Flowering and fruiting phenology of jackfruit (Artocarpus heterophyllus Lam.) from Sumatra landraces in ex situ conservation area in Karangmojo, Yogyakarta

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Abstract. This study aimed to determine the flowering and fruiting phenology of jackfruit originated from Sumatra landraces planted in ex situ conservation in Yogyakarta within the 2018 and 2019 flowering periods. Flowering ontogeny and phenology were observed following Owens and Pushpakumara methods. Results found five developmental stages of male inflorescences, which last in 64-101 days, ended by the drought and abscissed of the males. Female inflorescences undergo five stages which take 92-160 days in total. Differences in rainfall and the dry season period resulted in different onset and duration of flowering. In 2018, which has more rainfall and a shorter dry season, flowering initiates lately (February -June) with a longer duration (6 months). In 2019, the less rainfall and more extended dry season resulted in early flowering (January -April) with a shorter duration (4 months). The Medan landrace flowered later and longer. Flowering synchrony occurred between sexes within the same tree, but there was asynchronous flowering among individual trees. Water availability is crucial in flowering and fruit production. Flowering stimulation and pollination management may also be conducted to increase flower production, pollinating agents, and fruit production and synchronize the flowering.

1. Introduction

The phenology of flowering and fruiting plays an important role in plant reproduction since it determines the availability and fitness of the female and male reproductive organs in the population. The availability of male and female reproductive organs affects the success of the reproductive processes by ensuring fruit and seed production in a certain flowering period [1, 2]. Information on reproductive phenology is crucial in determining the timing of seed harvesting, as well as basic information in arranging the conservation and breeding strategies for a given species [2]. Particularly in fruit-producing species, knowledge of phenological stages is crucial in arranging the plan of nutrient management and harvesting [3].

Artocarpus heterophyllus Lam. (Moraceae), hereinafter referred to as jackfruit, is the most widespread species of the genus Artocarpus which has important value in supporting the economy in Southeast Asia [4, 5]. Jackfruit is native to India and is believed to have originated in the rainforest of Western Ghats. It was introduced in Bangladesh, China, Indonesia, Myanmar, Malaysia, Nepal, Philippines, Sri Lanka, Thailand, Vietnam, as well as its introduction in Latin American and East African countries [6-8]. Jackfruit is a multipurpose species with a broad utility for fodder, timber, fuel,
medicinal and industrial products [3]. Ripe fruits are primarily used as dessert, while the unripe ones are used for vegetables. Flakes and seeds are processed into various products considering their nutritional properties [9]. Jackfruit is a rich source of carbohydrates, protein, potassium, calcium, and vitamins, and therefore is used for antioxidative and medicinal properties [10].

Jackfruit grows well in equatorial to subtropical climates at 1 m to 1600 m above sea level (asl), with an average rainfall of 1000 to 2400 mm [4]. In better environments, such as in areas with continuous light and rainfall, jackfruit bears flowers and fruits all year round [11, 12]. However, in areas with distinct dry and wet seasons, jackfruit only flowers during the wet season [5]. Flowering frequency of jackfruit can be annual (once a year), biannual (once every two years), sub-annual (more than twice a year), or irregular (uncertain) [1, 12, 13]. Jackfruit is self-incompatible and has a cross-mating preference [13-15]. This difference in flowering can be due to climatic conditions [1, 3, 16, 17] and genetics [6, 11, 14, 16], which is represented in the variation of flowered individuals, flowers abundance, flowering initiation and duration, and final fruit production [1, 4, 5].

Jackfruit is widely adapted to climatic conditions in different agro-ecological zones, and therefore, it may affect its phenological patterns [3]. Each agro-ecological zone has its own pattern, which affects the onset and duration of flowering and fruiting [3, 16, 17]. As well as the effect of climatic conditions, the genetic factors might also be responsible for these differences [6, 11, 12, 16]. Accordingly, several studies reported the presence of early and late maturing varieties [12], the varieties which perform secondary flowering [11], and varieties that produce fruits throughout the year [7].

