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Study on the Phenology of Three Fruit Trees Species in Purwodadi Botanical Gardens, East Java, and Its Relationship with Mesoclimates

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Abstract

Nowadays the study of phenology has taken an important contribution to climate change research. Therefore this study observed local fruit trees species collected in the Purwodadi Botanical Gardens (PBG); they were Flacourtia rukam (Zoll & Moritzi), Limonia acidissima L., and Manilkara kauki (L) Dubard. We used fruit phenology data from 2014 to 2018 as secondary data to describe the changes. We also observed the weekly phenology of flowering and fruiting for three years from 2019 to 2022. At the same time, mesoclimates components included precipitation, maximum and minimum temperature were daily recorded by the PBG weather station measurement. Data pairs were then analyzed by using a structural modeling of WarpPLS to determine the relationship among mesoclimates and phenology variables. Research showed that phenology of flowering and fruiting of F. rukam, L. acidisissima, and M. kauki was significantly shifted from 2014 to 2022, along with changes in rainfall patterns, maximum and minimum temperatures in the PBG. Based on the Friedman test, it was shown that the maximum and minimum temperatures significantly changed (p-value<0.05). Five months of mesoclimates were significant predictors and affected before the measurement of phenological flowering and fruiting of three species. High precipitation significantly reduced maximum temperature, and increased minimum temperature. The high precipitation reduced the probability of flowering and fruiting initiation, except for those of L. acidissima. Increasing maximum temperature reduced flower and fruit set of F. rukam and L. acidisissima, while it reduced flowering of L. acidissima. Furthermore, minimum temperature induced flowering, except in L. acidissima.

Keyword: *phenology shift, fruit plant, precipitation, temperature*

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Introduction

Phenology, the timing of regular biological events known as phenophase, and its causes are prominent aspects (Lieth, 1974), often linked with climatic variables. It plays a fundamental role in the functioning of an agricultural system (Stucky et al., 2018). The growth of leaf, flowering, fruiting, seeding, and leaf senescence are all examples of plant's phenological processes that significantly link to ecosystem's function and services (Gray & Ewers, 2021). Because environmental parameters like temperature, precipitation, and photoperiod affect how plants grow and develop, including reproduction, plant phenology is a valuable indication of climate change (Zhou et al., 2014; Streher et al., 2017; Abernethy et al., 2018). The relationship between plant phenology and climate change has been extensively studied using field observations and satellite imaging in cold and temperate climates.

In the temperate climes, dormancy is significantly different in each season. Meanwhile, in the tropics, tropical habitats are seen as being almost aseasonal for a very long period, but only a few phenology investigations have been conducted. Tropical phenology data are quite scarce compared to the data from temperate regions (Abernethy et al., 2018), especially for perennial plants in Indonesia. Understanding the impact of climate change on the phenology of field and fruit crops is of great importance in economics, ecology, and conservation.

Climate change in Indonesia can be observed through various elements, as reported by Indonesia's Meteorology, Climatology, and Geophysics Agency (BMKG) on its website. The 1981–2018 data released by BMKG show that Indonesia's minimum, average, and maximum temperatures are in a positive trend with a magnitude of around 0.03 °C every year. This means that the temperature will increase by 0.03 °C every year, so in 30 years most locations in Indonesia will have a 0.9 °C temperature increase. Meanwhile, the precipitation patterns show that in most parts of Java, the increase in rainfall occurs at low and moderate levels (BMKG, 2021). The beginning of rainy and dry seasons has also changed. In the 2019–2022 period, dry season in most areas of Java started later, while rainy season started earlier. The island had shorter dry seasons and longer rainy seasons than in the past three decades. For Indonesia, 2016 was the hottest year with an anomaly value of 0.8 °C throughout the observation period from 1981 to 2020. 2021 was the eighth hottest year with an anomaly value of 0.4 °C, while 2020 and 2019 are second and third with anomaly values of 0.7 °C and 0.6 °C (BMKG, 2022)

Climatic factors affecting plant life are abiotic factors with several regional ranges: macroclimate, mesoclimate, and microclimate. Mesoclimate is influenced by altitude, aspect, slope, or distance from a large body of water. Its scale extends from tens of yards to many miles depending on topographical consistency. It is an average weather condition that describes an area's climate situation with dimensions of 1 to 100 km horizontally (Ackerly, 2010). It also describes the climate of a small area, usually within a wide plantation range of urban, agricultural areas, or hillsides (Lakitan, 2020)

The timing of phenological phenomena is impacted by climate change, such as the beginning, the end, and the length of each phenological phase. Understanding how phenology responds to climate change is very important and helpful for plant's life in various aspects. The phenological occurrence of living things reflects the current and accumulated state of environmental conditions, especially weather and climatic conditions, over the past. The magnitude of the phenological changes depends on the degree of climate changes in a particular region and the response mechanisms of the species (Cleland et al., 2007; Chen, 2017)

Indonesia has many types of biodiversity; studies on them can improve their quality and survivability. This research examines the phenological events of three local Indonesian fruit species grown at Purwodadi Botanical Garden in East Java, Indonesia. They are *Flacourtia rukam* (locally known as Rukem)*, Limonia acidissima* (locally known as Kawisto Batu), and *Manilkara kauki* (locally known as Sawo Kecik). They were once popular. As now they are not commonly cultivated, conservation and domestication efforts for them must be intensified. They were used for food, medicine, and land conservation. They grow and produce flowers and fruits all year round. Arisoesilaningsih et al. (2001) observed the reproductive activity of *F. rukam* and mentioned that this tree could flower one to three times in a year. *L. acidissima* fruits once a year, and so does *M. kauki* (Sleumer, 1954; Verheijh & Coronel, 1991; Jones, 1992; Sukamto, 2000). They live well on 50–450 m asl (Hamzah, 1977; Sukamto, 2000; Sudrajat & Suita, 2009). Those perennial plants are now rare because of competition with new fruit trees and due to other factors (Budiharta & Solikin, 2010; Nugroho et al., 2012; Zuriyati & Dahono, 2016). They are conserved in Purwodadi Botanical Garden of Pasuruan in East Java.

