Proceedings of the 18th International Workshop on Regional Innovation Studies

IWRIS2026

~THE SEEDS AND GROWTH OF REGIONAL INNOVATION~

October 15-16, 2026

Regional Innovation Hall, Mie University

Graduate School of Regional Innovation Studies,
Mie university, Tsu, Mie, Japan

MIE UNIVERSITY

Message from the conference chair

The 18th International Workshop on Regional Innovation Studies 2026 (IWRIS2026)
October 15-16, 2026, Mie University, Japan

It is our great honor and pleasure to welcome you to the 18th International Workshop on Regional Innovation Studies 2026 (IWRIS2026). We sincerely appreciate your participation in and support for IWRIS2026.

Since the end of the COVID-19 pandemic, our society has been undergoing rapid changes in values, lifestyles, and economic conditions. In particular, the past few years have witnessed the remarkable rise of artificial intelligence, AI, which is transforming various aspects of our lives and industries. In this context, regional innovation is a key driver for advancing communities and societies around the world into a new stage of development. It is also clear that the exchange of ideas and opinions among people from diverse backgrounds is essential for fostering such innovation. Based on this belief, Mie University established the Graduate School of Regional Innovation Studies in 2009. We also launched IWRIS as an international forum for discussing recent developments and future directions in the creation of shared values, including social, biological, industrial, educational, and cultural values. Since then, the workshop has been held continuously every year.

At IWRIS2026, we are pleased to offer 4 special lectures delivered by distinguished researchers from Indonesia, Korea, and Thailand, as well as 5 technical sessions covering Engineering, Biological Sciences, and Social Sciences. We will also host a banquet on the evening of the first day, providing an excellent opportunity for networking and interaction among participants.

We hope that this workshop will foster meaningful connections among all participants and stimulate collaborative activities that contribute to the future development of regional innovation. We wish you a productive, rewarding and enjoyable experience at IWRIS2026.



Keita Suwabe
Chair of Organizing Committee, IWRIS2026
Dean, Professor
Graduate School of Regional Innovation Studies, Mie University

IWRIS2026 Committees

International Workshop on Regional Innovation Studies 2026

Conference Leadership

General Chair	Keita Suwabe Dean, Graduate School of Regional Innovation Studies
Vice Chair	Hiroshi Suito Vice Dean, Graduate School of Regional Innovation Studies

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IWRIS2026 is supported by the Graduate School of Regional Innovation Studies, Mie University.

IWRIS2026 Timetable

Oct. 15(Thu)

Time	Session	Chairs
10:30	**Opening**: Keita Suwabe	
10:35	**Session 1** Engineering I for Regional Innovation	Naoki Maruyama Norihiro Nishimura
11:40	Lunch Break	
13:30	**Invited Lecture I**: Woncheol Kim	Sungwook Hong
14:00	**Invited Lecture II**: Jiae Seo	
14:30	Break	
15::00	**Session 2** Biological Science for Regional Innovation	Akihisa Nonaka Akio Ohyama
15:25	**Session 3** Social Science I for Regional Innovation	Kazuhiro Ajiki Akihisa Nonaka
17:05		
17:30 19:00	**Banquet**	

Oct. 16(Fri)

Time	Session	Chairs
10:30	**Session 4** Engineering II for Regional Innovation	Tadanori Hashimoto Hiroshi Suito
12:10	Lunch Break	
13:40	**Invited Lectures III**: Dwi Wulan Sari	Akihisa Nonaka
14:10	**Invited Lectures IV**: Hien Van Doan	Liqing Zang
14:40	Break	
15::00	**Session 5** Social Science II for Regional Innovation	Yuko Matsuda Chiharu Mizuki
16:20 16:25	**Closing**: Hiroshi Suito	

The 18th International Workshop on Regional Innovation Studies (IWRIS2026: October 15-16, 2026)

Workshop Room: Regional Innovation Hall, Building C, Regional Innovation Center, Mie University

(Presenters / 1~16)
Presentation time: total 15 minutes (presentation: 10 minutes + discussion: 5 minutes)
Bell Timing: 8 minutes, 10 minutes, 14 minutes *Switching time: 5 minutes
(Kyenote lectures / K-1 and K-2)
Presentation time: total 20 minutes (presentation: 15 minutes + discussion: 5 minutes)
Bell Timing: 13 minutes, 15 minutes, 19 minutes *Switching time: 5 minutes

I. First Day: October 15 (Thursday)

10:30-10:35 **Opening**
Keita Suwabe (Dean of Graduate School of Regional Innovation Studies, Mie University)

Session 1 Engineering I for Regional Innovation
(K-1) 10:35-11:00
Analysis of the parameters' sensitivity for cooling performance of copper pipe heat exchangers 1
Thiri Shoon Wai[1], Naoki Maruyama[1], Nappasawan Wongmongkol[2], Chatchawan Chaichana[2], Smith Eiamsa-ard[3] and Masafumi Hirota[4]
[1] Engineering Innovation Unit, Graduate School of Regional Innovation Studies, Mie University, Tsu, Japan
[2] Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand
[3] Department of Mechanical Engineering, School of Engineering and Industrial Technology, Mahanakorn University of Technology, Bangkok, Thailand
[4] Department of Mechanical Engineering, Faculty of Engineering, Aichi Institute of Technology, Toyota, Japan
1) 11:00-11:20
Classification of Imbalanced Defective Wafer Map Data Using VGG16 Features and LightGBM 5
Shu Konishi[1], Hiroharu Kawanaka[1], Takumi Kitajima[1]

[1] Graduate School of Engineering, Mie University, Tsu, Japan

2) 11:20-11:40

RGB Image Generation From RG Ultra-Widefield Fundus Images Using an Optimized CycleGAN 9

Haru Hirano[1], Takumi Kitajima[1] , Yoshitsugu Matsui[2] , Kumiko Kato[2] , Akiko Ota[2] , Hiroharu Kawanaka[1] , Mineo Kondo[2]

[1] Div. of Electrical and Electronic Eng., Graduate School of Eng., Mie University, Tsu, Japan

[2] Dept. of Ophthalmology, Mie University Graduate School of Medicine, Tsu, Japan

11:40-13:30 Lunch Time

Invited Lecture I

Presentation time: total 30 minutes (presentation: 20 minutes + discussion: 10 minutes)

(I-1) 13:30-14:00

The Effect of Robotic Assisted Gait Training on Physical Activity, Motor Function, and Quality of Life in Children with Spastic Cerebral Palsy: Exploratory Pilot Study 13

Yeon-Gyu Jeong[1], Won-Cheol Kim[2], Yeon-Jae Jeong[2], Ha-Neul Jang[3], Joo-Young Lee[3], Jae-Soon Chung[4], Kyu-Hoon Lee[2]

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[3] Department of Physical Medicine and Rehabilitation, SRC Hospital, Gwangju, Republic of Korea

[4] Department of Sports & Health Care, Korea National University of Transportation, Chungju, Republic of Korea

Invited Lecture II

Presentation time: total 30 minutes (presentation: 20 minutes + discussion: 10 minutes)

(I-2) 14:00-14:30

From Temporary Project to Sustained Collective Action: The Case of Sonmat-itgi Project in South Korea 17

Jiae Seo[1]

[1] Department of Civil Society and NGOs, Graduate School of Public Policy & Civic Engagement, Kyung Hee University, Republic of Korea

14:30-15:00 Break

Session 2 Biological Science for Regional Innovation

(K-2) 15:00-15:25

Rice Husk Utilization for Biomass Power: Energy Potential and Value Addition 21

Trissa Silvian[1], Dwi Wulan Sari[1], Thirtawati[1], and Yulian Junaidi[1]

[1] Department of Agricultural Socio-economics, Universitas Sriwijaya, Ogan Ilir Regency, Indonesia

Session 3 Social Science I for Regional Innovation

3) 15:25-15:45

The Performance Effects of Innovation Diversification under Different Levels of R&D Intensity: Evidence from Japanese Listed Firms 25

Chia-Hui Huang[1] and Yuan-Ru Chang[2]

[1] Department of International Trade, Takming University of Science and Technology, Taipei City, Taiwan

[2] Department of Economics, Aletheia University, New Taipei City, Taiwan

4) 15:45-16:05

Innovation without Expansion: Patents and Firm Performance in Taiwan's Electronics Industry 29

Chia-Hui Huang[1] and Chieh-Ling Chang[2]

[1] Department of International Trade, Takming University of Science and Technology, Taipei City, Taiwan

[2] Department of Economics, Aletheia University, New Taipei City, Taiwan

5) 16:05-16:25

Effects of Cross-Boundary Learning in Depopulated Local Communities on Corporate Employees: An Exploratory Study of Employee Engagement 33

Takashi Shibayama[1]

[1] Graduate School of Regional Innovation Studies, Mie University, Japan

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An Exploratory Case Study on the Knowledge Creation Process in a Non-Profit Organization 37

Ryoya OGURA[1]

[1] Graduate School of Regional Innovation Studies, Mie University, Tsu, Japan

7) 16:45-17:05

Exploring “Omotenashi” Through Sukiyaki: The Essence of Japanese Hospitality 41

Naoko Akatsuka[1]

[1] Graduate School of Regional Innovation Studies, Mie University

17:30-19:00 **Banquet**

II. Second Day: October 16 (Friday)

Session 4 Engineering II for Regional Innovation

8) 10:30-10:50

Numerical simulation of the heat transfer characteristics of serpentine heat exchangers for localized temperature control in greenhouse cultivation 45

Takumi Hirose[1], Naoki Maruyama[1,2], Thiri Shoon Wai[2], Koki Hirose[1], Hiroto Nakamura[3]

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[3] Course of Mechanical Engineering, Faculty of Engineering, Mie University, Tsu, Japan

9) 10:50-11:10

Evaluation of soil temperature distribution around heat exchangers installed for crop root zones thermal control 49

Masataka Noro[1], Naoki Maruyama[1,2], Thiri Shoon Wai[2], Shiuma Morimoto[3]

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[3] Course of Mechanical Engineering, Faculty of Engineering, Mie University, Tsu, Japan

10) 11:10-11:30

Influence of channel surface characteristics on compressor oil behavior and heat transfer in a CO_2 evaporator and its visualization 53

Atsuki Hatano[1], Naoki Maruyama[1,2], Thiri Shoon Wai[2], Hiroto Kawamata[1], Ami Hayashi[3]

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[3]Mechanical Engineering Program, Department of Engineering, Faculty of Engineering, Mie Uni-versity, Tsu, Japan

11) 11:30-11:50

Experimental investigation on heat transfer characteristics and flow visualization of CO_2 refrigerant in microchannels 57

Toru Saito[1], Naoki Maruyama[1,2], Thiri Shoon Wai[2], Yuta Sato[1], Kota Sato[3]

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[3] Course of Mechanical Engineering, Faculty of Engineering, Mie University, Tsu, Japan

12) 11:50-12:10

Experimental evaluation of Hypochlorous Acid production characteristics and bubble behavior in a flow-type electrolysis device 61

Koki Ito[1], Naoki Maruyama[1,2], Thiri Shoon Wai[2], Ota Makino[2], Yoshinari Nagao[3]

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[3] Mechanical Engineering Program, Department of Engineering, Faculty of Engineering, Mie University, Tsu, Japan

12:10-13:40 Lunch Time

Invited Lecture III

Presentation time: total 30 minutes (presentation: 20 minutes + discussion: 10 minutes)

(I-3) 13:40-14:10

Latest Status of Japanese-Style Vegetable Production and Distribution in Indonesia: A Case Study of OKIAGARU Farm in West Java 65

Dwi Wulan Sari[1], Akihisa Nonaka[2], Hiromi Tokuda[3], Trissa Silvian[1]

[1] Department of Agricultural Socio-economics, Universitas Sriwijaya, Ogan Ilir Regency 30139, Indonesia

[2] Graduate School of Regional Innovation Studies, Mie University, Tsu, Mie 514-8507, Japan

[3] Graduate School of Bioagricultural Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8601, Japan

Invited Lecture IV

Presentation time: total 30 minutes (presentation: 20 minutes + discussion: 10 minutes)

(I-4) 14:10-14:40

Effects of cricket powder (*Acheta domesticus*) on growth performance, immune response, and gene expression of Nile tilapia biofloc culture-based system 69

Khambou Tayyamath[1], Md Afsar Ahmed Sumon1[1] and Hien Van Doan[1]