Researches on the flowering and fruiting of jackfruit have been conducted in several areas in Malaysia, Sri Lanka, the Philippines [1, 16], Thailand [8], India [3, 6], Bangladesh [7, 14], Uganda [11, 18], China [12, 17] and South-Florida [13, 19], but similar research from Indonesia is still very limited. Therefore, this research is considered necessary since this species is a priority in the regional development program, particularly in Yogyakarta Region, Java Island [20]. Jackfruit is a primary source of ‘gudeg’, an iconic traditional food of Yogyakarta. The pulp of young fruit is cooked as dishes in several islands such as Java and Sumatra. Ripe fruit is eaten fresh or made into various local foods (‘dodol’ and ‘kolak’ in Java), jam, jelly and paste, or preserved as candy by drying. Jackfruit woods, having an orange or red-brown color, is highly resistant to termites and decays, and therefore are widely used for buildings and furniture. A yellow dye is extracted from the wood to dye fabrics. Moreover, the leaves are commonly used to feed the cattle [5].

The jackfruit genetic conservation program in Indonesia started in 2001 with the establishment of an ex-situ conservation area in Karangmojo, Yogyakarta; consists of 390 families originated from 11 landraces in Kalimantan, Sumatra, Sulawesi, Java and Nusa Tenggara. The best growth is performed by the landrace of Central Java, while the landrace of Sumatra is the best in wood quality [20]. Since fruit is the main product of this species, understanding flowering and fruiting phenology are important to gain the best quality and quantity of fruits. This study focused on landraces from Sumatra for several considerations. According to personal communication with the manager and local farmers, the Sumatra landraces produce the most abundant fruits compared to other landraces. The Sumatra landraces were also reported to have good wood quality [20] and could produce fruits through the year, both in the rainy and dry seasons [21]. Other landraces such as Kalimantan, Sulawesi and Nusa Tenggara performed less survival, adaptability and resistance [20]. However, some families produce more fruits [21]. This study aimed to determine the flowering and fruiting phenology of A. heterophyllus from Sumatra landraces in an ex-situ conservation area in Karangmojo, Yogyakarta. Information on the reproductive phenology of targeted landraces will help in determining the timing of fruit harvesting. This information is also crucial in arranging the conservation and breeding strategies, especially those related to flowering stimulation, controlled pollination (hybridization), and fruit production in the best quantity and quality.
2. Methodology

2.1. Study sites

This research was conducted at the jackfruit ex situ conservation area in Karangmojo, Gunungkidul, Yogyakarta (7°56’4.8” S to 110° 40’35.4” E; 160 m asl). According to Schmidt and Ferguson, this area is located in the Northern Zone of Gunung Sewu, Java Island, representing the tropical monsoon climate under the C type, with an annual rainfall of 1330 mm to 2409 mm. Soils are latosol with limestone rocks. The plantations are composed of 390 families originating from 11 landraces (East Java, Central Java and Yogyakarta, West Java, Bali, North Sumatra, Riau, Lampung, East Kalimantan, South Kalimantan, Southeast Sulawesi, and Lombok) [20]. The observation was made during two flowering periods, started in February 2018 at the emergence of the reproductive buds, and ended in August 2019 at the ripening phase of fruits of the second period.

2.2. Methods

2.2.1. Selection of trees and reproductive buds. Flowering and fruiting phenology was observed on three Sumatra landraces, i.e., Medan, Riau and Lampung. Medan landrace (3°30’ N to 98° 35’ E; 2-37 m asl) experiences tropical rainforest climatic type which receives rainfall throughout the year, with an annual rainfall of 2200 mm and temperature of 27°C. Pekanbaru landrace (0°25’ N to 101° 14’ E; 5-50 m asl) represents tropical climatic type with a distinct dry and wet season, with an annual rainfall of 435 mm and temperature 34-35°C. Lampung landrace (50°20’ S to 105° 28’ E; 3060 m asl) experienced humid tropical climatic type which received rainfall throughout the year, with an annual rainfall of 1800 mm and temperature of 26°C [22]. Each of the landraces was located in the community forest or local garden [20].

Each landrace was represented by three sample trees which were selected by purposive sampling method based on the following criteria: (1) have a sufficient number of reproductive buds (footstalks); and (2) the reproductive buds (footstalks) emerged simultaneously (at approximately the same time), both within the tree and between the trees sampled. Sample trees have similar spacing, 3 x 3 m, and are located in the middle of the ex-situ conservation area. The number of sample trees was based on the availability of flowering trees at the time of observation. The number of sample trees in this research was similar to [14], which also observed three landraces with three replications.

In each of sampled tree, five reproductive buds (footstalks) were selected following the methods of [1] and [14], in which purposive sampling was conducted following the criteria: (1) the reproductive buds had just emerged (at a very early initiation phase); and (2) within the sampled tree, the reproductive buds emerged simultaneously.

