Identification of the accumulation of excess temperature during one growing season as a basis for determining suitability for potato plant (*Solanum tuberosum* L.) in a tropical region

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**Abstract.** High temperature in tropical countries is a significant constraint for potato plant development. It is important to identify the accumulation of excess air temperature between the region with low-temperature and high-temperature during one growing season, as a basis for determining the suitable area for potato plants in a tropical region. Two series of experiments have conducted, the first had carried out in two locations, (1) in the high-temperature area (380 masl) and (2) in the low-temperature area (1360 masl). The second experiment had carried out in a high-temperature area (600 masl). The potato cultivars tested were sensitive to high temperatures. The results of the first experiment showed that the difference between the minimum/maximum air temperature accumulation of one growing season between 1360 masl and 380 masl was 179.49/330.42˚C and the decrease in tuber yield reached -76%, resulting in unmarketable potato tuber. The results of the second experiment showed that the difference in the accumulation of minimum/maximum air temperature between 1360 masl and 600 masl was 18.8/188.4˚C, which decreasing in tuber yield amount -15.2%. This study indicates, the temperature at 600 masl still exceeds the optimum temperature; nonetheless, the quantity and quality of the potato tubers produced were marketable.

1. **Introduction**

Potatoes (*Solanum tuberosum, L.*) are sub-tropical plants originating from the Andes Mountain in South America and cultivated at an altitude of 2000-4000 masl [1]. Areas which are suitable for potato cultivation concentrated in zones that have low to moderate temperatures during one growing season. The appropriate conditions in the tropical region found in two areas, first in the lowlands located at medium to high latitudes and in the highlands [2]. In Indonesia, the suitable agro-climatic conditions for growing potato could found in the highlands of 1000 - 3000 meters above sea level with a range of temperatures about 10 - 25 °C [3]. Indonesia's having some areas in which the agro-climate are
suitable for potato cultivation, which are the highlands of Central Java, West Java, East Java, West Sumatra, North Sumatra, and North Sulawesi [4].

The potato cultivation problem in the centres' production area of Indonesia is a sloping, steep, and loose soil condition which susceptible to erosion and landslides. On the other hand, very intensive cultivation causes the land to be open all year round, resulting in more prone to landslides, especially during the rainy season. Extra attention certainly needed to establish the sustainability of potato plantations’ development in Indonesia.

One of the efforts to overcome this problem is by extending the potato development area to more flat land in the medium altitude land area. The efforts to expand potato cultivation to lower areas in the medium altitude land (300-700 masl) had been conducted since the 1980s [5]. However, in its development, potato cultivation in the medium land has experienced several obstacles that caused the production to decline. The main problems faced by farmers in medium land are the high temperature condition that caused the reduction of tuber production.

Under 12-hours photoperiod, the cv. Norland showed the highest potato tuber dry weight at 16˚C and started declining when the temperature reaches 20˚C; at 24˚C it remained 50% than that at 16˚C and it was less than 2% at 28˚C [6]. In Indonesia, the only cv. Olympus which has a better adaptation to a high temperature about 500 m asl [7] and 26 others potato cultivars had been developed for low to moderate temperature condition which located in 1000 m asl and more. Based on previous research, so this experiment designed in three different locations with different temperature regimes. Benoit et al [8] concluded that a larger between mean day and night temperature, especially at higher temperature range, is favoured for the tuber production. According to those previous researchers, the objective of this experiment was to identify the accumulative air temperature excess between different temperature conditions during one growing season to determine the suitable area for growing potato in the tropical country.

2. Materials and methods
Two series of experiments were conducted; the first one was carried out in two locations, in the high-temperature area at 380 m asl of medium land and in the low-temperature area at 1360 m asl of high land. The second experiment was carried out in the high-temperature area at 600 m asl of medium land. The first experiment conducted in late July to late October 2016, using polybags for growing media and set up in the field condition. The second experiment was conducted in early July to late September 2017 with the addition of 3 cm straw mulch as cover [9] and plant growth retardant paclobutrazol (PBZ) was applied. The PBZ used was applied as 25% active ingredient in the solution, and the dosage used was 67.5 mg/plant [10]. The cultivar used for the experiments were Olympus (which has better adaptation to moderate to high-temperature condition), Andina and Amabile (the later two cultivars were initially developed for low-moderate temperature condition).