[1] Chiang Mai University/Department of Animal and Aquatic Sciences, Faculty of Agriculture,

239 Huai Kaew Road, Suthep, Muaeng, Chiang Mai, Thailand

14:40-15:00 Break

Session 5 Social Science II for Regional Innovation

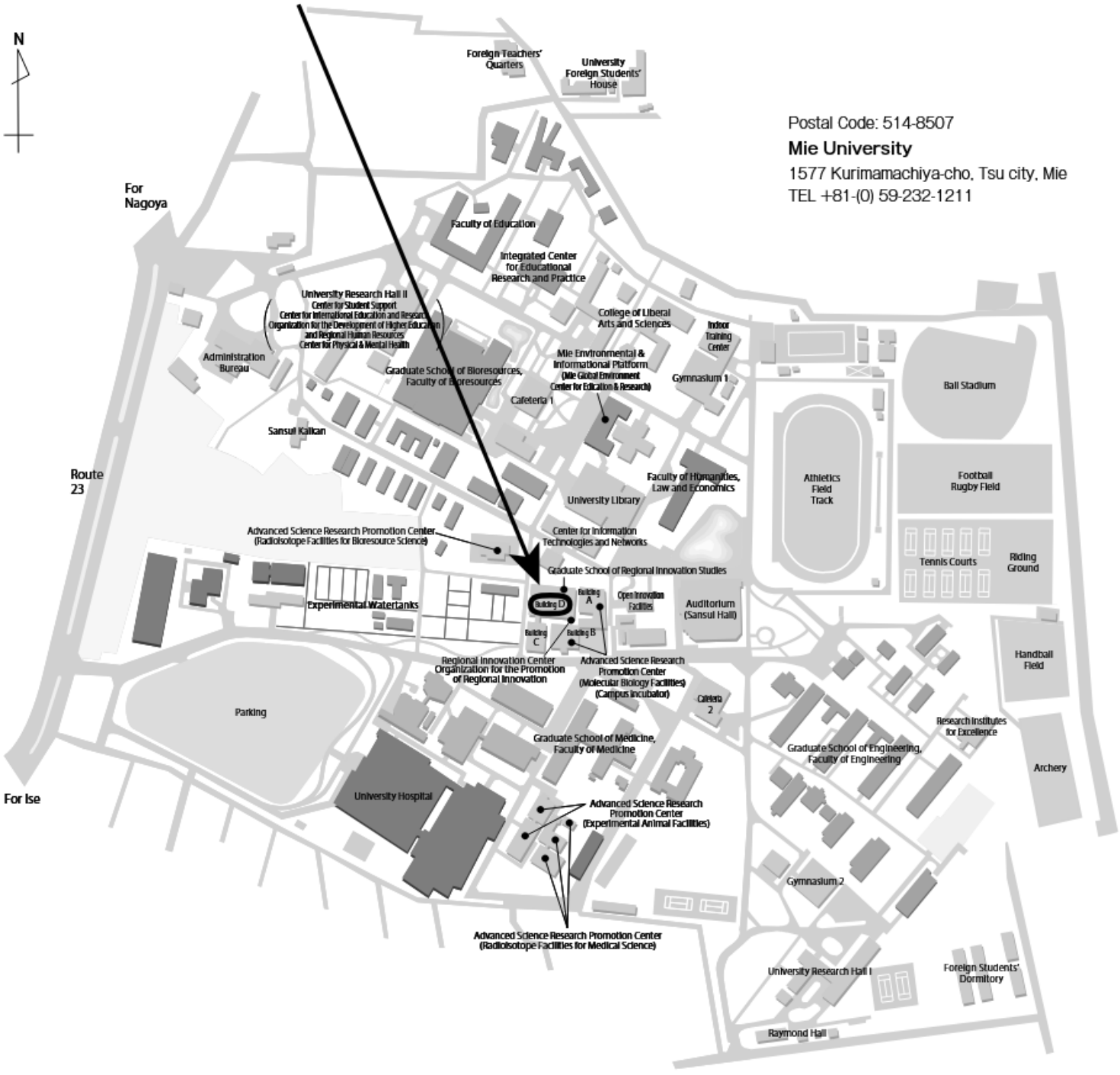
13) 15:00-15:20
Research Trends and Gaps in Court Interpreting Research in Japan: A Systematic Review 79
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[1] Graduate School of Regional Innovation Studies, Mie University, Tsu, Japan
14) 15:20-15:40
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Yuejuan Xu[1]
[1] Graduate School of Regional Innovation Studies, Mie University, Tsu City, Japan
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Satoshi Ikawa[1]
[1] Graduate School of Regional Innovation Studies, Mie University
16) 16:00-16:20
Marriage Intentions in Mie Prefecture in the Context of National Trends in Japan 91
Ryo Konishi[1]
[1] Graduate School of Regional Innovation Studies, Mie University

16:20-16:25 **Closing**

Hiroshi Suito (Vice Dean of Graduate School of Regional Innovation Studies, Mie University)

Campus Map

Venue of IWRIS2026 : Reginonal Innovation Hall(3rd Floor)



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Analysis of the parameters' sensitivity for cooling performance of copper pipe heat exchangers

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Abstract— **The purpose of this study is to analyze the sensitivity of the parameters to the serpentine copper pipe heat exchangers for greenhouse cooling. Two heat exchanger configurations were investigated: one with an outer pipe diameter of 12.7 mm and another with an outer pipe diameter of 15.88 mm. Both heat exchangers were designed with a pipe spacing of 50 mm. The length and the width of the heat exchangers were 700 mm and 253 mm, respectively. The experiments were conducted by varying inlet fluid temperature, fluid flow rate and surface area of the copper pipe heat exchanger. The inlet fluid temperature for cooling was varied from −5 to 10 °C whereas the water flow rate was changed between 0.3 to 3.0 L/min. The experimental data such as local air temperatures, inlet and outlet fluid temperatures, pressure drop were collected. The thermal performance of the heat exchangers was estimated with the data collected. The thermal performance was evaluated based on fluid properties (density, heat capacity), operating conditions (flow rate, inlet and outlet temperature difference), and heat transfer surface area. The sensitivity of each parameter to overall performance was then analyzed.**

The results show that the surface area of the copper pipe has the greatest influence on the thermal performance of the heat exchangers, followed by the inlet and outlet temperature difference. This indicates that changing surface area and fluid temperature have significant impact on the local air temperature and thermal performance than the flow rate. The results from this study could be useful for the optimization of the heat exchanger configuration to achieve more effective air temperature control in greenhouse cultivation.

Keywords— Fluid temperature, Flow rate, Surface area of heat exchanger, Sensitivity analysis.

I. Introduction

Modern greenhouses frequently integrate advanced cooling technologies to optimize plant growth conditions. This optimization often involves the precise regulation of environmental parameters such as air temperature, relative humidity, and other factors [1].

Heat exchangers are widely employed in industrial applications, including power generation and heating, ventilation, and air-conditioning systems [2–4]. In greenhouse cultivation, earth-to-air heat exchangers have been investigated as a method of controlling the thermal environment for crops [5–7]. These systems circulate indoor or outdoor air through pipes buried at a certain depth below the ground. Heat exchange resulting from the temperature difference between the soil and the circulating air enables the air to be cooled or heated before it is supplied to the greenhouse. Thus, earth-to-air heat exchangers can contribute to maintaining suitable greenhouse air temperatures. Although these cooling systems can maintain suitable greenhouse temperatures, controlling the entire greenhouse volume may require substantial energy, particularly under hot climatic conditions. On the other hand, heat exchanger configuration like pipe diameter impact on the performance of the heat exchanger. Sensitivity analysis is important because it can identify the parameters that have the greatest influence on cooling performance.

Therefore, this study experimentally investigates the sensitivity of heat transfer surface area and operating parameters affecting the cooling performance of serpentine copper-pipe heat exchangers for localized greenhouse cooling. Two heat exchangers with outer pipe diameters of 12.7 and 15.88 mm and the same pipe spacing of 50 mm were evaluated. The effects of heat-transfer surface area, inlet fluid temperature, and fluid flow rate were examined using sensitivity analysis method. The results provide the sensitivity level of each parameter as well as guidance for selecting heat-exchanger dimensions and operating conditions to achieve effective localized cooling.

II. Experimental

A. Experimental setup

Figure 1 shows the specifications of the two heat exchangers for local cooling. The configuration of the serpentine copper pipe heat exchangers was with a length and width of 700 mm and 253 mm, respectively, except for the bend areas. The thickness of the copper pipes is 0.8 mm. Each pipe is assembled in a U-bend, and these U-bends are insulated to evaluate the exact heat transfer from the straight pipe surfaces. Two heat exchangers with outer pipe diameters of 12.7 and 15.88 mm and the same pipe spacing of 50 mm. The experimental system was set up to evaluate local cooling assuming no crops were present. The experiments were conducted by

changing the two heat exchangers in the same test section area in the experimental system.

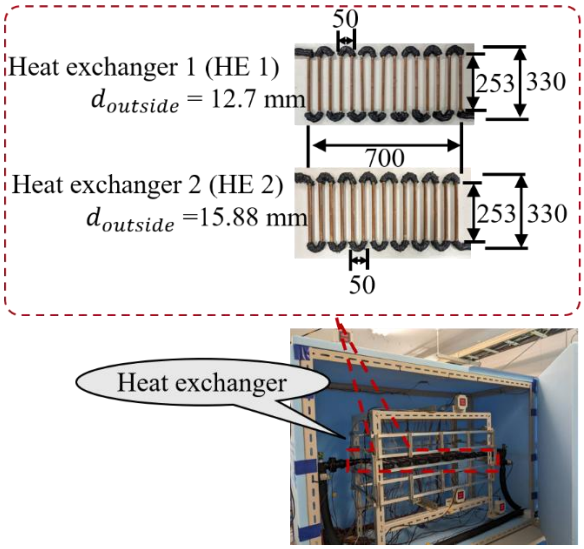
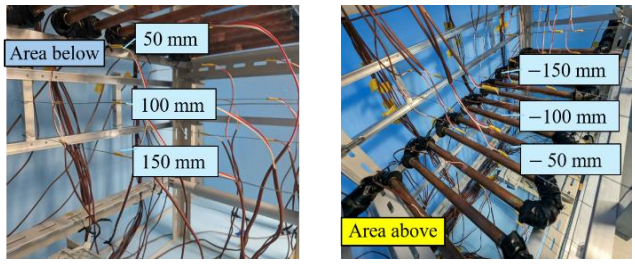


Fig. 1 Specification of the heat exchanger and experimental system.

B. Experimental data collection

The air temperatures in the area below and above the heat exchanger were measured to analyze the local air temperature profiles. The area below the heat exchanger was focused, and the area above it was used as a reference. Figure 2 shows the vertical air temperature measurements in the area below and above the heat exchanger. Three horizontal layers below and above the heat exchanger were installed. The layers below the heat exchanger were located 50 mm, 100 mm, and 150 mm from the center of the heat exchanger, as shown in Figure 2(a). The layer distance in the area below was assigned a (+) sign following the natural convection and gravitational force. The above layers are symmetrical to those below, and were −50 mm, −100 mm, and −150 mm away from the center of the heat exchanger, as shown in Figure 2 (b). There were nine thermocouples in each horizontal layer, resulting in 54 thermocouples in the six layers. Furthermore, the vertical uncertainty of the thermocouple's positions in each horizontal layer was ±2 mm.



(a) (b)

Fig. 2 Air temperature measurements in the area below and above of the heat exchanger.

Figure 3 illustrates the diagram of the experimental layout. The experimental system consists of a serpentine heat exchanger, a chiller to provide cooling, globe valves to control the fluid flow rates, thermocouples for measuring surface, inside room air, outside air, and local air temperatures, resistance thermal detectors for monitoring inlet and outlet fluid temperatures, and a pressure difference sensor to measure the pressure drop of the heat exchanger. Humidity sensors were used for reference. Experimental data were acquired using three data loggers. Before the experiments, all temperature sensors were calibrated under steady-state conditions to minimize measurement errors. The resistance temperature detectors (RTDs) were calibrated against a stable reference temperature and had an estimated measurement error of ±0.02 °C. The same calibration procedure was applied to the T-type thermocouples, with the most stable thermocouple selected as the reference. The calibrated thermocouples had an estimated measurement error of ±0.2 °C.