2.2.2. Observation on flowering ontogeny. The observation was conducted following modified methods described by [1] and [2]. Five single buds on each selected individual were marked, and the flowering phases were then observed during the flowering period to observe flowering ontogeny, which refers to the developmental phases of flowers. Observations were made every five days throughout the flowering season, starting from the formation of reproductive buds until the maturity of fruit and seeds. The observation interval is based on [1], which confirmed that three to six days is the ideal range for jackfruit flowering observation.

Flowering parameters (floral initiation, flowering period, and flowering developmental phases) were recorded, and flower structures were observed. Floral initiation, or the beginning of flowering, refers to the onset of the emergence of the first visible floral buds, while the flowering period is the interval of flowering from the bud emergence to the seed maturity. Flowering developmental phases are the stages and duration of each developmental phase in one flowering period. Observation in flower structures comprises (1) changes in morphology, size and color of flower parts, and (2) morphological signs of maturity of the reproductive organs [1, 2].

2.2.3. Observation on flowering phenology. Flowering phenology, which refers to the correlation between flowering and its environmental conditions, was observed following the method described by [2]. The flowering and fruiting ontogeny was correlated to the environmental factors, such as rainfall,
air humidity and air temperature, in the form of a phenological table. Air humidity and temperature were measured in a weekly-based measurement using a thermohygrometer. The rainfall data were obtained from the Department of Agriculture, Food Crops and Horticulture, Gunungkidul District.

3. Results and Discussion

3.1. The ratio of male and female inflorescences

In this study, the ratio of male flowers was higher than female flowers at the beginning of the flowering period (Table 1). However, the ratio of female flowers increases at the end of the flowering period since male flowers were dropped after the pollen lost its viability. A similar result was reported in Bangladesh [4, 14], Sri Lanka [1], India [3, 16], and Florida [13, 19], which confirmed that the ratio of jackfruit male flowers is generally higher than that of female ones at the beginning of the flowering period; but at the end of the flowering period, the ratio of female flowers was increased. In Bangladesh, 87.56% to 95.98% of the flowers produced are male, while 4.02% to 12.44% are female [14]. Another study [4] found 3% to 40% female flowers and more than 90% male flowers. In Sri Lanka, 97% of male flowers are found at the beginning of flowering, but decrease to 8% at the end of the flowering period [1]. In India, the ratio between female and male spikes varies with the genotype and climatic conditions, ranging from 4.2% to 26.8%. The initial reproductive phase in jackfruit is dominated by male inflorescences, which signifies its protandrous nature [3].

Table 1. The ratio of male and female inflorescences in each sample tree.

| Sample Tree         | Female Ratio (%) | Male Ratio (%) |
|---------------------|------------------|---------------|
| Medan 205 (2) VII   | 22.22            | 77.78         |
| Medan 205 (3) VII   | 20.00            | 80.00         |
| Medan 250 (1) VIII  | 63.16            | 36.84         |
| Pekanbaru 251A (1) VIII | 78.57            | 21.43         |
| Pekanbaru 292 (1) VIII | 82.61            | 17.39         |
| Pekanbaru 291 (3) VII | 22.22            | 77.78         |
| Lampung 317 (VIII)  | 30.23            | 69.77         |
| Lampung 308 (2)     | 24.00            | 76.00         |
| Lampung 327 (3) (VIII) | 42.86            | 57.14         |

However, the female flower ratio was higher in some individuals at the beginning of the flowering period. This condition was observed in two individuals from the Pekanbaru landrace and one from Medan. A similar anomaly was also reported in other studies, and this can be caused by genetic factors [3, 14, 16], tree age [14], or different allocations of energy reserves in each flowering period [1, 3].

3.2. Flowering ontogeny of jackfruit

The jackfruit flower is monoecious, with the separated male and female inflorescences in the same individual tree. Jackfruit has a cauliflory type, in which inflorescences emerge from the main stem or older branches rather than the axillary or terminal parts. At first initiation, floral buds covered with stipule emerge from the main stem or older branches, and within four to eight weeks, they gradually elongate. Some authors refer to the bud as footstalk, which is defined as the short axillary leafy twigs or buds that will develop to be the inflorescence [1, 12]. At the maximum elongation, the stipule opens, showing the male or female inflorescences (Figure 1).
Figure 1. Footstalk initiation (the emergence of floral bud covered with stipule) and elongation (a-c); footstalk in maximum elongation (d); the opening of stipules and emergence of inflorescences (e).

