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# Application of The Concept of Growing Degree Days to Determine The Optimal Mango Harvest Schedule in Situbondo

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## ABSTRACT

Determining the optimal harvest time for an agricultural commodity can be achieved by applying the concept of growing degree days (GDD). The purpose of this research is to determine the potential time of flowering to harvest, especially in developing Arumanis 143 mango cultivation off-season. The study was conducted at the Arumanis 143 mango plantation, owned by PT. Trigatra Rajasa, in Ketowan Village, Arjasa District, Situbondo Regency. The simulation method used in this research was calculating the cumulative GDD using daily average temperature data and the base temperature of mango at 10 °C. The simulation assumed a cumulative value of 543ºC at the beginning of the flowering phase, a value of 945ºC at the beginning of the fruiting phase, and a value of 2,942ºC at the harvest time for export quality. The simulation results indicated that during on-season conditions, mango flowers usually appeared between the third 10 days of May to the third 10 days of June (May III-June III), originating from shoots that emerged between April III to May III. The fruit emergence was estimated to occur around June II-July II, and harvest time around October II-November II. In off-season conditions, the initial emergence of shoots, flowers, fruit, and mango harvest was estimated to occur sequentially around March I-III, April I-III, April III-May II, and August III-September II. The simulation results suggested that the duration of fruiting is longer (20-30 days) compared to existing conditions, resulting in a delay of 20-30 days in fruit harvesting. This research emphasizes the importance of identifying the correct harvest time based on the growth phenology of Arumanis 143 mango plants.

**Keywords:** fruiting duration, growing degree days, harvest time, mango

## Introduction

Indonesia is one of the largest producers of mangoes in the world, after India, China, Thailand, and Mexico (Kiloes et al., 2021). In 2018, Indonesia produced 2,184,399 tons of mangoes (Murdaningsih, 2019). Mangoes are not only consumed domestically but they are also exported to other countries (Fitranto et al., 2020). To meet the increasing demand for mangoes, a mango development program has been implemented since the 1990s, using the Arumanis 143 and Gedong Gincu varieties. Recently, in 2010, new superior varieties such as Garifta Merah and Garifta Orange were developed in 11 provinces of Indonesia, which have suitable agro-

climates for mango cultivation (Rebin & Karsinah, 2010).

Mango plants have a unique fruiting characteristic where they bear fruit seasonally, usually once a year. In Indonesia, particularly in Java Island, the harvest season for mangoes, especially Arumanis 143 and Gedong Gincu, occurs between October and December. During this peak season, mangoes are available at a very low price, which results in low income for mango farmers. To address this issue and increase their income, one solution is to regulate mango fruiting and harvesting during the off-season. This will help prolong the availability of mangoes on the market, fulfill people's nutrition needs, and reduce fruit imports. One recommended approach to achieve off-season mango production is to use a comprehensive cultivation technique, choosing pruning techniques, fertilization, and growth regulators (Martha et al. 2019; Tim Mangga Balitbu Tropika, 2017).

Mangoes can grow ideally at an altitude of 0-300 meters above sea level, with an annual rainfall intensity of 750-2500 mm/year, an average air temperature ranging from 24 to 27ºC, duration of sunlight of 6 hours or more, and require seasonal 2-8 months of dry season to provide an opportunity for flowering and fruit (Bally, 2006; Broto, 2003; Morton, 1987). In tropical regions such as Indonesia, especially in mango plantation areas, it is possible to cultivate mangoes outside the season considering that the average temperature difference between the coldest month and the hottest month is not high. However, because there are differences in the amount of rainfall and average air temperature between the on-season and off-season periods, this will result in differences in plant growth performance. One of these differences is the length of their generative period. One way to identify the length of the generative period of a mango plant is through analysis of growing degree days (GDD).

GDD, also known as heat units (HU), is a concept that accumulates the difference between the average daily air temperature and the basic temperature of the plant. This accumulation happens from the beginning of plant growth until harvest or the end of a specific phase of plant development. The end of this phase is marked by the achievement of the cumulative value of the degree of heat required at the time of harvest or the end of the plant development phase (Gartska, 1964; Griffith, 1985). Degree days are calculated by taking the integral of temperature variation as a function of daily time (Elnesr & Alazba, 2016). This function intersects with an upper or lower limit value for each organism or refers to a certain threshold value, which is generally known as the basic temperature for certain plant or animal.