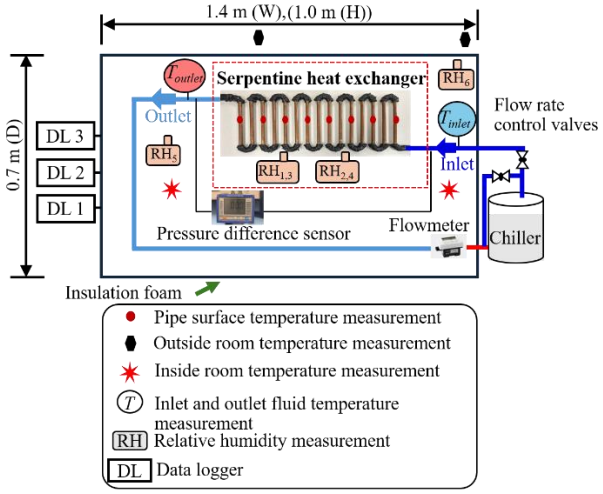


Fig. 3 Schematic diagram of the experimental system.

The inlet fluid temperature and flow rate varied from −5 to 10 °C and from 0.3 to 3.0 L/min, respectively, for both heat exchangers. The Reynolds numbers ranged from 63 to 1394 and 50 to 1100 for pipe diameters of 12.7 mm and 15.88 mm, respectively. The experimental inlet fluid temperatures are sufficient to maintain appropriate air temperature range for the crop. Moreover, a flow rate below 3.0 L/min is adequate, as the local temperature reduction shows no significant variation at higher flow rates based on preliminary experiments. Heat flux was evaluated at fluid flow rates of 0.3–1.3 L/min; higher flow rates were excluded because the measured fluid temperature difference was insufficiently accurate. To prevent freezing, the system operated on a 60/40 water-ethylene glycol volumetric mixture, with experiments conducted in 25 °C room air temperature. The Reynolds number was calculated as follows:

$$Re = \frac{\rho v d_i}{\mu} \quad (1)$$

where ρ is the fluid density (kg/m^3), v is the velocity of the fluid (m/s), d_i is the inner diameter of the copper pipe (m), and μ is the fluid dynamic viscosity (Pa·s).

Heat flux in the heat exchanger is evaluated using Eq. (2).

$$\dot{q}_t = \frac{\rho \dot{V} c_p (T_{outlet} - T_{inlet})}{A_s} \quad (2)$$

where $\dot{q}_t$ is the heat flux from the copper pipe surfaces (W/m^2), $\dot{V}$ is the volumetric flow rate of fluid (m^3/s), c_p is the fluid specific heat [J/(kg·K)], A_s is the outer surface area of the copper pipe without the U-bends (m^2), and T_{inlet} and T_{outlet} are the inlet and outlet fluid temperatures (°C), respectively.

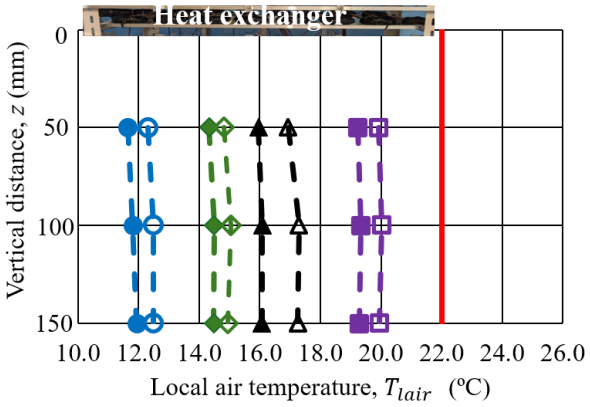
The sensitivity of the heat flux to each input parameter was evaluated using the Hoffman & Gardner method [8]. The sensitivity index is defined as:

$$S_i = \frac{\dot{q}_{t(x_i,max)} - \dot{q}_{t(x_i,min)}}{\dot{q}_{t(base)}} \quad (3)$$

where, S_i is the sensitivity index of the i^{th} input parameter, $\dot{q}_{t(x_i,max)}$ and $\dot{q}_{t(x_i,min)}$ are the heat fluxes evaluated at their maximum and minimum values, respectively. The $\dot{q}_{t(base)}$ is the heat flux calculated when all parameters are set to their base (nominal) values.

III. Results and Discussion

Figure 4 shows comparisons of the average local air temperature profiles at each vertical distance of the area below the Heat exchanger 1 and 2. The figure shows that local air temperatures vary moderately between 50 and 150 mm below the heat exchanger, indicating a relatively uniform vertical cooling region over the measured distance. The local air temperatures range from approximately 12 to 20 °C, below the 22 °C inside room air temperature. This pattern is consistent with cooled air descending from the pipe surfaces due to natural convection. The air temperature decreases around both heat exchanger types, demonstrating their effectiveness in providing localized cooling, particularly in the regions beneath them.



	Diameter of the copper tube	Inlet fluid temperature, T_{in} (°C)				Room air temperature (°C)
		-5 °C	0 °C	5 °C	10 °C	
T_{lair,avg_be}	12.7 mm	-⊖-	-◈-	-△-	-⊟-	—
	15.88 mm	-●-	-◆-	-▲-	-■-	

Fig. 4 Local air temperature profiles in the area below the two heat exchangers at $\dot{V}$ =0.9 L/min.

Figure 5 compares the local air temperature reduction of the area below the two heat exchangers relative to the room temperature for all the inlet fluid temperatures under fluid flow rates from 0.3 L/min to 1.3 L/min. The local air temperatures of the three layers below and above were averaged. Then, the average local air temperature reductions below and above the initial inside room air temperature were analyzed. Lower inlet fluid temperatures produce greater cooling, whereas increasing flow rate from 0.3 to 1.3 L/min has a comparatively small effect. Heat exchanger 2 generally provides a larger reduction than Heat exchanger 1, reaching approximately 10 °C at −5 °C inlet temperature. This is because the larger diameter increases the available external surface area at the same pipe length and generate more cooling. Because natural convection dominates, the denser cooled air sinks and creates downward buoyancy flow, producing lower temperatures beneath the heat exchanger than above it.

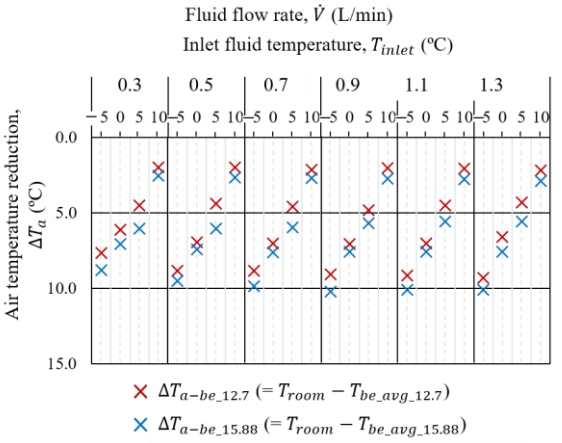


Fig. 5 Local air temperature reduction in the area below the two heat exchangers.

The outlet and inlet fluid temperature difference, ΔT_f (= $T_{outlet} - T_{inlet}$) of both heat exchangers range from 2.5 °C to 0.2 °C for all the inlet fluid temperatures under a fluid flow rate ranging from 0.3 L/min to 1.3 L/min. The pressure drop ranges from 0.3 kPa to 3.0 kPa for both types of heat exchangers.

Figure 6 presents a comparison of the heat flux in the Heat exchangers 1 and 2. The heat flux, $\dot{q}_t$, was calculated using Equation (2) and it presents the relationship between ΔT_f and $\dot{V}$. $\dot{q}_t$ exhibited 2–10% uncertainty for both the heat exchangers. In Figure 6, the uncertainties are represented as error bars, which were estimated based on the measurement uncertainty of ±0.02 °C of the resistance thermal detectors. At a fluid flow rate of 0.3 L/min, the heat flux of Heat exchanger 1 was approximately 330 and 150 W/m² at inlet fluid temperatures of −5 and 10 °C, respectively. The corresponding values for Heat exchanger 2 were approximately 250 and 100 W/m². For both heat exchangers, heat flux increased steadily with fluid flow rate.

Heat exchanger 1 exhibited a higher average heat flux than Heat exchanger 2, owing to its higher fluid velocity

and thinner thermal boundary layer at the same volumetric flow rate.

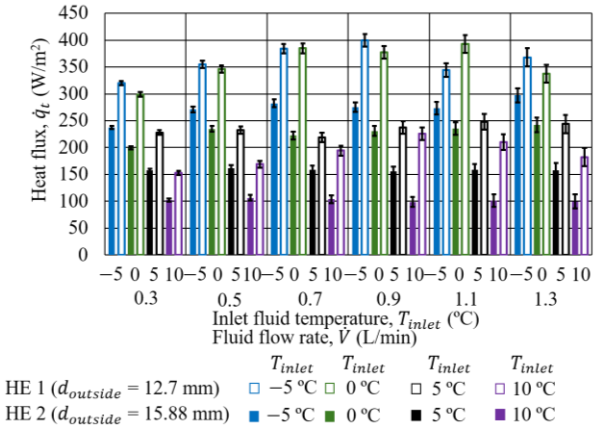


Fig. 6 Heat flux of the heat exchanger 1 and heat exchanger 2 at all inlet fluid temperatures

Table 1 and Figure 7 show the sensitivity ranking of the parameters affecting heat flux based on the absolute sensitivity index, $|S_i|$. Surface area was the most influential parameter (1.148) and the highest rank, followed by fluid temperature difference (0.410) and volumetric flow rate (0.060). Density and specific heat capacity shared the lowest rank. The negative index for surface area indicates that increasing surface area was associated with decreasing heat flux, whereas the positive indices for temperature difference and flow rate indicate increasing heat flux. These results suggest that heat flux was more sensitive to surface area and temperature difference than to flow rate within the investigated conditions.

Table 1 Sensitivity ranking for the parameters of heat flux.

Parameter	S_i (with sign)	$\|S_i\|$ (absolute)	Rank
Density, ρ	0.000	0.000	4
Specific Heat Capacity, c_p	0.000	0.000	4
Flow Rate, $\dot{V}$	0.060	0.060	3
Temperature Difference, ΔT_f	0.410	0.410	2
Surface Area, A_s	-1.148	1.148	1

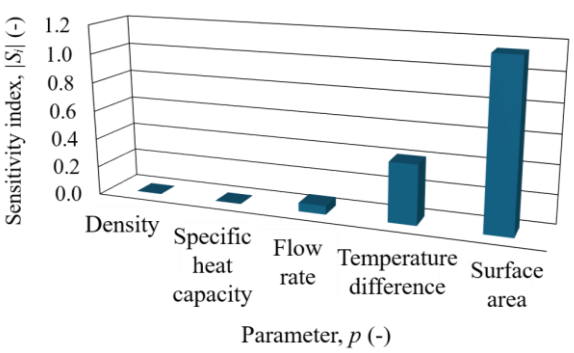


Fig. 7 Sensitivity index of the parameters on thermal performance.

IV. Conclusions

In this study, the cooling characteristics of two serpentine copper-pipe heat exchangers were examined. Results showed that lower inlet fluid temperatures increased local air-temperature reduction, while the effect of flow rate was comparatively small. Heat exchanger 2 (15.88 mm) generally provided stronger local cooling, whereas Heat exchanger 1 (12.7 mm) exhibited higher heat flux per unit area. For the sensitivity analysis, the highest sensitivity ranking was surface area followed by fluid temperature difference and flow rate. These results support considering heat exchanger's geometry and inlet fluid temperature when selecting operating conditions for localized cooling. In future work, the energy consumption by the heat exchangers in greenhouse farming will be analyzed and compared with that of traditional greenhouse farming.