Information about the phenological symptoms of plants' fruiting in the past few years was provided by the Botanical Garden's Seed Bank, but the symptoms will certainly change over time. The identification of the relationship between several mesoclimate factors and current phenology can show the level and the types of mesoclimate components that trigger phenological changes, and this is useful for environmental management to minimize the decline of plants' life quality.

Methods

Site and materials This research was conducted at Purwodadi Botanical Garden of Pasuruan Regency in East Java. Its area covers 85 ha of flat to curvy topography of land on 300 m asl. The primary data was collected from several VAKs (sites) according to the garden's map presented in Figure 1. The samples were selected based on the fruit-bearing status and insignificantly different plant ages.

Based on Schmidt Ferguson's climate division, tropical areas are marked by slightly wet weather (Group C) with a dry climate (Group E) that occurs periodically and frequent seasonal variations (Arisoesilaningsih & Soejono, 2001). The ratio of dry months to wet months is 60–100%, and the rainfall is approximately 60 mm month^{-1}. The minimum and maximum temperatures in Purwodadi are 15C and 35C. The humidity ranges from 40–100% (BMKG, 2023). This research was conducted from June 2019 to June 2022 using primary and secondary data. The phenological symptoms, which serve as primary data, were taken from three local fruit plants, namely *F. rukam, L. acidissima*, and *M. kauki*, each represented by three plants.

Data collection The monitored individual trees were selected based on the evidence of reproductive maturity and the species-specific of diameter at the breast height (dbh) threshold. The direct phenological observations were carried out every week by giving a score of 0 to 4, rating the flowering and fruiting of the plants; zero for no fruit, one for 1–25% of the total plant canopy, two for 26–50% of the total plant canopy, three for 51–75% of the total plant canopy, and four for 76–100% of the total plant canopy (Hatta et al., 2005). A number of 151 datasets were acquired from June 2019 to June 2022.

The first secondary data of this research is the mesoclimate data obtained from the Class II Unit Climate Station of East Java BMKG in the form of daily precipitation, maximum temperature, and minimum temperature from 2014 to 2022 in Purwodadi. The second secondary data is the monthly fruiting history of the three plants from 2014 to 2018 based on the garden's seed bank data.

Data analysis The phenological data of the fruiting period was directly measured, and the history of the ripe fruit was predicted to have significant changes from year to year. The magnitude of the change was tested using a non-parametric test, namely Friedman's test, based on the results of the data normality test (Conover, 1980).

The obtained phenological data is converted into continuous data, from which a sigmoid curve was acquired. This approach was carried out to acquire synchronized results with the accumulation of mesoclimate factors under statistical analyses. Six candidates of precipitation periods as well as maximum and minimum temperatures were used as the independent variables, namely 1, 2, 3, 4, 5, and 6 months. The best candidates for synchronization with phenological symptoms were obtained through Arima Multivariate analysis by looking at the lags corresponding to the peaks (Lütkepohl & Claessen, 1997).

The relationship between the influence of mesoclimate factors and phenological symptoms was obtained through SEM WarpPLS test, a variant-based SEM (Structural Equation Modeling) which is popular as Partial Least Squares (PLS), especially WarpPLS. It can estimate the

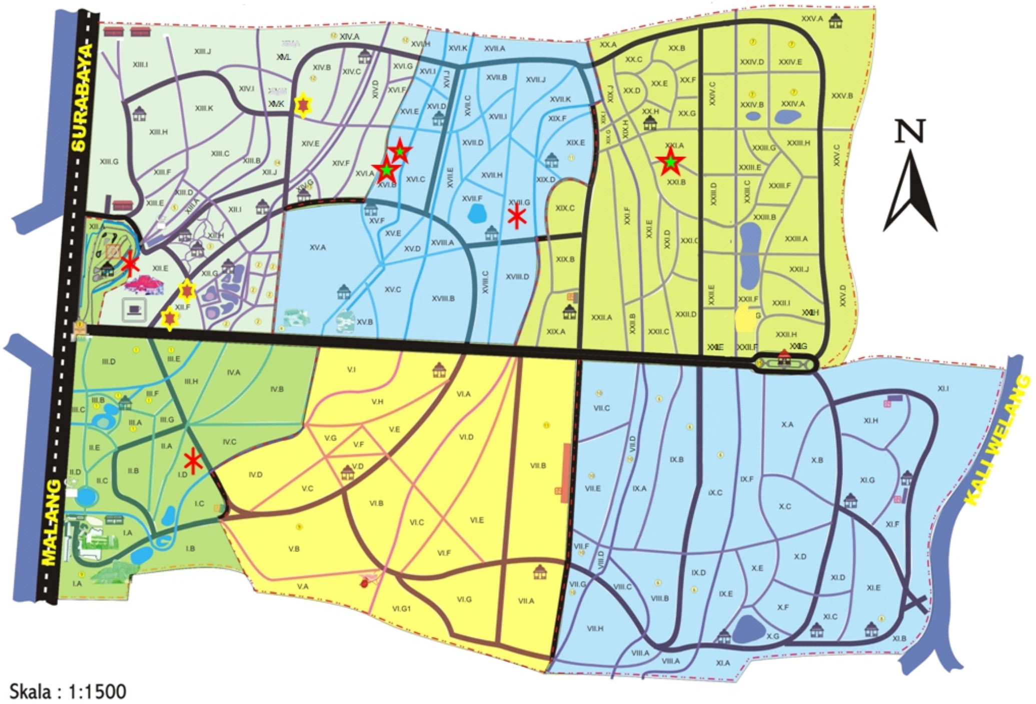


Figure 1 Map of observation points. ✳ *Flacourtia rukam* (Vak ID, XVII G, XII A); ✸ *Limonia acidissima* (Vak XII F1, XII F2, XIV B); ★ *Manilkara kauki* (Vak XVI B1, XVI B2, XXI A).

