Variability of harvest time of vegetable at different altitudes based on heat unit analysis

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Abstract. The concept of heat unit or degree days for a seasonal crop is calculated from the planting until harvest. Heat unit analysis can help in determining the optimum harvest time. The purpose of this paper was to determine the harvest time for tomato, chili, cucumber, and shallot based on the accumulation of heat unit in different altitudes, such as 8 m (low), 207 m (low), 517 meters (medium) and 920 meters above sea level (high). The heat unit (HU) = (T_{avg} - T_{base}) * age of each phase. The reference cumulative value of the heat unit at harvest as follows; tomato is 1,661°C days, chili is 1,690°C days, cucumber is 979.8°C days and shallot is 945.8°C days. Based on the analysis, it is known that in the lowlands the harvest is faster than in the highlands because heat accumulation is achieved more quickly. The harvest time in lowland and highland was vary, as follows; around 41-66 days on tomatoes, 41-66 days on chilies, 30-37 days on cucumbers, and 29-36 days on shallots. By knowing the span of harvest time, it is hoped that the planting schedule for these vegetables will be adjusted to the needs and location.

1. Introduction

Plants will provide a physiological response due to their interaction with the environment. Physiological responses determine growth and development, including the increase in plant production. In seasonal plants, growth is a change in size, while development is a process of changing plant phases. All climatic elements affect growth, while the dominant elements in development are mainly temperature and day length. Air temperature is a limiting factor for plant growth, development, and reproduction [1-3]. In important aspects of the plant body such as transpiration, respiration, photosynthesis, assimilate formation, root growth, and other processes are influenced by temperature [4-6]. Air temperature represents the heat energy received by plants which affect the processes that occur in the plant body. Therefore, the length of the plant growth phase is influenced by the air temperature. In low-temperature environmental conditions, the flowering process is difficult [7]. According to Park and Park [8], physiological processes in the plant body affect the results of photosynthesis, germination, flowering, fertilization, and ripening. Several physiological and metabolic processes in the plant body can be changed by high-temperature conditions which in turn can affect the vegetative and generative conditions of the plant [6,9,10].

Heat unit is a thermal unit concept used to explain plant phenology [11]. In terms of plant phenology such as prediction of flowering and timely maturity, the climate is very important to pay attention to, both for current and future yields, so that the impacts of future climate change can be studied [12]. The concept of heat units is based on the assumption that the rate of plant development is directly proportional to air temperature. Plant phenology is analysed quantitatively by using the accumulation of heat units because the plant’s energy needs have a certain interval. Calculation of heat units in a seasonal
crop is calculated from the period of growth, development to harvest. The need for heat energy to reach the stage of plant growth or development can be calculated by recording the plant's ambient temperature. Heat unit calculations usually take into account the base temperature of the plant. The determination of the base temperature is important because it affects the accuracy of the heat unit [13]. In most cases, the plant base temperature averages around 10°C. The base temperature of 10°C means that if the temperature is < 10°C, plant growth activity can stop. Given the lower temperatures, it is likely that vegetable crops in Indonesia will not be able to grow, develop, and flower normally. Too low a base temperature does not only require additional heat for flowering but also requires additional heat due to energy loss [7].

Environmental factors greatly affect the growth, development, flowering, and production of plants. The appropriate endogenous and exogenous factors are needed by productive plants, to obtain optimal flowering and production in the end. So the implications of the heat unit include observing the development of plants from climatic or environmental factors, especially air temperature [14]. The results of Chun-ling's research [15] on potato plants showed that temperature was very important. Potato yields can be low if potatoes are planted too quickly at low temperatures and insufficient water. Conversely, too high a temperature can also have an adverse effect. The maximum temperature and minimum temperature that are too high can cause heat stress especially at critical stages of the plant. Laborte [16] stated that at the critical stage of rice plants, heat stress can occur at night if the minimum temperature reaches 25°C for 15 days and the maximum temperature is 35°C for 10 days during the day. This can affect on heat unit accumulation.