There were five developmental stages of male inflorescences (Figure 2; Table 2). Phase 1 is the footstalk initiation and elongation, which lasts 30 to 45 days. The male inflorescences can be distinguished by the longer but thinner structure in comparison to the female ones. In phase 2, a maximum elongation, the opening of stipules, and the emergence of male inflorescences take 14 to 21 days. The yellowish-green male flower buds emerged on a thinner peduncle. Male inflorescences usually grow above the female ones. Male inflorescences consisted of abundant small single male flowers, and every single flower had one stamen. Male flowers are light green when young but turn into dark green to brown as the flowers aged. Phase 3 is the pollen maturity, which takes 14 to 21 days. At maturity, anthers will be dehisced to spread mature pollen. Mature pollens are yellowish and stickier, ready to fertilize within a week. Phase 4 is the end of viability which takes 3 to 7 days, recognizable when the yellow anthers turn brown or grey until finally abscissed. Unlike female inflorescences, the males do not continue growing after spreading pollens but abscissed within four to eight weeks after the stipule open. Male inflorescences will be covered by black mold in the last phase, indicating the viable phase's end. Male inflorescences were drought and abscissed at the end of the fertilization phase, and this may take 3 to 7 days. In total, 64 to 101 days were needed to complete the male developmental phases.

Table 2. Developmental stages of male inflorescences.

| Stage   | Developmental stages of male inflorescences                                                                 | Days    |
|---------|------------------------------------------------------------------------------------------------------------|---------|
| Stage 1 | Footstalk initiation and elongation (Figure 1a to 1c)                                                      | 30 to 45|
| Stage 2 | Maximum elongation of footstalk (Figure 1d), the opening of stipules, and the emergence of male inflorescences (Figure 1e) | 14 to 21|
| Stage 3 | Pollen maturity (pollen are sticky, yellow in color); anthers dehiscence; pollination and fertilization (Figure 2a to 2c) | 14 to 21|
| Stage 4 | End of pollen viability; the drought and abscission of anthers (Figure 2d)                                | 3 to 7  |
| Stage 5 | The dry up and abscission of male inflorescences (Figure 2e)                                             | 3 to 7  |
| Total   |                                                                                                           | 64 to 101|

Figure 2. Developmental stages of male inflorescences: the emergence of male inflorescences from the opening stipules of footstalk (a); pollen maturity (pollen are sticky, yellow in color); anthers dehiscence; pollination and fertilization (b-c); end of pollen viability; the dry up and abscission of anthers (d); and the dry up and abscission of male inflorescences (2e).
There are five stages of development of female inflorescences (Figure 3; Table 3). Phase 1 is the footstalk initiation and elongation, which occurs within 30 to 45 days. The female footstalks can be distinguished by the bigger but shorter size and more rounded shape in comparison to the male ones. Phase 2 is the maximum elongation of footstalks, followed by the opening of stipules and the emergence of female inflorescences, which take 10 to 21 days. The light green female inflorescences usually have a thicker peduncle in comparison to those of males. Female inflorescences bear abundant small single female flowers; each has one pistil and one ovary (unilocular) and is attached to receptacles (these receptacles are fleshy and edible when the fruit is ripe). The pistil is white and sticky, and the stigma is yellowish and lighter in color when receptive. Phase 3 is the beginning of stigma receptivity which will be followed by the pollination and fertilization processes. Stigmatic receptivity can be identified by liquid secretion, while pistil is straight in shape and white in color. Stigma remains receptive for 10 to 14 days. Phase 4 is the end of stigma receptivity. Stigma will dry out and abscissed, followed by the transformation into young fruits (syncarps). This phase takes 21 to 45 days. In the last phase, 21 to 45 days is needed to develop syncarps until maturity. In total, it takes 92 to 160 days to complete the female developmental phases. This result is similar to those reported in Bangladesh and India, in which fruits were mature after approximately 150 days [4]. However, jackfruit in a cooler environment required a longer period for maturity, such as those planted in the temperate regions of Srilanka and India, which needed 180-240 days to complete its developmental stages [1].

