Phenology of selected Rutaceae collections at Purwodadi Botanic Garden in East Java, Indonesia

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Abstract. Plants change their vegetative and reproductive activities as a mechanism to adapt to climate change. This study aimed to document the flushing, flowering and fruiting patterns of 16 Rutaceae species grown at Purwodadi Botanic Garden, East Java. Observations were conducted fortnightly for four years, covering abundances of leaves, flowers and fruits, and used a scoring method from 0–4. The results showed two species with differences in their vegetative activities. Murraya koenigii (L.) Spreng, and Zanthoxylum rethsa DC shed their leaves to a class of 2 (50%). The observed flowering and fruiting patterns included frequency (continual, sub-annual, annual and supra-annual) and class (regular and irregular). The observed species fell into four different frequencies of flowering patterns: annual (nine species), sub-annual (two species), continual (four species) and supra-annual patterns (one species). Most of the observed species performed flowering patterns that differ from their fruiting patterns. Seven species showed same flowering and fruiting patterns, namely Clausena lansium (Lour.) Skeels, Euodia suaveolens var. ridleyi, Glycosmis pentaphylla (Retz.) DC., Luvunga sarmentosa Kurz., Micromelun minutum Wight & Arn., Murraya paniculata (L.) Jack and Triphasia trifolia (Burm.f.) P.Wilson. Some species belonging to regular class performed same flowering time during observation, such as Euodia suaveolens var. ridleyi, Citrus lucida (Scheff.) Mabb., Glycosmis pentaphylla (Retz.) DC., Lunasia amara Blanco, Melicope latifolia (DC.) T.G. Hartley, Murraya paniculata (L.) Jack., Triphasia trifolia (Burm.f.) P.Wilson, and Zanthoxylum rhetsa DC.

1. Introduction
Phenology of plants plays an important role in climate change research as it changes as the climate shifts [1]. Precipitation and temperature shifts have caused some changes in plant phenology patterns [2]. The two climate variables change the patterns and productions of flowering and fruiting [3]. Some research on phenological responses to climate change has been published. Winarni et al [4] explained the changes in Dipterocarps phenology patterns in Bukit Barisan National Park, Lampung, as an adaptation to climate change. The study area's Dipterocarps did not produce mass flowering, but some major flowering preceded by droughts. Chapman et al [5] observed fruit phenology responses to climate change in dry tropical region Uganda for 30 years. They concluded that climatic factors (more rainfall and higher temperature) had changed the observed species' flowering and fruiting behaviors.

Botanical gardens as an ex-situ conservation institution play important roles in implication of climate change research. Botanical gardens, often with integrated herbaria, hold collections and other resources that enable them to do research and monitor plant behavior changes concerning climate changes, such as temperature and rainfall shifts. Thus, they contribute to our knowledge of how plants respond to climate change [1].
Purwodadi Botanic Garden (PBG) serves as an ex-situ plant conservation, especially dry, lowland tropical plants. The garden holds 179 families, 984 genera and 2098 species of plants [Registration Unit PBG, unpublished]. These collections originated from throughout the world, some of which were from places with different climates. The climate of PBG is categorized as rather wet to dry (Group C – Group E), often with seasonal changes [6].

Some research on phenology patterns had been carried out at PBG. Climatic seasonal variations appeared to affect the phenology of some collections at PBG. Some fruit trees collection changed their flowering and fruiting behaviors due to changes in rainfall [7]. Another research also showed shifts in the flowering and fruiting time and patterns of some Annonaceae collections [8]. Different phenological patterns, however, were performed by some Cinnamomum collections [9]. Three species of Cinnamomum (C. iners, C. sintoc and C. verum) perform flowering activities regularly, regardless of changes in the garden’s microclimate. The flowering of one species of C. burmanii, however, is influenced by drought. This collection produced fewer flowers for several years due to very low rainfall.