This paper describes the calculation of the accumulated heat units of four types of vegetables grown at four different heights. By determining the age based on heat requirements from the beginning of planting to harvest, it is hoped that it can determine a more precise harvest time when the plants are physiologically entering harvest time.

2. Materials and methods

The weather data used for calculations were air temperature data and plant base temperature. In this analysis, a base temperature of 10°C was used. The heat unit (HU) was calculated as the accumulation of the average daily air temperature minus the base temperature which varies from plant to plant. The analysis was carried out at four stations representing areas that have different heights, namely: Cilacap, Bogor, Kepahiang, Citeko (table 2) on four types of vegetables, namely tomatoes, red chilies, cucumbers, and shallots, from 1990 to 2019. Climate data use data from BMKG's data online [17]. The base temperature needs to be included in the calculation because the base temperature is the limit, at which time the growth rate is close to zero.

\[ HU = (T_{avg} - T_{base}) \times \text{age of each phase} \]  

where

\[ HU \] : Heat Unit (°C day)
\[ T_{avg} \] : The average temperature (°C)
\[ T_{base} \] : The base temperature (°C)

The average temperature used was the average temperature obtained from the climate station. A base temperature of 10°C is used; this is because the optimum temperature for photosynthesis ranges from 10 to 30°C [11]. Above or below this temperature the rate of photosynthesis will decrease, although it depends on the type of plant.

Phenology is calculated from seedling to planting, planting until the flower buds emerge, the flower buds emerge to the fruit, and the fruit is produced until it is physiologically ripe [11]. Accumulated heat units for tomato plants in the field (greenhouse), red chilies, cucumbers, and shallots are presented in table 1. Accumulated heat degrees were calculated starting January 1. Based on the heat requirements, the age to physiological maturity was calculated. Correlation analysis was applied to determine the level of relationship between temperature and heat unit accumulation at each location and type of vegetable.
Table 1. Four stations representing different altitudes from BMKG's data online.

| Station                  | District   | Latitude  | Longitude | Altitude (masl) |
|--------------------------|------------|-----------|-----------|-----------------|
| Stamet Tunggul Wulung    | Cilacap    | -7.71890  | 109.01490 | 8               |
| Staklim Bogor            | Bogor      | -6.50000  | 106.75000 | 207             |
| Stageof Kepahiang        | Bengkulu   | -3.55000  | 102.58900 | 517             |
| Stamet Citeko            | Bogor      | -6.70000  | 106.85000 | 920             |

Table 2. Heat unit accumulation reference for determining physiological age.

| Types of vegetables | Variety      | Accumulated Heat Unit (°C day) | Reference     | Remarks                  |
|---------------------|--------------|-------------------------------|---------------|--------------------------|
| Tomato              | Arthaloka    | 1.661                         | Syakur 2012   | Test in the greenhouse   |
| Chilli              | Seloka IPB   | 1.690                         | Siregar 2013  |                          |
| Cucumber            | Vanesa       | 979.8                         | Feriantini 2016|                          |
| Shallot             | Super Philip | 945.8                         | Yaqin et al. 2015 |                |

3. Results and discussion

Based on the calculation, it is known that there are variations in harvest time according to the altitude of the area. In lowland areas, plant life is shorter, because heat accumulation is achieved faster than in the highlands. Temperature is a measure of the degree of heat of an object. In plants, the environmental temperature has a dominant influence on growth, development, and ripening, because temperature activates the processes that occur in the plant body and controls the reactions that occur, both physiological and biochemical reactions. However, the air temperature is not linear, but rather becomes a constraint on a certain temperature, which, if it is passed, can cause the processes in the plant body to be disturbed.

The development of vegetable crops generally goes through phases such as; seedlings, flower buds, physiological ripening. Each phase has a different heat requirement value, which is in the range of 0 to 1, which usually starts from 0 at the time of seedling to one during physiological maturity [18]. Physiological maturity is generally characterized by a change in color towards maturity.