Acknowledgment

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Classification of Imbalanced Defective Wafer Map Data Using VGG16 Features and LightGBM

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Abstract— Wafer maps show the spatial distribution of defective chips and are used to identify process problems in semiconductor manufacturing. In practical wafer-map data, the classes, that is, the distributions of defective chips, are highly imbalanced. To address this problem, a hybrid framework has been proposed in which binary classifiers first identify the majority classes, and a clustering approach is then applied to the remaining data. However, minority-class samples that are incorrectly classified as majority classes are excluded from the clustering and cannot be detected. In this study, the support vector machine (SVM) classifier in the baseline VGG16 + SVM configuration is replaced with Light Gradient Boosting Machine (LightGBM) in order to reduce the false positive rate (FPR) of minority-class samples at the binary classification stage. ResNet50-based configurations were also evaluated for comparison. Experiments were conducted using a subset of the WM-811K dataset, with Edge-Ring and Random as the majority classes, four minority classes, and one unknown class. The proposed method reduced the FPR of the minority classes from 0.202 ± 0.061 to 0.109 ± 0.045. However, the recall of Random decreased, which left more majority samples for the clustering stage and reduced the precision and recall of several minority classes. These results show that the proposed method can reduce the misclassification of minority-class samples, but that further improvement of the clustering method is needed to reduce the effect of the majority samples that are mis-detected by the binary classifier.

Keywords— Wafer Map, Imbalanced Data, VGG16, LightGBM, Clustering

I. Introduction

In semiconductor manufacturing, the distribution of chips with electrical faults is represented as a wafer map, and this map is used to understand the causes of the faults. Wafer maps with similar patterns are considered to share a common cause. Therefore, to identify the cause of a fault quickly, it is important to group similar patterns properly. However, some unknown pattern can be sometimes observed in practical case, so a wafer map with unknown pattern should be detected. Also, the given data is quite imbalanced. The conventional clustering methods cannot form adequate clusters for the patterns of minority classes, and this leads to misdetection.

To address this problem, the previous study proposed a hybrid method that combines a classifier with clustering [1]. In this method, known majority patterns are first extracted by a classifier, and clustering is then applied to the remained (unclassified) data. This makes it possible to detect minority patterns and unknown patterns at the same time. Also, the conventional approach prepares one classifier for each known pattern, whereas this method limits the classification targets to the majority patterns that are common across products. As a result, it reduces both the number of classifiers and the effort required to prepare training data. However, if a sample of a minority class is misclassified as a majority class at the binary classification stage, then, the sample is excluded, and it can no longer be detected as a minority class.

This paper aims to reduce the misclassification of minority classes at the binary classification stage. In this study, we use VGG16 [2] and support vector machine (SVM) [3], which were employed in the previous study, as our baseline, and Light Gradient Boosting Machine (Light GBM) [4] is used instead of SVM for the proposed method. In the evaluation experiments, the effectiveness of the proposed method is verified by focusing on False Positive Rate (FPR), that is, the rate at which minority classes are misclassified as majority classes.

II. Materials

A. Dataset and Preprocessing

In this paper, WM-811K wafer-map dataset [5] was used in the experiments. Each wafer map is represented by a numerical array indicating the presence of chips and their pass/fail states. The maps were converted into binary images in which defective chips are white, and all other areas are black. Because the original image sizes were not uniform, all maps were resized to 64×64 pixels. The data and labels were rechecked by specialists of semiconductor manufacturing before use. Fig. 1 shows representative patterns in this paper. We used the seven labels, i.e., Center, Edge-Loc, Edge-Ring, Loc, Random, Scratch, and Donut.

Table 1 shows the outline of the dataset. To reproduce the imbalance observed in practical production, Edge-Ring and Random were defined as majority classes (with enough number of training samples), Loc and Scratch as minority classes (with enough number of training samples),

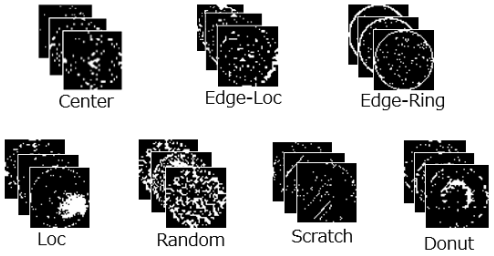


Fig. 1 Examples of Defect Patterns in WM-811K

Table 1 Outline of Dataset

Category/Class Name		# of Training Data	# of Test Data
Majority	Edge-Ring	462	231
	Random	770	385
Minority (*1)	Loc	812	9
	Scratch	815	9
Minority (*2)	Center	14	7
	Edge-Loc	20	9
Unknown	Donut	0	10

*1: enough # of training samples
*2: few training samples

Center and Edge-Loc as minority classes (with few training samples), respectively. Donut was treated as an Unknown pattern with no training samples. In this paper, the test set consists of 616 majority samples and 44 minority or unknown samples, so majority samples accounted for approximately 93% of the test set. This configuration allowed us to evaluate the method under a strongly imbalanced condition, while separately examining minority classes with different amounts of available training data, as well as an unknown pattern.

III. Methods

A. Binary Classification Approach

Fig. 2 shows the outline of the hybrid wafer-map classification framework. The conventional method is based on this architecture, and the proposed (revised) method is also based on the scheme. The baseline binary classifier uses VGG16 pretrained on ImageNet to extract features, then the extracted features are classified by an SVM.

In the proposed method, the VGG16 features are classified by LightGBM instead of SVM (Fig. 3). In addition to the above change, ResNet50 [6] was also used as an alternative feature extractor, and (1)ResNet50+SVM and (2)ResNet50+LightGBM frameworks were evaluated as comparison models. These additional models were used to examine whether the difference between SVM and LightGBM depends on the feature extractor.

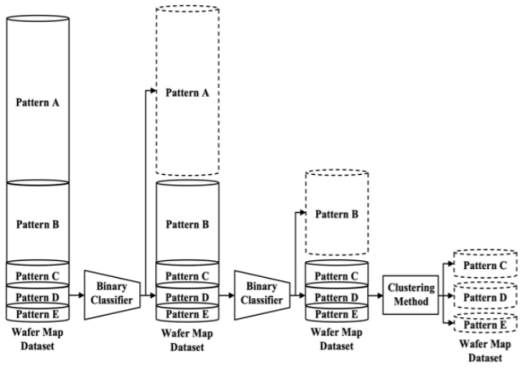


Fig. 2 Outline of Hybrid Wafer-map Classification Framework

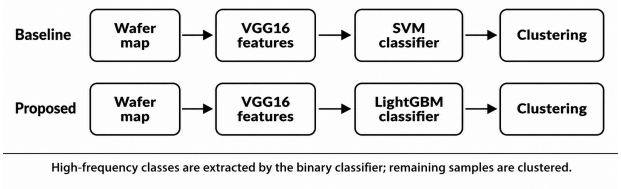


Fig. 3 Comparison between Baseline and Proposed Approach

LightGBM is a decision-tree-based gradient boosting method and can learn non-linear decision boundaries and handle high-dimensional features. In this paper, we adopted LightGBM because it was expected to handle imbalanced data flexibly and thereby prevent minority-class samples from being extracted as majority classes. ResNet50 uses residual learning, which alleviates the vanishing-gradient problem and allows deeper networks to acquire more advanced feature representations. However, ResNet50 is not the feature extractor proposed in this study, and it is used only for a comparative study. Both SVM and LightGBM used balanced class weights, and the SVM used an RBF kernel in this paper.

B. Evaluation Procedure and Metrics

In this paper, a repeated three-fold cross-validation with three different random seeds was used, and the mean and standard deviation were calculated. Precision and recall were used as general performance measures.

To directly evaluate the error of interest, we also calculated the FPR of minority-class samples. In this paper, the binary classifier is designed to extract majority samples (i.e., Random and Edge-Ring), so majority samples are treated as positive, and minority samples (i.e., Loc, Scratch, Center, Edge-Loc, and Donut) are treated as negative. Under this definition, False Positive means the number of minority samples incorrectly classified as majority classes, and True Negative is the number of minority samples correctly left unclassified. Therefore, the FPR is the proportion of actual minority samples incorrectly classified as majority classes.

$$FPR = \frac{FP}{TN + FP} \quad (1)$$

In the above formula, a smaller value indicates that fewer minority samples were removed from the clustering target.

IV. Results and Discussion

A. Result of Binary Classification

Table 2 shows the FPR for minority classes in the four combinations. The proposed approach (VGG16 + Light GBM) achieved the lowest FPR. The value was reduced from 0.202 ± 0.061 (baseline) to 0.109 ± 0.045. That was an improvement of 9.3 percentage points. In the additional comparison using ResNet50 features, LightGBM also achieved a lower FPR than SVM. The experimental results showed that LightGBM contributed to the reduction of FPR.

Table 3 shows the precision and recall for the majority classes. In particular, the decrease in the recall of Random class was large by using the proposed method. Except for the precision of Random, the baseline (VGG16 + SVM) achieved the best values. Reducing the minority-class FPR therefore introduced a trade-off: fewer minority samples were misclassified as majority-class samples, but more majority-class samples were missed.

Table 2 FPR for Minority Classes
(Mean ± Standard Deviation)

Feature Extractor	Classifier	FPR
VGG16	SVM (baseline)	0.202 ± 0.061
	LightGBM (proposed)	0.109 ± 0.045
ResNet50	SVM	0.273 ± 0.052
	LightGBM	0.136 ± 0.062

Table 3 Precision and Recall for Majority Classes
(Mean ± Standard Deviation).

Method	Class	Precision	Recall
VGG16 +SVM (baseline)	Edge-Ring	0.976 ± 0.007	0.961 ± 0.011
	Random	0.962 ± 0.005	0.902 ± 0.014
VGG16 +LightGBM (proposed)	Edge-Ring	0.976 ± 0.003	0.953 ± 0.016
	Random	0.969 ± 0.009	0.827 ± 0.015
ResNet50 +SVM	Edge-Ring	0.960 ± 0.017	0.932 ± 0.019
	Random	0.944 ± 0.009	0.865 ± 0.035
ResNet50 +LightGBM	Edge-Ring	0.976 ± 0.012	0.904 ± 0.020
	Random	0.960 ± 0.011	0.785 ± 0.026

B. Discussion for Binary Classification

The proposed method (VGG16 + LightGBM) suppressed the misclassification of minority classes and substantially reduced the FPR. LightGBM is relatively adaptable to class imbalance problem and can emphasize particular features through its tree structure, which may have prevented minority classes from being incorrectly extracted as majority classes.

On the other hand, the proposed method did not capture the characteristics of Random sufficiently, which resulted in a lower recall for that class. Generally, the Random pattern has little spatial regularity. That's a possible reason. The other patterns are defined by the position of the defects, such as a ring at the edge or a cluster near the center, whereas Random is defined by the absence of such structure. LightGBM builds its decision boundaries by selecting individual features and splitting on their values, therefore, it tends to rely on a limited number of localized features. This characteristic is well suited to patterns with a clear spatial structure, but it may be less effective for a pattern that must be characterized by the overall distribution of defects rather than by specific locations. The ResNet50 configurations were evaluated as additional comparisons rather than as proposed methods. In these configurations, the FPR was higher and the recall of the majority classes decreased substantially. One possible explanation is that, under the limited-data conditions, the high representational capacity of ResNet50 caused it to fit particular samples excessively. Another possibility is that the extracted features became too abstract to capture the differences among defect patterns. Therefore, replacing VGG16 with ResNet50 did not improve performance in this experiment.

C. Clustering Performance

To examine how the lower recall of Random in the proposed method affects the subsequent clustering stage, we compared VGG16 + LightGBM with the baseline VGG16 + SVM method. Tables 4 and 5 show the precision and recall after clustering. The proposed method achieved performance comparable to the baseline for some minority classes, including Donut and Center, but the precision and recall tended to decrease for many minority classes.

The main cause was the increased misdetection of majority samples. Although VGG16 + LightGBM reduced the FPR for minority classes, its lower recall of Random left more Random samples in the clustering input. This biased the data distribution and caused minority-class samples to be mixed into clusters dominated by Random. As a result, the detection of minority classes failed more frequently, which reduced the precision and recall. These results indicate that reducing the FPR at the binary classification stage does not necessarily improve the downstream clustering unless the majority classes are also removed sufficiently. Nevertheless, more minority samples remained available for detection, therefore improving the clustering method itself may increase the final detection rate.