The air temperature data during one growing season in the first experiment for 380 m asl medium land was obtained from BMKG Semarang and for 1360 m asl high land obtained from data logger HOBO U14-002 type with external sensor S-THB-M008 type. The air temperature observed for the second experiment in 600 m asl medium land was obtained by using the same data logger as in highland.

The potato fresh tuber yield was observed at 79 days after planting marked with 50% yellowing leaves starting from the basal leaves to the upper leaves. Five plants per experiment unit were used as samples of the experiment, and each potato tuber was measured using digital balance to get the potato fresh tuber weight per plant.

The method of calculation of cumulative maximum and minimum air temperature during one growing season, and means day-night temperature from three locations referring to [11]. The potato fresh tuber weight observed than analyzed using Analysis of Variance at α 5% and further analysis conducted with DMRT at α 5% using SAS version 9.4.
3. Results and discussion

3.1. First experiment
In the first experiment, the altitude difference between the two locations was about 980 m asl. The Braak postulate defines that every 100-meter level increase above sea level, the temperature will decline 0.6°C cooler. Based on this reference, the increasing temperature estimation that would occur between the two locations were about 5.5°C. The higher the temperature will exploit an adverse effect on potato plant growth and tuber development.

The high-temperature effect will be more concordant if the comparisons were based on the accumulation of excess temperature in one planting season instead of on day to day basis. The minimum temperature excess of 380 m asl medium land was very high compared to highland; it reached 163.3 folds and 15.4 folds of maximum temperature (Table 1). This result showed that during one growing season, the potato plant receives 194.8°C higher than the minimum temperature needed and 1056°C higher excess of the maximum temperature.

The reduction of potato fresh tuber weight showed at 380 m asl medium land as shown in Table 2 inline with the research of [12], which the accumulation of daily excess temperature showed consistent effect of the high temperature in the specific area. The first experiment result exhibited that the significant accumulation of air temperature excess, particularly the minimum temperature will result in a significant effect on the reduction of fresh tuber yield. It was proven by the tremendous fresh tuber weight reduction of adaptive cultivar Olympus which confirmed that the high-temperature condition at 380 m asl was not suitable with the temperature requirement of a potato plant.

Based on this experience, the next experiment was designed to be located in about 600 m asl with the addition of straw mulch to maintain soil humidity and soil temperature and applying the plant growth retardant to suppress shoot growth and enhance the tuber growth.

Table 1. The comparison of cumulative maximum and minimum temperature during one growing season between highland (1360 m asl) and medium plain (380 m asl) in the year 2016

| Environment | Max | Min | Max – HT\(^7\) | Min – HT\(^8\) | Mean day – night |
|-------------|-----|-----|----------------|----------------|-----------------|
| Medium land 380 m asl | 31.8 | 23.7 | 1.129 | 196 | 466.8 |
| Highland 1360 m asl | 21.3 | 16.9 | 73.1 | 1.2 | 125.8 |
| Difference | 10.5 | 6.8 | 1.056 | 194.8 | 341 |
| Excess degree day | | | 15.4 folds | 163.3 folds | |

\(^7\)Max-HT = the daily maximum air temperature – high air temperature threshold (20°C)
\(^8\)Min-HT = the daily minimum air temperature – high air temperature threshold (20°C)

Table 2. The comparison of potato tuber fresh weight between two different environment

| Cultivars | 1360 m asl | 380 m asl | \(\Delta\) |
|-----------|------------|------------|-----------|
|            | (g)        | (g)        | (%)       |
|            | A          | B          | (B-A/A)\(\times\)100 | |
| Olympus    | 875 a      | 212 c      | -75.7     |
| Andina     | 517 b      | 195 c      | -62.2     |
| Amabile    | 766 a      | 82 de      | -89.2     |
| Average    | 719        | 196        | -75.7     |

The same letter following the means in the same column shows no significant difference of DMRT at \(\alpha\) 5%.

3.2. Second experiment
The result of the second experiment showed that the differences in minimum and maximum temperature between 600 m asl and 1360 m asl high land were not too vast (Table 3). This condition was not yet optimized for the potato plant and may still give a negative effect to the potato plant growth and tuber development.
The potato tuber fresh weight in 600 m asl showed a better result when compared to the first experiment. The fresh tuber weight of Olympus as an adapted to moderate - high-temperature cultivar reached 771 gram per plant on average. This result is in line with its variety description [7], which stated that Olympus is adaptive to 500 m asl. The Andina and Amabile variety also showed increasing fresh tuber yield in 600 m asl with the addition of straw mulch and paclobutrazol application of 500 gram per plant in average, even though these both cultivars are not developed for the moderate to high-temperature condition.

