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Variation of Phenology of *Flacourtia rukam* in Two Different Habitats and Their Relation to Rainfall, Dry Days, and the Plant Water Status

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Abstract

The phenological shift of rukam (Flacourtia rukam [Zoll & Moritzi]) describes plant health. This local edible fruit is becoming increasingly rare. Trees of F. rukam were found in Pasuruan Regency, East Java, including the Purwodadi Botanic Garden (PBG), a conserved plant, and Sekarmojo Village as cultivated plants. This study aimed to analyze the spatial variation in the phenology of two Rukam populations and its relationship with rainfall intensity (RQ), dry days (DD), and plant water status. This study was conducted from 2020 to 2022 using secondary data from the BMKG, such as daily rainfall and the number of days without rain. Phenology and relative water content (RWC) were directly observed every week in two trees at each location. Phenological activities at the two locations were analyzed using the Mann-Whitney test, while the relationships among climate change, RWC, and phenology were analyzed using SEM WarpPLS. The research showed a spatial variation in phenology shown by fallen leaves, flower buds, and young and ripe fruits. Increased RWC was significantly influenced by increased RQ and decreased DD. Therefore, RWC was a mediator variable in influencing phenology, shown by a positive influence on young leaves, flower bloom, and fruit set, and a negative influence on fallen leaves and flower buds. RQ, DD, and RWC directly influenced the phenology of leaves, flowers, or fruits.

Keywords: *phenological shift, rukam, RWC, climate*

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Introduction

Plant phenology, a stage of plant development that repeats temporally, is essential for plant allocation, ecosystem services, and biophysical and biogeochemical feedback in climate systems (Piao et al., 2019). Phenological traits are usually plastic and change with abiotic and biotic variables across space and time. Moreover, plants are producers at the bottom of the trophic level, and changes in their phenology may affect community and species interactions, resulting in a fundamental disruption of ecosystem interactions and services (Maxwell, 2011; Smithers et al., 2018; Prevey et al., 2020).

The study of phenology has progressed rapidly in the last few decades, although in tropical countries, the progress is less significant than in subtropical or temperate countries. Seasonal tropical variations have not always occurred over a long time, and satellite sensing techniques are often unsuitable for species with less obvious phenological changes, such as coloration and leaf senescence in temperate countries (Myneni et al., 2007; Yu et al., 2015). Phenological studies have increasingly revealed that climate change has affected rapid and sizeable shifts of phenology in temperate ecosystems (Schwartz, 1998; Harrington et al., 1999) and in tropical climates (Chapman et al., 2005; Hatta et al., 2005; Polansky & Boesch, 2013; Dunham et al., 2018). Understanding the relationship between climate and plant phenology is critical for predicting and mitigating the effects of climate change on ecosystems and for the management of natural resources and agriculture.

Climate change has affected productivity, health, and ecosystem services. Rainfall is a climatic factor that significantly influences plants. Changes in rainfall intensity and period always occur in Indonesia. Darmayanti et al. (2023) reported that the daily rainfall pattern recorded by Indonesia's Meteorology, Climatology, and Geophysics Agency (BMKG) in the southern part of Pasuruan District fluctuated from 2014 to 2022 and showed a significantly different pattern. Past rainfall might affect plant phenology, even long after the last rainy day; therefore, the interaction between rainfall and plant phenology is a complex system and variable among species (Penuelas et al., 2002; Gordo & Sanz, 2010).

The quantity of dry days, which means days without rain, is an important variable influencing plant water status, rainfall intensity, and pattern. Drought increases abscisic acid (ABA) and other hormone contents that regulate root growth. It plays a significant adaptive role in plants by maintaining an adequate water supply during drought (Sharp et al., 2004). Moderate drought may have a positive impact on some plants, especially by promoting generative activities

(Rahayu et al., 2020). Drought and heat positively affected the optimum sugar content as nutrients and signals to regulate fruit and seed formation (Liu et el., 2013). However, long-term drought adversely affects photosynthesis and growth by triggering senescence (Kondo & Morizono, 2022).

In perennial fruit plants, reproductive success is principally controlled by regular flowering events. This phenomenon is influenced by various factors, such as environmental conditions and endogenic factors. Phenological shifts show temporal and spatial variations, even within the same species (Ibanez et al., 2010; Ovaskainen et al., 2013; Lee, 2017). Individual plants with well-drained soil retained their leaves throughout the dry season and flowered during the following rainy season. At the same time, individual trees of the same species drop their leaves and flower at different times (Wright & Calderón, 2018).

A marker that is suitable and commonly used to evaluate the degree of dehydration or state of stress is the relative water content (RWC). RWC is the hydration status or actual moisture content relative to its maximum water retention. RWC indicates the stress level of plants under drought and heat stress. RWC measurements integrate leaf water potential (ψ) with the effect of osmotic adjustment to produce a value of plant water status (turgor affects the growth and activity of stomata and protects and maintains photosystem complexity) (Mullan & Pietragalla, 2012; Bandurska, 2022). Rainfall affects the water status and phenological condition of plants. In the leaves of well-irrigated plants, the RWC was ≥90%, but with mild drought stress, it ranged from 60 to 70%, with moderate stress, it was 40 to 60%, and in cases of severe stress, it was lower than 40% (Laxa et al., 2019).