Rutaceae, commonly known as citrus family, is characterized by oil glands on its leaves responsible for the typical aromatic smell. Rutaceae has economic importance due to it is edible fruits in the genus Citrus. Other Rutaceae species are used as medicine, timber, spice, perfume, and ornamental. The habit of the family are shrubs, woody climbers, trees and a few herbaceous perennials. The family is distributed throughout the world, especially in warm temperate and tropical regions [10].

The PBG Rutaceae collections comprising 19 genera and 32 species were mainly collected through plant explorations and seed exchange from Indonesia and other countries. This study aimed to document the flushing, flowering and fruiting patterns of 16 Rutaceae species grown at PBG. It also provided information that will be useful to support the conservation of the Rutaceae species. In addition, knowledge of fruiting patterns could be considered when seed harvesting and propagation of these collections need to be done.

2. Methods
This study was carried out at Purwodadi Botanic Garden (PBG), Pasuruan, East Java. This garden is located at an altitude of 300 meters above sea level, with an average annual rainfall of 2283 mm. During 2006–2010, dry seasons (monthly rainfall <100 mm) took place from June to October, wet seasons (monthly rainfall >100 mm) occurred from November to May (Figure1) and average humidity was 78% and temperature 19–34 °C [Registration Unit PBG, unpublished].

![Figure 1. Rainfall, maximum and minimum temperature variation in PBG during four years](image)

Sixteen Rutaceae collections of PBG were selected for observation (Table 1). Three plants of each species were observed for their vegetative and reproductive activities fortnightly for four years. The selected samples covered trees, shrubs, and woody climbers with a life span of 8–27 years.
Table 1. List of Rutaceae collections of Purwodadi Botanic Garden used in the study

| No. | Species                      | Habitus | Local name          | Origin                          | Altitude (m asl.) | Uses         |
|-----|------------------------------|---------|---------------------|--------------------------------|-------------------|--------------|
| 1   | *Clausena harmandiana* (Pierre) Guillaumin | S, T    | Kasai               |                                 | 0–400             | medicine     |
| 2   | *Clausena lansium* (Lour.) Skeels, Arn. | T       | Wampi               | China                           |                   | edible fruit |
| 3   | *Citrus lucida* (Scheff.) Mabb. | T       | Kawista kerikil    | Java                            | 0–400             | edible fruit |
| 4   | *Euodia suaveolens* var Ridleyi DC. | S       | Zodia               | Papua                           |                   |             |
| 5   | *Glycosmis pentaphylla* (Retz.) DC. | S       | Ki kopo             | Moluccas                        | 0–1000            | medicine     |
| 6   | *Lunasia amara* Blanco          | S, T    | Sanrego, Kemaitan, Pamaitan, Betta beta | Yamdena, Moluccas | 0–900             | medicine     |
| 7   | *Luvunga sarmentosa* Kurz.     | WCl     | Saluang bilung, Ki racun |                   | 0–1700            | medicine     |
| 8   | *Melicope latifolia* (DC.) T.G. Hartley | T       | Telor ujat          | Bualemo, Gorontalo               | 0–600             | medicine     |
| 9   | *Micromelun minutum* Wight & Arn. | T       | Lada, Kayu sirit, Sesi |                   | 0–1000            | medicine     |
| 10  | *Murraya exotica* L.          | S       | Jeruk jasmin        | Java                            | 0–300             | ornament     |
| 11  | *Murraya koeningii* (L.) Spreng. | S       | Asam india, Kemuning cina, Daun kari | Semarang, Central Java | 0–300             | spice, medicine |
| 12  | *Murraya paniculata* (L.) Jack | S       | Kemuning            | Sempu Is.                       | 0–300             | perfume, medicine |
| 13  | *Swinglea glutinosa* (Blanco) Merr. | T       | Tabog               | Bogor Botanic Garden            | 0–1500            | medicine     |
| 14  | *Triphasia trifolia* (Burm.f.) P.Wilson | S       | Jeruk kingkit, Jeruk ranti | Lamongan, East Java | 0–300             | medicine     |
| 15  | *Zanthoxylum rethsa* DC.       | T       | Kayu lema, Panggal buaya | Sumba                        | 0–400             | medicine, timber |
| 16  | *Zanthoxylum ovalifolium* Tutcher | S       | -                   | Kangean Is.                     |                   | essential oil|

