Journal of Applied Horticulture, 26(4): 475-479, 2024
https://doi.org/10.37855/jah.2024.v26i04.90
Journal of Applied Horticulture
ISSN: 0972-1045

Utilizing fan cooling to reduce leaf temperatures in ginseng cultivation

Byungsoon Kim[1]*, Myung Hwan Jang[1] and Ilkyeun Ra[2]

*[1]Department of Computer Education, Andong National University, Gyungbook, South Korea. Punggi Ginseng Research Institute, Gyungbook, South Korea. [2]Department of Computer Science and Engineering, University of Colorado Denver, Colorado, United States. *E-mail: bsgim@anu.ac.kr*

Abstract

Due to climate change, there have been more frequent heat waves and a notable rise in global temperature. This change hinders ginseng's cultivation, a crop that grows well in cooler and shaded environments. This study evaluated the effectiveness of air-circulation fans in alleviating heat stress and lowering the leaf temperatures when cultivating ginseng. The experiment defined two groups: control group and an experimental group. The experimental group tracked the influence of fans' activation as they will be activated when the temperature rises beyond 30°C. The control group, however, did not include fans. We monitored three sets of data: ambient, leaf temperatures, and humidity levels, using a custom data acquisition system. The experimental results showed that the leaf temperature tended to decrease more significantly than the relative temperature decrease due to a slight increase in relative humidity caused by the flow fan. The experiment results presented a more significant decrease in leaf temperature with an average of 0.65 °C among the experimental group compared to the control group due to an increase in relative humidity. Through the Mann-Whitney U test, we confirmed a meaningful difference in the temperature and humidity distribution between the experimental and control groups when fans were activated. Such results indicate that air-circulation fans can be an effective temperature mitigation instrument for relieving heat stress when farming ginseng. The research enhances the ginseng farming conditions by mitigating the risk of rising temperatures and further contributes to sustainable agriculture.

Key words: Ginseng, heat stress, air circulation, leaf temperature

Introduction

The current climate change caused by global warming is significantly endangering plant growth, crop yield, and quality (Ahuja *et al.*, 2010; Backer *et al.*, 2018; Boyer *et al.*, 1982; Krasensky *et al.*, 2012; Mittler *et al.*, 2006). The global temperature is forecasted to rise by 1.5-4.8 °C by 2100 (Malhi *et al.*, 2021; Mohammadi *et al.*, 2023). A drastic loss in crop yield seems inevitable due to the constantly rising global temperature (Choi *et al.*, 2019; Engler *et al.*, 2021, Ortiz *et al.*, 2008; Pörtner *et al.*, 2022).

To sustain agricultural productivity, various efforts are invested to mitigate heat stress. They include enhancing airflow for heat dissipation and employing fog systems for cooling through evaporation. However, the use of fog systems is minimal as fog has a side effect on plant diseases due to excessive moisture.

Previous research has prevalently focused on the role of air-circulation fans in greenhouses. They were designed to improve ambient conditions, enhance photosynthesis, and control internal temperatures. Engler *et al.* (2021) and Lim *et al.* (2022) research reported that air-circulation fans reduced energy consumption and were more effective when used with fog systems. Similarly, Oh *et al.* (2016) showed improved pollination rates and fruit yields in cucumber cultivation when air-circulation fans were used during high temperatures.

Ginseng is a commercially high-value medicinal crop and is particularly sensitive to high temperatures. This trait of ginseng makes it particularly vulnerable to Korea's hot summers. This study investigates how air-circulation fans influence temperatures to reduce heat stress in ginseng fields. The fans will be installed in shaded areas and activated when the temperature rises above 30°C. Their impact on ambient, leaf temperature and humidity levels will be closely examined. We will compare the experimental group with fans and the control group without the fans to evaluate the fans' effects in cooling down ginseng's growing environment. This study offers crucial insights into the broader range of ways to alleviate climate change risk in crop cultivation.

The paper will cover the following topics in order. First, the outline of the experiment's design and methodology; second, an in-depth analysis of the results; and third, the implications of the results, exploring how temperature control using fans can serve as a viable strategy for enhancing ginseng farming against global warming. In conclusion, this research contributes to mitigating climate change and further emphasizes the importance of innovative cooling strategy for sustainable agricultural productivity.

