

## IDENTIFICATION OF HIGH-TEMPERATURE TOLERANCE OF SOME POTATO VARIETIES BASED ON STRESS TOLERANCE INDICE AND CLUSTER ANALYSIS

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### ABSTRACT

*Potato self-sufficiency in Indonesia faces three main problems: rising air temperatures, limited availability of low-temperature land suitable for potato cultivation, and lack of high-temperature tolerant potato varieties. Therefore, it is necessary to identify the tolerance of potato variety to high-temperature. This research was conducted in two locations: the optimum temperature location and the high-temperature location, using nine varieties, are Agria, Andina, Amabile, Cingkariang, Granola L, Granola K, Margahayu, Olympus, and Tedjo-MZ. The study design uses a split plot with three replications. Differences in temperature as the main plot and varieties as subplots. Parameters observed were air temperature, growth, and yield of potato tubers. The analysis carried out were the Stress Sensitivity Index (SSI), Stress Tolerance Index (STI), Yield Stability Index (YSI), and Cluster Analysis. The results showed that there were no tolerant to high-temperature varieties. Based on the STI, only Olympus was a medium tolerant of high temperatures. Based on the Stress Sensitivity Index (SSI), four varieties are moderately susceptible to high temperatures (Olympus, Andina, Cingkariang, and Margahayu). The YSI analysis shows the same results as the SSI. The cluster analysis results showed harmony between the results of the stress index analysis and cluster analysis. Nine varieties had a high similarity (87.3%), meaning that all varieties had the same characteristics and less tolerance to high temperatures. Olympus was the more tolerant variety to high temperatures, followed by Andina, Cingkariang, and Margahayu. The four varieties consider promising potato lines in high-temperature areas.*

**Keywords:** High temperature stress, Potato, Olympus, Andina, Cingkariang, Margahayu.

## INTRODUCTION

Potato (*Solanum tuberosum*, L) is one of the horticultural commodities that play an important role in the development of food diversification, its demand continues to increase from year to year. The center of potato production in Indonesia is in the highlands of more than 1000 meters above sea level (masl) which is characterized by low temperatures (10-22°C) and has a high level of land slope (more than 8%) so it has a high vulnerability. against erosion and landslides (Duaja, 2012, Prabaningrum et al., 2014).

The achievement of self-sufficiency in potato consumption in Indonesia is achieved through the intensification and extensification of the highlands by planting potatoes throughout the year and opening new land on hillsides (Ngabekti et al., 2007; Prabaningrum et al., 2014; Handayani, et al., 2007). al., 2014). Data from the Ministry of Agriculture stated that the harvested area and potato production in Indonesia in 2015-2019 was very volatile, ranging from 66,450- to 75,611 ha, with production between 1.2- 1.3 million tons a year. This gives a signal that the carrying capacity of upland land as a buffer for potato production has reached its maximum or will experience a slope if intensification is carried out over a long period. Therefore, in the long term, a breakthrough is needed so that domestic potato production can still be fulfilled while maintaining environmental sustainability. According to the Agency for Agricultural Research and Development (1989), to anticipate environmental damage in highland potato production centers, it is very necessary to expand production areas outside the highlands, one of which is to the medium plains. The condition of the medium plains is more sloping, safer from erosion, and the availability of the medium plains area is very

wide. About 300,000 hectares of irrigated rice fields and dry land in the medium plains have the potential for potato commodity development.

Potato is a horticultural commodity that is very sensitive to high air temperatures. Potato plants have different optimum temperature limits for shoot development and tuber development (Van Dam et al., 1996, Rykaczewska 2015). The optimum temperature for crown growth is no more than 25°C and the optimal temperature for tuber growth is no more than 20°C (Levy & Veilleux, 2007). The process of initiation and formation of tubers in potato plants is more sensitive to high-temperature stress than the photosynthesis process (Minhas et al., 2006). Meanwhile, the average air temperature in the midland area is around 25°C, so it is assumed that potato plants will thrive in the vegetative part, but the yield is greatly reduced because the air temperature is too high for the tuber formation process.