Table 4 Precision after Clustering
(Mean ± Standard Deviation)

Class	Baseline Method	Proposed Method
Edge Ring	0.976 ± 0.007	0.976 ± 0.003
Random	0.962 ± 0.005	0.969 ± 0.009
Loc	0.333 ± 0.500	0.111 ± 0.333
Scratch	0.333 ± 0.500	0.222 ± 0.441
Center	0.624 ± 0.391	0.612 ± 0.364

Edge Loc	0.500 ± 0.500	0.185 ± 0.377
Donut	1.000 ± 0.000	1.000 ± 0.000

Table 5 Recall after Clustering
(Mean ± Standard Deviation)

Class	Baseline Method	Proposed Method
Edge Ring	0.961 ± 0.011	0.953 ± 0.016
Random	0.902 ± 0.014	0.827 ± 0.015
Loc	0.037 ± 0.056	0.014 ± 0.042
Scratch	0.037 ± 0.056	0.025 ± 0.049
Center	0.397 ± 0.265	0.429 ± 0.303
Edge Loc	0.111 ± 0.124	0.049 ± 0.098
Donut	0.389 ± 0.127	0.389 ± 0.162

The per-class results clarify the effect of this trade-off. Donut, for which no training samples were available, retained the same precision and almost the same recall under both methods. Center also showed comparable performance. In contrast, Loc, Scratch, and Edge-Loc showed lower precision and recall with VGG16 + LightGBM. These differences are consistent with the larger amount of Random data remaining after binary classification, which likely made it more difficult to separate minority-class samples during clustering.

The baseline and the proposed binary classifiers therefore have different advantages. VGG16 + SVM removes majority samples stably, and it thus provides a more favorable input distribution for the subsequent clustering stage. On the other hand, the proposed approach preserves more minority samples by reducing the misclassification of minority samples as majority classes. This benefit leads to improved detection of minority patterns only when the clustering stage can separate the additional minority samples from the majority samples that were missed. Therefore, improving the clustering stage will be necessary to exploit the FPR reduction achieved by the proposed method.

V. Conclusions

In this study, we proposed a new approach to reducing the false positive rate for minority classes of the binary classifier in the hybrid wafer-map classification framework. The proposed method reduced the minority-class FPR from 0.202 ± 0.061 to 0.109 ± 0.045, and it was effective in suppressing the removal of minority-class samples before clustering. The additional comparisons using ResNet50 also showed that LightGBM reduced the FPR compared with SVM. However, the proposed method increased the misdetection of the Random class. As a result, more majority samples remained in the clustering input, which reduced the precision and recall of several minority classes. As future work, we will investigate clustering methods that can detect minority classes while reducing the effect of majority samples.

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RGB Image Generation From RG Ultra-Widefield Fundus Images Using an Optimized CycleGAN

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Abstract—While modern RGB ultra-widefield (UWF) fundus imaging systems exist, their high cost leaves vast repositories of legacy red-green (RG) images. To enhance the clinical utility of this data, this study investigated RGB image generation from RG UWF images. Previous methods like Pix2Pix, which rely on paired data, often resulted in boundary blurring. To address this, we developed CycleGAN_Optos, incorporating three key optimizations: an SSIM component in the cycle-consistency loss to preserve anatomical structures, a VGG-based style loss to improve perceptual quality, and multi-layer architecture. Quantitative evaluations demonstrated our optimized model yields higher sharpness, mitigates blurring, and achieves a superior balance between perceptual fidelity (assessed by NIQE) and structural fidelity compared to baselines. This structure- and style-aware framework effectively generates RGB images from legacy RG data without paired training, enhancing practical use.

Keywords—Fundus imaging, CycleGAN, RGB generation, Ultra-widefield, Unpaired data

I. Introduction

Fundus imaging is a cost-effective, non-invasive modality widely used for evaluating retinal pathology. Recently, the emerging field of oculomics has developed, utilizing retinal vascular and neural information to predict systemic health metrics (sex, age, blood pressure) and risks of diabetes [1] and neurodegenerative diseases [2], alongside AI-based diagnostic models.

Scanning laser ophthalmoscopes (SLOs) first emerged in 1990; however, low resolution and equipment size hindered their clinical adoption [3]. Subsequently, ultra-widefield (UWF) fundus imaging systems employing red and green (RG) lasers were introduced in the early 2000s. Unlike conventional cameras (capturing ~10% of the retina), these systems enabled instantaneous, non-mydriatic imaging of over 80% of the retina (200° field of view), revolutionizing clinical ophthalmology [3, 5]. However, RG devices remained the primary standard for decades. Even today, true three-color RGB UWF systems are not universally available in standard clinics [3, 5]. Consequently, vast historical repositories of legacy RG fundus images remain stored in medical facilities worldwide.

RGB images synthesize reflected light from different retinal layers based on wavelength penetration (Fig. 1): blue (488 nm) illuminates the superficial retina, green (532 nm) highlights the sensory retina, and red (635 nm) penetrates the choroid. A recent clinical study at Mie University Hospital evaluated the detectability of ten common retinal lesions (vessel sheathing, optic disc cupping, cotton wool spots, epiretinal membrane, laser photocoagulation scars, retinal drusen, retinal hemorrhage, retinal/choroidal detachment, chorioretinal atrophy, and macular degeneration) using an RGB UWF SLO [4]. Evaluations by 26 ophthalmologists demonstrated that RGB imaging provided significantly superior visibility across all ten lesion categories compared to RG imaging ($P < 0.01$) [4]. Notably, the blue channel enhanced the contrast and delineation of superficial (e.g., epiretinal membranes) and white lesions (e.g., vessel sheathing, optic disc cupping, cotton wool spots) [4].

Therefore, adding blue channel (B ch) information to perform RGB image generation from existing RG images holds significant clinical usefulness for enhancing the value of legacy RG fundus images. This study investigates a deep learning-based method for RGB image generation from RG UWF fundus images using CycleGAN.

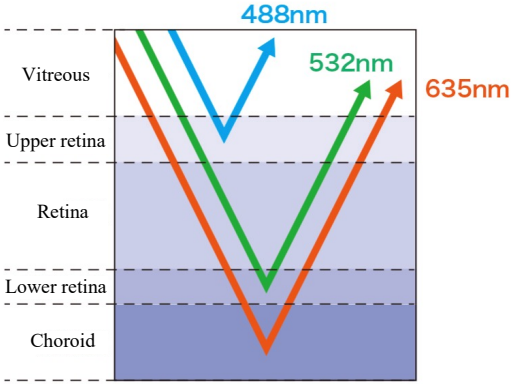


Fig. 1 Schematic representation of light penetration in retinal layers based on wavelength: blue (488 nm), green (532 nm), and red (635 nm).

II. Model Investigation

A. Previous results

We previously performed RGB image generation using Pix2Pix [5]. Fig. 2 shows the generated RGB images and a magnified view of the optic disc. The model achieved high quantitative accuracy (SSIM: 0.969, LPIPS: 0.0904) and generally reproduced the true RGB images, confirming the effectiveness of Pix2Pix for RGB image generation from RG UWF fundus images

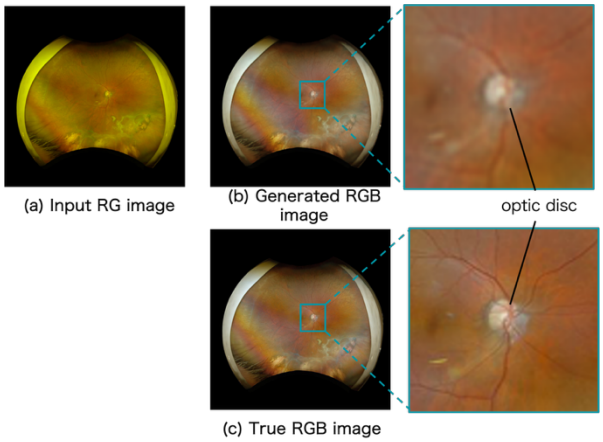


Fig. 2 Examples of Pix2Pix-generated RGB images relying on paired training data, showing blurred anatomical structures in the magnified optic disc view.

[5] . However, as shown in the magnified optic disc view (Fig. 1), fine anatomical structures such as disc boundaries and vessels were blurred, indicating insufficient quality for practical use.

B. Limitations of the Conventional Pix2Pix Model

Pix2Pix relies on paired training data of perfectly aligned RG and true RGB images (Fig. 2), mapping inputs directly to ground-truth targets. This approach presents two limitations. First, model scalability is constrained because acquiring perfectly aligned paired datasets in routine clinical workflows is virtually impossible. Second, prioritizing global color reproduction often over-constrains pixel-wise correspondence, resulting in blurred edges and inadequate preservation of anatomical structures.

C. Characteristics of the Proposed CycleGAN Model

The proposed CycleGAN model eliminates the need for paired training data, enhancing its clinical usefulness. Fig. 3 illustrates its architecture for learning bidirectional translations between domains A and B. When training the A-to-B mapping, generator X takes image A and inverse-generated image Y(B) as inputs. Reconstructed image $X(Y(\mathrm{B}))$ and dataset image B are evaluated by discriminator X as a pseudo-pair. CycleGAN combines adversarial loss with cycle-consistency loss to realize unpaired translation.

Adversarial loss encourages generated RGB images to match the target domain distribution. To prevent structural deviation from the input during unpaired learning, cycle-consistency loss is introduced, minimizing pixel-wise reconstruction errors in pseudo-pairs to ensure the preservation of anatomical structures. By adjusting the balance between two losses, CycleGAN achieves quality comparable to that of Pix2Pix [6]. Furthermore, CycleGAN has been adopted for structural fidelity and artifact reduction in fundus photography [7]. Therefore, we investigated a CycleGAN-based model for RGB image generation from RG UWF fundus images.

III. Materials and Methods

A. Materials

We utilized 575 UWF fundus images acquired at Mie University Hospital (460 training, 115 validation). Images were resized to 512 × 512 pixels. A Region of Interest (ROI) mask identified the effective retinal area, and standard data augmentation (random horizontal flipping and cropping) was applied during training.

B. Model Optimization

RGB image generation from UWF fundus images requires ensuring the preservation of anatomical structures and achieving high perceptual quality. Because baseline CycleGAN relies primarily on cycle-consistency loss, we implemented three key optimizations to satisfy both requirements.

First, to enhance structural fidelity, we introduced an SSIM loss component to account for spatial interrelationships between pixels. Combining SSIM with cycle-consistency loss (cycle-SSIM loss) improves the preservation of anatomical structures. Second, to improve perceptual quality, a style loss using pre-trained VGG19 was introduced to minimize feature-level differences, enhancing color reproduction. Third, to improve the capture of global color distribution and abstract features alongside fine local structures, the baseline single-layer patch discriminator was replaced with a multi-layer architecture that progressively downsamples spatial resolution.