| Stage  | Developmental stages of female inflorescences                                      | Days   |
|--------|------------------------------------------------------------------------------------|--------|
| Stage 1| Footstalk initiation and elongation (Figure 1a to 1c)                               | 30 to 45 |
| Stage 2| Maximum elongation of footstalk (Figure 1d), the opening of stipules, and the emergence of female inflorescences (Figure 1e) | 10 to 21 |
| Stage 3| Stigma receptivity (stigma are sticky, straight, white in color); pollination and fertilization (Figure 3a to 3c) | 10 to 14 |
| Stage 4| End of stigma receptivity; the dry up and abscission of stigma; the formation of young fruits (syncarps) (Figure 3d) | 21 to 45 |
| Stage 5| The development of syncarps until maturity (Figure 3e to 3f)                        | 21 to 35 |
| Total  |                                                                     | 92 to 160 |

**Figure 3.** Developmental stages of female inflorescences: the emergence of female inflorescences from the opening stipules of footstalk (a); stigma receptivity (stigma are sticky, straight, white in color); pollination and fertilization (b-c); end of stigma receptivity; the dry up and abscission of stigma; the formation of young fruits (syncarps) (d); and the development of syncarps until maturity (e-f).
Jackfruit has a multiple aggregate type, arranged by the fusion of multiple flowers in an inflorescence. The fruit consists of white and sticky fibrous pulp, which bears abundant seeds. Several authors refer to mature fruit as syncarps [1, 3-5]. The single fruit axis is the modified structure of the mature inflorescence axis which was rigid and slightly fleshy. The axis contains elongated broad parenchyma and vascular elements as well as numerous laticiferous, which are inedible. The fruitlets (true fruits) were indehiscent and consisted of the fleshy pericarp (aril) surrounding the seeds. The lower free part of the perianth became fleshy and edible [1, 9, 10]. In this study, syncarps matured 92 to 160 days after the initiation of inflorescence from the stipule.

3.3. Flowering and fruiting phenology of jackfruit during 2018 and 2019

Rainfall affects water availability and soil moisture. In the rainy season, plants maximize the nutrients and water uptake to accumulate food reserves and store as much energy. Therefore, vegetative growth is more dominant in the rainy season. The transition to the dry season is marked by reduced rainfall, which results in increased light intensity, length of exposure and air temperature.

Water stress promotes flower initiation, especially in tropical tree crops [2]. Therefore, most flowering in the tropics occurs during the transition from the rainy to the dry season. The transition to the dry season is marked by reduced rainfall, which results in increased light intensity, length of exposure and air temperature. These changes increase metabolic activity in plants, which provides abundant energy for flowering.

The length of the dry and wet months differed between the two years of observation in Karangmojo. The year 2018 had a longer rainy season, and the dry period only occurred from April to September 2018 (6 months). The rainfall in 2018 was 1807 mm year\(^{-1}\). Meanwhile, 2019 had a longer dry season. The rain did not occur from March to October 2019 (8 months). As a result, the rainfall in 2019 was 1490 mm year\(^{-1}\).

Compared to the environmental conditions in the area of origin, the highest rainfall in Medan is 2200 mm year\(^{-1}\), Pekanbaru is 435 mm year\(^{-1}\), and Lampung is 1800 mm year\(^{-1}\). Therefore, the environmental conditions in the Sumatra region are almost similar to those in Karangmojo. Therefore, it might explain the ability of Sumatra landraces to adapt to environmental conditions in Karangmojo.

Observation on flowering and fruiting phenology requires tree samples that consistently bear flowers and fruits in the two years of observation (2018 and 2019). A two-year observation confirms three individuals with a consistent flowering: Medan 205 (2), Medan 205 (3), and Pekanbaru 291 (1). Therefore, phenological comparisons over the two years of observation can only be made on these three individuals.
Figure 4. Flowering and fruiting phenology of three Sumatra landraces of jackfruit in 2018 (a) and 2019 (b).
The difference in rainfall and the dry season period seemed to impact the different phenology of jackfruit flowering within two years of observation (Figure 4). In 2018 when the rainfall is higher and the dry season is shorter, flowering initiate lately (February to June) with a longer duration (approx. six months). In 2019, the lower rainfall and the longer dry season resulted in the early flowering (January to April) with a shorter duration (approx. four months). This result is similar to several studies in Bangladesh, India and Sri Lanka, which reported an earlier, shorter, and more frequent flowering in a warmer region, but was delayed, prolonged and less frequent in the cooler sites [1, 3, 4]. In many parts of warmer regions, jackfruit flowered twice a year in a 150 days flowering period and had mass fruit harvesting at the end of the dry season.