relationship between latent variables, whether they are linear or non-linear (Hair et al., 2014). In the PLS analysis, the analyzed variables are precipitation as the exogenous variable (X) and maximum temperature (X2) and minimum temperature (X3) as the endogenous and mediating variables. At the same time, flowering phenology (Y1) and fruiting phenology (Y2) are endogenous variables directly affected by X1, X2, and X3, or indirectly influenced by X1 through X2 or by X1 through X3. Flowering phenology (Y1) is a latent variable that can be measured by indicators of budding flowers and blooming flowers, and the fruiting phenology (Y2) can be measured using the indicators of young fruit and ripe fruit.

Results and Discussion

Phenological shift *F. rukam* fruits two times a year, with major fruiting periods are in rainy season. In 2015 and 2016, this plant only fruited once a year, possibly due to the impact of El Nino that hit Indonesia in 2015. In 2014 and 2015, *F. rukam* had the second highest rate of flowers, which means that it was quite abundant (Hatta et al., 2005). In the following period, the number continually decreased. The results of the Friedman test at a 95% confidence level show a significant difference between the data on ripe fruit phenology of *F. rukam* on 12-month observation from 2014 to 2022; the result can be seen in Table 1.

The fruiting period of *L. acidissima* is uncertain, but it occurs once a year. In 2020, it was fruited at the beginning of the year, which was different from the previous years. However, in 2021, *L. acidissima* fruited twice a year. *M. kauki* fruits yearly in the dry season, except in 2017 and 2020 when it did not produce any. The Friedman test also shows the significant difference between the fruiting period of *L. acidissima* and *M. kauki*.

The monthly phenological history data was recorded by Purwodadi Botanical Garden Seed Bank from 2014–2018, and it was continued with direct observation in the 2019–2022 period, which is depicted in Figure 2.

Mesoclimate shift The meteorological data collected at Purwodadi Botanical Gardens for the last nine years are shown in Figure 3. The average monthly precipitation from 2014 to 2022 was 194.213 mm. High fluctuations occurred between 2015 with low annual average precipitation (129 mm) as compared to 2016 and 2017 of 255.67 mm and 282.83 mm. The rainy season mainly occurred from November to April, except in 2016, when the rainy season lasted longer, i.e., from October 2015 to July 2016. Likewise in 2022, the rainy season occurred throughout the year. Based on the non-parametric Friedman test at a 95% confidence level, it was found that the precipitation patterns from 2014 to 2022 were significantly different.

The maximum monthly temperature fluctuation value was always high at the end of the year, except in 2022, where fluctuations occurred from June to July and continued until December. Compared with the same month every year, the maximum temperature fluctuated significantly from July to December in 2022. The yearly average show that the maximum temperature has consistently increased from 2014 to 2022.

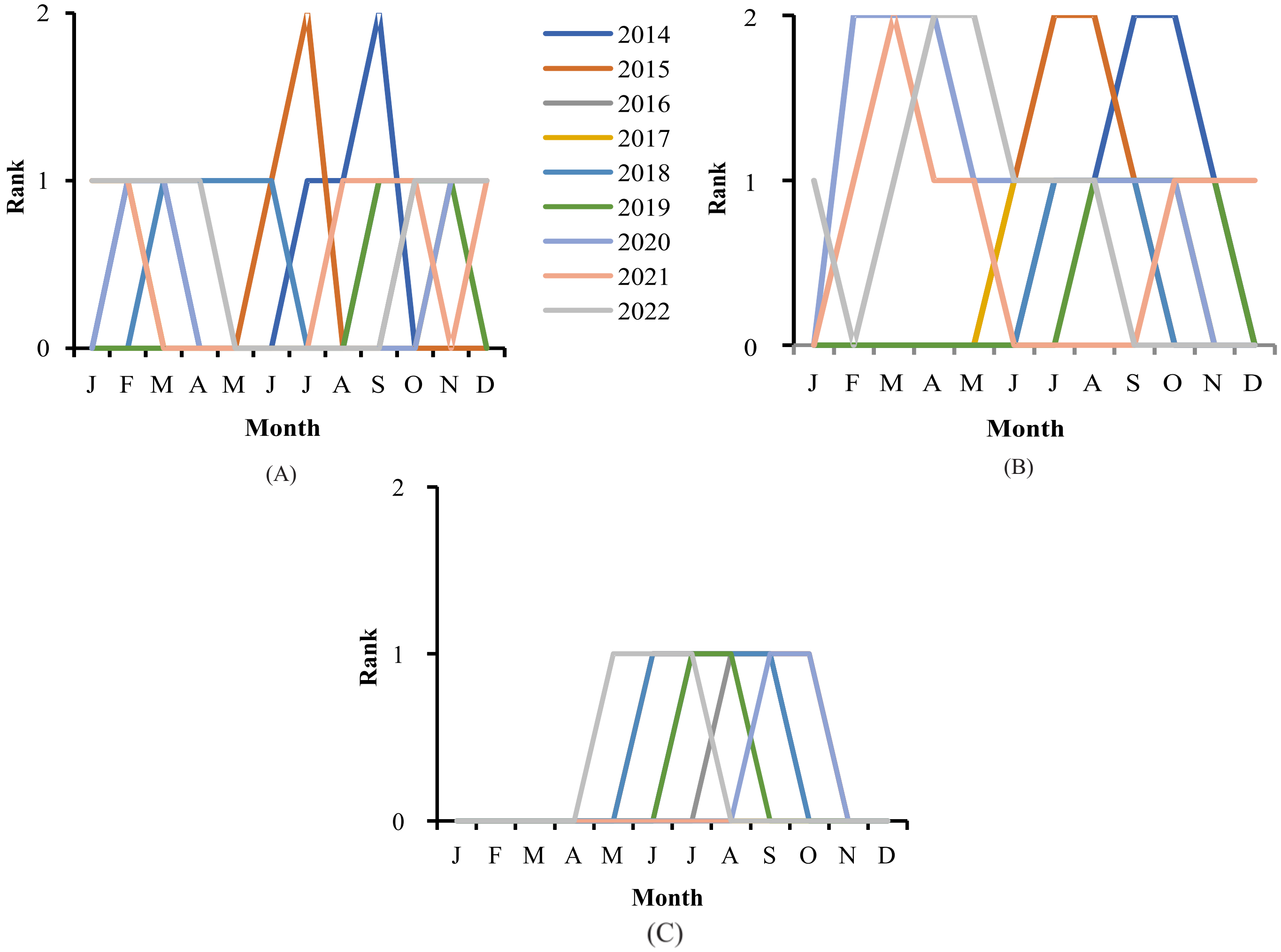
The minimum temperature also significantly fluctuated in 2022. In October and November 2022, the minimum temperature substantially decreased up to 1.71 °C. In November 2022, the lowest minimum temperature took place, and the difference was significant compared to other Novembers (Figure 3c). The year 2022 was marked by stability of minimum temperatures until November, contrasting with the minimum temperatures in previous years, which decreased in June. This is likely because, there was no significant dry season in 2022, as described previously. Reduced rainfall causes low air humidity, which means less water vapor near the earth's surface, and it occurred simultaneously with the sky condition, which tended to be clear of clouds. This long wave back radiation heat is immediately released into the outside of atmosphere, making the air near the surface feel cooler, especially at night until morning (BMKG, 2023). Based on Friedman's non-parametric test at a 95% confidence level, the maximum and minimum temperatures from 2014 to 2022 were significantly different, and the most visible difference was in 2022.