Indonesia is well-known as a mega biodiversity country, and studying it improves its quality and survival. A local Indonesian fruit tree species, *Flacourtia rukam* (Zoll & Moritzi) belonging to the family Salicaceae, locally known as *rukam*, is currently difficult to find in the community, although several regions trade it seasonally. In the past, *rukam* was a popular fruit tree in the community because it was used as an edible fruit for land conservation and showed good potential as a raw material for antioxidants owing to its high phenolic compound content (Budiharta & Solikin, 2010; Fadiyah et al., 2019; Andriani et al., 2020).

Rukam grew and produced flowers and fruits year-round. Arisoesilaningsih et al. (2001) observed the reproductive activity of *F. rukam* and reported that this tree might flower one to three times a year. *Rukam* was naturally distributed in secondary forest and farming area in the Java Island. In East Java, it can be found in some districts, such as Pasuruan, Malang, and northern East Java. In Pasuruan, *rukams* are conserved in the Purwodadi Botanic Gardens (PBG) and were found in some villages in Purwosari District, one of which was in Sekarmojo Village.

Based on the interviews, *rukam* in the PBG and in Sekarmojo showed differences in the timing and quantity of flowering and fruiting. PBG seed bank observation data also noted that there was a seasonal shift in *rukam* in the PBG. Intensive observations are needed to determine whether the phenology of *rukam* in the two habitats is different. If mesoclimate in the Pasuruan Regency is a causative factor, at least the plants in the same coverage area will have similar phenological conditions. It was supposed that plants responded differently due to microclimatic and edaphic variations, as shown by the amount of available water and determined by the plant water status. Variations in plant responses occur because of differences in environmental conditions, wider mesoclimatic elements, and genetic characteristics (Yang et al., 2021). The second purpose of this research was to investigate the relationship between rainfall and dry days with plant water status as a mediating variable that influenced the occurrence of phenological events (spring leaves, fallen leaves, flower buds, flower blooms, young fruits, and ripe fruits).

Methods

Site and materials This research was conducted at two locations in Pasuruan Regency, East Java, whereas the Purwodadi Botanic Garden (PBG) 300 m above sea level (asl) and Sekarmojo Village 400 m asl are located in the southern part of Pasuruan Regency (Figure 1). Both locations were 10 km from each other, selected because of similar mesoclimatic and geographical conditions and different interests in *rukam* cultivation (conservation and natural). Pasuruan Regency is located in the lowland area, with an average minimum temperature of 15 °C, a high of 35 °C, and an average annual rainfall of 60 mm month^{-1} (BMKG, 2023). The research was conducted for 27 months from August 2020 to October 2022, and phenology was recorded weekly; therefore, there were 117 datasets. Samples were taken from two trees in each location because of the similarity in habitat origin, age, trunk diameter, and reproductive history.

Data collection *Phenology data* Phenology data were observed weekly using binoculars by recording a score of 0 to 4 to assess the phases of leaf emergence, flowering, and fruiting of plants. Score 0 was for trees without leaves, flowers, or fruits; score 1 was for 1–25% total abundance; score 2 for 26–50% total abundance; score 3 for 51–75% total abundance; and score 4 for 76–100% total abundance (Hatta et al., 2005).

Mesoclimate data The secondary data were obtained from the Climatology Station Class II BMKG East Java in the form of daily rainfall quantity (RQ) and dry days (DD) in the southern part of Pasuruan.

Soil data Soil properties were taken as supporting data and analyzed in the Laboratory of Soil Physics and Chemistry, Faculty of Agriculture, Universitas Brawijaya, Malang. Soil was sampled in the middle of the rainy and dry seasons to determine significant seasonal differences. Soil samples were collected using disturbed and undisturbed methods. Soil was sampled using an auger, and undisturbed soil was placed in a plastic bag for further laboratory analysis, including soil bulk density, specific gravity, and porosity. To determine the soil moisture content and texture, the soil was sampled by digging to a depth of 10–20 cm. The soil texture was determined using the pipette method, water content and bulk density were determined using the graphimetric method, specific gravity was determined using the volumetric method, and porosity was determined using the formula shown in Equation *[1]*.

$$\text{Soil porosity} = (1\ [\text{Bulk density/Particle density}]) \times 100 \quad [1]$$

The relative water content (RWC) of the three leaves of each tree was determined by sampling leaves at three different canopy sites (top, middle, and lower parts). The process was performed twice, in the morning between 6.00 to 7.00 am and midday between 11.00 am and 13.00 pm and weighed as fresh weight. Turgid weight was determined by immersing a leaf sample in water for 4 hours, drying using a paper towel, and then weighing. The leaves were heated in a drying oven at 110 C for 18 hours and the dry weight was determined. RWC was calculated using the formula suggested by Barrs and Weatherley (1962), as shown in Equation *[2]*.

$$\text{RWC} = (\text{Fresh weight} - \text{Dry weight})/(\text{Turgid weight} - \text{Dry weight}) \times 100 \quad [2]$$

Data analysis Phenological ordinal data were converted into continuous data before the ARIMA analysis. Six rainfall periods were used as independent variables, namely 1, 2, 3, 4, 5, and 6 months as predictor variables. Time series data of climate, RWC, and phenology were analyzed to obtain the best ARIMA model using R studio software. RWC and phenological characteristics as dependent variables. The smallest Akaike information criterion (AIC) value indicates the best ARIMA model.