On the contrary, jackfruit in cooler regions was flowered only once a year, with a later flowering period which is prolonged until 180 to 240 days [1, 4]. In cooler sites in India, footstalks emerge on the trunk and old branches during the reproductive phase (November-January). Footstalks usually start producing reproductive buds after 5-6 weeks of their initiation. Under the warmer eastern tropical climatic condition, the reproductive phase in jackfruit starts earlier from October and continues till February. The development of footstalks completes in a shorter period (4-5 weeks), followed by the development of reproductive buds and male and female spikes [3]. Another study reported the scarcity of fruiting in the Northern region of Uganda, which might be attributed to the warmer climate due to seasonal bush burning [11].

The difference in climatic conditions over the two years of observation also resulted in different fruit production. Lack of rainfall and the prolonged dry season resulted in the loss of female flowers, even before they transformed into young fruits (Figure 4). This condition confirms the theory that in areas with continuous light and rain, jackfruit bears flowers and fruits throughout the year, while in areas with distinct dry and wet seasons, jackfruit flowered only during the wet season [3, 5, 12].

Results showed that the flowering season started at the beginning of the dry season in February 2019. The early flowering season was dominated by male flowers until the middle of the dry season. In the second month of the dry season, female flowers appeared more abundantly than at the previous rainy season since a low water content in the dry season triggers the initiation of female flowers. At the end of the dry season, female flowers dominate the trees. However, many females did not develop into fruits and dropped since they were not pollinated by pollens due to the low availability of male flowers at the end of the dry season.

3.4. Flowering and fruiting phenology of jackfruit in different landraces

In 2019, a comparison of phenology was also conducted among landraces (Figure 5). Differences in the onset and duration of flowering were also observed among landraces. The Medan landrace flowered later with a longer duration than that of Lampung and Pekanbaru landraces. In their area of origin, the Medan landrace receives much more rainfall compared to the recent site in Karangmojo. Meanwhile, the landraces of Pekanbaru and Lampung receive approximately similar rainfall in both the previous origin and the current site in Karangmojo. A similar case was also reported in the jackfruit landrace trial in Bangladesh, in which landraces originating from areas with higher rainfall or lower temperatures will flower later, usually with a longer duration [14]. A study conducted in Uganda revealed that one of the jackfruit varieties genetically related to samples from Asia performed a similar phenological pattern, suggesting that they might share the ancestral origin and require similar growth precondition [11]. More flowering and fruiting were also reported in the eastern coastal region of India, which experiences a tropically hot and humid climate with an annual rainfall of 1550 mm and a mean annual temperature of 27 °C [3].

Fruit production of jackfruit throughout the year has been reported in Australia, Indonesia, Malaysia, Thailand [11] and China [12]. However, it differed in the onset, duration and peak season. The climatic differences might be responsible for the different flowering and fruiting seasons of jackfruit among countries [3, 8, 11]. The peak season of jackfruit is from March to May in the Philippines, April to May in Thailand, September to December and June to August in India [7], and December to January in Uganda [11]. In a warmer season in Uganda, jackfruit has two fruiting seasons in March to April and November to December, with the latter season produces more fruits [18]. In a
temperate region such as Florida, the main fruiting season is in summer and fall. Some fruit may ripen at other times, but usually not in winter and early spring [19]. In China, the flowering and fruiting of jackfruit are classified as annual and biannual mature types, which refers to the varieties which produce fruits once and twice a year [12].

This study reported synchrony between the maturity of the female and male flower within the same tree, but in contrast, there was asynchronous flowering among individual trees. High synchrony between male and female flowers within the same tree was also observed in Bangladesh [6] and India [3]. This condition may increase the probability of selfing. At the time of the study, only a few pollinating insects were visiting the jackfruit flowers. The most common agents were ants (Hymenoptera), while the flies group (Diptera) was present in smaller numbers. Although less pollinator was observed in this study due to the asynchronous flowering, some other studies reported pollination events in jackfruits. Jackfruit flowers are monoecious, open-pollinated, and reported to be pollinated by both insects and wind [1, 4, 5, 14, 15]. Several beetles, ants, and flies visited both male and female flowers [4, 5, 14, 15]. Insects usually visit the scented male flowers, which release pollen that is transferred to female flowers [1].