Materials and methods

The experiment was been designed to utilize a custom sophisticated data acquisition system to accurately assess the impact of fan-assisted temperature control on reducing heat stress in ginseng cultivation. This system consisted of two main components: sensors for real-time monitoring of environmental conditions and a private cloud server for data aggregation.

Real-time monitoring system: The system included various sensors, the LT-1T (Implexx Sense, 2024) to measure precise leaf temperature, and the AM2315C (Aosong Electronic, 2024) to monitor ambient temperature and relative humidity. To ensure comprehensive monitoring of environmental factors, the sensors were employed within the ginseng farming area. The collected data were then transmitted to our private cloud server using a wireless sensor network with long-range (LoRa) technology.

Table 1 summarizes the technical specifications of the sensors used. The LT-1T is a high-precision, glass-encapsulated thermistor designed as a subminiature touch probe to measure leaf temperature. It shows an accuracy of ±0.08 °C and operates within a 5 to 24 volts voltage range, communicating through the SDI-12 protocol. The AM2315C sensor, however, offers dual functionality and measures ambient temperature with an accuracy of ±0.3 °C and relative humidity (RH) with an accuracy of ±2%. The AM2315C sensor communicates with the I2C protocol and operates on a voltage range of 2.2 to 5.5 volts.

Table 1. Technical specifications of leaf temperature, ambient and humidity sensors.

Model	Implexx LT-1T	AM2315C
Accuracy	±0.08 °C	Temperature: ±0.3 °C, RH: ±2%
Protocol	SDI-12	I^2C
Supply voltage	5 ~ 24 V	2.2 ~ 5.5 V

Fig. 1 depicts the customized network architecture of the ginseng environmental monitoring system (Kim, 2023). It highlights the flow of data, starting from the sensors to the gateway, and then to the cloud server. The system consists of one private cloud server with MySQL 8.0, Mosquitto broker 2.0, Grafana 9.0, and Node-RED 1.3. It employs a wireless sensor network based on LoRa technology, connected to the Internet with Long Term Evolution (LTE), to monitor real-time leaf temperatures using thermistors and infrared thermometers. The gateway acts as a sink node of the wireless sensor network and converts this data into JavaScript Object Notation format. Then, it transmits to the cloud server through the Message Queuing Telemetry Transport (MQTT) protocol.

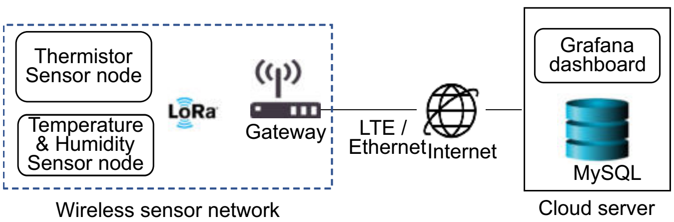

Fig. 1. Network architecture of ginseng environmental monitoring system.

Fig. 2 is the block diagram of our custom sensor node. It shows the connectivity between the sensors, microcontroller, and RFM95W module. The AM2315C sensor connects to the ATmega328P microcontroller, via the I2C (Inter-Integrated Circuit) protocol. Meanwhile, the LT-1T connects through the SDI-12 communication protocol communication protocol (Kim, 2023). The sleep mode is applied to the microcontroller and RFM95W module to save power consumption.

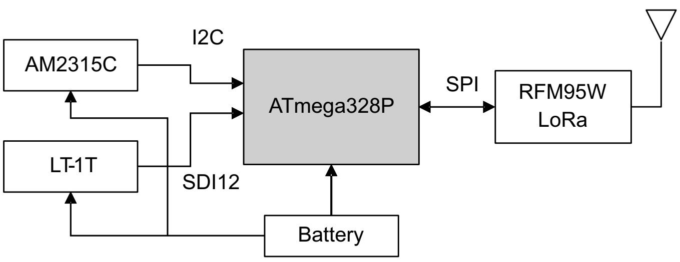

Fig. 2. Block diagram of custom sensor node

Experimental setup: The study was designed to examine the effects of fan activation on ambient and leaf temperatures, and humidity. The research was conducted during field experiments at the Punggi Ginseng Research Institute of Gyeongsangbuk-do, a ginseng cultivation environment. The geographical location was latitude 36.4833° N and longitude 128.3230 ° E, at an altitude of 180 m above sea level. The two distinct groups, a control group and an experimental group, are illustrated in Fig. 3. Each group consisted of two ridges with the size of 24 meters in length and 90 cm in width, and was planted with three rows of 4-year-old native strain ginseng (Kim *et al.*, 2023). In order to precisely control the environment, three air circulation fans, with an outer diameter of 30 cm and a power consumption of 65 Watts, were installed at a height of one meter on support posts, behind the shade screens in the experimental group. These fans were programmed to automatically activate when the ambient temperature reached 30°C to ensure consistent cooling intervention activation.