The difference in *rukam* phenological properties between PBG and Sekarmojo was tested using the Mann-Whitney statistical test. The relationships between rainfall, dry days, RWC, and phenological properties were analyzed using structural equation modeling (SEM) with WarpPLS software. WarpPLS is suitable for multidimensional research, which can estimate the relationship between independent/exogenous variables, mediators, and dependent/endogenous variables, and can work with small samples but complex models (Hair et al., 2013). WarpPLS can describe the relationship as linear or non-linear, with U-, J-, or S-curve relationships, which are very common (Hair et al., 2017). Rainfall quantity (RQ) and dry days (DD) were exogenous variables, and RWC was a mediating variable. Young leaves, fallen leaves, flower buds, flower bloom, young fruits, and ripe fruits were endogenous variables that were directly influenced by RW, DD, and RWC, and indirectly influenced by RQ, DD, and RWC through RWC.

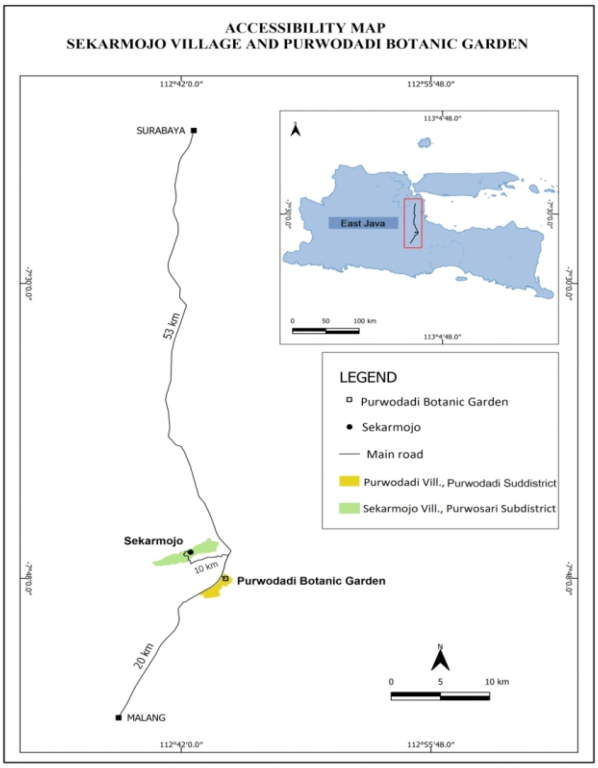

Figure 1 Map of observation.

Results and Discussion

Selection of observation Time The suitable model to predict the plant water status was the cumulative time of 1 month of rain, shown by the smallest AIC value among the other options. Rain patterns in Indonesia vary every year. In this study, the rainfall patterns for 2021 and 2022 were different. The rainy season in 2021 started in the middle of the year, whereas in 2022, the rainy season occurred throughout the year, even though the intensity in the middle of the year was not higher than that at the beginning or end of the year. The rainfall in the PBG and Sekarmojo was assumed to be the same because the closed distance between the two locations is only 10 km. The number of DD per month during the dry season and RQ per month during the rainy season also varied.

Phenological characteristics of two locations Twenty-seven months of research recorded phenological activities: vegetative growth (young leaves and fallen leaves) and reproductive growth (flower buds, flower bloom, young fruits, and ripe fruits). The growth patterns of each are shown in Figure 2.

The results of the Mann-Whitney test at the 95% confidence level showed significant differences in the phases of fallen leaves, flower buds, young fruits, and ripe fruits between the two locations. However, there were no significant differences between the young leaves and ripe flowers (Table 1).

The flushing pattern (simultaneous emergence of young leaf shoots) and fallen leaves recorded in the PBG showed higher peaks each year than in Sekarmojo (Figure 2a). Several plants, even within the same species, show different characteristics in reducing transpiration due to a deficit in water status (Sambatti & Caylor, 2007). Moreover, Bandurska (2022) reported that plants were more tolerant to drought due to their ability to delay the dehydration process, as shown by high stomatal resistance and its osmotic regulation mechanism. Plants maintain leaf water status under drought conditions by closing their stomata or increasing groundwater extraction (Buckley, 2019).