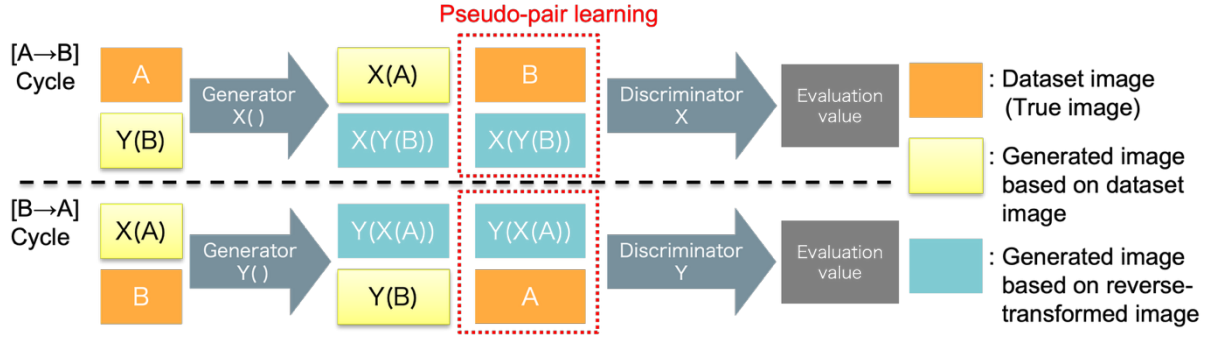
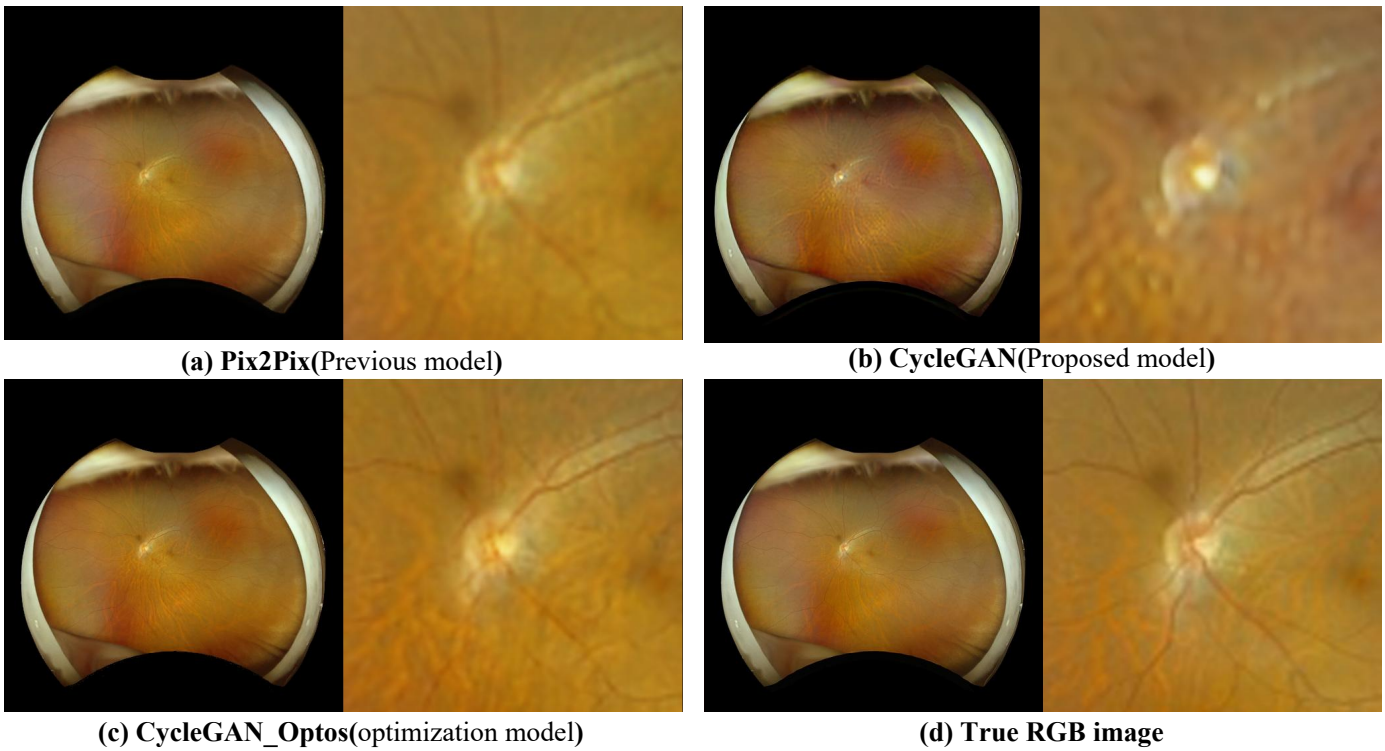


Fig. 3 CycleGAN model architecture for unpaired image-to-image translation.

Table 1 Quantitative evaluation results.

Model	SSIM ↑	LPIPS(vgg)↓	Sharpness↑	Contrast↑	NIQE↓
Pix2Pix	0.969	0.0904	47.89	53.65	6.20
CycleGAN	0.937	0.169	113.41	55.71	6.87
CycleGAN_Optos	**0.941**	**0.106**	**106.37**	**58.91**	**5.27**
True RGB image	1.00	0.000	94.95	53.53	5.02



(a) Pix2Pix(Previous model**)** **(b) CycleGAN(**Proposed model**)**

(c) CycleGAN_Optos(optimization model**)** **(d) True RGB image**

Fig. 4 Visual comparison of generated RGB images (right side; full view, left side; magnified view)

C. Experimental Setup and Evaluation Metrics

Training was conducted for 500 epochs across three models: Pix2Pix, baseline CycleGAN, and our proposed model, referred to as CycleGAN_Optos. We evaluated performance using SSIM, LPIPS(VGG), SHARPNESS, CONTRAST, and NIQE. SSIM and LPIPS evaluate structural fidelity and perceptual fidelity against true RGB images, respectively. SHARPNESS measures second-order derivative variance (edge detection), and CONTRAST evaluates intensity variance based on grayscale standard deviation.

Furthermore, we incorporated the Natural Image Quality Evaluator (NIQE), a no-reference metric evaluating perceptual quality based on statistical luminance patterns from high-quality natural images. NIQE is widely adopted for evaluating perceptual quality and artifact reduction in retinal image processing, such as annotation-free restoration networks [8].

IV. Results and Discussion

Table 1 summarized the quantitative evaluation results. Pix2Pix achieved high SSIM and LPIPS scores, generally reproducing structure and color in a paired setting. However, its lower SHARPNESS and NIQE scores quantitatively confirm that Pix2Pix-generated RGB images suffer from boundary blurring and reduced sharpness compared to true RGB images.

Baseline CycleGAN showed an inferior LPIPS score, indicating difficulty with accurate color reproduction despite preserving basic structures. Its higher SHARPNESS and NIQE scores reflect inadequate and visually unrefined global perceptual quality.

Finally, CycleGAN_Optos improved SSIM over baseline CycleGAN and achieved an LPIPS score comparable to Pix2Pix. Its SHARPNESS and CONTRAST scores aligned closely with those of true RGB images,

and it achieved the best NIQE score among the three models, suggesting that it does not suffer from the degradation in perceptual quality observed in the baseline CycleGAN. This result that it does not exhibit the excessive edge enhancement observed in the baseline CycleGAN. These results indicate that despite using unpaired data, CycleGAN_Optos generates sharp, well-defined RGB images with high perceptual quality and structural fidelity. Fig. 4 shows representative generated RGB images. While full-view and magnified images suggest the possibility of generating sharp, well-defined RGB images, this evaluation is currently limited to visual impressions of individual images, representing a major limitation of the present study. Additionally, CycleGAN-based models successfully reduced imaging artifacts, such as light scattering and reflection present in true RGB images and Pix2Pix-generated RGB images.

V. Conclusion and future work

This study presented CycleGAN_Optos, a structure- and style-aware CycleGAN incorporating SSIM-based cycle-consistency loss, VGG-based style loss, and a multi-layer discriminator, for generating RGB images from legacy RG UWF fundus images without paired training data. Quantitative and visual evaluations confirmed that CycleGAN_Optos despite being an unpaired learning model improves the balance between structural and perceptual quality compared to the baseline CycleGAN model and generates RGB images with reduced blur, a problem observed in Pix2Pix, thereby enhancing the clinical usefulness of existing RGB image repositories. To address the current limitation of relying solely on visual impressions, future studies must prioritize the clinical evaluation of generated images from the perspective of ophthalmologists. Specifically, it is necessary to assess the clinical and diagnostic usefulness of the generated RGB images by evaluating the differences in image features. Furthermore, future work will apply this framework to fundus images with severe pathologies where conventional RG diagnosis is challenging to develop a model capable of accurately preserving disease-specific lesions during RGB image generation.

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The Effect of Robotic Assisted Gait Training on Physical Activity, Motor Function, and Quality of Life in Children with Spastic Cerebral Palsy: Exploratory Pilot Study

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Abstract— Background: Children with spastic cerebral palsy (CP) experience motor impairments and reduced physical activity, negatively impacting health and quality of life. Objective: The study aimed to assess the effects of wearable exoskeleton robot-assisted gait training on physical activity, motor function, and quality of life in children with CP.

Methods: Ten children with spastic CP (mean age 9.20 ± 2.57 years; gross motor function classification system levels I–IV) received twelve 30-min sessions of robot-assisted gait training over six weeks at a university hospital rehabilitation center. Physical activity was measured using a tri-axial accelerometer to assess energy expenditure, metabolic equivalents (METs), intensity levels, vector magnitude counts per minute (VM CPM), and step counts. Motor function was evaluated using the Gross Motor Function Measure (GMFM-88), Timed Up and Go Test (TUG), and 6-Minute Walk Test (6MWT). Quality of life was assessed with the Cerebral Palsy Quality of Life questionnaire (CP-QOL). Repeated measures MANOVA and Cohen's d were used for statistical analysis.

Results: Significant improvements were observed in METs ($p = 0.02$, $d = 0.38$), light ($p = 0.03$, $d = 0.51$) and moderate physical activity time ($p = 0.01$, $d = 0.42$), and VM CPM ($p = 0.01$, $d = 0.44$), along with reduced sedentary time ($p = 0.02$, $d = -0.49$). Functional outcomes improved in GMFM-88 ($p<0.01$, $d = 0.22$), TUG ($p = 0.03$, $d = -0.33$), and 6MWT ($p = 0.02$, $d = 0.52$). No significant changes were found in CP-QOL scores.

Conclusion: Wearable robot-assisted gait training appears to enhance physical activity and mobility in children with spastic CP and may be considered a promising therapeutic intervention.

Keywords— robot-assisted gait training, cerebral palsy, physical activity, motor function, wearable exoskeleton

I. INTRODUCTION

Cerebral palsy (CP) is a non-progressive neurodevelopmental disorder caused by early brain damage, affecting posture, muscle tone, movement, and gait [1]. These impairments result in muscle weakness, spasticity, joint contractures, and fatigue, leading to reduced intermuscular coordination and challenges in maintaining a normal gait pattern [2, 3]. Consequently, children with CP experience gait instability and restricted segmental movements, which diminish mobility, hinder independence in daily activities [4], and significantly reduce quality of life [5, 6].

Recent advancements in rehabilitation have highlighted robot-assisted gait training (RAGT) as an effective intervention for improving gait function in children with CP [7]. RAGT provides repetitive and precise gait patterns tailored to a child's physical characteristics and functional levels, promoting motor learning while improving gait speed, balance, and endurance [7, 8]. Among stationary exoskeleton systems, the Lokomat is widely used, offering customized gait training by adjusting body weight support and speed [9]. However, stationary systems have limitations, such as restricted voluntary participation and a primary focus on gait, which may hinder broader functional improvements [10, 11].

To address these limitations, wearable exoskeleton robots have been developed, enabling voluntary and active participation while providing a more natural gait experience. Devices such as ReWalk, Indego, Hybrid Assistive Limb, Ekso, and Angel-legs allow training in diverse environments [12, 13]. These devices operate on an assist-as-needed principle, delivering torque only when necessary and encouraging children to independently control weight shifting and balance [14]. This approach fosters motor learning, self-directed movement, and adaptability to real-world scenarios [15].

Despite the promise of wearable exoskeletons, research has largely focused on functional metrics, with limited evaluation of real-world outcomes such as physical activity levels and perceived exertion [15]. This pilot study aimed to address these gaps by investigating the effects of wearable exoskeleton RAGT on physical activity, motor function, and quality of life in children with spastic CP.

II. METHODS

A. Participants

The inclusion criteria for this study were: (1) children aged 5 to 14 years with a diagnosis of CP confirmed by MRI or CT; (2) gait impairment due to lower limb weakness, with a Functional Ambulation Classification (FAC)

score of at least 2 [16]; and (3) lower limb spasticity graded below 3 on the Modified Ashworth Scale (MAS) [17]. Exclusion criteria were: (1) structural or functional limitations of the lower limbs, such as contractures, deformities, or skin conditions, or other neurological, cardiovascular, or medical conditions unrelated to CP that could interfere with RAGT; and (2) significant cognitive impairments preventing the ability to follow study instructions. The study protocol was approved by the Institutional Review Board of Hanyang University (HYUH 2023–02-001). Written informed consent was obtained from the parents or guardians of all participants.

B. Apparatus

A wearable exoskeleton gait robot (Bambini Teens; COSMO ROBOTICS Co., Ltd., Seoul, Republic of Korea), designed for children aged 5 to 14 years, was used in this study. This powered lower extremity exoskeleton received medical device certification from the Korean Ministry of Food and Drug Safety (MFDS) in 2022. The device offers multiple operating modes including standing, sitting, walking in place, and walking forward, controlled via a tablet PC. Three distinct gait training modes were available: step-by-step, continuous, and active. In active mode, participants overcame adjustable resistance levels (0–10), facilitating natural gait patterns through ankle dorsiflexion and plantarflexion. Adjustable gait parameters including step height, step length, and step duration allowed individualized training tailored to each participant's functional capacity. The exoskeleton weighs approximately 24.5 kg and operates continuously for up to 4 hours on a rechargeable battery.

C. Procedures

Participants completed 12 sessions of RAGT over six weeks (two 30-min sessions per week). All sessions were supervised by a pediatric physical therapist with over 10 years of experience. Training progressed through step-by-step, continuous, and active modes, with parameters adjusted individually according to each participant's functional capacity.