Table 1 Data result of the fruiting level of the three plants by Friedmann test

Parameter	*F. rukam*	*L. acidissima*	*M. kauki*
N	108	108	108
Chi-Square	123.29	123.005	136.757
df	2	2	2
Asymp. Sig.	0.000*	0.000*	0.000*

Note: * = significant difference in the number of ripe fruits p-value< 0.05, based on monthly data from 2014 to 2022

The selected climate period In the VARIMA (Multivariate Arima) test, one of the phenological symptoms was used as the dependent variable. The predictor variable was the probability of the period of climatic factors that are thought to have an effect (we made the probability of 1 month to 6 months before the measured phenological symptoms). The calculation of the AIC value has been carried out, and the smallest value was found at time (t), which is five months for all dependent or response variables. Hence, it can be concluded that the best/optimal model is five months, if compared to other tested models.



(A)

(B)

(C)

Figure 2 Annual variation of fruiting phenology in the Purwodadi Botanical Garden from 2014 to 2022. *F. rukam* (A); *L. acidissima* (B); *M. kauki* (C).

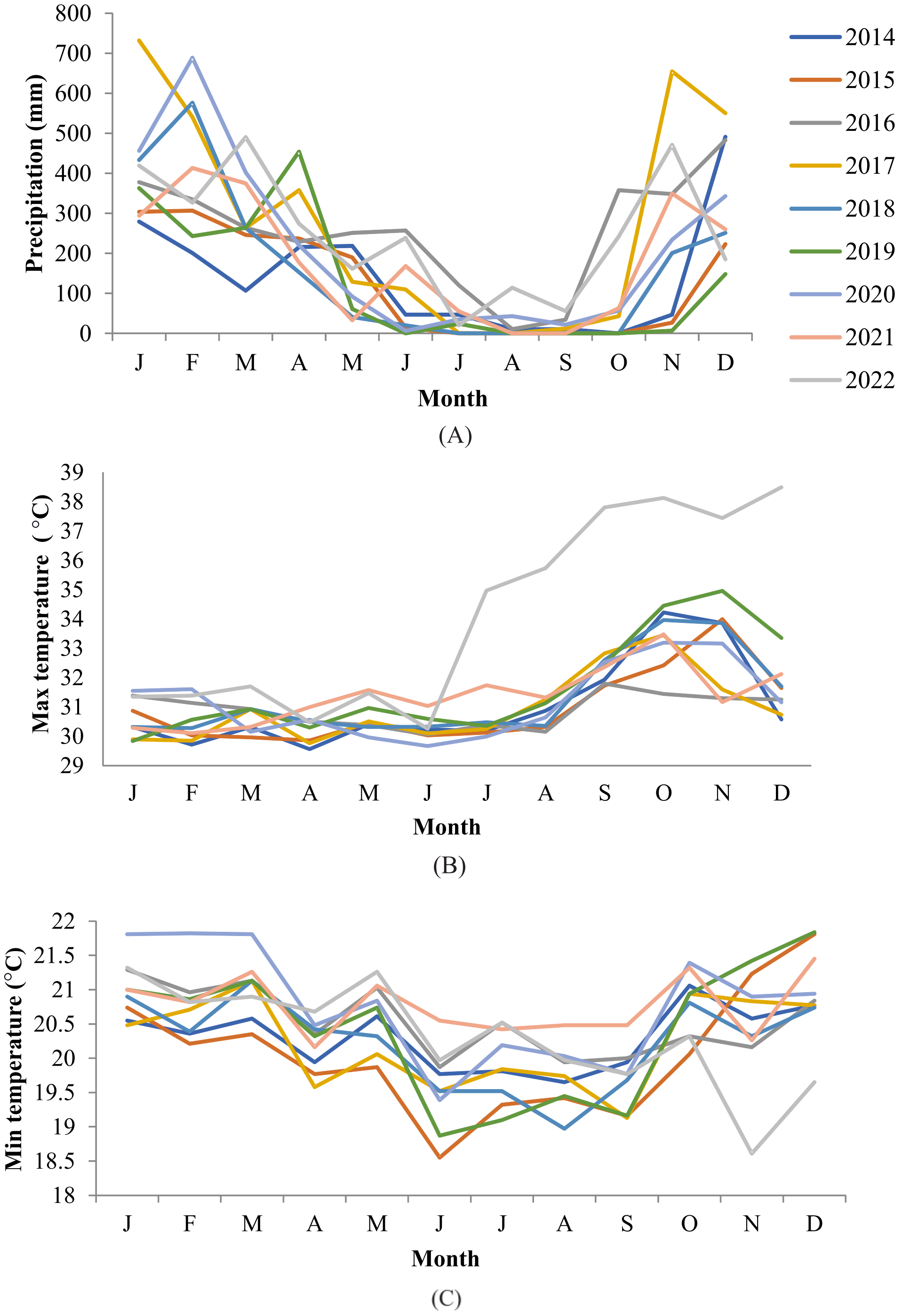


Figure 3 Annual mesoclimates variation in Purwodadi Botanical Garden from 2014 to 2022. Precipitation (A); Max-temperature (B); Min-temperature (C).

In several previous studies, many periods of climatic factors that have been tested were found to affect phenology. The final objective was the selection of periods that sync most with the occurring phenology. Putz (1979) found that the strongest correlation between the number of flowering species and precipitation was in the last two and three months. Brearley (2007) found that the correlation between the percentage of flowering trees and total precipitation in the last days is vital for the total precipitation over the previous 150 days. In comparison, some used weather factors when the phenology occurs. The disadvantage of selecting a short period is that it is less effective in showing that drought is an essential factor that can cause phenology to occur. In choosing the climate period considered appropriate and correlated with the phenological phenomena, previous researchers commonly used linear or multiple regression, sigma plot, Spearman, and COR test (Chapman et al., 2005; Brearley, 2007; Robert, 2012; Polansky & Boesch, 2013) to identify any strong, weak, or even nonexistent correlation between climatic factors and phenology. Researchers have tried to perfect the previous statistical analysis method using the Varima method in choosing the most suitable climate period and in conducting further tests to determine the effect using SEM-WarpPLS. WarpPLS is the most appropriate method when several unmeasured variables (flowering and fruiting) are to be measured with other indicators. In addition, WarpPLS also accommodates seasonal events which are not linear in function, which is more profitable than SEM-AMOS or SmartPLS (Hair et al., 2017).