Several researchers have applied the concept of degree days to mango plants. In Brazil, Lemos et al. (2018) determined the cumulative value of GDD during the flowering and fruit formation stages of the Uba variety of mango. According to Lemos et al. (2020), the cumulative GDD value during the flowering phase was 543ºC. The

**Table 1.** Scenarios of mango flowering, fruiting, and harvest schedules in on- and off-seasons under GDD simulation.

| Season Scenario | Generative Development Phase | Month | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | | | Feb | | | Mar | | | Apr | | | May | | | Jun | | | Jul | | | Aug | | | Sep | | | Oct | | | Nov | | | Dec | | | | | | | |
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| On-season | Flowering | | | | | | | | | | | | | | | | x | x | x | x | | | | | | | | | | | | | | | | | | | | | | |
| | Fruiting | | | | | | | | | | | | | | | | | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | | | | | | | |
| | Harvest | | | | | | | | | | | | | | | | | | | | | | | | | | | | x | x | x | x | | | | | | | | | |
| Off-season | Flowering | | | | | | | | | | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fruiting | | | | | | | | | | | | | x | x | x | x | x | x | x | x | x | x | x | x | | | | | | | | | | | | | | | | | |
| | Harvest | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | x | x | x | | | | | | | |

cumulative value from the start of shoot emergence to fruit harvest was 3,173ºC, and the period required for development from growing shoots to harvesting fruit was 168 days in 2011 and 154 days in 2012. In Junagadh, Gujarat, India, Kanzaria et al. (2015) conducted research on degree days of mango plant growth. They found that the duration of each plant development phase and the cumulative GDD value of mango plants were as follows: the flowering phase was 60.4-75.8 days with a cumulative GDD between 381.0-444.7ºC, the fruiting phase from start to harvest was 250.8-254.9 days with cumulative GDD between 2,364.3 and 2,832.4ºC. Additionally, Rai et al. (2003) conducted a study of GDD on 71 varieties of mango plants in East India. They found that the cumulative GDD for mango from the start of fruit formation until harvest ranged from 1,660.4 to 3,222.3ºC.

This paper presented a simulation and study on the accumulated degree days required for the growth of the Arumanis 143 mango plant in Situbondo, both during the on-season and off-season. The study covers the period from the beginning of shoot growth to flowering, as well as the fruit formation phase at the end of the flowering period until harvest. The start of flowering was determined using growth phase data observed between 2015 and 2019.

## Materials and Methods

This study utilized daily climate data such as rainfall and means of air temperature. Moreover, the analysis of the study also required information regarding the management schedule for mango plants in that particular location, and secondary information of cumulative GDD for different stages of mango plant development during the generative phase. Growth phase data was obtained from January 2015 to December 2019 at the Arumanis 143 mango plantation owned by PT. Trigatra Rajasa in Ketowan Village, Arjasa District, Situbondo Regency,East Java, Indonesia.

*Compilation and analysis of climate data*

The data related to the agronomy of mango was collected through observation and respondent interviews using the SWOT (Strengths, Weaknesses, Opportunities, Threats) and QSPM (Quantitative Strategic Planning Matrix) questionnaires. The climate data consisted of daily rainfall data and daily average air temperature from the Banyuwangi Meteorological Station, the station that provides climate data closest to the study location.

*GDD analysis*

The sum of heat units for GDD was calculated using the equation:

$$GDD = \sum_{t1}^{t2} (T_{AVERAGE} - T_{BASE})$$

where GDD is the growing degree days value (ºC), $T_{AVERAGE}$ is the average of daily air temperature, $T_{BASE}$ is the basic

