The potency of mulch and paclobutrazol treatments to increase potato (*Solanum tuberosum* L.) tuber production in a high-temperature area

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Abstract. Climate change, in this case, global warming causing a direct effect on the future production of potatoes in Indonesia by reducing the suitable area in high altitude land. The optimum temperature for potato crop growth is 10-25°C. Temperature above 30°C causing the delay of tuber initiation, increase shoot growth and decrease potato tuber production. The research aims to enhance potato tuber production under the above-optimum temperature was conducted in July – September 2017. The experiment took place in the field at 600m asl. The experiment design used was factorial with a split-split plot design. The three factors tests were with and without paclobutrazol application (67.5 ml/plant), straw mulch (SM) and plastic mulch (PM), and cultivars. The cultivars tested were fresh-potato cultivars (Olympus) and processed-potato cultivars (Andina and Amabile). The result showed that the temperature range during the experiment was 18 - 35°C. Soil temperature under SM showed 1.17°C lower than that under PM. No significant effect of a paclobutrazol application for growth and tuber production. In average, Olympus produced 712 g fresh tuber that was significantly higher than Andina and Amabile, which were 516 g and 461 g respectively. The percentage of small size tuber per plant (< 80 gram) of all cultivar was more than 60%, which showed that the assimilates translocation to tuber still not maximal. This experiment suggested increasing paclobutrazol dosage to enhance the assimilate translocation from the source to the tuber sink and increase the fresh tuber weight per plant.

1. Introduction
In tropical areas, the potato plant is only cultivated in the highlands (1000 - 3000 masl) with low to moderate temperatures. On the other hand, the global temperature average is predicted to increase by between 1 and 7°C caused by climate change [1]. The increasing temperature caused by climate change will affect the sustainability of potato cultivation in tropical countries such as Indonesia. The optimum temperature limit for each phase of potato plant growth is different [2]. The optimum temperature for crown growth is not more than 25°C, and the optimum temperature for tuber growth is not more than 20°C [3]. The process of initiation and tuber formation in potato plants is more sensitive to high-
temperature stress than in the photosynthesis process [4]. The low night minimum temperature is a very important factor for potato plants because tuber initiation is highly dependent on the minimum night temperature than the average daytime temperature [5]. Subba and Dukpa [6] reported that an increase in air temperature 10-15°C from its optimum temperature had been temporally considered high-temperature stress.

In addition to air temperature, high soil temperatures will also reduce the yield of potato tubers, especially when combined with an increase in environmental temperatures of up to 30°C during the day and 23°C at night [6]. Therefore, if due to global warming, the air temperature increases until it exceeds the optimum temperature limit, especially during the tuber growth phase, then the potato tuber productivity will be disturbed, and the yield will decrease.

Several studies to reduce high soil temperatures have been carried out. Prabaningrum et al. [7] stated that the problem of high soil temperatures could overcome by using straw mulch which could reduce evaporation so that the soil temperature is lower because the groundwater content is better preserved. In high-temperature areas, the use of straw mulch significantly increased the yield of potato tubers from 362.5 g per plant to 650.6 g per plant in Granola cultivar [8].

The important impact of high temperature is the change in the distribution of assimilates between leaves and tubers. The character of potato plants that experienced high-temperature stress was the initiation of tubers was inhibited due to the greater shoot growth, and the reduction of tubers yield [9]. There are growth-inhibitor compounds that can reduce shoot growth without reducing plant productivity [10]. Paclobutrazol is a growth regulator compound that has widely used to protect plants from abiotic stress [11]. In this case, Paclobutrazol plays a role in regulating plant growth by increasing leaf chlorophyll content, maintaining a balance between source and sink, improving assimilate translocation, and increasing plant yield.

Based on the description above, an experiment carried out with the treatments of Paclobutrazol and mulching in areas with a temperature greater than the optimum to determine its potential to increase the yield of potato tubers that are less tolerant of the high-temperature using fresh and processed potatoes.

2. Method and material
The experiment carried from June to September 2017, located in irrigated rice fields at medium land 600 masl. The experimental design used was factorial with three factors arranged in a Split - Split - Plot design. The application of Paclobutrazol (PBZ) as the main factor, that was with applied and without applied by PBZ. The PBZ used is the Patrol brand with a concentration of 25% active ingredients. It applied around the age of 39-42 DAP with a dose of 67.5 mg per plant by dissolving it in 250 ml of water and spraying it all over the plant canopy, referring to Tekalign and Hammes [12]. The mulch type, plastic mulch, and straw mulch as the first sub-factor. The cultivar was a second factor, which was Olympus and Andina, and Amabile. The experiment had three replications.

Observations of soil temperature conducted using the HOBO data logger type U14-002 with a sensor type S-THB-M008. The observation of air temperature conducted using the HOBO type TidbiT® v2 Temp (UTBI-001). Soil temperature loggers buried in the soil between the potato fields as deep as 20 cm, for each type of mulch. The air and soil temperature logger set to measure the temperature once every hour for 24 hours from planting to harvest.