Davis (1941) (Levy & Veilleux, 2007) found that the yield of *Solanum commersonii* was higher at 25°C than at 12°C. This is important information about potato species that prefer higher temperatures, and the findings could be the basis for breeders to get high-temperature tolerant varieties. Currently, plant breeders from potato-producing countries in the world have developed several potato varieties that are tolerant of high temperatures. On the other hand, Indonesia only has one variety that can adapt quite well to high temperatures, namely the Olympus variety. Sahat and Sulaeman (1989) reported that in the 80s seven kinds of potato varieties, namely Granola, Morene, Nicola, Sputa, Cipanas, Desiree, and Katela were able to adapt in the middle plains in Magelang and Malang with a productivity range of 12.86-21, 15 tons/ha. Wardiyati (2005) reported that

DTO 28, Cipanas, Aquila, and Cosima varieties produce tubers in the medium plains of 300 masl with yields of 2-8 tons/ha and at medium plain 500 masl reaching 13-24 tons/ha. The tuber production of Katela, Desire, and AVRDC varieties reached 20-24 tons/ha at 300 meters above sea level. Asandhi (1989) reported that the tuber production of DTO 33 reached 20 tons/ha in the medium plain. However, most of them were imported varieties which no longer cultivated in Indonesia. Currently, potato breeders have developed high-yielding varieties that are suitable for optimum temperature areas. However, these varieties have not been extensively studied and adapted to high-temperature conditions to determine their tolerance level to temperatures above the optimum for potato tuber growth and production.

Adapted superior potato varieties to high-temperature conditions are one solution to obtain genetic material for high-temperature tolerant potatoes for the assembly process of high-temperature tolerance potato varieties by breeders. Therefore, this study aims to identify the tolerance ability of national superior potato varieties

## RESEARCH METHOD

The experiment was conducted in the field and carried out in two locations. The highlands with optimum temperature for potato plants, at Bandongan Village, Ngablak District, Magelang Regency (1300 masl) is the first location. The medium plains with temperatures more than optimum for potato plants, at Sidomukti Village, Ungaran District, Semarang Regency (380 masl) is the second location. The study was conducted from June to September 2016, months when the air temperature in the medium plains is at its lowest throughout the year. The

distance between the two locations is about about 65 km. To arrange the observation schedule, planting time in the high land was conducted one week earlier than in the medium plains. The materials tested were eight varieties of potato suitable for highlands (>1000 masl) that are Agria, Andina, Amabile, Cingkariang, Granola L, Granola K, Margahayu, and Tedjo-MZ, and one variety suitable for highlands to medium plain (500 -1000 masl), that is Olympus.

The experiment data consisted of primary and secondary data. Secondary data are daily maximum and minimum air temperature at both locations during one growing season. Data on air temperature was obtained from the BMKG Semarang. To analyze the stress sensitivity index and stress tolerance index, the tuber yield data used were the fresh tuber weight per plant per variety. Observation of tuber yields carried out at harvest. Harvesting time was conducted when more than 50% of the plant leaves turn yellow. Harvest age at highland is 90 days after planting and for medium plans is 96 days after planting. To perform cluster analysis, the growth data used consists of plant height, number of leaves, leaf area, rate of photosynthesis, dry tuber weight, dry canopy weight, fresh tuber weight per plant, and each fresh-tuber weight observed at the age of 60 days after planting.

## Data Analysis

### 1. Stress Sensitivity Index (SCI)

$SCI = [1 - (Y_{si}/Y_{pi})] / [1 - (Y_s/Y_p)]$  (Fischer, 1978), (Bousslama and Schapaugh 1984).

If the SCI value  $\leq 0.5$ , then the genotype is tolerant. If  $0.5 < SCI \leq 1.0$ , then the genotype is classified as medium tolerant. If the  $SCI > 1.0$ , then the genotype is sensitive.

2. Stress Tolerance Index (STI)

$$STI = (Y_p \times Y_s) / Y_p^2$$

If the STI value  $\leq 0.5$ , then the genotype is sensitive, if  $0.5 < STI \leq 1.0$ , then the genotype is classified as medium tolerant, and if  $STI > 1.0$ , then the genotype is tolerant.