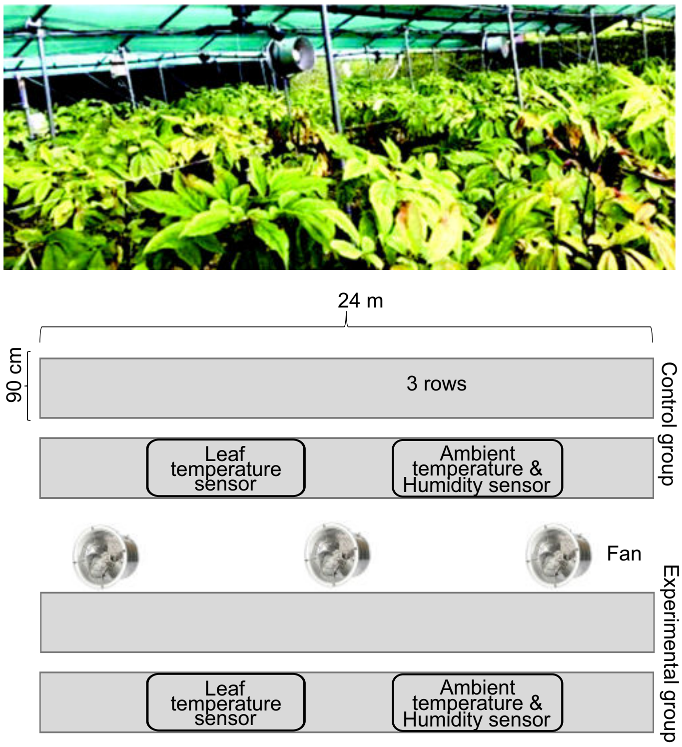

Fig. 3. Experimental test bed: 4-year-old native strain ginseng (above), testbed layout (below)

From August 12 to September 11, 2023, data was continuously collected every 5 minutes from the control and experimental groups. The implanted sensors recorded ambient temperature, humidity, and leaf temperature parameters at regular intervals.

Data analysis: Python's Pandas library was utilized for data analysis purposes. Pandas library categorized the dataset based on the ambient temperature readings. Data points with an ambient temperature of 30°C or higher were classified as the 'fan-activated' category, whereas those under 30°C were considered 'non-activated.' To ensure the accuracy of the analysis, any rows containing null values were excluded from the dataset.

Results and discussion

The effect of circulating fans in lowering the temperature of leaves has been examined. Differences in ambient temperature, leaf temperature, and humidity between the experimental and the control groups were examined while also focusing on the effects of the fan's operation status by comparing two different conditions of "Fan On" and "Fan Off." The results indicate that the activation of the fan significantly reduced both the ambient and leaf temperatures in the experimental group compared to the control group.

Fig. 4 illustrates the distribution of ambient temperatures for both the experimental and control groups. The experimental group's histogram is filled with darker gray color, indicating where the fan was activated. In contrast, the control group's histogram is filled with light gray color and marked with a diagonal pattern, depicting the conditions without fan activation. Thus, Kernel Density Estimation (KDE) curves overlay each histogram, providing a smooth estimate of the probability density function for each group's distribution and enhancing the visual comparison between the fan-activated and non-activated conditions.

Ambient temperature comparison: According to Fig. 4(a), the distribution of ambient temperature for the experimental group when fans were activated, is narrow. Thus, the peak of the distribution is located in the low-temperature range. This indicates that the ambient temperature maintains a constant and low range with the fans' activation. In contrast, Fig. 4(d) shows that when the fan does not work, the ambient temperature distribution is much wider and the volatility is much higher. This showcases that ambient temperature control is less effective in terms of microclimate. Therefore, it can be concluded that ambient temperature remains more stable when operating fans.

