum* (P. J. Bergius) Willd. | Oleaceae | Shrub | Jan–Feb | - | - |
| 68 | *Lantana camara* L. | Verbenaceae | Climber | Jun–Feb | Jun–Mar | Fleshy |
| 69 | *Leea indica* (Burm. f.) Merr. | Vitaceae | Shrub | Jul–Aug, Nov | Oct–Jan, Aug | Fleshy |
| 70 | *Leucas aspera* (Willd.) Link | Lamiaceae | Herb | Jan–Feb, Sep–Oct | Dec–Feb | Dry |
| 71 | *Leucas decemdentata* (Willd.) Sm. | Lamiaceae | Herb | Dec | Dec | Dry |
| 72 | *Lindernia ciliata* (Colsm.) Pennell | Linderniaceae | Herb | Sep–Jan | Sep–Dec | Dry |
| 73 | *Lindernia crustacea* (L.) F. Muell. var. *crustacea* | Linderniaceae | Herb | Sep–Jan | Oct–Jan | Dry |
| 74 | *Ludwigia hyssopifolia* (G. Don) Exell | Onagraceae | Herb | Sep–Nov | Oct | Dry |
| 75 | *Mammea siamensis* (Miq.) T. Anderson | Clusiaceae | Tree | Feb–Mar | - | - |
| 76 | *Memecylon scutellatum* (Lour.) Hook. & Arn. var. *scutellatum* | Melastomataceae | Shrub | Mar–Jun | Jul–Dec | Fleshy |
| 77 | *Merremia bambusetorum* Kerr. | Convolvulaceae | Climber | Dec–Mar | Jan–Mar | Dry |
| 78 | *Merremia hirta* (L.) Merr. | Convolvulaceae | Climber | Nov | - | - |
| 79 | *Merremia vitifolia* (Burm. f.) Haller f. | Convolvulaceae | Climber | Jan–Apr | Jan–Apr | Dry |
| 80 | *Mikania micrantha* Kunth | Asteraceae | Climber | Oct–Mar | Nov–Mar | Dry |
| 81 | *Mimosa diplotricha* C. Wright ex. Sauvalle | Fabaceae | Herb | Aug–Dec | Nov–Jan | Dry |
| 82 | *Mimosa pudica* L. | Fabaceae | Herb | Jul–Mar | Oct–Mar | Dry |
| 83 | *Momordica charantia* L. | Cucurbitaceae | Climber | Sep–Dec | - | - |
| 84 | *Murdannia gigantea* (Vahl) G. Brückn. | Commelinaceae | Herb | Jul, Nov | Jun–Nov | Dry |
| 85 | *Murdannia nudiflora* (L.) Brenan | Commelinaceae | Herb | Oct | Oct | Dry |
| 86 | *Ochna integerrima* (Lour.) Merr. | Ochnaceae | Shrub | Mar–Jun | Mar–Aug | Fleshy |
| 87 | *Olax psittacorum* (Lam.) Vahl | Olacaceae | Climber | May | Jun | Fleshy |
| 88 | *Oldenlandia corymbosa* L. | Rubiaceae | Herb | Aug–Dec | Aug–Dec | Dry |
| 89 | *Paederia pilifera* Hook. f. | Rubiaceae | Climber | Dec–Mar | Jan–Apr | Dry |
| 90 | *Parinari anamensis* Hance | Chrysobalanaceae | Tree | Oct–Jun | Oct–Nov | Fleshy |
| 91 | *Passiflora foetida* L. | Passifloraceae | Climber | Apr–Aug | Jan, Apr–Sep | Fleshy |
| 92 | *Phyllanthus urinaria* L. | Phyllanthaceae | Herb | - | Sep–Dec | Fleshy |
| 93 | *Phyllanthus virgatus* G. Forst. | Phyllanthaceae | Herb | Jun–Sep, Nov–Dec | Jul–Dec | Fleshy |
| 94 | *Phyllodium pulchellum* (L.) Desv. | Fabaceae | Shrub | Sep, Nov | Nov–Feb | Dry |
| 95 | *Polygala elongata* Klein ex Willd. | Polygalaceae | Herb | Aug–Oct | Sep–Oct | Dry |
| 96 | *Praxelis clematidea* (Griseb.) R.M. King & H. Rob. | Asteraceae | Herb | Jan–Dec | Jan–Dec | Dry |
| 97 | *Premna herbacea* Roxb. | Lamiaceae | Shrub | Jun | Jun–Sep | Fleshy |
| 98 | *Pueraria phaseoloides* (Roxb.) Benth. | Fabaceae | Climber | Nov | Nov | Dry |
| 99 | *Rotheca serrata* (L.) Steane & Mabb. | Lamiaceae | Shrub | Aug–Oct | Aug–Nov | Fleshy |
| 100 | *Sauropus androgynus* (L.) Merr. | Phyllanthaceae | Shrub | Jul–Jan | - | - |
| 101 | *Senna hirsuta* (L.) H. S. Irwin & Barneby | Fabaceae | Shrub | Nov–Dec | Nov–Dec | Dry |
| 102 | *Sida acuta* Burm. f. | Malvaceae | Shrub | Jan, Oct, Dec | Oct–Jan | Dry |
| 103 | *Sida cordata* (Burm. f.) Borss. Waalk. | Malvaceae | Shrub | Nov–Feb | Nov–Feb | Dry |
| 104 | *Sida cordifolia* L. | Malvaceae | Shrub | Oct–Feb | Oct–Mar | Dry |
| 105 | *Sida rhombifolia* L. subsp. *rhombifolia* | Malvaceae | Shrub | Nov | - | - |
| 106 | *Sindora siamensis* Teijsm. ex Miq. var. *siamensis* | Fabaceae | Tree | Apr–May | May–Jan | Dry |
| 107 | *Smilax luzonensis* C. Presl | Smilacaceae | Climber | Apr–Jun | Jul–Oct | Fleshy |