3. Yield Stability Index (YSI)

$$YSI = Y_{si} / Y_{pi}$$
 (Bousslama and Schapaugh 1984)

The tolerance classification is using the median of the YSI results of all studied varieties. Then the value is divided into two, above and equal to or below the median value. Furthermore, the tolerance criteria are compared with the results on the stress sensitivity index.

Information :

$Y_{si}$  = tuber yield of a genotype under stressed conditions (high temperature)

$Y_{pi}$  = tuber yield of a genotype at optimum conditions (optimum temperature)

$Y_s$  = Average tuber yield of all genotypes under high-temperature stress

$Y_p$  = Average tuber yield of all genotypes at optimum conditions

4. Cluster analysis conducted using SPSS version 23 program.

**RESULT AND DISCUSSION**

Based on the observations of air temperature results, it is known that there is a huge difference in air temperature between the two locations.

The difference in minimum air temperature (night) is 6.6°C and 8.9°C at maximum temperature (day) (Table 1).

The air temperature at the study site in the middle plains, both the minimum and maximum temperatures, both exceed the optimum temperature requirements. According to Subba and Dukpa (2019), an increase in air temperature of 10-15°C from the temporal optimum temperature has caused plants to experience high-temperature stress. In this study, the increase in temperature has not reached 10-15°C, but the tuber yields obtained have decreased drastically (Table 2). This finding provides information that the varieties studied are intolerant to high-temperature conditions with an average of 27.8°C. The plants have been subjected to high-temperature stress resulting in a high decrease in tuber yield. Levy & Veilleux (2007) reported that the optimum temperature for crown growth was no more than 25°C and the optimal temperature for tuber growth was no more than 20°C. Minhas et al., (2006) also stated that the process of initiation and formation of tubers in potato plants is more sensitive to high-temperature stress than the process of photosynthesis or the vegetative phase. A high night (minimum) temperature is more detrimental to the formation and growth of potato tubers than a higher day (maximum) temperature.

**Table 1** Minimum, maximum, average, and the difference in air temperature between highland and medium plains

Air temperature	Highland	Medium plains	Kenaikan suhu
	°C		
minimum	17.1	23.7	6.6
maximum	22.9	31.8	8.9
Average	20.0	27.8	7.8

Muthoni (2018) also added that the low minimum temperature at night is an eminent important factor for potato plants because tuber initiation is highly dependent on the minimum night temperature rather than the average daytime temperature. (Zaag, 1992; Ghosh et al., 2000) also stated that when potato plants enter the tuber growth phase from the vegetative growth phase, a lower optimum temperature is required, namely 22°C during the day (maximum) and 15°C at night (minimum). Likewise, if the soil temperature is more than 20°C, it will reduce potato tuber yields (Levy & Veilleux, 2007), especially when followed by high ambient temperatures (30°C during the day/ 23°C at night) (Wolf & Olesinski, 1990; Rykaczewska, 2013). The increase in soil temperature is influenced by the large ratio of the energy absorbed from solar radiation and the amount of energy that can be released from the soil. When the soil temperature reaches 30°C the activity of several enzymes that play a role in starch metabolism becomes depressed, resulting in a decrease in starch content in tubers (Krauss & Marschner, 1984).

Liao et al. (2016) confirmed that soil temperature at a depth of 20 cm from the soil surface is one of the most important factors that determine the yield of potato tubers

The results of these studies confirmed that the decrease in tuber yield in this study occurred because the night temperature (minimum) during the tuber formation phase exceeded the optimum temperature required by potato plants. Thus, it is known that the decrease in tuber yield in nine varieties that were not developed for high-temperature conditions was more influenced by night temperatures that exceeded the optimum temperature than the magnitude of the increase in temperature that occurred.