The leaves proline content at 56 and 70 DAP based on Bates et al. [13]. Canopy and tuber dry weight was observed at 56 and 70 DAP, using destructive methods. The harvest index is calculated at 70 DAP. The tuber yields observed were fresh tuber weight per plant, tubers number, percent of tubers grade Super, A, B, and C-D.

The observed data then tabulated and analyzed using Analysis of variance and the significantly different parameters resulted were further analyzed using Duncan’s Multiple Range Test at the 5% significance level [14] with the SAS program version 9.4 [15].
3. Result and discussion

The air and soil temperature during one growing season in the medium land 600 masl are still above the optimum temperature for plant and potato tuber growth. Soil temperature conditions under straw mulch (SM) were lower than those under plastic mulch (PM). The use of straw mulch was proven to reduce soil temperature by around 1-1.6 °C [7][8].

![Figure 1. Minimum and maximum air temperature.](image1)

![Figure 2. Soil temperature under straw and plastic mulch.](image2)

The PBZ application (67.5 mg/plant) did not cause differences in leaf proline content of the three cultivars tested. However, there was a tendency that proline content showed lower in the plant applied with PBZ and straw mulch (Table 1). Many plant species naturally accumulate proline when exposed to abiotic stress, but not all plants increase the accumulation of these compounds in large numbers, because this ability depends on the character of each species or cultivar [16]. No significant interaction in PBZ application on leaf chlorophyll content within the mulch and cultivar tested (Table 1). Handayani et al. [17] reported that high temperature (27°C) increased chlorophyll content in high-temperature tolerant cultivars. In this study, the average temperature was 24.9°C, but the cultivars were less tolerant of high temperatures.
At 56 DAP, all cultivars had already formed tubers and continued to increase up to 70 DAP. According to Hijmans [18], the harvest index of potato plants in normal conditions is 80%. In this research, the Olympus harvest index was 0.79, which means Olympus was more tolerant of above optimum temperature conditions and followed by Andina.

The use of straw mulch and PBZ significantly increased the number of potato tubers and freshuber weight of the Olympus cultivar than Andina and Amabile. It was a tendency showed that the tuber fresh weight of Olympus and Amabile was higher than Andina with and without PBZ and under straw or plastic mulch. This study shows that Olympus tends to be more tolerant of high temperatures since its proline accumulation is lower than Andina and Amabile, which indicating that Olympus experiences the least high-temperature stress compared to Andina and Amabile.

Table 1. Proline content and total chlorophyll content after PBZ application at 60 DAP

| Treatment | Proline (µmol.g\(^{-1}\)) | Total chlorophyll (mg.g\(^{-1}\)) |
|-----------|--------------------------|----------------------------------|
| PBZ       |                          |                                  |
| - Without PBZ | 46.16 a                  | 55.61 a                          |
| - With PBZ   | 44.44 a                  | 57.57 a                          |
| Mulch      |                          |                                  |
| - PM       | 45.99 a                  | 56.65 a                          |
| - SM       | 44.61 a                  | 56.32 a                          |
| Cultivar   |                          |                                  |
| - Olympus  | 42.98 a                  | 55.95 a                          |
| - Andina   | 43.18 a                  | 56.68 a                          |
| - Amabile  | 49.74 a                  | 57.15 a                          |
| PBZ*Mulch*Cultivar | (-)                 |                                  |

Description: (-) no significant interaction between factor treatment. The same letter following the means in the same column shows no significant difference in DMRT at α 5%.

Table 2. Shoot dry weight, tuber dry weight, and harvest index.

| Treatment | Tuber DW (g) | Shoot DW (g) | Harvest Index |
|-----------|--------------|--------------|---------------|
|           | 56 DAP | 70 DAP | 56 DAP | 70 DAP | 70 DAP |
| PBZ       |         |         |         |         |         |
| - Without PBZ | 10.32 b | 35.88 a | 21.59 a | 29.81 a | 0.72 a |
| - With PBZ   | 18.40 a | 40.43 a | 20.86 a | 25.51 a | 0.74 a |
| Mulch      |         |         |         |         |         |
| - Plastic  | 13.37 a | 37.11 a | 19.71 a | 27.60 a | 0.69 a |
| - Straw    | 15.35 a | 39.20 a | 22.74 a | 27.71 a | 0.77 a |
| Cultivar   |         |         |         |         |         |
| - Olympus  | 16.68 a | 40.81 a | 18.51 c | 25.04 b | 0.79 a |
| - Andina   | 13.80 a | 42.39 a | 23.92 a | 30.87 a | 0.73 ab |
| - Amabile  | 12.60 a | 31.26 a | 21.25 b | 27.07 ab | 0.67 b |
| PBZ*Mulch*Cultivar | (-) | (-) | (-) | (-) | (-) |