**Table 1** Continued

| No. | Scientific name | Family | Life form | Flowering period | Fruiting period | Fruit type |
|---|---|---|---|---|---|---|
| 108 | *Solena heterophylla* Lour. | Cucurbitaceae | Climber | Jun–Sep, Nov–Jan | Jan–Apr | Fleshy |
| 109 | *Spermacoce ocymoides* Burm. f. | Rubiaceae | Herb | Sep–Feb | Oct–Feb | Dry |
| 110 | *Streptocaulon juventas* (Lour.) Merr. | Apocynaceae | Climber | Aug–Sep | Oct | Dry |
| 111 | *Strychnos nux-blanda* A. W. Hill | Loganiaceae | Tree | - | Oct–Jul | Fleshy |
| 112 | *Stylosanthes humilis* Humb., Bonpl. & Kunth | Fabaceae | Herb | Jun–Feb | Dec–Feb, Sep–Oct | Dry |
| 113 | *Telosma pallida* (Roxb.) Craib. | Apocynaceae | Climber | Jun–Aug | - | - |
| 114 | *Tephrosia vestita* Vogel | Fabaceae | Shrub | Oct–Dec | Oct–Jan | Dry |
| 115 | *Thunbergia fragrans* Roxb. | Acanthaceae | Climber | Sep–Feb | Oct–Feb | Dry |
| 116 | *Toxocarpus villosus* (Blume) Decne. | Apocynaceae | Climber | Oct–Feb | Jan–Feb | Dry |
| 117 | *Tridax procumbens* L. | Asteraceae | Herb | Jan–Dec | Jan–Dec | Dry |
| 118 | *Triumfetta pilosa* Roth | Malvaceae | Herb | Sep–Feb | Oct–Feb | Dry |
| 119 | *Urena lobata* L. | Malvaceae | Shrub | Dec | Dec | Dry |
| 120 | *Urena rigida* Wall. ex Mast. | Malvaceae | Shrub | Nov–Feb | Dec–Feb | Dry |
| 121 | *Uvaria cherrevensis* (Pierre ex Finet & Gagnep.) L. L. Zhou, Y. C. F. Su & R. M. K. Saunder | Annonaceae | Shrub | Jun–Sep | Jul–Sep, Dec | Fleshy |
| 122 | *Vangueria pubescens* Kurz | Rubiaceae | Shrub | May | Jun–Oct | Fleshy |
| 123 | *Ventilago denticulata* Willd. | Rhamnaceae | Climber | Oct–Nov | Jan–Apr | Dry |
| 124 | *Waltheria indica* L. | Malvaceae | Shrub | Feb, Jun–Jul | - | - |
| 125 | *Ziziphus oenoplia* (L.) Mill. var. oenoplia | Rhamnaceae | Climber | Aug–Nov | Oct–Dec | Fleshy |
| 126 | *Zornia gibbosa* Span. | Fabaceae | Herb | Oct | Oct | Dry |

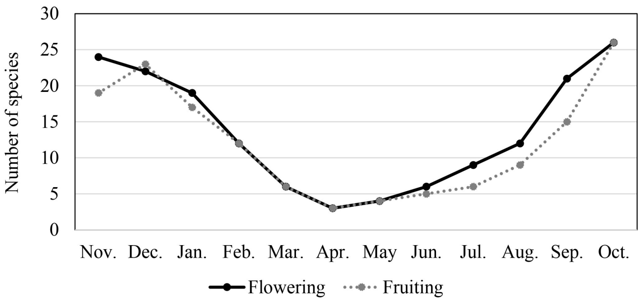


**Fig. 2** Flowering and fruiting periodicity expressed as the number of herbaceous plants (including terrestrial orchids) in the deciduous dipterocarp forest at Lampang province.

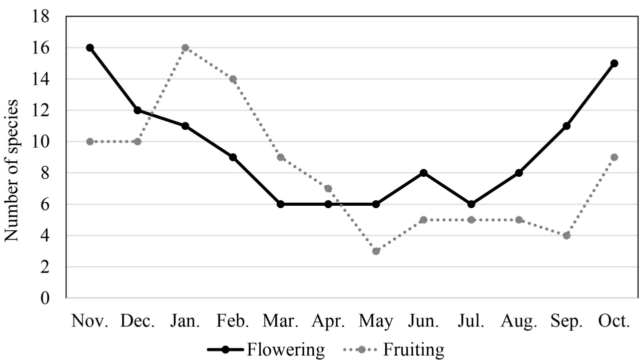


**Fig. 3** Flowering and fruiting periodicity expressed as the number of climbers in the deciduous dipterocarp forest at Lampang province.