Leaf temperature comparison: The peak leaf temperatures show a similar pattern across both groups when the fan is turned off in Fig. 4(e). However, in Fig. 4(b) where the fans are operated, the experimental group's peak temperatures are slightly higher than the control group's. Also, the experimental group demonstrates a relatively compact range of leaf temperatures compared to the control group. This implies that the fans' variables contribute to a more even temperature range across all leaves. Although there is still a considerable amount of overlap in the temperature distributions regardless of fan situations, such data suggests that the effect of fans on leaf temperature maintains a level of consistency despite the specific conditions.

Relative humidity comparison: The peak humidity levels were constantly lower when fans were activated in Fig. 4(c). The peak humidity levels for the experimental group were slightly below that of the control group under both fan conditions. The control group displays a broader range of humidity levels, which suggests that fan operations provide greater variability. However, humidity levels showed a definite tighter distribution with the experimental group when fans were deactivated. This trait highlights more stable humidity conditions. Despite such differences, the general humidity distributions between the control and experimental groups for both fan conditions show high similarity, with the experimental group depicting a more compact spread and lower peak humidity levels.

Fig. 5 shows the ambient temperature, leaf temperature, and relative humidity trend when fans are activated. Ambient temperature shows a weak fluctuation, with the temperatures of the experimental group generally being lower compared to the control group in Fig. 5(a). This suggests the fans' effectiveness in moderating ambient temperature conditions. The leaf temperature data shows that the experimental group's leaf surfaces remained cooler than the control group in Fig. 5(b). This shows that air-circulation fans can reduce the leaf surface temperature of crops. Also, the experimental group maintained slightly higher humidity levels than the control group throughout the experiment in Fig. 5(c). The differences in Fig. 5 can be attributed to the fan, as it probably facilitated increased transpiration rates among the plants within the control group by enhancing air circulation.

Table 2. Comparative descriptive statistics for environmental conditions under fan-activated and non-activated scenarios

Condition	Variable	Control			Experimental			Mean difference between experimental – control group
		Range	Mean	Standard deviation	Range	Mean	Standard deviation	
Activated fan	Ambient temperature	27.68 –36.55	32.27	1.37	30.00 -36.10	31.93	1.32	-0.34
	Leaf temperature	37.15	32.66	1.34	36.20	32.01	1.31	-0.65
	Relative humidity	41.38 –100	56.80	7.83	43.40 -85.72	61.32	8.02	+4.52
Non-activated fan	Ambient temperature	12.76 –30.75	22.90	3.64	12.73 -28.98	22.88	3.56	-0.02
	Leaf temperature	13.00 –31.62	23.39	3.67	13.20 -31.12	23.17	3.53	-0.22
	Relative humidity	41.32 –100	90.96	14.28	44.85 -100	93.52	12.56	+2.56

Table 2 compares the different ambient temperatures, leaf temperature, and relative humidity depending on the activation of the fan. Each variable's range, mean, and standard deviation are tracked for both the experimental and control groups. Also, the mean difference between the two groups is provided to indicate the impact of fan operation on these environment and plant-related parameters. When fans are activated, the ambient temperature shows a clear decrease of 0.34 °C and the leaf temperature drops by an average of 0.65 °C. Thus, the margin of relative humidity difference is apparent as the relative humidity increases by 4.52%, compared to 2.56% when the fans are not turned on.

These results indicate that the wind from fan operation stimulated the plant's transpiration and increased the relative humidity of the ambient temperature, further decreasing the temperature of both ambient and leaves. The leaf temperature dropped, especially due to the greater cooling effect of transpiration on the plant's surface.

Mann-Whitney U Test: The results of the Mann-Whitney U test show that there were considerable differences in the temperature and relative humidity of the experimental and control groups when the fans were activated.