Fig. 1. Wearable exoskeletal gait robot training. Publication of this photograph has been approved by the patient's guardian through informed consent.

D. Outcome Measures

Demographic data (gender, age, height, and weight) and clinical characteristics (CP type, extremity distribution, GMFCS level, FAC score, spasticity, and walking aids) were obtained from medical records and parent reports. All outcomes were assessed at baseline and immediately post-intervention by a pediatric physical therapist with over five years of experience who was not involved in the intervention.

Physical activity was measured using a tri-axial accelerometer (ActiGraph wGT3X-BT; ActiGraph LLC, Pensacola, FL), worn continuously at the midaxillary line for one week pre- and post-intervention, except during bathing and sleeping. A minimum of 10 h of daily wear time was required [18]. Raw data were processed using ActiLife software (version 6.13.6) with 10-s epochs and the low-frequency extension algorithm [19]. Non-wear periods were defined as 150 consecutive minutes of inactivity [20]. Energy expenditure and METs were calculated using validated child-specific algorithms [21], and activity intensity (sedentary, light, moderate, vigorous) was categorized using youth-specific thresholds [22]. Key metrics included VM CPM, MVPA, and step counts. Perceived exertion was assessed during sessions 3–10 using the Borg RPE scale (6–20) [23].



Fig. 2. The tri-axial accelerometer (ActiGraph wGT3X-BT) used in this study

E. Statistical Analysis

Data analysis was performed using SPSS Statistics version 18 (IBM Corp., Armonk, NY, USA). Repeated measures MANOVA was used to evaluate intervention effects across two time points (pre- and post-intervention) for physical activity variables (METs, MVPA, VM CPM, step counts) and CP-QOL, and across three time points (pre-, interim-, and post-intervention) for GMFM-88, TUG, and 6MWT. Mauchly's test of sphericity was performed for three-point comparisons, with the Greenhouse–Geisser correction applied when violated. When significant multivariate effects were observed, Bonferroni-adjusted pairwise comparisons were conducted. All tests were two-tailed ($p < 0.05$). Effect sizes (Cohen's d)

were calculated as supplementary measures: small (d = 0.2), medium (d = 0.5), and large (d = 0.8) [24].

III. RESULTS

A. Physical Activity

Following RAGT, significant improvements were observed in METs (p = 0.02, d = 0.38) and VM CPM (p = 0.01, d = 0.44). Sedentary time significantly decreased (p = 0.02, d = −0.49), while time in light (p = 0.03, d = 0.51) and moderate physical activity (p = 0.01, d = 0.42) significantly increased. No significant changes were found in Energy expenditure (Table 1).

B. Motor Function and Quality of Life

All three functional outcomes improved significantly and exceeded their Minimal Clinically Important Difference (MCID) thresholds. GMFM-88 scores increased by 4.9 points (p < 0.01, d = 0.22), TUG completion time decreased by 24.7 s (p = 0.03, d = −0.33), and 6MWT distance increased by 38.4 m (p = 0.02, d = 0.52). CP-QOL scores did not change significantly (p = 0.29, d = 0.04) (Table 2).

Table 1 Physical activity outcomes at baseline and post-intervention.

Variable	Baseline	Post	p	d
Energy expenditure	472.46±378.01	526.82±300.43	0.91	0.16
METs	1.34±0.17	1.41±0.20	0.02	0.38
Sedentary (%)	83.26±5.53	80.08±7.12	0.02	– 0.49
Light PA (%)	15.14±4.82	17.92±5.97	0.03	0.51
Moderate PA (%)	1.16±0.69	1.52±0.99	0.01	0.42
VM CPM	356.05±163.02	438.26±205.36	0.01	0.44

Table 2 Motor function and quality of life results.

Measure	Baseline	Interim	Post	p	*Effect size* (Cohen's d)
GMFM-88 (score)	59.04±21.94	61.22±21.96	63.89±22.13	<0.01	0.22
TUG (sec)	97.34±78.62	87.48±67.85	72.64±70.56	0.03	– 0.33
6MWT (m)	63.47±54.81	83.73±77.72	101.85±87.88	0.02	0.52
CP-QOL (score)	52.34±4.49	51.17±4.17	52.50±4.24	0.29	0.04

IV. DISCUSSION

This pilot study demonstrated that wearable RAGT produced statistically significant and clinically meaningful improvements in physical activity and motor function in children with spastic CP. The observed shift from sedentary to light and moderate physical activity suggests that wearable robot training carries over into daily life behaviors, beyond what is measured in the clinic [13, 15].

All functional outcomes exceeded their respective MCID thresholds, indicating changes that are perceptible and meaningful to patients and clinicians. The assist-as-needed design of the wearable exoskeleton likely promoted active muscle recruitment and motor learning through repetitive, task-specific training [14, 15].

Despite measurable functional gains, CP-QOL scores did not change significantly. This is consistent with prior studies reporting that short-term motor improvements may not immediately translate into perceived psychosocial benefits [25, 26]. Quality of life in children with CP is influenced by multiple environmental and social factors beyond physical function, and longer follow-up periods are likely necessary to capture meaningful changes.

Heterogeneous individual responses were observed: six of ten participants showed increased METs and walking distance, while four showed stable or slightly reduced values. This variability underscores the need for individualized robot settings and adaptive training protocols. From a regional innovation perspective, the use of a domestically certified wearable exoskeleton (Bambini Teens, COSMO ROBOTICS) demonstrates a viable model for technology-driven healthcare solutions aligned with SDG 3 (Good Health) and SDG 10 (Reduced Inequalities).

V. CONCLUSIONS

Wearable exoskeleton RAGT produced meaningful improvements in real-world physical activity and motor function in children with spastic CP across multiple GMFCS levels. All functional outcomes exceeded MCID thresholds, confirming clinical relevance despite the small sample size. Quality of life did not change significantly over the six-week period, highlighting the need for longer interventions and community-based follow-up. Future studies should employ randomized controlled designs with larger samples and explore cost-effective implementation within regional rehabilitation systems.

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From Temporary Project to Sustained Collective Action: The Case of Sonmat-itgi Project in South Korea

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Abstract — **This paper examines Sonmat-itgi ("connecting the taste of hands"), a collective-impact initiative in Wonju, South Korea, in which ten elderly women were trained and certified as gochujang-making instructors to deliver food education and emotional care to isolated older adults. Implemented in 2025 through a partnership among a public anchor institution, two social enterprises, a welfare center, and an intermediary agency as a backbone organization, the program reached 303 vulnerable older adults and 63 children and youth and achieved an overall impact score of 90 out of 100 on an eleven-indicator scorecard spanning social, economic, and environmental dimensions. However, this paper argues that the project's most consequential outcome was not fully visible within its 2025 measurement window. It raises a broader question for collective-impact-based social economy initiatives: is impact a result measurable within a project's funded period, or a process in which the relationships and collective capacity a project builds mature afterward into self-sustaining collective action? Drawing on collective-impact and collective-agency theory, this paper proposes a "temporary project paradox" — project-based interventions are effective at forming collaborative relationships, but their very temporariness threatens the durability of what they form — and extends the conventional input-output-outcome-impact chain with relational and organizational stages to better capture how small-scale collective-impact initiatives generate impact over time.**

Keywords — **collective impact, collective agency, community capacity, social economy, impact measurement**

I. Introduction

As social problems such as population aging, social isolation, and regional economic decline deepen and intersect, no single actor — public, private, or civil society — can resolve them alone, and the need for cross-sector "collective impact," in which multiple organizations align around a common agenda to address a shared problem, has grown correspondingly [1]. For regional innovation scholarship, such collaborations constitute a distinctive category of place-based social innovation, reorganizing underused local resources — here, older women's dormant productive capacity and locally grown produce — rather than deploying new technology [2]. However, collective impact initiatives often rely on grant-based and relatively short-term funding, which can constrain long-term planning and sustainability; yet what happens to the collaborative relationships they build once external funding ends remains comparatively underexamined [3].

Sonmat-itgi ("connecting the taste of hands") responds to a couple of local problems in Wonju, Gangwon Province: economic and social isolation among older women, the care needs of older adults living alone, a shortage of local care services, and underused traditional food culture. Ten women over fiftyfive were trained as a 'grandmother instructor corps' who delivered gochujang-making education and the resulting gochujang to older adults living alone. The program's own planning documents explicitly describe it as a collective-impact initiative, coordinating a public anchor institution, a welfare center, an intermediary agency, and two social enterprises, each with a distinct role, toward simultaneous value across employment, emotional care, intergenerational relationships, cultural transmission, and local economic circulation [1], [4].

An eleven-indicator, self-administered impact scorecard documented substantial achievement at project completion in 2025: 90 of 100 points across social, economic, and environmental dimensions [5]. However, the program's most consequential development was not visible within that measurement window. During implementation, uncertainty about whether Sonmat-itgi would continue produced visible anxiety and tension within the instructor corps — observed directly by the author in the project-coordinator role — straining relationships the project itself had built. Partner institutions did not resolve this uncertainty; they indicated only that they would make their best effort to secure continuation, without being able to guarantee it. It was this absence of certainty, rather than any reassurance, that appears to have led the instructors to recognize their own dependency on institutions they could not control, and to begin preparing to form an informal voluntary association to sustain their activity independent of any single agency's funding cycle. This trajectory poses a question current impact-measurement frameworks are not designed to answer: is impact a result measurable within a project's funded period, or a process in which the relationships and collective capacity a project builds mature afterward into self-sustaining collective action?

II. Theoretical Background

A. Collective Impact

Collective-impact theory holds that large-scale social change requires cross-sector actors to align around a common agenda, shared measurement, mutually reinforcing activities, continuous communication, and a

"backbone" organization providing coordination capacity [1]. Sonmat-itgi's planning documents explicitly invoke this model, assigning the intermediary agency the backbone role. The theory, however, says little about the temporal dynamics of collaboration once a specific funded project cycle ends — a gap this paper addresses [6].

B. Collective Agency and Community Capacity

Collective agency refers to a group's shared belief in its capacity to organize and execute courses of action to produce given outcomes [7]. Community-capacity scholarship similarly holds that durable community change depends less on any single program than on the relationships, trust, and organizational skill a community accumulates through repeated collective action [7]. Together, these literatures suggest that a project's lasting contribution may lie less in its measured outputs than in whether it leaves behind a group capable of continued, self-directed action.

C. Project-Based Intervention and the Temporary Project Paradox

Project-based funding efficiently mobilizes people around a shared task within a bounded period, but its very temporariness can threaten the durability of what it creates: participants whose role and income depend on a project's continuation may experience uncertainty about the project's end as a threat to the relationships the project itself built [8]. This study terms this the temporary project paradox — a project is effective at forming a collective, but the collective's stability depends on resolving, through either continued funding or a shift to self-organization, the uncertainty the project's own temporariness creates. Sonmat-itgi's 2025 instructor-corps tension over continuation, and its 2026 shift toward forming an independent association once continuation was assured, illustrates this dynamic directly.

III. Research framework and questions

Building on this literature, this paper extends the conventional input-activity-output-outcome-impact chain [9] with two intermediate stages — relational outcomes (trust, network ties, collective identity) and organizational outcomes (collective agency, joint decision-making, self-organization) — positioned between outputs and sustained impact: Project → Interaction → Relationship/Trust → Collective Identity → Collective Agency → Self-Organization → Sustained Collective Action → Long-Term Impact. Impact measurement is treated as a device that captures results at a particular point along this process, not the process itself.

This study asks: (i) how did uncertainty about project continuation affect relationships within the instructor corps during 2025 implementation; (ii) what changed once continuation was assured, and how did this relate to the instructors' move toward self-organization in 2026; and (ii) what aspects of this relational and organizational trajectory were, and were not, visible within the program's 2025 impact scorecard.

IV. Case and methods

Sonmat-itgi was implemented May–July 2025 in Wonju, a secondary city in Gangwon Province, registered under the intermediary agency's 2025 Collective Impact Creation Project (budget KRW 7,090,000, about USD 5,000) and coordinated among six institutions: an agricultural social enterprise, a senior consumer social cooperative, a welfare center, a public health-insurance agency as anchor institution, a local social-economy support center, and the intermediary agency as backbone [6]. Table I summarizes the roles of the six participating institutions.