3.5. Implications on designing the conservation and improvement programs

The difference in flowering can be due to climatic conditions [1, 3, 11] and genetics [12, 14, 16], which is represented in the variation of flowered individuals, flowers abundance, flowering initiation and duration, and final fruit production [1, 4, 5, 11, 12]. Flowering and fruit production in jackfruit are strongly affected by rainfall and solar radiation, which determine the groundwater status, soil and air temperature, and humidity [3, 14]. In this study, the groundwater status increases during the rainy season. Hence, the soil reserve a large supply of water which may reduce temperature and increase moisture in the soil. The abundance of water increases the water reserves for the trees during the dry season, as well as providing energy to produce flowers at the beginning of the dry season. Rainfall differences resulted in different onset and duration of flowering. Individuals in Karangmojo flowered earlier with a shorter period during the drier season and acted oppositely in the wetter season when the onset of flowering is delayed and the period is prolonged. A long dry season failed in flowering and fruit production in most of the jackfruit landraces observed. It is important to ensure water availability to increase the flowering and fruit production of Sumatra landraces.

Flowering is also affected by genetic differences, which may be caused by variation within individuals and landraces [12, 14, 16]. It is reflected in the differences in the onset of flowering, flowering duration, and flower and fruit production (including the proportion of male and female flowers) among individuals and landraces of jackfruit in Karangmojo. In addition, landraces received higher rainfall in their previous origin, i.e., Medan landrace, flowered later with longer duration, even when planted in an area with lesser rainfall such as Karangmojo.

A monoecious floral type may still increase the probability of cross-breeding through both temporal and spatial separation of sexes. This genetic mechanism separates male and female organs through the different maturity times or physical barriers [23]. However, monoecy type is ineffective in preventing selfing, particularly when both female and male inflorescences mature coincidently within the same tree as was the case in this study, increasing geitonogamy. A longer floral receptivity and an extended flowering period may increase the pollen transfer in jackfruit but can reduce outcrossing in this self-compatible species, which undergo flowering synchrony [1, 3, 6]. Therefore, jackfruit is self-incompatible and has a cross-mating preference.

Consequently, the inbred embryos failed to develop seeds due to the inbreeding depression [13, 14]. Flowering stimulation and pollination management may be conducted to increase flower production, pollinating agents, and fruit production. Flowering stimulation may also be aimed to synchronize the flowering between individuals in the area. The application of paclobutrazol at 1 g m⁻¹ of canopy diameter increased the female inflorescence production by 18.10% in jackfruit [24]. Another study reported the occurrence of female inflorescences in the offseason, which did not occur in untreated trees [17]. Individuals with abundant flowers and fruits can be propagated for mass production and genetic infusion.
Figure 5. Flowering and fruiting phenology of three Sumatra landraces of jackfruit (Medan, Pekanbaru and Lampung) in the 2019 flowering period.
4. Conclusion
The ratio of male flowers was higher than female flowers at the beginning of the flowering period. The ratio of female flowers increases at the end of the flowering period, as the male flowers were dropped after the pollen lost its viability. Ontogeny observation revealed five developmental stages of male inflorescences, which last in 64 to 101 days. In the last phase, male inflorescences will be drought and abscissed, indicating the viable phase's end. Female inflorescences undergo five stages which take 92 to 160 days in total. The two-year phenological observation showed that differences in rainfall and the dry season period resulted in different onset and duration of flowering. In 2018 when the rainfall is higher and the dry season is shorter, flowering initiated lately (February to June) with a longer duration (approximately six months). In 2019, the lower rainfall and the longer dry season resulted in the early flowering (January to April) with a shorter duration (approx. four months). Lack of rainfall and the prolonged dry season resulted in the loss of female flowers, even before they became young fruits.

Phenological differences, particularly in the onset and duration of flowering, were also observed among landraces. In general, the Medan landraces flowered later with a longer duration than that of Lampung and Pekanbaru. Genetic control is reflected in the differences in the onset of flowering, flowering duration, and flower and fruit production (including the proportion of male and female flowers) among individuals and landraces. Flowering synchrony was reported between the female and male flowers' maturity within the same tree, but in contrast, there was asynchronous flowering among individual trees in the plantation. This condition may increase the probability of selfing. It is important to ensure water availability to increase the flowering and fruit production of Sumatra landraces of jackfruit in Karangmojo. In addition, flowering stimulation and pollination management may also be conducted to increase flower production, pollinating agents, fruit production, and flowering synchrony. Individuals with abundant flowers and fruits can be propagated for mass production and genetic infusion.

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