Generally, the reproductive pattern in the form of ripe fruits in both *rukam* populations was dissimilar. There were three peaks of fruiting every year in Sekarmojo until they reached three abundances. *Rukam* in PBG at the end of 2020 showed a long period of fruiting from the end of March of the year, indicating non-simultaneous fruit ripening (Figure 2b). The abundance of fruits in PBG was lower than that in *rukam* in Sekarmojo. This fruiting pattern did not occur in the following years, unlike in *rukam* in Sekarmojo, where fruiting was more regular. Sunlight, pests, and diseases could be the cause. The fruit position on the tree canopy causes different chances of exposure to sunlight. Fruits of the bottom canopy tend to ripen more slowly than those at the top, and are exposed to more sunlight and wind, which can speed up the ripening process (Jajo et al., 2014; Zhang et al., 2020). During these weeks, the rainfall was relatively high, making it cloudy, and sunlight was limited. Meanwhile, pests

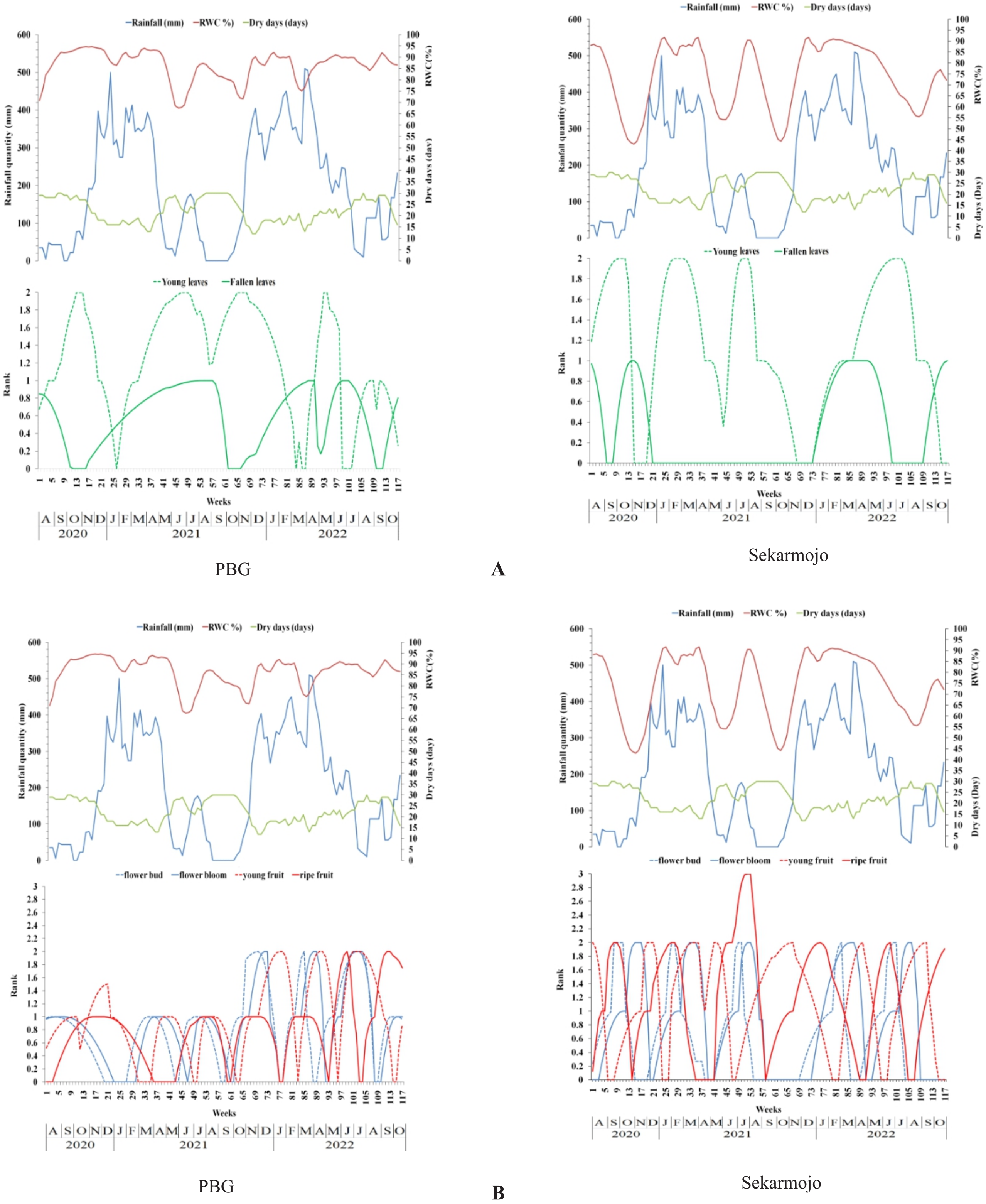

Figure 2 4-trends the phenology data set, RWC, rainfall, and drought (A) vegetative phenology (B) generative phenology.