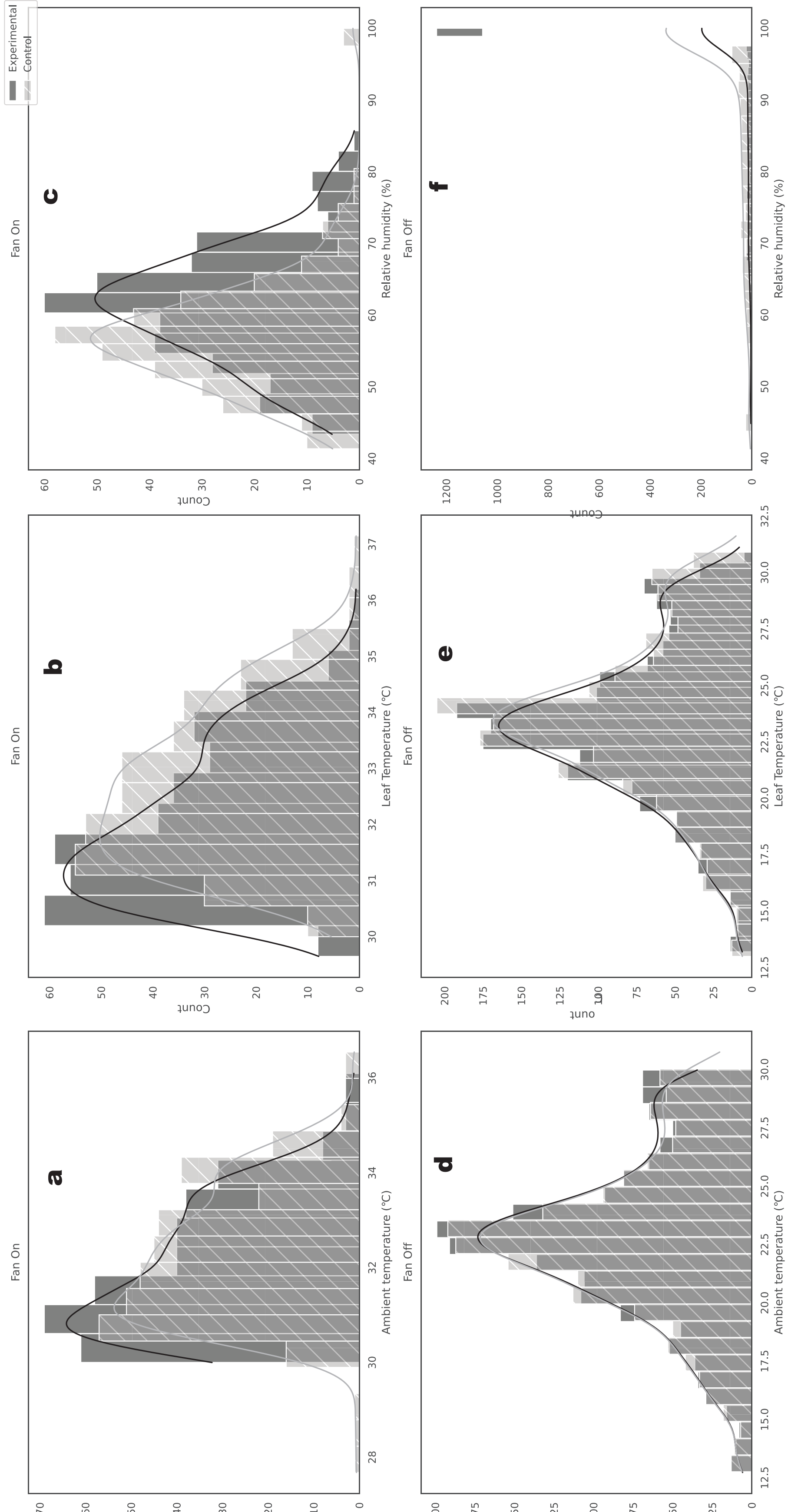

Fig. 4. Comparative analysis of temperature and relative humidity Distributions with experimental vs. control group: (a) Comparing the distributions of ambient temperature under fan-activated conditions, (b) Comparing the distributions of leaf temperature under fan-activated conditions, (c) Comparing the distributions of relative humidity under fan-activated conditions, (d) Comparing the distributions of ambient temperature under fan-nonactivated conditions, (e) Comparing the distributions of leaf temperature under fan-nonactivated conditions, (f) Comparing the distributions of relative humidity under fan-nonactivated conditions