Based on fresh tuber weight per plant, the nine varieties studied showed different sensitivity levels, tolerance, and yield stability to high-temperature stress encountered in the middle plains. The Stress Sensitivity Index (SSI) analysis showed that four varieties had a medium tolerant category ( $0.5 < ISC < 1.0$ ) which are Olympus, Andina, Cingkariang, and Margahayu. The other five varieties

**Tabel 2** Stress Sensitivity Index (SSI) and Yield Stability Index (YSI) under high-temperature conditions

Cultivar	Yp	Ys	SSC	Category	YSI	Ranking	STI	Kategori
Olimpus	874	212	0,93	Medium Tolerant	0,24	3	<u>0,54</u>	Medium Tolerant
Andina	517	195	0,76	Medium Tolerant	0,38	1	0,30	Sensitive
Margahayu	412	150	0,78	Medium Tolerant	0,37	2	0,18	Sensitive
Cingkariang	496	115	0,94	Medium Tolerant	0,23	4	0,17	Sensitive
Agria	618	98	<u>1,03</u>	Sensitive	<u>0,16</u>	5	0,18	Sensitive
Amabile	766	82	1,09	Sensitive	0,11	6	0,19	Sensitive
Granola K	583	47	1,12	Sensitive	0,08	7	0,08	Sensitive
Tedjo MZ	510	39	1,13	Sensitive	0,08	8	0,06	Sensitive
Granola L	475	14	1,18	Sensitive	0,03	9	0,02	Sensitive
Median	517	98	1,03		0,16		0,18	

included in the sensitive category ( $SSI > 1.0$ ) are Agria, Amabile, Granola L, Granola K, and Tejo MZ (Table 2). The SSI analysis represents the genotype that is more tolerant of non-stressful environmental conditions. The greater the value, the more sensitive the genotype is to a stressful environment. SSI is relative because it only divides the genotypes involved in the study, if new genotypes are added, the results will change (Talebi et al., 2009). Fischer and Maurer (1978) reported that the stress sensitivity index analysis was the average reduction in tuber fresh weight of each genotype under stressed conditions compared to the average reduction in tuber fresh weight of all genotypes studied under stressed conditions. The results of the SSI analysis in this study indicate that Olympus, Andina, Cingkariang, and Margahayu have a higher tolerance level to high-temperature stress in the medium plains than the other five varieties.

Meanwhile, in the analysis of the Stress Tolerance Index (STI), only Olympus is a medium tolerant variety, while the other eight varieties are sensitive to high temperatures. The STI analysis represents a genotype that is capable of high production both under stressed and unstressed conditions (the higher the value, the greater the product produced in two environmental conditions (Talebi et al., 2009). Thus, based on the STI analysis, the Olympus variety is indicated to have the ability to produce higher when exposed to high temperatures in the middle plains with a temperature range of  $23.7 - 31.8^{\circ}\text{C}$  compared to the other eight varieties. This result is in line with the description of the Olympus variety which states that this variety can adapt well in the middle plains

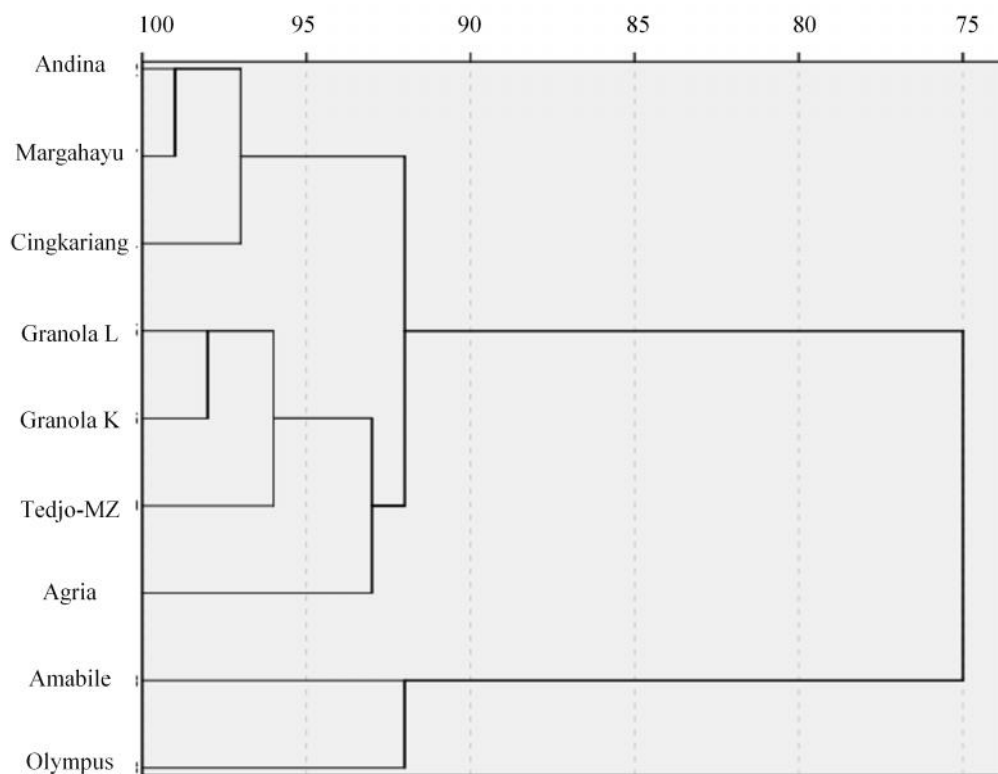
to an altitude of 500 m above sea level. carried out at an altitude of 380 m above sea level, the yield of tubers of the Olympus variety fell by more than 50% so that it was only classified as a medium tolerant of high temperatures.