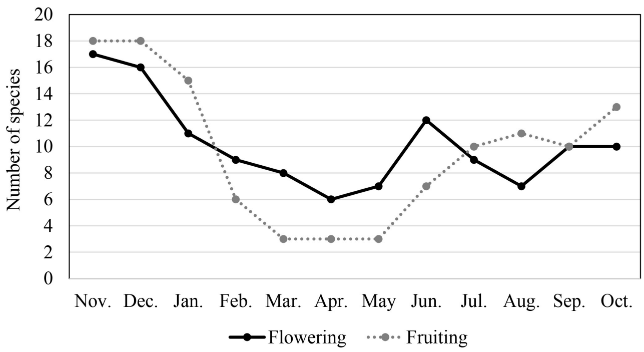


**Fig. 4** Flowering and fruiting periodicity expressed as the number of shrubs in the deciduous dipterocarp forest at Lampang province.

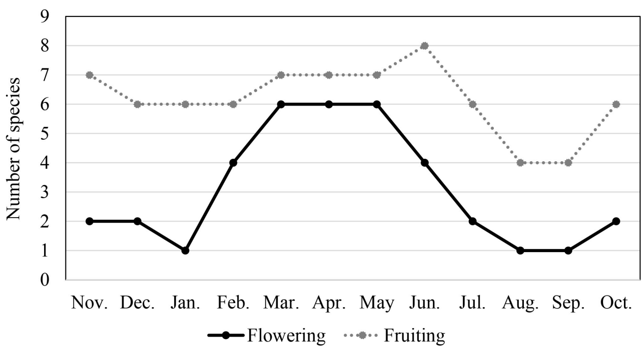


**Fig. 5** Flowering and fruiting periodicity expressed as the number of trees in the deciduous dipterocarp forest at Lampang province.

51.68), as well as between the winter and rainy seasons ($p$ = 0.030; 95% CI = 2.46, 45.21) (Table 4). However, there was no significant difference in the mean numbers of fruiting species between the summer and rainy seasons ($p$ = 0.912) (Table 4).

A one-way ANOVA was also conducted to determine the

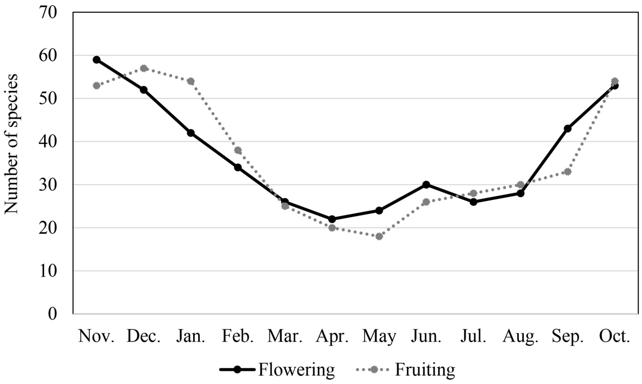


**Fig. 6** Flowering and fruiting periodicity of herbs, climbers, shrubs, and trees combined in the deciduous dipterocarp forest at Lampang province.

differences in the number of flowering and fruiting species among various plant life forms. Groups of herbs, climbers, shrubs, and trees were compared. The number of flowering species varied significantly among the various types of life forms at the 0.05 level, $F_{(3, 44)} = 9.560$, $p < 0.001$ (Table 5). According to Scheffe's post hoc test, the mean numbers of flowering species were significantly different between herbs and trees ($p < 0.001$; 95% CI = –16.45, –4.72), shrubs and trees ($p = 0.012$; 95% CI = –12.95, –1.22), and climbers and trees ($p = 0.027$; 95% CI = –12.28, –0.55), respectively (Table 6). However, there were no significant differences between the mean numbers of flowering species between herbs and climbers ($p = 0.249$), herbs and shrubs ($p = 0.400$), and climbers and shrubs ($p = 0.991$) (Table 6).

**Table 2** Results of the Spearman's correlation of flowering and fruiting with rainfall and temperature

| | Rainfall | | Temperature | |
|---|---|---|---|---|
| | Flowering | Fruiting | Flowering | Fruiting |
| $r_s$ | –0.123 | –0.232 | –0.774 | –0.947 |
| *p*-value | 0.704 | 0.469 | 0.003 | <0.001 |

$r_s$: Spearman's correlation; $p < 0.01$.