The use of the heat unit system is limited by several things, namely; soil fertility, soil type, topography and slopes, altitude and latitude, the presence of frost, and sunlight intensity. The difference in altitude affects the accumulation of heat units and the age of each phase because altitude is a function of air temperature. The fluctuation in the average air temperature between years and regions is presented in figure 1 and fluctuation in monthly temperature is presented in figure 2.

Figure 1. Fluctuation in mean temperature in four different altitude regions in the period of 1990 to 2019.
Figure 2. Fluctuation in monthly temperature in four different altitude regions.

The results of the analysis of the age determination of each vegetable in each region are presented in figures 3 to 6. For tomatoes, the physiological harvest age range corresponds to the heat accumulation of 1,661°C days [18] in Cilacap between 92 to 99 days, in Bogor between 103 to 112, in Kepahiang between 114 to 124 and Citeko between 139 and 157 days (figure 3). After planting, the tomatoes can be harvested after 2-3 months, depend on plant conditions and variety[19]. For chilies, the physiological harvest age corresponds to heat accumulation of 1,690°C days [20] ranging from 93 to 101 days in Cilacap, between 104 to 113 in Bogor, between 116 to 127 in Kepahiang, and in Citeko between 141 and 159 days (figure 4). In the lowlands, red chilies can be harvested 70-75 days after planting, while in the highlands it is around 4-5 months [19]. The physiological harvest age range for cucumber corresponds to heat accumulation of 978.9°C days [21] in Cilacap between 54 to 59 days, in Bogor between 61 and 67, in Kepahiang between 68 and 75, and in Citeko between 84 and 96 days (figure 5). Cucumbers can be harvested at ± 75-85 days after planting [19]. By the heat accumulation of 945.8°C days [22], the physiological harvest age of shallots was obtained between 53 and 57 days in Cilacap, in Bogor between 59 and 65, in Kepahiang between 65 and 72, and in Citeko between 82 and 93 days (Figure 6). Harvesting shallots can be done after the plants are 60 to 70 days old [19]. It can be seen that the fluctuation from day to harvest is inversely proportional to the air temperature graph. An example is seen in 1998, at that time, the temperature was higher than average, so heat accumulation was achieved more quickly. Plants can harvest faster than at lower temperature conditions. Based on the Oceanic Nino Index (ONI) data [23], it is known that in 1998, at the beginning of the year, El-Nino was very strong and then followed by strong La-Nina. This heat unit is calculated at the beginning of the year (starting January 1), so strong El-Nino events are recorded.

Figure 3. Number of days required until harvesting of tomatoes in four different altitude regions.
Figure 4. Number of days required until harvesting of chili in four different altitude regions.

Figure 5. Number of days required until harvesting of cucumber in four different altitude regions.

Figure 6. Number of days required until harvesting of shallot in four different altitude regions.

Table 3. Average harvest time of four commodities in the period of 1990 to 2019 (dates).

| Station               | Tomatoes   | Chili      | Cucumber   | Shallot    |
|-----------------------|------------|------------|------------|------------|
| Stamet Tunggul Wulung | 5 April    | 6 April    | 26 February| 23 February|
| Staklim Bogor         | 17 April   | 19 April   | 4 March    | 2 March    |
| Stage of Kepahiang    | 29 April   | 1 May      | 12 March   | 10 March   |
| Stamet Citeko         | 29 May     | 31 May     | 31 March   | 28 March   |
Table 4. Harvest time based on heat unit accumulation period 1990 to 2019 (dates).