Note: S = shrub, T = tree, WCl = woody climber

The phenology of selected Rutaceae species was documented from September 2006 to August 2010 (except *Citrus lucida* observed from 2009–2012). The observation covered phenological characteristics, such as the abundances of leaves (young, mature, senescence), flowers (bud, bloom) and fruits (immature, ripe). These characteristics were assigned to five different classes based on the crown coverage, namely 0 (0 %), 1 (1–25 %), 2 (26–50 %), 3 (51–75 %) and 4 (> 75 %) [11].

Anderson et al [12] defined vegetative activities as the formation and development of leaves (young, mature, senescence, and reproductive activities as the formation and development of flowers and fruits (from buds to blooms and from immature to ripe fruits). Vegetative activity patterns were classified as continual and periodic. Reproductive activity patterns were determined by flowering and fruiting frequency per year and classified into continual (producing flowers or fruits continually throughout a year with sporadic brief breaks), sub-annual (producing more than one cycle of flowering or fruiting per year), annual (producing one major cycle of flowering or fruiting per year) and supra-annual (producing
one cycle of flowering or fruiting in more than one year). Flowering and fruiting patterns were also assigned to classes (regular and irregular) [13].

3. Results and discussions

3.1. Vegetative activities patterns

All observed Rutaceae species showed variation in vegetative growth patterns. Seven species appeared to be continual leaf-flushing/leaf-falling and ten species were periodic. Continual species, such as *Clausena lucida*, *Euodia suaveolens* var. *Ridleyi*, *Lunasia amara*, *Melicope latifolia*, *Murraya exotica*, *M. paniculata* and *Triphasia trifolia* produced young, mature and senescence leaves throughout the year. Whereas, leaf-flush and leaf falling of the periodic species occurred at the end of dry seasons to the onset of wet seasons (*Clausena harmandiana*, *C. lansium*, *Micromelum minutum*, *Swinglea glutinosa*, *Zanthoxylum ovalifolium*) or only in wet seasons (*Glycosmis pentaphylla*, *Luvunga sarmentosa*). All above species were categorized as evergreen species with continual mature leaves and continual/periodic young and senescence leaves. Two species showed differences in their vegetative activities, namely *Murraya koenigii* and *Z. rhetsa*. Both species presented periodic leafless at the end of dry seasons (September–October) in four years (Figure 2). They sprouted young buds after shedding their leaves to class of 2–3 (more than 50%) (Figure 2.). *Murraya koenigii* is a more or less deciduous shrub or tree, and has aromatic leaves [14], while *Z. rhetsa* is categorized as deciduous shrub or tree [15].

![Vegetative activities patterns of M. koenigii and Z. rhetsa.](image)

**Figure 2.** Vegetative activities patterns of *M. koenigii* and *Z. rhetsa*. *yl* = young leaves, *ml* = mature leaves, *sl* = senescence leaves

3.2. Flowering and fruiting patterns

Based on the flowering and fruiting time, most of the observed Rutaceae species flowered and fruited in both dry and rainy seasons (Table 2). Some species showed differences in their flowering and fruiting times, such as *Clausena lansium*, *Murraya koenigii*, *Zanthoxylum ovalifolium* and *Z. rhetsa*. *Clausena lansium* flowered in dry seasons, but they fruited in rainy and dry seasons. In contrast, *Murraya koenigii* flowered in rainy and dry seasons, but they fruited in rainy season. *Micromelum minutum* was the only species that flowered and fruited in rainy season.
Table 2. Vegetative and reproductive patterns of selected Rutaceae species