**Table 3** Results of one-way ANOVA for the number of flowering and fruiting species among different seasons

| Source of variation | Sum of squares | Degree of freedom | Mean square | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Flowering | | | | | |
| Between groups | 944.083 | 2 | 472.042 | 4.664 | 0.041 |
| Within groups | 910.833 | 9 | 101.204 | | |
| Total | 1,854.917 | 11 | | | |
| Fruiting | | | | | |
| Between groups | 1,413.833 | 2 | 706.917 | 6.585 | 0.017 |
| Within groups | 966.167 | 9 | 107.352 | | |
| Total | 2,380.000 | 11 | | | |

**Table 4** Results of Scheffe's post hoc test for multiple comparisons of the number of flowering and fruiting species in different seasons

| Season | Mean | Flowering | | | Mean | Fruiting | | |
|---|---|---|---|---|---|---|---|---|
| | | Winter | Summer | Rainy | | Winter | Summer | Rainy |
| Winter | 51.00 | - | 24.000* | 17.167 | 54.67 | - | 27.000* | 23.833* |
| Summer | 27.00 | | - | 6.833 | 27.67 | | - | 3.167 |
| Rainy | 33.83 | | | - | 30.83 | | | - |

-: not applicable.
*$p < 0.05$.

**Table 5** Results of one-way ANOVA for the number of flowering and fruiting species among different plant life forms

| Source of variation | Sum of squares | Degree of freedom | Mean square | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Flowering | | | | | |
| Between groups | 700.229 | 3 | 233.410 | 9.560 | <0.001 |
| Within groups | 1,074.250 | 44 | 24.415 | | |
| Total | 1,774.479 | 47 | | | |
| Fruiting | | | | | |
| Between groups | 227.229 | 3 | 75.743 | 2.769 | 0.053 |
| Within groups | 1,203.750 | 44 | 27.358 | | |
| Total | 1,430.979 | 47 | | | |

**Table 6** Results of Scheffe's post hoc test for multiple comparisons of the number of flowering and fruiting species in different plant life forms

| Plant life form | Mean | Flowering | | | | Mean | Fruiting | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Herb | Climber | Shrub | Tree | | Herb | Climber | Shrub | Tree |
| Herb | 13.67 | - | 4.167 | 3.500 | 10.583** | 12.08 | - | 4.000 | 2.333 | 5.917 |
| Climber | 9.50 | | - | 0.667 | 6.417* | 8.08 | | - | 1.667 | 1.917 |
| Shrub | 10.17 | | | - | 7.083* | 9.75 | | | - | 3.583 |
| Tree | 3.08 | | | | - | 6.17 | | | | - |

-: not applicable.
*$p < 0.05$, **$p < 0.001$.

**Table 7** Results of two-way ANOVA of the effect of seasons and plant life forms on the number of flowering and fruiting species

| Effect | Degree of freedom | Flowering | | Fruiting | |
|---|---|---|---|---|---|
| | | *F*-value | *p*-value | *F*-value | *p*-value |
| Season | 2 | 7.306 | 0.002 | 11.369 | <0.001 |
| Plant life form | 3 | 13.277 | <0.001 | 4.472 | 0.009 |
| Season × plant life form | 6 | 2.649 | 0.031 | 2.782 | 0.025 |
| Model | 12 | 26.680 | <0.001 | 24.869 | <0.001 |

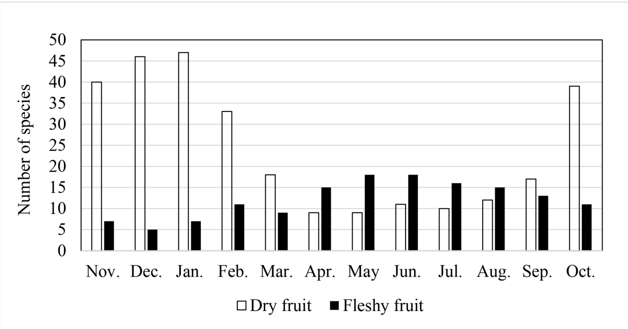


**Fig. 7** Fruiting periodicity of dry- and fleshy-fruited species in the deciduous dipterocarp forest at Lampang province.

**Table 8** The accumulated number of fruiting events of dry- and fleshy-fruited species during the dry and wet periods

| Fruit type | Period | | |
|---|---|---|---|
| | Dry | Wet | Total |
| Dry | 193 | 94 | 287 |
| Fleshy | 54 | 91 | 145 |
| Total | 247 | 185 | 432 |

Values are presented as number only.
Dry period: winter and summer seasons; Wet period: rainy season.

Moreover, there was no statistically significant difference in the number of fruiting species across the various categories of life forms ($p = 0.53$) (Table 6).

The effect of seasons and plant life forms on the number of flowering and fruiting species was studied using a two-way ANOVA. As shown in Table 7, the results demonstrated statistically significant interactions between the effects of seasons and plant life forms on the number of flowering ($F_{(6, 36)} = 2.649$, $p = 0.031$) and fruiting ($F_{(6, 36)} = 2.782$, $p = 0.025$) species, respectively. Seasons and plant life forms both demonstrated statistically significant effects on the number of flowering and fruiting species ($p < 0.05$), according to a simple main effects analysis.