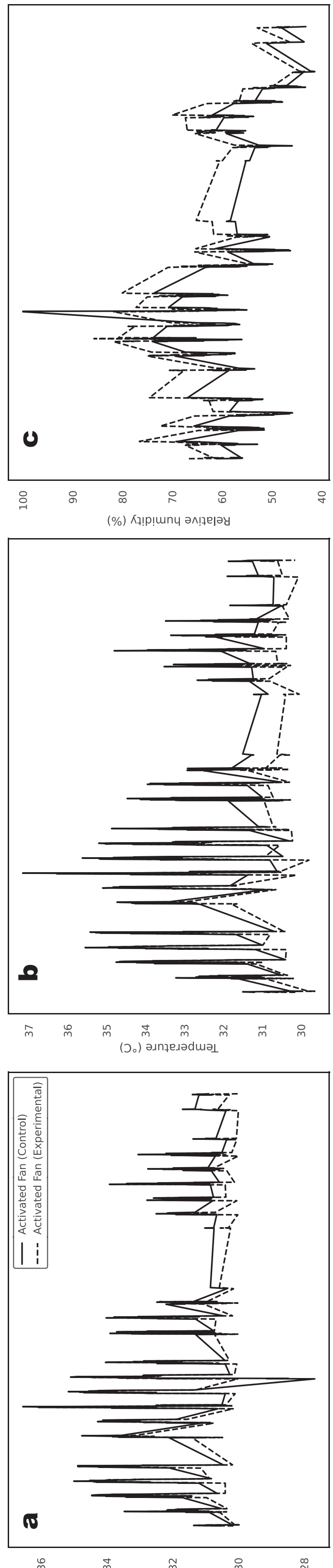

Fig. 5. Ambient temperature, leaf temperature and relative humidity varying over time under activated fan condition: (a) Ambient temperature, (b) Leaf temperature, (c) Relative humidity

Table 3. Mann-Whitney U test results

Condition	Variable	U-statistics	*P*-value
Activated fan	Ambient temperature	51901.5	0.00031
	Leaf temperature	44474.5	1.83×10^{-10}
	Relative humidity	83402.5	4.85×10^{-16}

Regarding the ambient temperature, the U-statistics of 51,901.5 and the *P*-value of 0.0003 were recorded (Table 3). There is a significant difference in temperature distributions between the two groups when the fan was activated. The leaf temperature showed even more noticeable effects with the U-statistic of 44,474.5 and a remarkably low *P*-value of 1.83 x 10-10. This result also asserts a difference between the two groups. Lastly, the relative humidity measurements hold the U-statistic of 83,402.5 and a *P*-value of 4.85 x 10-16. The distribution of humidity levels when the fans were activated seems to hold a noticeable difference.

The *P*-value of less than 0.05 was considered statistically meaningful when evaluating data. This denotes that the observed differences in distributions across all three variables are unlikely to be coincidental.

Linear regression analysis: In the regression model, ambient temperature was selected as the independent variable to predict leaf temperature. The analysis showed a significant positive relationship, with ambient temperature proving to be a strong predictor of leaf temperature (R^2=0.89, RMSE = 0.46 °C; Fig. 6).

Leaf temperature=0.9445×Ambient temperature+2.0213

In this equation, the coefficient 0.9445 indicates the change in leaf temperature per 1°C increase in ambient temperature, while 2.0213 is the estimated leaf temperature when ambient temperature is zero.

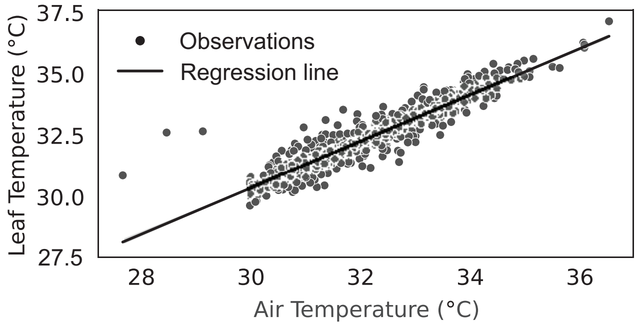

Fig. 6. Relationship between ambient temperature and leaf temperature

This research confirmed that fans effectively reduced the leaf temperature of 4-year-old ginseng. In the experimental group with fans, ambient and leaf temperatures dropped by an average of 0.34°C and 0.65°C, respectively. Additionally, relative humidity increased by 1.96%, indicating that fans also impact humidity. These results demonstrate that fan operation can effectively lower crop leaf temperatures by adjusting the surrounding environment.