Table 1 Data result of phenology rank of *F. rukam* at PBG and *F.rukam* at Sekarmojo by Mann Whitney test

	Young leaves	Fallen leaves	Flower buds	Flower bloom	Young fruits	Ripe fruits
Mann-Whitney U	6,581	4,198	4,846.5	6,482.5	5,753	5,722
Wilcoxon W	13,484	11,101	11,749.5	13 ,268.5	12,656	12 ,625
Z	-0.51	-5.214	-3.885	-0.593	-2.011	-2.072
Asymp. Sig. (2-tailed)	0.61	0.000*	0.000*	0.553	0.044*	0.038*

*Significant difference on the parameters of phenology p-value < 0.05.

and diseases were not observed; therefore, it seemed that this variation was not caused by either biotic factor.

According to previous observations, *rukam* in Sekarmojo bore more fruits than those in the PBG. The fruits were also bigger than those in the PBG, even though the architecture and size of the trees and their vegetative activities were similar. This was possibly due to the higher effectiveness of storing carbohydrates for the generative activities of *rukam* in Sekarmojo. This could also be due to the better generative response to the fluctuating RWC values in Sekarmojo. A very low RWC value indicates the drought stress level of the plant. Usually, drought conditions trigger faster and denser flowering (Kobayashi et al., 2013; Yang et al., 2015; Satake et al., 2019).

The results of the statistical analysis are shown in Figure 3. It showed that the model in the PBG had a predictive-relevance value of 0.851 or 85,1%. Meanwhile, in Sekarmojo, the predictive-relevance value was 0.769 or 76.9%, indicating that the structural model can predict the value of the dependent variables well. Some relationships can be explained in the model, such as the influence of rainfall quantity and dry days on plant water status, influence of plant water status on phenology activities, influence of rainfall quantity and dry days on phenology activities, and interaction between phenology parameters.

Influence of rainfall quantity and dry days on plant water status In this study, we used two climate variables: the total rainfall quantity (RQ) and the number of dry days (DD) per month. DD might also be shown as rainfall variability. RQ and DD may directly influence RWC. The total quantity and temporal variability of rainfall were recorded to determine their impact on water availability, plant water stress, and physiological and metabolic functions. Some studies have examined the relationship between rainfall variability and plant water stress by long-term direct measurements, one of which was the study by Gu et al. (2016). Photoperiodism in the tropics generally has no significant effect because there are no extreme variations in day length. The most apparent seasonal change is in water availability (Comita & Engelbrecht, 2009).

Figure 3 shows that in the PBG, the R^2 value for RWC was 0.17 or 17%, indicating that RQ and DD influenced RWC at 17% and 83%, respectively, which were explained by error or other variables not described in the model. Meanwhile, in Sekarmojo, the R^2 value for RWC was 0.52 or 52%, indicating that RQ and DD influenced RWC at 52% and 48%, respectively, which were explained by error or other variables not described in the model. Based on the structural model, the direct impact of RQ on RWC in both the PBG and Sekarmojo was positive and significant (Figure 3). In contrast, the direct impact of DD on RWC in the PBG was negative and significant, while in Sekarmojo, it was not significant.

In Sekarmojo, RQ better explained RWC than PBG. It seemed that other factors influenced RWC in the PBG. Plant water status was also closely related to soil humidity, water availability, and transpiration rate. The rain intensity also affected the soil humidity differently, since a low rainfall intensity wetted the canopy or litter layer on the floor, but it quickly evaporated (Sharafatmandrad et al., 2010). Thus, rainfall intensity correlated with other factors before affecting RWC, including tree canopy width, plant litter, and absorption of the root system (Darmayanti et al., 2023).

Rainfall increased soil humidity and recharged groundwater during the rainy season; however, in the dry season, soil humidity decreased, causing a low RWC, reaching a minimum value of 40% in Sekarmojo. Contrast with RWC in the PBG as long as the lowest observed value was 67.5%. It seemed that these plants had a lower daily fluctuation of water status, possibly due to irrigation in the PBG. Irrigation channels were established around the research site to reduce drought stress and maintain soil humidity. Moreover, under the avoidance strategy, tobacco plant water status was maintained high by reducing stomatal transpiration losses and increasing water uptake from well-established root systems (Dobra et al., 2010). However, the overdevelopment of these structures decreases plant productivity and the average plant size of vegetative and reproductive parts (Wasaya et al., 2018).

RWC maintenance in the PBG may also be related to soil properties that play a significant role in water availability. The soil texture in PBG was silty clay and that in Sekarmojo was silty loam (Figure 4). Water availability in silty soil is more limited, and the higher clay content provides higher water retention (Jabro et al., 2009). Thus, in silty loam, drought stress was higher, as evidenced in Sekarmojo, and the RWC value was more variable.