The fruit types of fruiting species were shown in Table 1. There were 104 species that produced fruits during the study period. Among these taxa, 73 species (70.19%) were dry fruits, and 31 species (29.81%) were fleshy fruits. Dry-fruited species showed a peak in the winter season (January), while the lowest number was found from the end of summer season to the beginning of rainy season (April–May) (Fig. 7). On the other hand, fleshy-fruited species showed a peak in the rainy season (May–June), and the lowest of fruiting occurred in the winter season (December). To assess the association between the fruit types (dry and fleshy) and the periods (wet and dry), a chi-square test of independence was used. The result revealed that they were strongly associated (chi-square = 35.423; $p < 0.001$; Table 8). As shown in Figure 7, the dry fruits appeared to demonstrate a positive trend toward the dry period, whereas the fleshy fruits were more frequently detected during the wet period.

## Discussion

There was a first record on the diversity of plants among four selected sites in the deciduous forest at Lampang Campus of Thammasat University, which included an overview of flowering and fruiting phenology (Inuthai 2021). However, the author reported the information in terms of the combination data of whole community. Thus, the phenological pattern is quite similar to Figure 6 in the present study. As mentioned above, each species has its phenological strategy (Boyle and Bronstein 2012; Medeiros et al. 2007), so if only the whole community is considered, much essential information might be lost. Therefore, the present study attempted to go deeper into details for filling in the missing data and completing the phenological information of plants in the area.

The results from the present study indicated that herbaceous plants produced many flowers during the rainy to winter seasons (October–November). The highest peak of fruiting was observed in the winter season (December). This is similar to previous reports from other tropical forests in Southeast Asia (Bhat and Murali 2001; Nakar and Jadeja 2015; Sivaraj and Krishnamurthy 1989). Flowering and fruiting were found in numerous species from the end of the rainy season to the beginning of the winter season, then the number of species gradually dropped during the summer season. This is probably due to the seasonal changes. The diminished rainfall from the wet to dry periods (rainy to winter and summer) probably forces water stress on plants. Several herbaceous plants struggle to survive in the dry period, thus some of them disappear from their habitats during this time (Inuthai 2021).

Two flowering peaks of climber community were observed in the present study: a major peak in the winter season (November) and a minor one in the rainy season (June). Flowering activity declined during the summer season. This result conforms with the previous studies in a semideciduous forest in Brazil (Morellato and Leitão-Filho 1996) and the Barro Colorado Island (Croat 1975). They suggested that the herbaceous vines are seasonal with a flowering peak in the late wet season to early dry season, while the June peak represents species that appear to be triggered by wet rather than dry conditions. The peak period for fruiting phenology in the present study was observed in the winter season (January), which was a part of the dry period. This is consistent with the finding by Morellato and Leitão-Filho (1996), who reported that most climber species produce fruits during the dry period. This circumstance is probably the fact that many species of lianas have wind-dispersed fruits even though they may flower in the rainy season (Croat 1975).

The results showed two peaks of flowering in shrub species, viz. one in the winter season (November), and another in the rainy season (June). This phenology seems to have a similar pattern with climbers. The peak of fruiting period was found in the winter season (November–December). The results conform to the study of aromatic species including shrubs in India, where flowering and fruiting are seen mostly in December (Pandey and Tripathi 2010), and the phenological study of woody species in an arid environment of the Brazilian Chaco (Carvalho and Sartori 2015). The minor peak of flowering in the rainy season may be explained by the moisture stress in shallow-rooted plants during the dry period. This stress is perhaps adequately high to inhibit flower initiation and may experience a period of protective dormancy during the dry months (Murali and Sukumar 1994). Then, the first rains in May might act as a cue to flowering that lead to the peak in June.

The flowering of trees in the present study peaked in the summer season which conforms to the various studies on phenology of tree species in the dry deciduous forests (Bhat 1992; Murali and Sukumar 1994; Nanda et al. 2009; Nanda et al. 2014; Yap 1982). This is possibly due to the influences of the high temperature, low humidity, low soil moisture, and daylight changes during the dry period, which help in bud break and flower opening (Borchert et al. 2005; Frankie et al. 1974; Mohandass et al. 2016; Njoku 1958). In the present study, the peak period of fruiting in tree species was in the rainy season (June), which is similar to the phenological studies of trees in the dry deciduous dipterocarp forest in Thailand (Elliott et al. 1994; Sukwong et al. 1975) and other studies (Mohandass et al. 2016; Nanda et al. 2014).

Numerous tree species in the present study produced fruits during the summer season and the beginning of the rainy seasons. The different seasons of fruiting time might be due to whether they are wind-dispersed or animal-dispersed species. Elliott et al. (1994) suggested that wind-dispersed species expose the peak in the period of highest mean wind speed in April, whereas animal-dispersed species happen in July to August during the migration time of animals and birds from the evergreen forests to the deciduous forests to take advantage of increase food resources during the rainy season. Wind-dispersed species in the present study, such as *Butea monosperma* (Lam.) Taub., *Dipterocarpus obtusifolius* Teijsm. ex Miq., which fruiting times obviously appeared during the summer season and the beginning of the rainy season. Another possibility of fruiting in the rainy season, perhaps because rainfalls are necessary for seed germination and seeding survival of plants.