Using Varima, the mesoclimate period that is most suitable to be compared with phenological symptoms is five months before the symptoms. This five-month period was then entered and analyzed together with the dependent variable of flowering and fruiting into WarpPLS.

Correlation between mesoclimate and phenology The calculation results show that the predictive-relevance value of 0.7640 or 76.40% is in *F. rukam*. The predictive relevance value of 76.40% also indicates that the model can explain 76.40% of the data, while the remaining 23.60% is explained by errors or other variables which have not been included in the model. Thus, the structural model that has been formed is appropriate, likewise to the model that occurred in the analysis results of *L. acidissima* and *M. kauki* plants, whose predictive-relevance values are 86.85% and 70.38%, respectively.

Budding flowers and blooming flowers, significantly measured flowering variables, while young fruits and ripe fruits significantly measured the fruiting phenology variable, as seen from the indicator's weight value. In the structural model, significant effects of one variable on another variable occur if the *p*-value <0.05. Based on the analysis results, the direct impact of precipitation on maximum temperature, minimum temperature, flowering phenology, and fruiting phenology on *F. rukam* is significant. The direct effect of maximum temperature on the phenology of flowering and fruiting phenology is significant, and the direct effect of minimum temperature on the phenology of flowering and fruiting phenology is also significant.

The Measurement and Structural Model obtained from the PLS analysis that has been carried out on the three plants can be seen in Table 2. In the three models, the significant effect of precipitation (X1) on maximum temperature (X2) is inversely proportional, which means that the higher the precipitation (X1), the lower the maximum temperature (X2). In contrast, the significant effect of precipitation (X1) on minimum temperature (X3) is directly proportional, which means an increase in precipitation (X1) will increase minimum temperature. Precipitation only explains minimum temperature by 6% (R^2-value in Figure 4), but it explains minimum temperature by 48% (Figure 4). ^{2}