In future research, a more diverse environment setting must be considered to examine the effects of fans under a broader scope, along with diverse fan durations and speeds. Moreover, the effect of fans on ginseng of different ages was not addressed, which leaves room for additional studies.

Acknowledgment

This work was supported by a Research Grant of Andong National University

References

Ahuja, I. , R.C. de Vos, A.M. Bones and R.D. Hall, 2010. Plant molecular stress responses face climate change. *Trends. Plant Sci.,* 15: 664-674.

Aosong Eletronic, 2024, <http://aosong.com>

Backer, R., J.S. Rokem, G. Ilangumaran, J. Lamont, D. Praslickova, E. Ricci, S. Subramanian and D.L. Smith, 2018. *Front. Plant Sci.,* 9.

Boyer, J.S., 1982. Plant productivity and environment. *Sci*., 218:443-448.

Choi, N. and M.I. Lee, 2019. Spatial variability and long-term trend in the occurrence frequency of heatwave and tropical night in Korea. *Asia-Pac. J. Atmos. Sci.*, 55: 101-114.

Engler, N. and M. Krarti, 2021. Review of energy efficiency in controlled environment agriculture, *Renewable Sustain. Energy Rev.*, 141: 110786.

Fahad S., A.A. Bajwa, U. Nazir, S.A. Anjum, A. Farooq, A. Zohaib, S. Sadia, W. Nasim, S. Adkins, S. Saud, M.Z. Ihsan and *et al.*, 2017. Crop production under drought and head stress: plant responses and management options. *Front. Plant Sci*., 8: 1147.

Implexx Sense, 2024, <http://implexx.io>

Kim, B. 2023. Assessing accuracy over warm-up time of Lepton 3.5 thermal imaging for measuring leaf temperature of crops. *J. Appl. Hortic.*, 25(1): 39-42.

Kim, B., M.H. Jang and I. Ra, 2023. Effect of fan systems for lowering leaf temperature of Korean ginseng. *Proc. 15th Int. Conf. on Internet*. Hochiminh, Vietnam, 2023, p.328-329.

Krasensky, J. and C. Jonak, 2012. Drought, salt, and temperature stress-induced metabolic rearrangements and regulatory networks. *J. of Exp. Bot.,* 63: 1593-1608.

Lim, R., J. Son, M. Park and S. Yun, 2022. Evaluation study on the effect of greenhouse cooling and tomato cultivation by airflow fan and fog combined system. *J. Korea Acad.-ind. Coop. Soc.*, 23(12): 343-354.

Malhi, G.S., M. Kaur and P. Kaushik, 2021. Impact of climate change on agriculture and its mitigation strategies: A review. *Sustain.*, 13(3): 1318.

Mohammadi, S., K. Rydgren, V. Bakkestuen and M.A.K. Gillespie, 2023. Impacts of recent climate change on crop yield can depend on local conditions in climatically diverse regions of Norway. *Sci. Rep.*, 13: 3633.

Mann, H.B. and D.R. Whitney, 1947. On a test of weather one of two random variables is stochastically larger than the other. *Annals of Math. Stat.,* 18:50-60.

Mittler, R. 2006. Abiotic stress, the field environment and stress combination. *Trends Plant Sci.*, 11:15-19.

Oh, J.Y., C.G. An, S.Y. Lee, W.K. Joung and K.P. Hong, 2016. Effect of air flow utilization in high-temperature seasons*. Proc. Hortic. Sci. and Technol.*, 3: 99.

Ortiz, R., H.-J. Braun, J. Crossa, J.H. Crouch, G. Davenport, J. Dixon, S. Dreisigacker, E. Duveiller, Z. He, J. Huerta and A.K. Joshi, 2008. Wheat genetic resources enhancement by the International Maize and Wheat Improvement Center (CIMMYT). *Genet. Resour. Crop Evol.,* 55:1095-1140.

Pörtner, H.-O., D.C. Roberts, H. Adams, C. Adler, P. Aldunce, E. Ali, R.A. Begum, R. Betts, R.B. Kerr and R. Biesbroek, 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. IPCC Sixth Assessment Report, Cambridge University Press, Cambridge, UK..

Received: June, 2024; Revised: August, 2024; Accepted: October, 2024