The results showed that many tree species had phenological patterns that synchronized flowering and fruiting in the dry months. Thus, flowering and fruiting during the summer season provide the selective advantages. Wright and van Schaik (1994) and Nanda et al. (2009) mentioned that flowering in the dry period is a response to the rapid resource-use rate, which more efficient to transfer assimilates directly into growing organs rather than having to store and translocate them later. Moreover, the timing of flowering peak during the dry season attracts more pollinators. This is because many trees are leafless during dry period, thus flowers are more visible and available to pollinators (Bawa et al. 2003; Elliott et al. 1994; Janzen 1967; Mohandass et al. 2016; Wright and Calderon 1995). This conforms to the observation in the present study that a large amount of leaf fall happened during January to April, corresponding with the dry period.

The statistical analysis supported the phenological patterns of flowering and fruiting in the present study. There were significant negative correlations between the number of flowering and fruiting species and temperature. Moreover, the number of flowering and fruiting species varied significantly by seasons, particularly between the winter and summer seasons. These results matched the circumstances that the flowering and fruiting species were more common in the winter season, when temperatures were at their lowest, and less common in the summer season when they were at their highest. Furthermore, the interactions between seasons and plant life forms have significant effects on the number of flowering and fruiting species. There was also statistically significant difference in the number of flowering and fruiting species depending on seasons or types of life forms.

Most of the dry-fruited species were found during the dry period (winter and summer seasons), while the majority of fleshy-fruited species occurred in the wet period (rainy season). A chi-square result showed a significant relationship between the fruit types and the periods. The present study corresponds with a previous report from a dry tropical forest in Ghana (Lieberman 1982). The author mentioned that dry fruits (frequently wind-dispersed) are more common during the dry season, whereas fleshy fruits (generally animal-dispersed) are most abundant during the wet season. In addition, dry fruits especially explosive-dispersed fruits are improved to dehiscing during the dry period when relative humidity is low (Murali and Sukumar 1994).

In the present study, herbaceous plants and climbers were triggered by conditions of drought, whereas shrubs and trees did not respond so quickly to the changes in the environment. It is perhaps to the fact that shrubs and trees are less exposed to the environment than other life forms. Most of the herbaceous plants, climbers, and shrubs flowered at the end of the rainy season, continuing until the beginning of the winter season. This phenomenon is probably because of the declining photoperiod (Singh and Kushwaha 2006). The flower blooming at the same time among herbs, climbers, and shrubs may increase the visits of shared pollen vectors. Many pollinators help to increase the possibility of better fertilization (Staggemeier et al. 2010). Climbers, which were usually found on the tree crowns, were able to flower in a period of low reproductive activity of trees. Both plant life forms might compete for the same habitat to show their flowers and consequently to be found by pollinators. So, a shift of flowering time of climbers and trees is expected to reduce competition for pollen vectors among species (Morellato and Leitão-Filho 1996). In addition, statistical results revealed that the mean numbers of flowering trees varied significantly from herbs, shrubs, and climbers. Conversely, there were no differences among groups of herbs, climbers, and shrubs.

## Conclusions

The present study revealed the diversity of flowering and fruiting patterns among different plant life forms based on 126 species in the deciduous dipterocarp forest at Lampang province of Northern Thailand. The present study confirms that different life forms cause different phenological patterns. Most of the herbaceous plants, climbers, and shrubs flowered from the end of the rainy season to the beginning of the winter season, while trees produced a peak of flowering during the summer season to the beginning of the rainy season. The fruiting periods showed a peak in the rainy season for herbaceous plants and trees, while climbers and shrubs usually presented their fruits in the winter season. These phenological patterns seem to be related to abiotic (e.g., rainfall, temperature, photoperiod, etc.) and biotic (e.g., pollinator, animal disperser, animal migration, etc.) factors. However, long-term study and in-depth phenological observations are needed for better understanding. The present study would be helpful for comparison to the other phenological studies in the dry forests, which are decreasing year by year due to human activities. Moreover, knowing the behavior of flowering and fruiting plants will be able to help with conservation planning in the future.

### Abbreviations

CI: Confidence interval

ANOVA: Analysis of variance

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### Consent for publication
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The author declares that they have no competing interests.

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## References

Anderson DP, Nordheim EV, Moermond TC, Gone Bi ZB, Boesch C. Factors influencing tree phenology in Taï National Park, Côte d'Ivoire. Biotropica. 2005;37(4):631-40. https://doi.org/10.1111/j.1744-7429.2005.00080.x.

Balslev H, Chantaranothai P. Leguminosae-Papilionoideae. In: Santisuk T, Chayamarit K, Balslev H, editors. Flora of Thailand, volume 4, part 3.1. Bangkok: Forest Herbarium, Royal Forest Department; 2018. p. 221-371.

Bawa KS, Kang H, Grayum MH. Relationships among time, frequency, and duration of flowering in tropical rain forest trees. Am J Bot. 2003;90(6):877-87. https://doi.org/10.3732/ajb.90.6.877.

Bhat DM. Phenology of tree species of tropical moist forest of Uttara Kannada district, Karnataka, India. J Biosci. 1992;17(3):325-52. https://doi.org/10.1007/BF02703158.

Bhat DM, Murali KS. Phenology of understorey species of tropical moist forest of Western Ghats region of Uttara Kannada district in South India. Curr Sci. 2001;81(7):799-805.