Analysis of the Yield Stability Index (YSI) showed results that were in line with the SSI, namely the four varieties at the top of the YSI analysis were four varieties with the tolerant medium category in the ISC analysis, namely Olympus, Andina, Cingkariang, and Margahayu. YSI analysis represents a genotype that is more tolerant under stressed conditions, the higher the YSI value, the more tolerant a genotype is to stressed conditions and its nature is more absolute because it is calculated from each individual/genotype, which is a comparison of the productivity in stressed conditions with unstressed conditions (Talebi et al., 2009). Therefore, because the results of the YSI analysis are more absolute, after comparing them with the results of the SSI and STI analysis, the varieties with the most potential to have greater tolerance to high temperatures are Olympus and followed by Andina, Cingkariang, and Margahayu. Meanwhile, the other five varieties, which are Agria, Amabile, Granola L, Granola K, and Tedjo MZ have a lower tolerance and are not recommended to be developed in the high-temperature medium plains as in the location of this study. The results of this study provide information that varieties that are not specifically assembled for high-temperature abiotic stress conditions are thought to be unable to cope with high-temperature stress and have an impact on the resulting low economic yields.

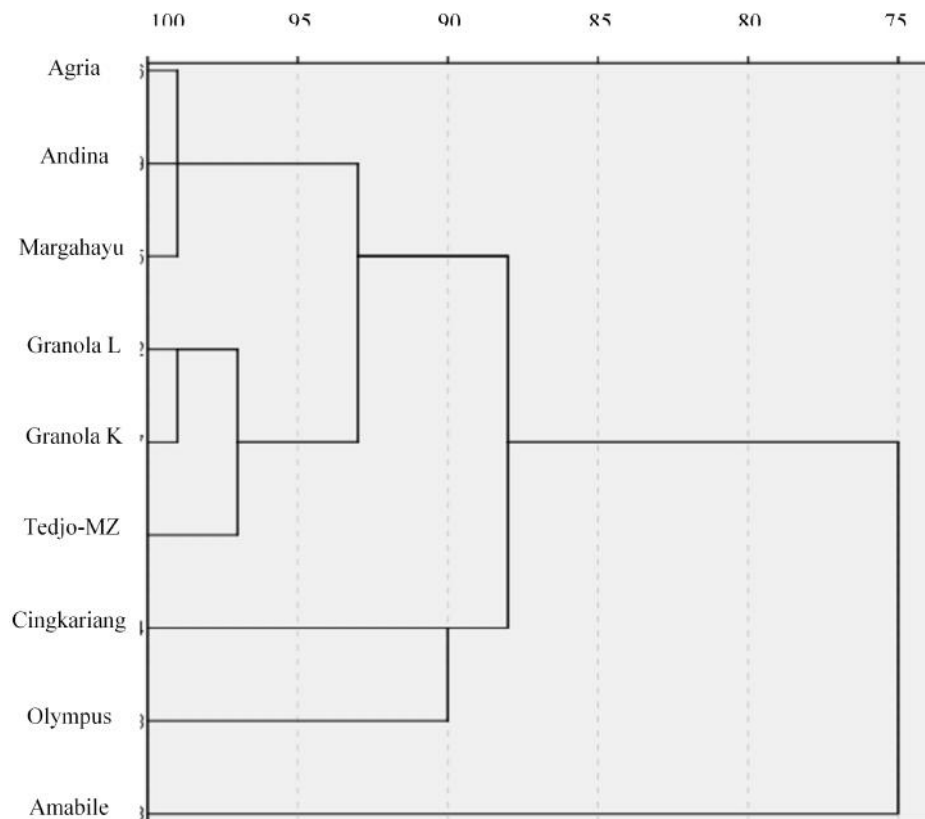
The nine varieties studied were divided into two groups of high-temperature tolerance based on ISC < ITC and ISH analysis. Then cluster analysis was carried out to see if there were similarities in terms of growth, physiology, and tuber production. Based on the cluster analysis from the highlands and medium plains, there was a change in varieties clusters between the highlands and the medium plains. In the highlands, nine varieties were divided into three clusters (Figure 1), while in the medium plains, they were divided into five clusters (Figure 2).