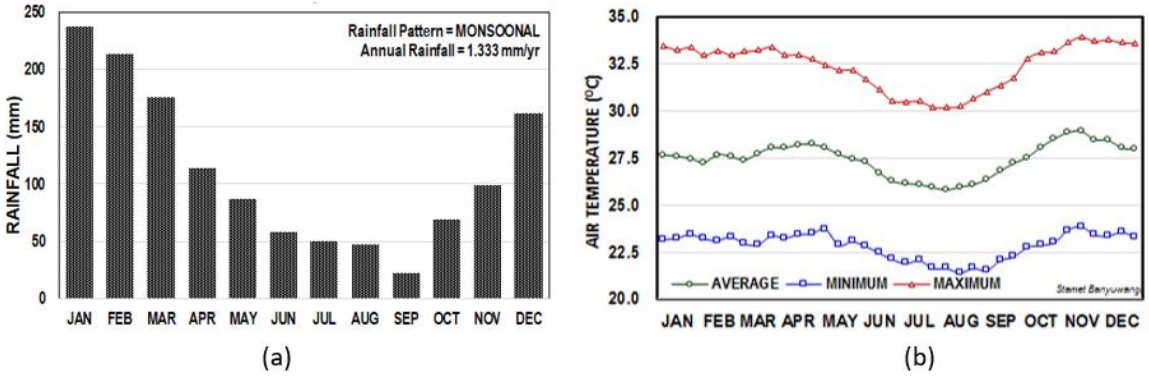



**Fig. 1** Graphic of (a) monthly rainfall patterns and (b)10-day air temperature fluctuations at the study location.

**Table 2.** The record of shifting of the beginning of the dry season (DS) and rainy season (RS) in the 2000-2019 period.

| Year | Start of Dry Season | Start of Rainy Season | Additional information |
|---|---|---|---|
| 2000 | Jun | Oct | The start of the dry season is delayed |
| 2001 | Apr | Oct | - |
| 2002 | Mar | Dec | Long drought |
| 2003 | Apr | Oct | - |
| 2004 | Jun | No rainy season | The start of the dry season and the rainy season are delayed |
| 2005 | Apr | Dec | - |
| 2006 | Apr | Dec | - |
| 2007 | May | No rainy season | The start of the dry season and the rainy season are delayed |
| 2008 | Apr | Dec | - |
| 2009 | May | Dec | - |
| 2010 | Jun | Oct | The start of the dry season is delayed |
| 2011 | Feb | Dec | Earlier start of the dry season, Long Drought |
| 2012 | Feb | Dec | Earlier start of the dry season, Long Drought |
| 2016 | Mar | Dec | Long Drought |
| 2017 | Mar | Nov | |
| 2018 | Apr | Nov | |
| 2019 | May | No rainy season | The start of the rainy season is delayed |

temperature for mango plants, in this case, the value is 10ºC, t1 indicates the beginning of a development phase, and t2 indicates the end of a phase plant development when a certain GDD value is reached.

*GDD simulation during on-season and off-season*

The simulation for cumulative GDD calculation was conducted from the growth of shoots to the harvest time. The initial shoot growth time is adjusted according to the Arumanis mango management schedule, which was typically associated with the location (Table 1). According to Lemos et al. (2020), Kanzaria et al. (2015), Rai et al. (2003) and also based on the observation in the field, in the simulation, the cumulative GDD values used are 543ºC for the start of the flowering phase, 945ºC for the beginning of the fruiting phase, and 2,942ºC for the time of fruit harvest.

## Results and Discussion

*Climate Condition in Situbondo Regency*

The study was conducted in Arjasa District, Situbondo Regency. This location has an annual rainfall of around 1,333 mm/year, with a monsoonal rainfall pattern, which is characterized by two distinct periods - a wet period and a dry period, that alternate with each other. During the wet period, there is a significant amount of rainfall, while the dry period is marked by a significant decrease in rainfall. Average monthly rainfall ranges from the lowest average rainfall of 22 mm/month in September to the highest average rainfall of 237 mm/month in January. There are two months with rainfall intensity above 200 mm per month, four months with rainfall intensity below 60 mm per month, three months with rainfall intensity between 60-100 mm per month, and three months with rainfall intensity between 100-200 mm per month (Figure 1.a).