| No. | Species                                      | Vegetative Activity | Time of Flowering | Pattern of Flowering | Pattern of Fruiting | Class     |
|-----|---------------------------------------------|---------------------|-------------------|---------------------|---------------------|-----------|
|     |                                             |                     |                   |                     |                     |           |
| 1   | Clausena harmandiana (Pierre) Guillaumin   | P                   | C                 | P                   | P                   | RD RD RD v v r r |
| 2   | Clausena lansium (Lour.) Skeels, Am.       | C                   | P                 | P                   | P                   | RD RD v v r r |
| 3   | Citrus lucida (Scheff.) Mabb.              | C                   | C                 | P                   | P                   | RD RD v v r r |
| 4   | Eudodia suaveolens var Ridleyi            | C                   | C                 | P                   | P                   | RD RD v v r r |
| 5   | Glycosmis pentaphylla (Retz.) DC.          | P                   | C                 | P                   | P                   | RD RD v v r r |
| 6   | Lunasia amara Blanco                       | C                   | C                 | P                   | P                   | RD v v r r |
| 7   | Luvunga sarmentosa                         | C                   | C                 | P                   | P                   | RD v v r r |
| 8   | Melicope latifolia (DC.) T.G. Hartley     | C                   | C                 | P                   | P                   | RD - v v r |
| 9   | Micromelun minutum Wight & Am.             | P                   | C                 | P                   | C                   | R RD RD v v r |
| 10  | Murraya exotica L.                         | C                   | C                 | R                   | C                   | RD v v r |
| 11  | Murraya koenigii (L.) Spreng.              | P                   | C                 | P                   | P                   | RD R v v r |
| 12  | Murraya paniculata (L.) Jack               | C                   | C                 | P                   | P                   | RD RD v v r |
| 13  | Swinglea glutinosa (Blanco) Merr.          | P                   | C                 | P                   | P                   | RD RD v v i |
| 14  | Triphasia trifolia (Burm.f.) P.Wilson      | C                   | C                 | P                   | P                   | RD RD v v r |
| 15  | Zanthoxylum ovalifolium Tutche             | P                   | C                 | P                   | C                   | RD R v v r |
| 16  | Zanthoxylum rethsa DC.                     | P                   | C                 | P                   | C                   | RD R v v r |

Note: yl= young leaves; ml= mature leaves; sl = senescence leaves; P= periodic; C= continual; sA= sub Annual; A= Annual; spA= supra Annual; R= rainy season; D= dry season; RD = rainy & dry season; r= regular; i= irregular

This study showed three different frequencies of flowering patterns: annual (ten species), sub-annual (two species), and continual (four species). Most of the observed Rutaceae species produced flowers once a year (annual pattern), namely Clausena lansium, Citrus lucida, Glycosmis pentaphylla, Luvunga sarmentosa, Melicope latifolia, Micromelun minutum, Murraya koenigii, Swietenia glutinosa, Zanthoxylum ovalifolium and Z. rethsa. Sub-annual patterns (flowered 2–3 times a year) were presented by Clausena harmandiana and Murraya exotica (Table 3). Meanwhile, some species flowered throughout the year; Eudodia suaveolens var. Ridley, Lunasia amara, Murraya paniculata and Triphasia trifolia. Two species indicated flowering pattern changes, namely Luvunga sarmentosa and Citrus lucida. Obvious changes occurred in the flowering pattern of Luvunga sarmentosa, in which this species was unable to produce flowers in 2009 (Table 3). The decreasing of annual rainfall from 2140 mm (2008) to 1763 mm (2009) appeared to affect the species’ flowering. The same phenomenon also occurred to Citrus lucida, in which the decreasing of annual rainfall from 3242 mm (2010) to 2619 mm (2011) and 1930 mm (2012) caused shorter flowering times (Figure 3).
Table 3. Timing of flowering and fruiting of Rutaceae collections at Purwodadi Botanic Garden