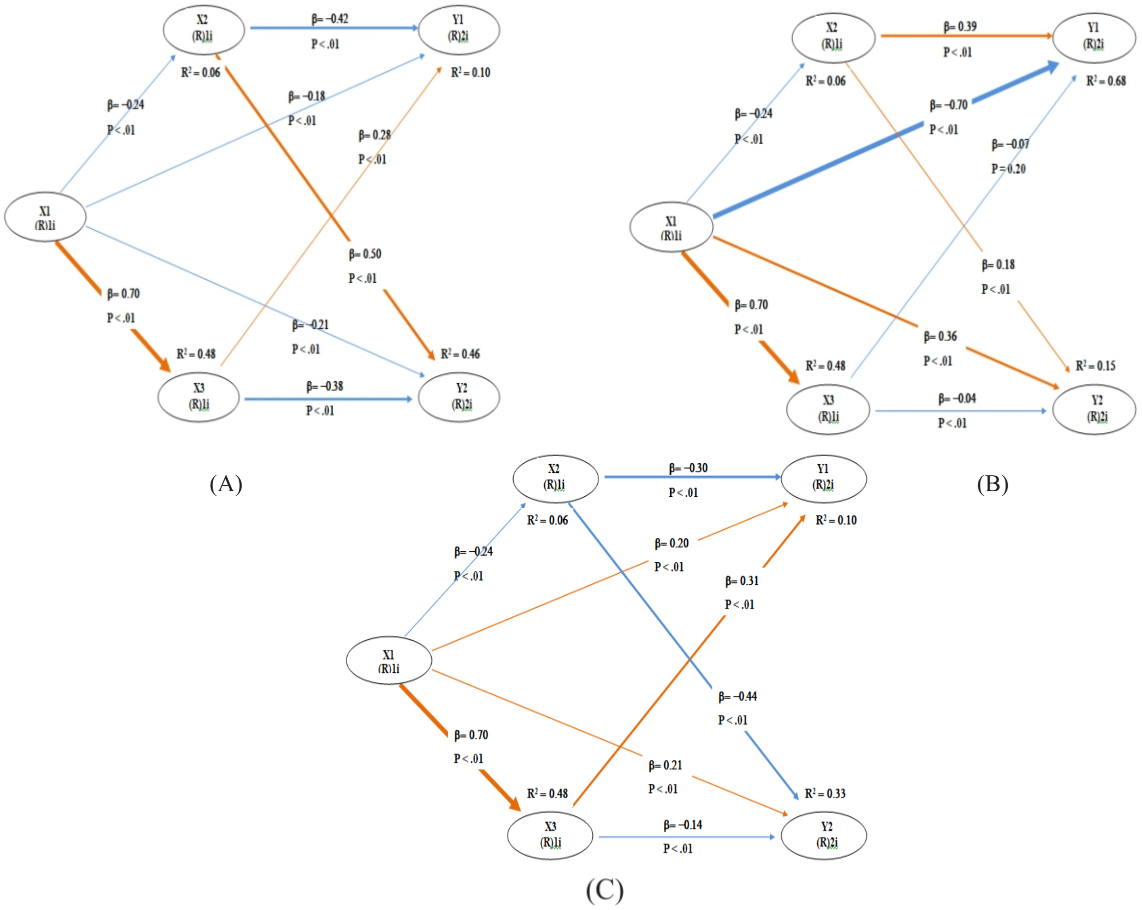
In all three species, flowering (Y1) was positively or unidirectionally influenced by Y1.1 (budding flower) and Y1.2 (blooming flower). Then, fruiting (Y2) was positively affected by Y2.2 (young fruit) and Y2.2 (ripe fruit). The flowering process is most easily observed through the flower buds and blooms, while fruit can be seen from the presence of young and ripe fruits. Ripe fruit is characterized by color, texture, size, shape, and aroma (Hatta et al., 2005). However, the process of flowering and fruiting is more complex than that. Many biochemicals occur in the reproductive organs, but they cannot be observed using the eye. Therefore, to produce good phenological observation data, the observer's perception must be similarized to decide whether the observed flowers and fruits are already formed or ripe.

In the three plants, high precipitation during the five months prior to phenological observations reduced the chance of flowering (Table 2). In contrast, low precipitation or even dry conditions increased the chances of flower bud formation. Water or drought stress can trigger flowering induction before the shoot initiation occurs (Davenport, 2009; Ramirez et al., 2014). The phenology of several Asian tropical forest plants in Central Kalimantan suggests that drought is a more important cue than the minimum temperature at night (Sakai et al., 2006; Brearley et al., 2007), particularly if this dry condition is triggered by El Nino phenomena such as the ENSO (The EL Nino Southern Oscillation) event at fruiting stage in Kalimantan and the eastern Malay peninsula (Curran et al., 1999; Wich & van Schaik, 2000). The impact of ENSO can last for months or even years after ENSO. El Nino occurs in Indonesia every four years, on the average. The year 2015 witnessed El Nino at a high level, while the one in 2019 was moderate (BMKG, 2022). The peak of *F. rukam's* annual fruiting was mainly in sync with the value of low precipitation accumulation (Figure 5a), meaning that it occurred during the dry season or the end of the dry season in November 2019 and August 2020. However, in 2021, it bore flowers and peaked twice,

Table 2 The measurement and structural model of *R. rukam, L. acidissima*, and *M. kauki*

Model type	Equation	*F. rukam*	*L. acidissima*	*M. kauki*
MM	$Y1 = \pi_1 Y1_{.1} + \pi_2 Y1_{.2}$	$Y1 = 0.561Y1_{.1} + 0.561Y1_{.2}$	$Y1 = 0.526Y1_{.1} + 0.526Y1_{.2}$	$Y1 = 0.539Y1_{.1} + 0.539Y1_{.2}$
	$Y2 = \pi_3 Y2_{.1} + \pi_4 Y2_{.2}$	$Y2 = 0.733Y2_{.1} + 0.733Y2_{.2}$	$Y2 = 1.151Y2_{.1} + 1.151Y2_{.2}$	$Y2 = 0.542Y2_{.1} + 0.542Y2_{.2}$
SM	$X2 = \beta_1 X1 + z_1$	X2 = -0.24X1	X2 = -0.24X1	X2 = -0.24X1
	$X3 = \beta_2 X1 + z1$	X3 = 0.70X1	X3 = 0.70X1	X3 = 0.70X1
	$Y1 = \beta_3 X1 + \beta_5 X2 + \beta_8 X3 + z_3$	Y1 = -0.18X1 - 0.42X2 + 0.28 X3	Y1 = -0.70X1 + 0.39X2 + 0.36X3	Y1 = 0.20X1 - 0.3X2 + 0.31 X3
	$Y2 = \beta_4 X1 + \beta_7 X2 + \beta_6 X3 + z_4$	Y2 = -0.21X1 + 0.5X2 - 0.38X3	Y2 = 0.36X1 + 0.18X2 - 0.04X3	Y2 = -0.21X1+ 0.44X2 - 0.14X3

Note: MM = measurement model, SM = structural model



(A)

(B)

(C)