Mango plants usually start flowering at the beginning of the dry season, which generally starts in April at the study location. However, if the dry season is delayed, mango flowering will also be delayed, and if it is advanced, preparations for flowering management will need to be done earlier. Table 2 provides data on the

**Table 3.** Summary of simulation results of growing degree days to estimate flowering, fruiting, and mango harvest time in Arjasa District, Situbondo Regency.

| Duration of growth of shoots-harvest (Days) | The date of the beginning of vegetative shoots | Duration of the beginning of flowering-harvest (Days) | The date of flowering | Duration of the beginning of fruiting-harvest (Days) | Time of beginning of fruiting | Time of fruit harvest |
|---|---|---|---|---|---|---|
| | | | *On-Season* | | | |
| 176 | 21 Apr-01 May | 145 | 21 May-31 May | 122-123 | 12 Jun-23 Jun | 13 Oct-23 Oct |
| 176 | 02 May-10 May | 144-145 | 01 Jun-10 Jun | 121 | 25 Jun-03 Jul | 24 Oct-01 Nov |
| 175-176 | 11 May-20 May | 143-144 | 11 Jun-20 Jun | 119-120 | Jul 04-Jul 14 | 02 Nov-10 Nov |
| 174-175 | 21 May-29 May | 141-143 | 21 Jun-30 Jun | 117-118 | Jul 14-Jul 24 | 11 Nov-18 Nov |
| | | | *Off-Season* | | | |
| 173 | 02 Mar-11 Mar | 142 | 01 Apr-10 Apr | 120-121 | 23 Apr-01 May | 21 Aug-31 Aug |
| 174 | 12 Mar-21 Mar | 143 | 11 Apr-20 Apr | 122 | 02 May-11 May | 01 Sep-10 Sep |
| 174-175 | 22 Mar-01 Apr | 143-145 | Apr 21-Apr 30 | 122-123 | 12 May-22 May | 11 Sep-22 Sep |

occurrence of the dry season and the rainy season from 2000 to 2019, based on rainfall data series. The average rainfall fluctuations, as shown in Figure 1, revealed that the average start of the dry season was in April, while the average start of the rainy season was in December. Historical data in Table 2 shows that there were instances when the start of the dry season changed. For example, it moved forward to March in 2002, 2016, and 2017, and even to February in 2011 and 2012. Meanwhile, there were times when the start of the dry season moved back to May, in 2007, 2009, and 2019, or even to June in 2000, 2004, and 2010. These changes have an impact on mango production, including the start of flowering and fruiting.

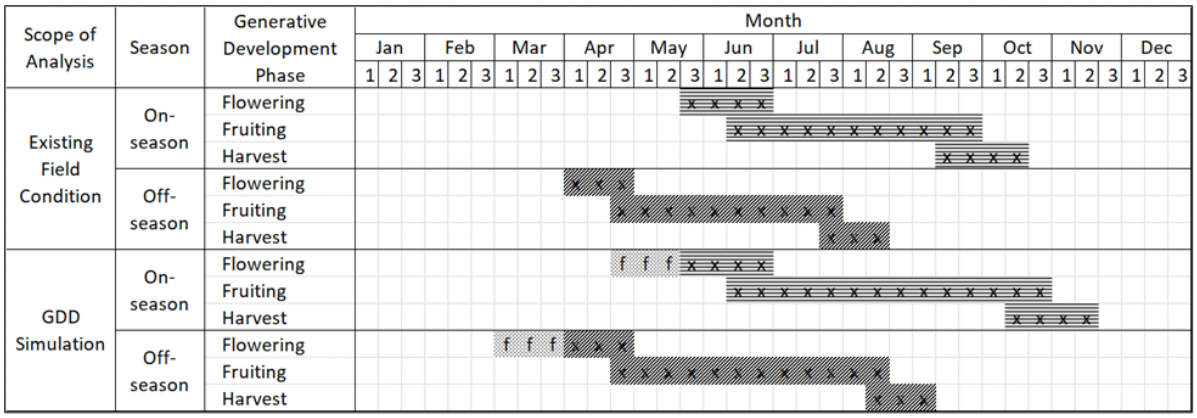
The 10-day average air temperature ranged from 25.8ºC in August I to 28.9ºC in November II. The 10-day minimum air temperature ranged from 21.4ºC in August II to 23.9ºC in November II. The 10-day maximum air temperature ranged from 30.2ºC in July III-August I to 33.9ºC in November II (Figure 1.b).