| Species | 2006   | 2007   | 2008   | 2009   | 2010   |
|---------|--------|--------|--------|--------|--------|
|         | S O N D| J F M A M J | AS O N D| J F M A M J | AS O N D| J F M A M J | AS O N D| J F M A M J | AS O N D| J F M A M J |
| 1 Clausena harmandiana (Pierre) Guillaumin | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 2 Clausena lansium (Lour.) Skeels, Arn. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 3 Euodia suaveolens var. Ridleyi | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 4 Glycosmis pentaphylla (Retz.) DC. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 5 Lamasia amara Blanco | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 6 Luvunga sarmentosa Kurz. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 7 Melicope latifolia (DC.) T.G. Hartley | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 8 Micromelum minutum Wight & Arn. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 9 Murraya exotica L. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 10 Murraya koenigii (L.) Spreng. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 11 Murraya paniculata (L.) Jack | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 12 Swinglea glutinosa (Blanco) Merr. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 13 Triphasia trifolia (Burm.f.) P.Wilson | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 14 Zanthoxylum ovalifolium Tutcher | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |
| 15 Zanthoxylum rethusa DC. | Y Y Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y | Y Y Y Y Y Y |

Note: Ŷ = flowering time; ● = fruiting time

Most of the observed Rutaceae species showed flowering patterns that differ from their fruiting patterns. There were, however, species that showed same flowering and fruiting patterns, namely Clausena lansium, Euodia suaveolens var. ridleyi, Glycosmis pentaphylla, Luvunga sarmentosa, Micromelum minutum, Murraya paniculata and Triphasia trifolia (Table 2 and Table 3). In general, the different flowering and fruiting patterns were due to duration of the longer fruiting time. Melicope latifolia did not produce fruit because the observed plants appeared to be male plants.
Based on the regularity of the reproductive activity, most of the observed Rutaceae species belonged to the regular class and performed the same flowering and fruiting time (Table 2). This showed that they were adaptable to the microclimate at PBG. Some species were categorized as irregulars, such as *Clausena lansium* and *Luvunga sarmentosa*. *Clausena lansium* was originated from China through a seed exchange, therefore it had to adapt to the new microclimate.

Flowering plants' production is greatly influenced by regular phenological activities, such as flushing, flowering, and fruiting. In the tropics, climatic variables, such as rainfall and temperature, influence these activities. The shifts of wet seasons have impacted the phenological activities as they depend on the habitat's hydro condition [16]. *Micromelum minutum* produced flowers regularly in rainy seasons. This is similar to the phenomena in its natural habitat. This species grows in areas with a pronounced dry season and flowering is restricted to the wet season [17]. However, this species' fruiting was categorized as irregular due to its fruiting activity only recorded in 2007. *Zanthoxylum ovalifolium* also showed a similar reproductive class to *Micromelum minutum*.

**3.3. Phenological implications for ex situ conservation of the Rutaceae species**

The final phase of conservation is successful establishment of seedlings and saplings in an environment where they can grow into reproductively mature trees. This successful regeneration allows a species to be maintained over time at a particular habitat, or successful regeneration away from the existing population allows each species to extend its range into new habitats. Reproductive phenology has a great role in designing successful ex situ conservation management plans for any plant population, particularly the endangered plant population [18]. Therefore, reproductive phenology data are very important, particularly for species experiencing changes in reproductive patterns and having irregular reproductive activities, such as *Citrus lucida*. *Luvunga sarmentosa*, *Micromelum minutum* and *Zanthoxylum ovalifolium*. Such species should be given more considerations in collection management, particularly concerning mitigating climate change in the future. Some efforts should include watering plant collections before their reproductive activity.

**4. Conclusion**

Vegetative activities of Rutaceae species grown at Purwodadi Botanic Garden took place continually and periodically. This activity did not change much for four years. However, the reproductive activities of some species indicated some changes in their flowering and fruiting patterns, such as those of *Citrus lucida* and *Luvunga sarmentosa*. *Micromelum minutum* and *Zanthoxylum ovalifolium* showed a regular flowering time and an irregular fruiting time.
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