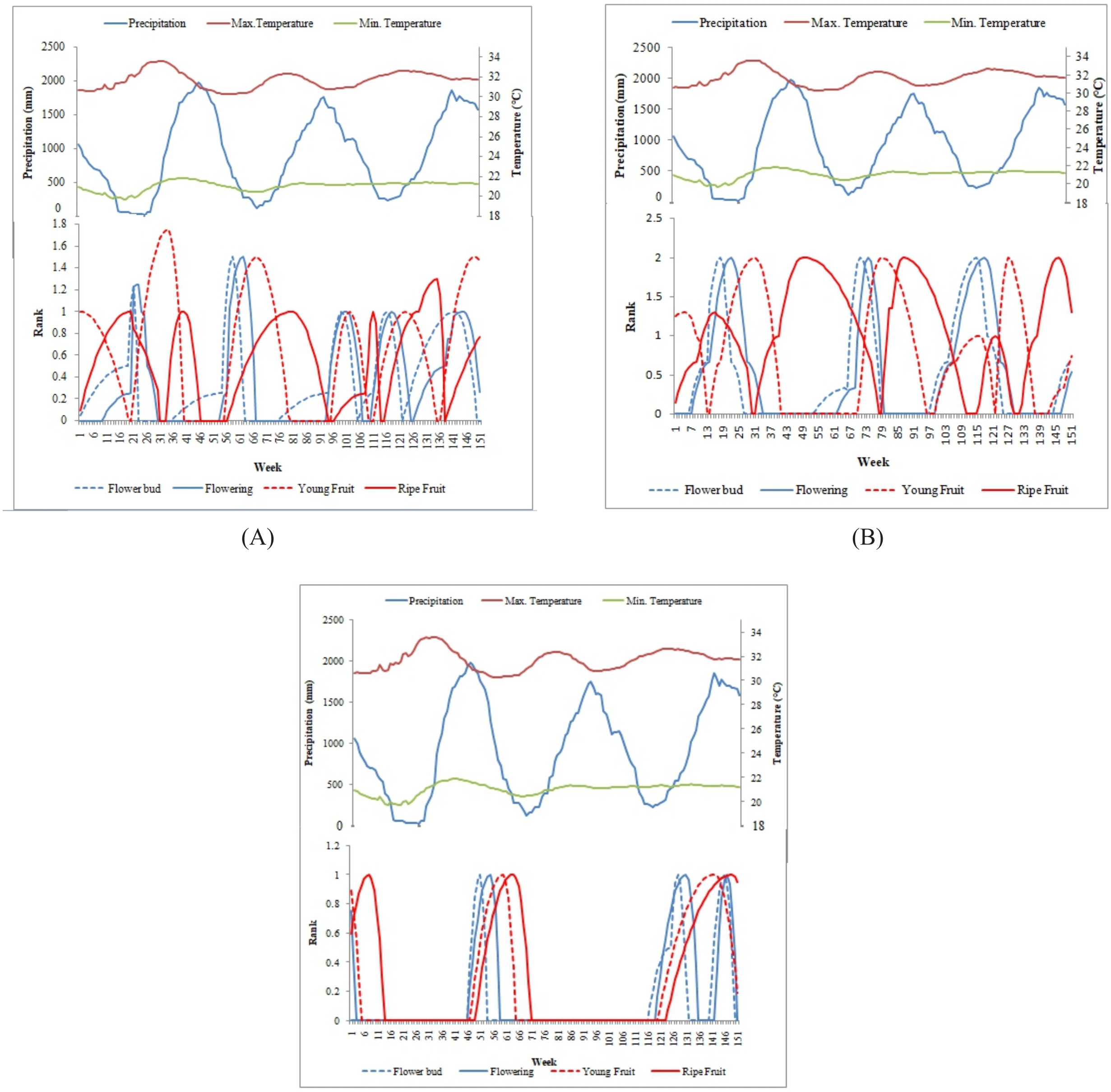
Figure 4 Structural equation modeling of phenology of fruit trees based on WarpPLS *F. rukam* (A); *L. acidissima* (B); *M. kauki* (C). Note. X1 = precipitation, X2 = max temperature, X3 = min Temparature, Y1 = flowering, Y2 = fruiting. Orange solid line for positive regression relationships, blue solid line for negative ones. The thicker line indicates a greater relationship.

i.e., in June and October. In 2022, the peak of the flowering season was in May. In October and November 2020, the precipitation was low enough, causing a drought and triggering flowers. Meanwhile, the flowers may appear in May and June due to the large daily temperature fluctuations, as found by Brearley (2017). Wycherley (1973) also implied that rapid temperature changes during the dry season could be another significant stimulus for flowering and that daily accumulation between the minimum and maximum temperature strongly influenced the emergence of flowering. The flowering in 2021 and 2022 in two periods was also driven by the very high daily fluctuations, which reached 13 C.

The appearance of *L. acidissima*'s flower was always in sync with the value of low precipitation accumulation (Figure 5b), that was during the dry season or near the end of the dry season in October 2019 and October 2020 and in September 2021. This result is also supported by the model in Figure 4 and Table 2, in which precipitation affected flowering negatively.

The peak appearance of flowers for *M. kauki* was generally in the middle of the dry season (JuneJuly) of 2018, 2019, 2020, and 2022 (Figure 5c). However, in 2021, there was a delay in the flowering season, which peaked in December with flower initiation in October. This event may be caused by the fact that in that month, *M. kauki* just found the right combination of high precipitation and low maximum temperature to trigger its flowering. As explained in Table 2, the flowering of *M. kauki* was positively affected by precipitation and negatively affected by maximum temperature. When *M. kauki* usually bloomed in the previous months, the formed precipitation was too low, with a maximum temperature that was higher than the flowering in October 2021.