Influence of plant water status on plant phenological activities Based on the results of the WarpPLS analysis (Figure 3), the enhancement of the RWC value on Rukam in PBG significantly increased several phenological activities (p-value < 0.05), including flower bloom, young fruit, and ripe fruit. In contrast, a decrease in RWC led to an increase in the number of fallen leaves and flower buds. In Sekarmojo, increasing the RWC significantly increased the number of young leaves. However, a decrease in RWC increased the abundance of fallen leaves and flower buds. When RWC decreases as a manifestation of reduced rain, plants adapt by

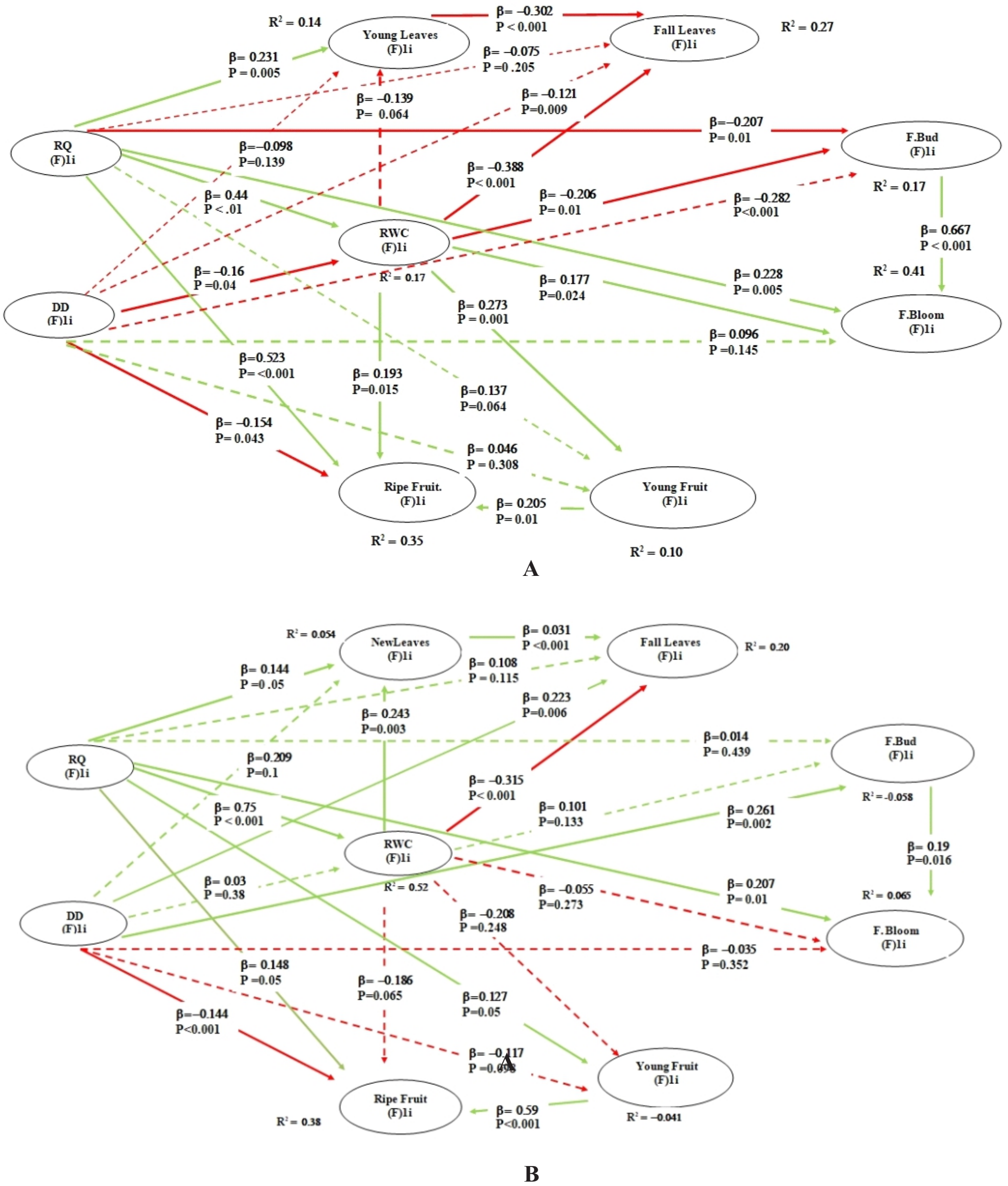

Figure 3 Structural equation modelling of phenology of fruit trees based onWarpPLS. (A) *F. rukam* in PBG, (B) *F. rukam* in Sekarmojo.

reduced transpiration by dropping their leaves, as happened in PBG and Sekarmojo. Griffiths (2014) reported that some leaves that fell when the RWC reached 60% were old or dehydrated.

Figure 2b shows that in the 84–88th week occurred fruit loss occurred in the PBG, which might be due to the sharp decrease in RWC value. When the plant's water status decreasesd, the auxin hormone also decreasesd, whereas ethylene and ABA hormonese increased and caused leaf, flower, and fruit loss (Bijalwan et al., 2022). When the water status of a plant is restored, it grows again and develops new leaves, flowers, and fruits. As observed in Sekarmojo, increasing RWC promoted the growth of young leaves. The emergence of young leaves occurred continuously or periodically with a flushing process. In some tropical species, flushing is relatively constant and rapid (Calle et al., 2010) because plant growth is determined by the duration and intensity of the dry season (Borchert et al., 2002). On *rukam* trees, young leaves develop in approximately 7 to 10 days until they reach mature leaves.