Three varieties have great similarities and their clusters either in the highlands or medium are consistent, are Granola L, Granola K, and Tedjo MZ. This result shows that these three varieties have similarities in terms of performance of growth parameters, physiology, and tuber yields in both locations. The other

varieties which have high similarity in both the highlands and the medium plains are Andina and Margahayu. Meanwhile, Amabile and Olympus, when in the highlands grouped into one cluster in highland, but in the medium plains, they separated into other clusters. This condition shows that Olympus and Amabile have different adaptability when exposed to high-temperature and are under the results obtained in the analysis of ISC, TC, and ISH. Meanwhile, Agria in the highlands became one cluster with Granola L, Granola K, and Tedjo-MZ, but in the medium plains, it became a cluster with Andina and Margahayu. The same condition to Cingkariang, which became one cluster with Andina and Margahayu, but in the medium plains, it separated and formed a separate cluster, and Amabile which in the highlands became one cluster with Olympus, but in the medium plains, it



**Figure 1** Dendrogram of the cluster analysis result of nine cultivars in the highland



**Figure 2** Dendrogram of the cluster analysis result of nine cultivars in the medium plains

divided to form a separate cluster. The change of Agria, Amabile, and Cingkariang indicated that they have differences in growth performance, physiology, and tuber yields obtained due to high-temperature stress, which showed different tolerance abilities. Agria and Amabile tend to be less tolerant of high temperatures, while Cingkariang shows a more high-temperature tolerance. Also confirmed from the ISC and ISH analysis, that Cingkariang is categorized as medium-tolerant while Agria and Amabile are sensitive to high temperatures.

Cluster changes that occurred between the highlands and the middle of the six varieties other than Granola L, Granola K, and Tedjo-MZ indicated that there were differences in adaptability or tolerance to high-temperature stress that occurred during one growing

season. Especially for the varieties Granola L, Granola K, and Tedjo-MZ did not experience a change in the cluster arrangement between the highlands and the middle, indicating that the three varieties had a high similarity, as well as when subjected to high-temperature stress in the medium plains, these three varieties tended to experience the most temperature stress. the highest height compared to the other six varieties. This can be confirmed from the results of the analysis of SSI, STI, and YSI where Granola L, Granola K, and Tedjo MZ experienced a very large and drastic decrease in yield.

The results of this study indicate that cluster analysis and stress index analysis of potato varieties against high temperatures can confirm each other because the results



obtained are in line. However, because this study was limited to the agronomic aspect, it was not possible to trace whether the similarities and differences in tolerance levels between these varieties were also due to the close or distant genetic kinship. Therefore, research on molecular aspects of DNA analysis should also be carried out to determine the close kinship between the nine varieties.

## CONCLUSIONS

1. None of the nine varieties studied were tolerant to high temperatures in the range of 23.7 – 31.8°C based on the analysis of SSI, STI, and YSI.
2. Olympus is a variety that is more tolerant of high temperatures than other varieties followed by Andina, Cingkariang, and Margahayu.
3. The Olympus, Andina, Cingkariang, and Margahayu varieties can be used as one of the considerations in assembling high-temperature tolerant varieties by breeders because they have a medium tolerant character to high temperatures.

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