Borchert R, Renner SS, Calle Z, Navarrete D, Tye A, Gautier L, et al. Photoperiodic induction of synchronous flowering near the Equator. Nature. 2005;433(7026):627-9. https://doi.org/10.1038/nature03259.

Boyle WA, Bronstein JL. Phenology of tropical understory trees: patterns and correlates. Rev Biol Trop. 2012;60(4):1415-30. https://doi.org/10.15517/rbt.v60i4.2050.

Bridson D, Forman L. Herbarium handbook 3rd ed. Richmond: Royal Botanic Gardens, Kew; 1998.

Carvalho FS, Sartori ÂLB. Reproductive phenology and seed dispersal syndromes of woody species in the Brazilian Chaco. J Veg Sci. 2015;26(2):302-11. https://doi.org/10.1111/jvs.12227.

Corlett RT. Flora and reproductive phenology of the rain forest at Bukit Timah, Singapore. J Trop Ecol. 1990;6(1):55-63. https://doi.org/10.1017/S0266467400004028.

Croat TB. Phenological behavior of habit and habitat classes on Barro Colorado Island (Panama Canal Zone). Biotropica. 1975;7(4):270-7. https://doi.org/10.2307/2989739.

eFloras. 2022. http://www.efloras.org. Accessed 22 Jun 2022.

Elliott S, Promkutkaew S, Maxwell JF. Flowering and seed production phenology of dry tropical forest trees in Northern Thailand. Paper presented at: Proceedings : International Symposium on genetic conservation and production of tropical forest tree seed; 1993 Jun 14-16; Chiang Mai, Thailand. Saraburi: ASEAN-Canada Forest Tree Seed Centre, 1994. p. 52-62.

Frankie GW, Baker HG, Opler PA. Comparative phenological studies of trees in tropical wet and dry forests in the Lowlands of Costa Rica. J Ecol. 1974;62(3):881-919. https://doi.org/10.2307/2258961.

Handayani T. [Flowering and fruiting time of annonaceae species in Bogor Botanic Gardens]. Bul Kebun Raya. 2016;19(2):91-104. Indonesian.

International Plant Names Index (IPNI). The Royal Botanic Gardens, Kew, Harvard University Herbaria & Libraries and Australian National Herbarium. 2023. http://www.ipni.org. Accessed 15 Jan 2023.

Inuthai J. Diversity of vascular plants in deciduous dipterocarp forest at Thammasat University, Lampang Campus, Lampang Province, Thailand. Sci Technol Asia. 2021;26(3):125-41. https://doi.org/10.14456/scitechasia.2021.52.

Inuthai J. Preliminary notes on floristic composition and structural profiles of lowland deciduous forest fragments: a case study in Lampang Campus of Thammasat University, Northern Thailand. ScienceAsia. 2022;48(2):209-14. https://doi.org/10.2306/scienceasia1513-1874.2022.016.

Janzen DH. Synchronization of sexual reproduction of trees within the dry season in Central America. Evolution. 1967;21(3):620-37. https://doi.org/10.1111/j.1558-5646.1967.tb03416.x.

Janzen DH. Tropical dry forests the most endangered major tropical ecosystem. In: Wilson EO, Peter FM, editors. Biodiversity. Washington DC: National Academy Press; 1988. p. 130-7.

Kachenchart B, Kosakul T, Artchawakom T. Phenology of edible plants at Sakaerat Forest. Proceedings of the FORTROP II: Tropical Forestry Change in a Changing World. Bangkok: Kasetsart University; 2008.

Khemnark C. Natural regeneration of the deciduous forests in Thailand. Paper presented at: Tropical agriculture research series : proceedings of a symposium on tropical agriculture researches; 1978 Oct 2; Tsukuba, Japan. Tsukuba: Tropical Agriculture Research Center, Ministry of Agriculture and Forestry; 1979. p. 31-43.

Koyama H, Bunwong S, Pornpongrungrueng P, Hind N. Compositae (Asteraceae). In: Chayamarit K, Balslev H, editors. Flora of Thailand, volume 13, part 2. Bangkok: Forest Herbarium, Royal Forest Department; 2016. p. 143-428.

Kurten EL, Bunyavejchewin S, Davies SJ. Phenology of a dipterocarp forest with seasonal drought: insights into the origin of general flowering. J Ecol. 2018;106(1):126-36. https://doi.org/10.1111/1365-2745.12858.

Lampang Agromet. Climatological Data for the Period 2018-2020, Northern Meteorological Center, Meteorological Department. 2020. http://www.cmmet.tmd.go.th/forecast/pt/pt_Data/Northern_Metdata.php. Accessed 5 Feb 2023.

Lieberman D. Seasonality and phenology in a dry tropical forest in Ghana. J Ecol. 1982;70(3):791-806. https://doi.org/10.2307/2260105.

Lord Medway FLS. Phenology of a tropical rain forest in Malaya. Biol J Linn Soc. 1972;4(2):117-46. https://doi.org/10.1111/j.1095-8312.

1972.tb00692.x.