Maximum temperature is negatively correlated with the formation of flowers, which means that the plants being studied do not require a high maximum temperature to start biochemical and enzymatic processes to begin a flowering process. Furthermore, the minimum temperature is positively correlated with flowering, which means that the higher the minimum temperature, the more the likeliness of flowering to be triggered. This symptom indicates that the minimum temperature has the optimum value to trigger flowering. What happened to *L. acidissima* is different. The maximum temperature increase triggers the flowering process, while the decreasing minimum temperature triggers the flowering process. However, if compared to the minimum temperature on the flowering of *L. acidissima*, the



(A)

(B)

(C)

Figure 5 3-year trends in the phenology data set and mesoclimate. *F.rukam* (A); *L. adissima* (B); *M. kauki* (C).

effect given by the maximum temperature is more significant than that exerted by the maximum temperature (Table 2). This event illustrates that these plants require a higher maximum temperature to trigger flower growth than a minimum temperature, as happened in citrus plants in South Africa, which prefer temperatures above the optimum point that are not too high than the minimum temperature to trigger flowering (Stander, 2015). High temperatures affect plants directly or indirectly in different ways for different species. Temperatures under climate change will cause acceleration in the phenological process (Wolfe et al., 2005; Webb et al., 2007). Generally, a higher temperature of 31–32°C increases the ripeness of bananas (Turner et al., 2007), but warm temperatures will accelerate the ripening of grapes (Hoppula & Karhu, 2006). To a certain extent, high temperatures cause pollinating insects to decrease significantly, affecting fruit formation.

The fruiting period of *F. rukam* took place one to two times a year. Significant fruiting periods were detected in the rainy season. In 2020, it bore young fruit in October and ripened in January 2021, while in 2021, young fruiting retreated to November and ripened in February 2022. Many tropical areas experience peak fruit production at the beginning of the rainy season, that is for those experiencing short fruit ripening and peaking at the peak or end of the rainy season and for those requiring more extended maturation (Justiniano & Fredericksen, 2000; Bollen & Donati, 2005). In contrast, the minor fruiting period of *F. rukam* was in the dry season from March to June. The ripening period took 1215 weeks. The number of ripe fruits in the rainy season was reduced compared to young fruit. The high rain intensity in the month's weeks causes the maturity to fail, fruits even fall before ripening. As modeled in Figure 4, precipitation accumulation during the five-month period before fruiting had an inverse effect on fruiting. Higher precipitation will result in fewer young and mature fruits being formed. Likewise, the lower the temperature (high or low), the higher the chances of the temperature significantly increasing flowering and fruiting.

The peak of fruiting for *L. acidissima* every year is still to be determined. From 2019 to 2020, it only went with one fruiting cycle. Meanwhile, in 2021, it fruited two times, i.e., from March to November. The maturity period of the fruit found on *L. acidissima* was around 17 to 24 weeks. The fruit ripened after 24 weeks probably due to biased observations because there were too many fruits formed and ripened simultaneously. This event occurred in 2020 and 2022. Uneven ripening was due to the influence of the position of the fruit on the tree. Flowers and fruit in the terminal position usually ripen more quickly than those in the lateral position (Krajewski & Rabe, 1995). A decrease in temperature increases fruiting, as does a decearse in rainfall.

M. kauki fruits in August or September every year, except in 2017 and 2021 when fruiting did not occur (Figure 2c). *M. kauki's* fruit ripening process was between 68 weeks. Here precipitation directly influenced the effect of maximum and minimum temperature. The failure to produce fruit may be caused by multiple factors, including a lack of pollinators, poor climatic conditions, or insufficient carbohydrate reserves. In addition, there was also a shift in flowering time towards the end of the year so that when it produced fruit in the following year, the tree did not bear fruit that year (Rajatiya et al., 2018).

For *F. rukam* and *M. kauki*, the indirect effect of precipitation on fruiting and flowering phenology through maximum and minimum temperatures was all significant. At the same time, for *L. acidissima*, the value was significant only on the indirect effect of precipitation on flowering and fruiting through maximum temperature. In all three plants, precipitation through maximum temperature is one of the most dominant indirect effects. Likewise, in the process of fruit formation, indirect interactions that affect the fruiting process were more dominant, given by precipitation through maximum temperature.

Conclusion

Significant changes occurred in the phenology of *F. rukam, L. acidisissima*, and *M. kauki* from 2014 to 2022, in this regard the fruiting time, fruiting frequency, and – especially in F. rukam – the number of ripe fruits. In 2015, 2016, and 2019, *F. rukam* only fruited once a year, and less than 50% compared to previous years. A decrease in the period's fruits of *L. acidissima* occurred in 2015, 2018, and 2019 (less than five months). *M kauki* experienced a reduction in the frequency and period of fruiting in 2016, 2017, and 2021. They followed the hydroperiod symptoms that occurred. Five months of mesoclimate were significant predictors and affected before the measurement of phenological flowering and fruiting of three species. Precipitation patterns, maximum and minimum temperatures in PBG also changed significantly from 2014 to 2022 in the form of shifts in seasons, frequency, and rainfall levels. Changes in rain are always accompanied by changes in temperature. High precipitation significantly reduced maximum temperature, and increased minimum temperature. The high precipitation reduced probability of flowering and fruiting initiation, except those of *L. acidissima.* Increasing maximum temperature reduced flower and fruit set of *F. rukam* and *L. acidisissima*, while it reduced flowering of *L. acidissima*. Furthermore, minimum temperature induced flowering, except in *L. acidissima*

Recommendation

Conducting phenological research requires shared perception among observers in determining when the flower buds, blooms, or when the fruit is young or ripe. The ranking of the abundance of the phenological symptoms is expected to be supported by a genetic examination of plant body parts. We also recommend that researchers review not only the meso climate observations, but also the microclimates that are thought to influence plant phenology. There is a broader observation of climatic factors that are thought to influence plant phenology

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