The three cultivars exhibited different responses to the paclobutrazol application. Olympus and Amabile showed the same response which their fresh tuber weight with the paclobutrazol application was higher than that without it. On the other hand, Andina showed the vice versa; its fresh tuber weight was higher without paclobutrazol application. This response was notable information which never reported by other researcher before. The implication of this result is essential that for the future research or development of Andina and Amabile in medium land, the addition of straw mulch has positive effect for Andina and Amabile; however paclobutrazol addition only needed for Amabile.

This experiment result suggests that these three cultivars have a good adaptation and potential to be developed in the 600 m asl medium land with adding straw mulch and paclobutrazol application for Olympus and Amabile.

**Table 3.** The comparison of cumulative degree day during one growing season between highland (1360 m asl) and medium plain (600 m asl) in the year 2017

| Environment          | Max   | Min   | Max – HT$^\text{a}$ | Min – HT$^\text{b}$ | Mean day – night |
|----------------------|-------|-------|---------------------|---------------------|------------------|
| Medium plain 600 m asl | 31.0  | 20.6  | 763.7               | 56.9                | 358.9            |
| Highland 1360 m asl  | 21.3  | 16.9  | 575.3               | 38.2                | 274.3            |
| Differences          | 9.7   | 3.7   | 188.4               | 18.7                | 84.6             |
| Excess degree day    | 1.33 folds | 1.49 folds |

**Table 4.** The potato fresh tuber weight at 600 m asl medium plain with adding straw mulch and paclobutrazol treatments in the year 2017

| Treatments                          | Olympus | Andina | Amabile |
|-------------------------------------|---------|--------|---------|
| Straw mulch – Without Paclobutrazol | 699     | 593    | 432     |
| Straw mulch – With Paclobutrazol    | 843     | 519    | 574     |
| Average                             | 771     | 556    | 503     |

The same letter following the means in the same column shows no significant difference of DMRT at α 5%.

**Table 5.** Mean comparison of potato fresh tuber weight of three different temperature regime

| Cultivars     | 1360 m asl (high land) | 600 m asl (medium land) with straw mulch + PBZ | 380 m asl (medium land) |
|---------------|------------------------|---------------------------------------------|------------------------|
|               | (g)                    | (g)                                         | (g)                    |
| Olympus       | 875                    | 771 (-11.89)$^\text{c}$                     | 212 (-75.77)           |
| Andina        | 517                    | 556 (+7.54)                                 | 195 (-62.28)           |
| Amabile       | 766                    | 503 (-34.33)                                | 82 (-89.29)            |
| Average       | 719                    | 610 (-15.16)                                | 163 (-77.33)           |

$^\text{a}$Value on the parentheses is the percentage of the potato fresh tuber weight difference between high land and each medium plain.

The summary of potato fresh tuber yield of 2 years of experiments from three different temperature conditions shown in Table 5. The reduction of tuber yield in the 600 m asl was 15.16% on average. The Andina fresh tuber yield was higher in 600 m asl than in 1360 m asl. The difference of fresh tuber weight between 380 m asl with 600 m asl medium land was about 73.2%. A lower temperature
especially the minimum temperature which resulting in a lower excess of temperature degree day in one growing season in 600 m asl. The interaction of lower temperature and the addition of straw mulch and paclobutrazol approaching the optimum condition for potato tuber development.

There is no information about how much the specific value of cumulative minimum temperature excess that can still be tolerated by potato plant for its growth and tuber development. The result of this experiment is the first information about the effect of cumulative minimum and maximum degree day to the potato plant under high-temperature condition.

4. Conclusion

The average minimum and maximum temperature in the 380 m asl, 600 m asl and 1360 m asl were 23.7/31.8°C, 20.6/31.0°C, 16.9/21.3°C respectively. The excess minimum and maximum temperature between 380 m asl to 1360 m asl and between 600 m asl to 1360 m asl were 15.4/163.3 folds and 1.49/1.33 folds respectively. The average reduction of potato tuber fresh weight between 380 m asl to 1360 m asl and 600 m asl to 1360 m asl were -75.7% and 15.2% respectively. The reduction of potato fresh tuber weight between medium land and high land was more consistent with the value of excess minimum-maximum temperature than with the average of minimum-maximum temperature during one growing season. Olympus, Andina and Amabile cultivars had good adaptation to 600 m asl temperature condition with added by straw mulch and paclobutrazol application.

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