A reduced RWC might increase flower bud growth, which can be explained by the drought stress mechanism that causes the accumulation of carbohydrates and activation of the florigen. When it reaches optimal dry conditions, this flowering hormone is increasingly activated. RWC influenced flower bud emergence by 20% in PBG and 10% in Sekarmojo, indicating that many other factors influenced the emergence of flower buds. Besides exogenous factors, flowering is also influenced by endogenous factors, one of which is the flowering hormone. Some chemicals (flowering hormones) are synthesized in the leaves and passed to the top of flowering, namely, florigen. This caused most plants to not grow flower buds when they had no leaves because the leaves were the site of perception of photoperiodic signals (Kalra & Lal, 2018). Other endogenous factors include carbohydrates (nutrients) and circadian rhythm. Furthermore, the interaction of exogenous and endogenous factors allows plants to synchronize reproductive development with the environment. Increasing RWC in PBG might increase flower blooms, young fruit, and ripe fruit because every development and growth of plant organs requires water as the main ingredient in cell metabolic processes. Relative water content describes the actual moisture content (relative to its maximum water retention) that might be used for plant growth and development, even during the dry season, especially in evergreen plants in tropical areas (Ewusie, 1986). Evidence of this can be seen in Figure 2b; in Sekarmojo, even though the RWC value was low, the plants might still produce good fruits.

The influence of rainfall quantity and dry days on plant phenological activities RQ and DD influenced phenological activity directly or through RWC mediation. Based on Figure 3a in the PBG, an increase in RQ directly increased the emergence of young leaves, blooming flowers, and ripe fruit but decreased the flower buds. In the PBG, an increase in DD might have deceased ripe fruits. Figure 3b shows that in Sekarmojo, an increase in RQ might increase young leaves, blooming flowers, young fruit, and ripe fruit. An increase in DD in Sekarmojo had a positive effect on fallen leaves and flower buds, while it had a negative effect on ripe fruit.

Indirectly or through RWC mediation, an increase in RQ in the PBG might significantly increase young leaves and mature flowers. RQ in Sekarmojo had a positive and significant effect on the emergence of young leaves and a negative effect on leaf fall and flower buds. Meanwhile, DD in both locations did not have an indirect influence on any of the *rukam* phenology parameters.

Adequate RQ resulted in sufficient water availability to support the development and condition of plant roots, plant health, maintenance of growth, and evaporation needs; played an important role in metabolic processes, including photosynthesis; might prevent several things, including decreased water status, decreased assimilation, decreased dry weight of leaves, and increased stomata (Xu et al., 2013; Bijalwan et al., 2022); and might support regular phenological processes as in previous years. Young leaves, as a form of vegetative growth, simultaneously or through flushing was triggered by sufficient RQ. Providing sufficient water influences cell elongation (enlargement of new cells) during vegetative growth. This process also requires the presence of certain hormones that allow cell walls to stretch, as well as the presence of sugar (Almeida et al., 2007; Sandip et el., 2015).

DD describes the number of days without rain. Longer days without rain indicate water shortage or higher water stress. It has an impact on various aspects of plant life (morphology, physiology, and biochemistry) and several aspects of plant phenology, such as the effects of leaf shedding, closing of stomata, cessation of the photosynthesis process, reduced RWC, increasing internal plant temperature, and faster fruit maturity (Takeno, 2016).

The abundance of flowers and fruits in *rukam* in Sekarmojo was higher than that in the PBG, which might be explained by the level of drought that occurred. Long dry days caused the RWC in Sekarmojo during the dry season to be lower than the PBG. Optimal dry conditions resulted in maximum flowering. As seen in Figure 2b, DD significantly influenced flower bud emergence in Sekarmojo. A large number of flower buds would result in the emergence of many flowers and fruits if other environmental conditions were favorable. As in the study by Riboni et al. (2013), flowering in *Arabidopsis* was strongly triggered by drought, and in addition to flowering, also supported the accumulation of carbohydrates in the yield of *Averrhoa carambola* (Pingping et al., 2017). Grain yields are also higher under moderate drought stress conditions (Yang & Zhang, 2006; Landi et al., 2007).

Interaction between phenology parameters In the structural model shown in Figure 3, the relationship between phenological parameters is also known. An increase in young leaf abundance influenced an increase in fallen leaf abundance in Sekarmojo, and an increase in flower buds and young fruit increased the abundance of blooming flowers and ripe fruit, both in the PBG and Sekarmojo. This indicates good development of plant organs with the support of appropriate internal and external factors.