Description: (-) no significant interaction between factor treatment. The same letter following the means in the same column shows no significant difference in DMRT at α 5%.
Table 3. Potato tuber fresh weight and tuber number per plant.

| Treatments | Tuber fresh weight (gram) | Tuber number (tuber) |
|------------|--------------------------|---------------------|
| PBZ*Cultivar With PBZ |   |   |
| Olympus | 761.7 a | 13.8 a |
| Andina | 499.6 b | 9.9 bc |
| Amabile | 504.6 b | 8.1 cd |
| Olympus | 662.2 a | 10.6 b |
| Without PBZ |   |   |
| Andina | 533.3 b | 10.4 b |
| Amabile | 416.5 b | 7.5 d |

| Mulch*Cultivar |   |   |
| PM |   |   |
| Olympus | 652.9 ab | 9.7 bc |
| Andina | 476.7 cd | 9.5 bc |
| Amabile | 417.9 d | 7 d |
| SM |   |   |
| Olympus | 770.9 a | 14.7 a |
| Andina | 556.3 bc | 10.8 b |
| Amabile | 503.2 cd | 8.6 cd |

| PBZ*Mulch*Cultivar |   |   |
| (-) |   |   |

Description: (-) no significant interaction between factor treatment. The same letter following the means in the same column shows no significant difference in DMRT at α 5%.

Table 4. Percentage of potato tuber grading.

| Treatment | Grade A (120-200g) | Grade B (80-120g) | Grade C-D (< 80g) |
|-----------|---------------------|------------------|------------------|
| PBZ*Cultivar With PBZ |   |   |   |
| Olympus | 8.9 ab | 14.9 a | 74.8 a |
| Andina | 6.1 b | 16.8 a | 79.0 a |
| Amabile | 9.9 ab | 18.4 a | 70.7 a |
| Olympus | 13.5 a | 15.7 a | 69.1 a |
| Without PBZ |   |   |   |
| Andina | 4.9 b | 12.0 a | 81.2 a |
| Amabile | 8.6 ab | 16.5 a | 74.8 a |

| Mulch*Cultivar |   |   |   |
| PM |   |   |   |
| Olympus | 13.4 a | 16.9 a | 67.2 a |
| Andina | .3 b | 14.5 a | 80.0 a |
| Amabile | 8.6 ab | 19.5 a | 71.8 a |
| Olympus | 9.0 ab | 13.7 a | 76.8 a |
| SM |   |   |   |
| Andina | 4.8 b | 15.2 a | 80.9 a |
| Amabile | 9.9 ab | 15.4 a | 75.7 a |

| PBZ*Mulch*Cultivar |   |   |   |
| (-) |   |   |   |

Description: (-) no significant interaction between factor treatment. The same letter following the means in the same column shows no significant difference in DMRT at α 5%.

The fresh weight of tubers of the three cultivars tested was close to normal because they could produce Grade A and B tubers, however, the percentage of small grade (C-D) was still larger. The high soil temperature causing the reduction of assimilates translocation to the tubers and ineffective tuber development [19]. The dry weight of the tubers, which was not significantly different after PBZ
treatment was also an indicator that the tuber production still not maximum. Therefore, there is an assumption that the PBZ used in this study is not yet attain the optimum dosage.

Olympus is a fresh-potato type, while Andina and Amabile are processed-potato types. Genetically vegetable potatoes have lower starch levels than processed potatoes. It explains why the high-temperature conditions led to a lower yield of processed potato types. The synthesis of glucose into starch that occurs in tubers is disturbed by the high soil temperature is greater in processed potatoes than fresh potatoes. This research suggests that the increase of PBZ dose were enhance the translocation of assimilates to the tubers and lead to an increase the glucose synthesis into starch and compensate for the exceeded respiration that occurs due to high-temperature stress. This result in line with the research of Geigenberger et al. [20] that suggest the increasing temperature up to 30°C reduce starch synthesis in the tuber up to 50% and the research of Tekalign and Hammes [21] which reported that the proper dosage of PBZ will increase assimilation to the potato tuber cultivated under high temperature.

4. Conclusion
Global warming is still occurring and will be increasing air and soil temperatures. The temperature above the optimum is a major limiting factor for potato growth and production. The straw mulch treatment gave a better effect on the growth and yield quality of the tubers compared to plastic mulch. However, the application of paclobutrazol at a dose of 67.5 mg/plant is thought not to be optimal so that the translocation of assimilates to the tubers is not optimal. As a result, the fresh weight of tubers per plant produced is close to normal, but the percentage of small tubers (Grade C-D) is more than large tubers (Grade A and B). It is recommended to increase the dose of paclobutrazol given, so that the translocation of assimilating to the tubers increases and the synthesis of glucose into starch in the tubers also increases so that the percentage of small tubers is reduced.

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