Medeiros DPW, Lopes AV, Zickel CS. Phenology of woody species in tropical coastal vegetation, northeastern Brazil. Flora. 2007;202(7): 513-20. https://doi.org/10.1016/j.flora.2006.11.002.

Mishra RK, Upadhyay VP, Bal S, Mohapatra PK, Mohanty RC. Phenology of species of moist deciduous forest sites of Similipal biosphere reserve. Lyonia. 2006;11(1):5-17.

Mohandass D, Hughes AC, Davidar P. Flowering and fruiting patterns of woody species in the tropical montane evergreen forest of Southern India. Curr Sci. 2016;111(2):404-16.

Morellato PC, Leitão-Filho HF. Reproductive phenology of climbers in a Southeastern Brazilian forest. Biotropica. 1996;28(2):180-91. https://doi.org/10.2307/2389073.

Mosissa D. Flowering and fruiting phenology of some forest plant species in the remnants of *Combretum-Terminalia* woodlands of Western Ethiopia. Acta sci agric. 2019;3(11):126-32. https://doi.org/10.31080/ASAG.2019.03.0697.

Murali KS, Sukumar R. Reproductive phenology of a tropical dry forest in Mudumalai, Southern India. J Ecol. 1994;82(4):759-67. https://doi.org/10.2307/2261441.

Nakar RN, Jadeja BA. Flowering and fruiting phenology of some herbs, shrubs and undershrubs from Girnar Reserve Forest, Gujarat, India. Curr Sci. 2015;108(1):111-8.

Nanda A, Suresh HS, Krishnamurthy YL. Phenology of a tropical dry deciduous forest of Bhadra wildlife sanctuary, southern India. Ecol Process. 2014;3:1. https://doi.org/10.1186/2192-1709-3-1.

Nanda A, Prakasha HM, Murthy YLK, Suresh HS. Seasonality, flowering and fruiting patterns in a tropical dry deciduous forest of Bhadra wildlife sanctuary, Southern India. Funct Plant Sci Biotechnol. 2009; 3(1):49-54.

Njoku E. The photoperiodic response of some Nigerian plants. J West Afr Sci Assoc. 1958;4:99-111.

Pandey AK, Tripathi NN. Diversity and distribution of aromatic plants in forests of Gorakhpur division, U.P., India. Biol Forum. 2010;2(2):25-33.

Pooma R, Suddee S. Tem Smitinand's Thai plant names, revised edition. Bangkok: Office of the Forest Herbarium, Department of National Parks, Wildlife and Plant Conservation; 2014.

Pooma R, Poopath M, Newman MF. Dipterocarpaceae. In: Santisuk T, Balslev H, editors. Flora of Thailand, volume 13, part 4. Bangkok: Forest Herbarium, Royal Forest Department; 2017. p. 557-685.

Puff C, Chayamarit K, Chamchumroon V, Esser HJ. Rubiaceae. In: Chayamarit K, Balslev H, editors. Flora of Thailand, volume 15, part 1. Bangkok: Forest Herbarium, Royal Forest Department; 2021. p. 1-235.

Ramírez N, Briceño H. Reproductive phenology of 233 species from four herbaceous-shrubby communities in the Gran Sabana Plateau of Venezuela. AoB Plants. 2011;2011:plr014. https://doi.org/10.1093/aobpla/plr014.

Singh KP, Kushwaha CP. Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Ann Bot. 2006;97(2): 265-76. https://doi.org/10.1093/aob/mcj028.

Sivaraj N, Krishnamurthy KV. Flowering phenology in the vegetation of Shervaroys, South India. Vegetatio. 1989;79(1-2):85-8.

Staggemeier VG, Diniz-Filho JAF, Morellato LPC. The shared influence of phylogeny and ecology on the reproductive patterns of Myrteae (Myrtaceae). J Ecol. 2010;98(6):1409-21. https://doi.org/10.1111/j.1365-2745.2010.01717.x.

Sukwong S, Dhamanitayakul P, Pongumphai S. Phenology and seasonal growth of dry dipterocarp forest tree species. Agric Nat Resour. 1975;9(2):105-14.

Thaithong O, Kidyoo A, Kidyoo M. Handbook of 'Asclepiads' of Thailand. Bangkok: Amarin; 2018.

Utteridge TMA, Bramley G. The Kew tropical plant families identification handbook. Richmond: Royal Botanic Gardens, Kew; 2014.

van Schaik CP. Phenological changes in a Sumatran rain forest. J Trop Ecol. 1986;2(4):327-47. https://doi.org/10.1017/S0266467400000973.

World Flora Online Plant List. 2021. https://wfoplantlist.org/plant-list/background. Accessed 22 Jun 2022.

Wright SJ, Calderon O. Phylogenetic patterns among tropical flowering phenologies. J Ecol. 1995;83(6):937-48. https://doi.org/10.2307/2261176.

Wright SJ, van Schaik CP. Light and phenology of tropical trees. Am Nat. 1994;143(1):192-9. https://doi.org/10.1086/285600.

Yap SK. The phenology of some fruit trees in a lowland dipterocarp forest. Malays For. 1982;45(1):21-35.