*Estimation of Mango Harvest Time during on- and off-seasons*

The simulation of cumulative GDD calculation used daily average temperature data and a mango base temperature of 10ºC. The initial simulation of GDD accumulation was carried out from the initial date of bud flushing to harvest, by referring to various alternative initial flowering dates based on historical management data in the field. In the simulation, the GDD value of 543ºC referred to the beginning of the flowering phase, the GDD value of 945ºC referred to the beginning of the fruiting phase, and the GDD value of 2,942ºC referred to harvest time (Lemos et al., 2020; Kanzaria et al., 2015; Rai et al., 2003). The daily simulation results were summarized in a 10-day summary and presented in Table 3.

The results of the simulation presented in Table 3 show that during the on-season conditions, Arumanis 143 mango flowers that were generated from shoots appeared in May III (21-31 May), although they commonly emerged in April III (21 April-01 May). The flowers that appeared during this period were expected to start fruiting in June II (12 June-23 June) and be ready for harvest in October II (13-23 October). The mango flowers that appeared in June I (01-10 June) were expected to grow from shoots that emerged in May I (02-10 May). Flowers that appeared during this period were expected to start fruiting in June III (25 June-03 July) and ready for harvest in October III (24 October-01 November). The mango flowers that appeared in June II (11-20 June) were expected to come from shoots that emerged in May II (11-20 May). Flowers that appeared during this period were expected

**Table 4.** Comparison of fruiting and harvest time for Arumanis mangoes in on-season and off-season was simulated using growing degree days (GDD) and compared to existing




to start fruiting in July I (04-14 July) and ready for harvest in November I (02-10 November). The mango flowers that appeared in June III (21-30 June) were expected to come from shoots that emerged in May III (21-29 May). Flowers that appeared during this period were expected to start fruiting in July II (14-24 July) and ready for harvest in November II (11-18 November). In on-season conditions, the estimated time from the beginning of shoot growth to harvest was around 174-176 days.

During off-season conditions, Arumanis 143 mango flowers that appeared in April I (01-10 April) were believed to come from buds that typically sprouted in March I (02-11 March). These flowers were estimated to start bearing fruit in April III (23 April-01 May) and reach the harvesting stage in August III (21-31 August). Mango flowers that appeared in April II (April 11-20) were believed to come from shoots that emerged in March II (March 12-21). Flowers that appeared during this period were estimated to start bearing fruit in May I (02-11 May) and reach harvest time in September I (01-10 September). Mango flowers that appeared in April III (April 21-30) were believed to come from shoots that emerged in March III (March 22- April 1). Flowers that appeared during this period were estimated to start bearing fruit in May II (12-22 May) and reach harvest time in September II (11-22 September). Under off-season conditions, the time from the beginning of shoot growth to harvest was estimated to take 173-175 days.

*Comparison between Simulation Results and Existing Conditions*

Table 4 presents the existing conditions for the management time frame of Arumanis 143 mango cultivation at the study location in the on-season and off-season, as well as the time frame based on the simulation results of GDD by setting the same flowering time. Comparing the simulation results with existing conditions, the fruiting time in the on-season, according to the simulation results, had a longer duration of 3 decades than the existing conditions. Thus, according to the simulation results, the mango harvest time was three decades slower than the existing conditions. In the off-season, the simulation results produced a longer duration of 2 decades than existing conditions. Thus, according to the simulation results, the mango harvest time was two decades slower than the existing conditions. The difference in harvest time during the on-season and off-season was possibly due to differences in the average accumulated temperature during the budding phase until approximately before harvest.

## Conclusion

The study location had an annual rainfall of around 1,333 mm/year, a monsoon rainfall pattern with two wet and four dry months. The period from the

growth phase from emergence of shoots to harvest in on-season and off-season conditions was estimated to reach 174-176 and 173-175 days, respectively. The simulation results showed a setback at harvest of 30 and 20 days from existing conditions in the on-season and off-season, respectively.

**Conflict of Interest**

We confirm that we have no conflict of interest regarding any financial, personal, or other affiliations with individuals or organizations related to the subject matter discussed in the manuscript.

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