The generative process in PBG was very long (Figure 2b), causing the generative process in the following period to be hampered. This occurred at the end of 2019 (observation weeks 4 to 37). The presence of fruit on a tree was a factor that regulated flowering and fruit yield the following year. Fruit load may affect flower induction. The presence of fruit transmitted signals to more distant shoots, thereby inhibiting their transition to the apical meristem (Munoz-Fambuena et al., 2012). The generative shoots were supposed to start in the 19th to 22nd week but were postponed until the 43rd week in May 2021. Shalom et al. (2012) explained that a higher fruit load might inhibit the recognition of inductive flowering signals so that flowers do not appear or shoots break (Gene Albrigo & Saúco, 2002; Verreynne & Lovatt, 2009) and inhibit vegetative growth in new plants, both shoots and mature leaves, as occurs in olive trees (Haberman et al., 2017). The bud break of orange fruit is also influenced by the presence of fruit on the tree (Verreynne & Lovatt, 2009).

Soil condition supports As a provider of primary needs for plants, the soil is one factor explaining how rain and drought can affect plant phenology. Soil texture and structure usually cannot directly affect plant growth development, but through roots, they mainly influence porosity, aeration, permeability, air holding capacity, and irrigation conditions (Flaig et al., 1975). The silty clay in the PBG had more water retention than the silty loam in Sekarmojo. This caused the RWC in Sekarmojo to be lower than that in the PBG during drought or low rainfall.

Figure 4 shows the dynamics of a change in bulk density, specific gravity, water content, and porosity of soil. Observations on the physical properties of the soil were carried out in the middle of the rainy season (March 2021 and April 2022). At the beginning of the rainy season (October

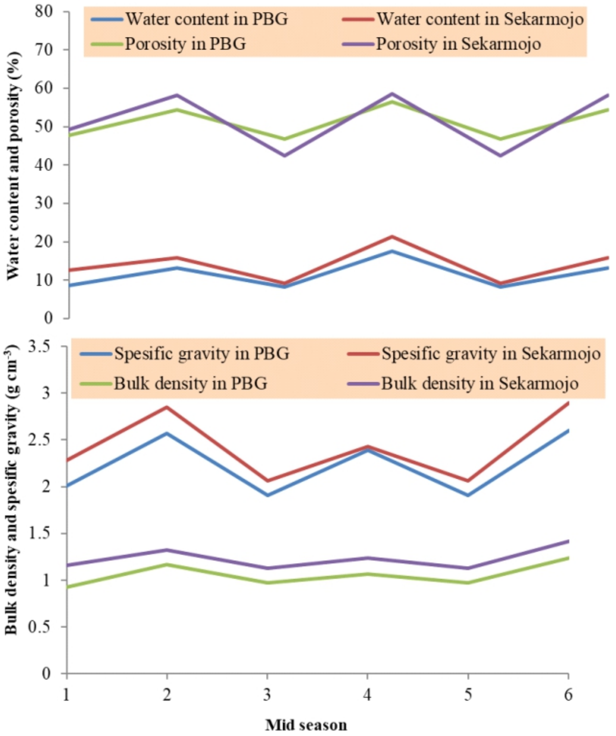

Figure 4 Dynamics of changes in physical properties of soil at *rukam* in two locations.

2022), the bulk density, specific gravity, and water content values were greater than those in the middle of the dry season (August 2020, August 2021, and August 2022). However, heavy and long rains reduced the high bulk density of the soil because the pores were penetrated by soil particles that were hit by rain (Xu et al., 2012). In contrast, porosity was lower during the rainy season than during the dry season. Pores contribute to soil friability. Microorganisms developed more actively in the soil at moderate friability, and root development was maximized. The death of microorganisms and roots is also a source of nutrients that creates high soil porosity.

Conclusion

This study revealed that the same species could experience different phenological impacts during the same period owing to climatic and environmental influences. There are few findings on this tropical plant because it can serve as a reference for similar research on other commodities. There were significant differences in the activity of fallen leaves, flower buds, young fruit, and ripe fruit between the two locations. *Rukam* in Sekarmojo produced more and larger fruits than in the PBG, which may be due to the better generative response to the fluctuating RWC values in Sekarmojo. The direct impact of RQ on RWC in both the PBG and Sekarmojo was positive and significant. In contrast, the direct impact of DD on RWC in the PBG was negative, while in Sekarmojo, it had no significant effect. RWC positively and significantly influenced flower blooms, young fruit, ripe fruit (in PBG), and young leaves (in Sekarmojo). Meanwhile, it had a negative effect on fallen leaves and flower buds (at both locations). Directly, an increase in RQ increased the abundance of young leaves, flower blooms, and ripe fruit (in PBG and Sekarmojo) and decreased the abundance of flower buds in PBG. An increase in DD directly increased the abundance of fallen leaves and flower buds (in Sekarmojo) and decreased the abundance of ripe fruit (in both locations). Indirectly, increasing RQ increased the abundance of young leaves (in both locations) and flower blooms (in Sekarmojo). The RQ in Sekarmojo had an indirect negative effect on fallen leaves and flower buds. DD in the two locations did not have an indirect effect on any of the *rukam* phenological parameters.

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