| Station                | Tomatoes   | Chili       | Cucumber    | Shallot     |
|------------------------|------------|-------------|-------------|-------------|
| Stamet Tunggul Wulung  | 1-8 April  | 3-10 April  | 23-28 Feb   | 22-26 Feb   |
| Staklim Bogor          | 12-21 April| 13-22 April | 1-7 March   | 28 Feb-5 Mar|
| Stage of Kepahiang     | 23 April-3 May | 25 April-6 May | 8-14 Mar   | 5-12 Mar   |
| Stamet Citeko          | 18 May-5 June | 20 May-7 June | 24 March-5 Apr | 22 March-2 Apr |

Based on the analysis with the assumption that planting was carried out on January 1, the harvest time was obtained as shown in tables 3 and 4. The harvest time in lowland and highland was vary, as follows; around 41-66 days on tomatoes, 41-66 days on chilies, 30-37 days on cucumbers, and 29-36 days on shallots. Figure 7 shows a different pattern between the delta of temperature and the delta of the number of days of heat unit accumulation in Bogor for cucumber plants. Both show a trend, which states that an increase in temperature can reduce the accumulation of heat unit days. In figure 8, the anomalous value of the air temperature is presented with the anomaly from the harvest time in tomatoes from 1990 to 2019 at four altitudes. From delta T it is known that there is a trend of increasing temperature near the end of the year of data use. In this condition, it can be said that the harvest can be done faster than in the early years of data use. This was particularly evident in Cilacap, Bogor, and Citeko, while in Kepahiang, the trend was less noticeable. The three locations are areas with monsoonal rainfall patterns that are highly affected by extreme climates, while Kepahiang is included in the bimodal area (two peaks of rain). In general, in areas of the Bimodal rain pattern, the influence of extreme climates is not very visible. It is inversely proportional to the temperature anomaly, the heat accumulation anomaly until harvest is seen more with an anomalous value that is lower than the average. The highest heat accumulation anomaly was seen in Citeko in 2016 which reached >10 days or could harvest more quickly >10 days.

Figure 7. The anomalous value of the mean temperature and heat accumulation cucumber in Bogor from 1990 to 2019.

Table 5. Correlation means temperature with the day of heat accumulation (Pearson Correlation).

| Station                | Tomatoes | Chili  | Cucumber | Shallot |
|------------------------|----------|--------|----------|---------|
| Stamet Tunggul Wulung  | -0.829   | -0.782 | -0.716   | -0.701  |
| Staklim Bogor          | -0.837   | -0.851 | -0.830   | -0.850  |
| Stage of Kepahiang     | -0.716   | -0.730 | -0.714   | -0.720  |
| Stamet Citeko          | -0.742   | -0.730 | -0.671   | -0.666  |
Figure 8. The anomalous value of the mean temperature and heat accumulation tomatoes from 1990 to 2019.

To determine the closeness between the average temperature and the number of days of accumulated heat units, a correlation between the two was carried out using Pearson Correlation and P-value $= 0.000$ for all commodities and locations (table 5). The results show that between average temperature with the number of days of accumulated heat units have high negative correlation as shown in table 5, figure 7 and figure 8. There is a close relationship, it can be shown by the large coefficient of determination for all commodities. Knowing the harvest age of the plants is expected to increase the timeliness of harvest for each of these commodities.

4. Conclusions
Based on the heat unit, different air temperatures give different ripening times for plants. In lowland areas, heat accumulation is achieved more quickly than in the highland, so that plants are more mature and harvest faster. For tomatoes the physiological harvest age range in Cilacap between 92 to 99 days, in Bogor between 103 to 112, in Kepahiang between 114 to 124, and Citeko between 139 to 157 days. For chilies, ranging from 93 to 101 days in Cilacap, between 104 to 113 in Bogor, between 116 to 127 in Kepahiang and Citeko between 141 to 159 days. For cucumber, in Cilacap between 54 to 59 days, in Bogor between 61 and 67, in Kepahiang between 68 and 75 and in Citeko between 84 and 96 days. The physiological harvest age of shallots was obtained between 53 to 57 days in Cilacap, in Bogor between 59 to 65, in Kepahiang between 65 to 72, and in Citeko between 82 to 93 days.

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