TABLE I. PARTICIPATING INSTITUTIONS AND ROLES

Institution	Role
Chomam Co. (agricultural social enterprise)	Trained/certified instructor corps; manufactured gochujang kits
Wonju Senior Consumer Social Cooperative	Recruited instructor candidates
Myeongryun Welfare Center	Hosted sessions; recruited beneficiary older adults
HIRA (health-insurance agency)	Anchor institution; core funding
Wonju Social Economy Support Center	Co-funding; training venue
Korea Social Enterprise Promotion Agency	Backbone: design, coordination, monitoring

Source: 2025 Collective Impact Creation Project: Implementation Plan for the 'Sonmat-itgi' Project for Emotional Care of Older Adults, Korea Social Enterprise Promotion Agency (2025)

Data are drawn from four sources: (i) the program's April 2025 collective-impact implementation plan and June 2025 impact-measurement plan; (ii) its September 2025 results-sharing report, including an eleven-indicator, 100-point scorecard (40 social, 30 economic, 30 environmental); (iii) instructors' own written reflections, collected as open-ended responses on the post-program satisfaction questionnaire rather than through structured interviews; and (iv) the author's own field observations as the program's coordinating evaluator, present throughout instructor training, delivery, and the transition into 2026. The relational and organizational events described in Section V draw specifically on this fourth source; because no independent record of these events exists beyond the author's own notes, they are presented as direct, reflexive observation rather than as documented fact, consistent with insider or practitioner case-study methodology [10]. This is an important limitation. The findings cannot yet be independently verified. Future research should therefore conduct structured interviews with instructors and partner staff at several points after the project ends.

V. Findings and Discussion

A. Measured Achievement in 2025 and What the 2025 Scorecard Did, and Did Not, Capture

Table II summarizes the 2025 scorecard. The program scored 90 of 100 points: full marks on all five social indicators (10 instructors trained; 303 older adults and 63 children/youth served; average satisfaction above 4.5/5.0), and full marks on two of three indicators each in the economic and environmental dimensions, with partial credit only on indicators requiring prospective, forward-looking evidence — future revenue-model conversion (5/10) and additional carbon-footprint-reduction practices (5/10).

TABLE II. SONMAT-ITGI 2025 IMPACT SCORECARD SUMMARY

Dimension	Indicator	Score
Social	Participation opportunities for older adults	8/8
	Reduced social isolation (instructors)	8/8
	Partner-institution cooperation satisfaction	8/8
	Vulnerable-group beneficiaries reached	8/8
	Beneficiary satisfaction	8/8
Economic	New job creation	10/10
	Local economic circulation	10/10
	Future revenue-model conversion	5/10
Environmental	Local agricultural produce use ratio	10/10
	Additive-free, low-sodium provision	10/10
	Carbon-footprint reduction practices	5/10
	Total	**90/100**

Source: 2025 Sonmat-itgi project impact measurement report, Korea Social Enterprise Promotion Agency (2025)

The 2025 scorecard registered high achievement on indicators available at project completion — participation, training, satisfaction, sourcing — but contained no indicator corresponding to relational or organizational outcomes, because no such indicator existed in a measurement plan designed before the instructor corps had cause to organize independent of the project. And the scorecard's own partner-cooperation indicator measured satisfaction with cross-institutional cooperation during the funded project, not the instructor corps' own emerging capacity for self-organization afterward. This is not necessarily a flaw specific to Sonmat-itgi's instrument so much as a structural limit of project-period measurement: the relational and organizational stages proposed in Section III are, by definition, difficult to observe using an instrument fielded only during, or immediately after, the funded period itself.

B. The Temporary Project Paradox in Practice

During May–July 2025 implementation, uncertainty about whether Sonmat-itgi would receive continued support produced visible tension among the ten-woman instructor corps. Because their instructor role, and the modest income and social participation it provided, depended on the project's continuation, unresolved questions about the project's future strained relationships the group had built through weeks of shared training and delivery — consistent with the temporary project paradox proposed in Section II-C.

"Teaching has given me great pride — knowing that I can help and bring joy to someone, and ease someone's loneliness. Through this work I feel more energy and joy in my own life, and it has been a real economic help as well. Thinking of a life in which we look after one another, I sincerely hope this program will continue, and not just be temporary."— Sonmat-itgi instructor, post-program written reflection, 2025

This reflection, one of several the instructors submitted at project completion, illustrates why the tension over continuation was relational rather than merely financial: instructors described their role in terms of pride, vitality, and mutual care before mentioning income, suggesting that what was at stake for them was not only a source of pay but a valued way of relating to others. The partner institutions did not, in fact, resolve this tension by confirming continuation; what they communicated was that they would make their best effort to secure support for 2026, without being able to guarantee it. This fell short of removing the underlying uncertainty — but it appears to have been the moment at which the instructors themselves came to recognize what was actually driving their anxiety and the friction it was producing among them: not the funding shortfall as such, but the corps' own dependency on institutions whose support they could not control. It was this recognition of dependency — rather than any reassurance the institutions were able to offer — that appears to have prompted the instructors to decide, on their own initiative, to organize their own association. By 2026 the instructors and partner organizations were preparing to form an informal voluntary association to sustain the instructor corps independent of any single agency's annual funding cycle. Read against the framework in Section III, this sequence traces a shift from project dependence ("we can only act if the project continues") to collective agency ("we can organize to continue acting ourselves") that was triggered not by institutional certainty but by the instructors' own recognition of its absence — a transition external observers might describe as organizational, but which instructors appear to have experienced first as relational and self-directed.

VI. Conclusions

This paper examines the case of Sonmat-itgi in Wonju to ask whether impact is best understood as a result measurable within a project's funded period, or as a process in which relationships and collective capacity accumulated through a project mature afterward into sustained collective action. Its central claim is that the impact of a small, community-based social economy project cannot be fully explained by the social, economic, and environmental outcomes measurable within its funded period alone; it must also account for how the relational capital and collective agency formed during the project develop, after the project ends, into self-organization and sustained collective action. The case supports this claim directly: the program's 2025 scorecard registered strong, largely uniform achievement (90 of 100 points), yet its most consequential development — a shift from anxious project dependence to an emerging collective agency capable of self-organization — became visible only in 2026, and, notably, was triggered not by institutional reassurance but by the instructors' own recognition of the limits of that reassurance.

Theoretically, the paper makes three contributions. First, it extends collective-impact scholarship, which specifies conditions for cross-sector alignment but says little about what happens once a funded project cycle ends, with an explicit temporal dimension [3]. Second, it proposes the temporary project paradox as a specific mechanism linking project-based intervention design to the relational risks such designs create, and shows that this paradox can be resolved from within a group rather than only through continued external funding. Third, and most specifically, the case suggests a refinement to collective-agency theory: agency was not produced by the removal of uncertainty but by the group's own recognition of an uncertainty that external actors could not remove — a micro-mechanism linking dependency-awareness to self-organization that existing accounts of collective efficacy do not foreground [7].

Moreover, the case has implications for how collective-impact partnerships and their funders design and evaluate small-scale social economy projects. Evaluators should track relational and organizational indicators — trust, cohesion, and a group's own sense of continued capacity — across, not only within, funding cycles, since the present scorecard's complete silence on this dimension was not a matter of a poorly chosen indicator but of an absent one. Funders and backbone organizations should also recognize that offering only a "best effort" toward continuation, rather than either a firm commitment or a candid acknowledgment of its absence, may itself function as an unintended catalyst for self-organization: ambiguity, not certainty, appears to have been what moved this group to act. Whether funders should rely on such dynamics or address them earlier and more directly remains an open question that this single case cannot answer. However, the case highlights the importance of this question for future research.

As a single, reflexively observed case without independent corroboration of the relational events described, these conclusions should be treated as an initial account inviting further verification, comparative case work, and the design of relational and organizational impact indicators for small-scale, collective-impact-based social economy initiatives. In addition, the instructors' reflections highlight a limitation of output-oriented impact measurement: it may capture what a project delivers during its funding period, but not the relationships, collective identity, and sense of purpose that may persist beyond the project itself.

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Rice Husk Utilization for Biomass Power: Energy Potential and Value Addition

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Abstract— **Rice husk is an abundant agricultural residue with considerable potential as a renewable biomass resource, yet its utilization in Indonesia remains limited. South Sumatra, a major rice-producing province, has significant opportunities to convert rice husk into renewable electricity. This study aims to analyze the electricity generation potential and economic value added from rice husk utilization in South Sumatra. A quantitative descriptive approach was employed using primary data from PT Buyung Putra Pangan and secondary data from Statistics Indonesia. Rice husk availability and electricity generation potential were estimated using the husk-to-grain ratio (HGR), calorific value, and energy conversion factors, while economic value added was analyzed using the Modified Hayami Method. The results show that rice husk in South Sumatra has the potential to generate 2,331.89 GWh of electricity annually. At an 80% plant capacity factor, effective generation reaches 1,865.51 GWh per year, equivalent to 28.28% of the province's annual electricity demand. Rice husk utilization generates annual electricity sales of US$209.31 million, with a value added of US$111.43 million, a value-added ratio of 53%, and a processing margin of US$205.87 million. Of the total margin, 54% represents business profit and 46% is allocated to other production inputs. These findings highlight the potential of rice husk to support renewable energy development, increase the economic value of agricultural residues, and promote circular bioeconomy practices in South Sumatra.**

Keywords— Biomass power, circular bioeconomy, renewable energy, rice husk, value added

I. Introduction

Rice husk is one of the main residues generated during the rice milling process. It has been utilized for various purposes, including animal feed, traditional fuel, growing media, and organic fertilizer [1]. However, despite its various applications, rice husk remains underutilized in many rice-producing countries, with substantial quantities being burned or discarded. Therefore, its conversion into energy provides an alternative pathway for utilizing this agricultural residue while generating electricity [2]. The use of rice husk and other rice-processing residues as renewable energy sources has been widely investigated through combustion, gasification, pyrolysis, and other energy conversion technologies [3][4].

South Sumatra Province is one of the rice-producing regions in Indonesia. Large-scale rice production generates substantial quantities of rice husk. The average rice production in South Sumatra during 2023–2025 reached 3,123,069.20 tons of dry unhusked rice [5]. This production level provides a considerable supply of rice husk that can be further utilized as biomass fuel. Rice production data in South Sumatra were therefore used as the basis for estimating rice husk availability and its electricity generation potential.

The utilization of rice husk as biomass fuel has been developed by PT Buyung Putra Pangan in Ogan Ilir Regency. PT Buyung Putra Pangan is a rice milling company with a processing capacity of 400 tons per day. The company receives rice supplies from several regions, including Banyuasin, Ogan Ilir, Belitang, and Lampung. This large milling capacity and extensive supply network result in substantial quantities of rice husk. To reduce husk accumulation and utilize the available energy resource, the company constructed a rice husk-fired biomass power plant in 2018, which was completed in 2020. The plant is managed by PT Buyung Putra Energi, and the electricity generated is used to meet the electricity requirements of the rice milling operation. The biomass power plant is capable of converting approximately 4 tons of rice husk into 3 MW of electricity per hour. However, its operation still faces several challenges, particularly the availability of skilled personnel and a sufficient supply of rice husk as fuel [6].

The operation of the biomass power plant at PT Buyung Putra Pangan demonstrates the practical application of rice husk as an energy source within the rice milling industry [7]. This experience also provides an opportunity to examine the broader potential of rice husk utilization in South Sumatra Province. Therefore, this study analyzes not only the electricity generation potential of rice husk but also the value added generated from its conversion into electricity. Value-added analysis is important for examining the increase in the economic value of rice husk after processing. Accordingly, this study aims to analyze the electricity generation potential of rice husk in South Sumatra Province and evaluate the value added generated from processing rice husk as fuel for a biomass power plant.

II. Materials and Methods

A. Location and Time

This research was conducted in South Sumatra Province, Indonesia, with primary data collected at PT Buyung Putra Pangan. The location was purposively selected because the company utilizes rice husk from rice milling activities as fuel for a biomass power plant. South Sumatra was also selected due to its substantial rice production and rice husk availability. Data collection was carried out from May to July 2026.

B. Methodology

This study employed a quantitative descriptive approach using both primary and secondary data. To analyze the electricity generation potential, rice husk availability was estimated based on rice production and the *husk-to-grain ratio* (HGR). Previous studies have reported that the husk-to-grain ratio generally ranges from approximately 20% to 22% [1][8]. In this study, an HGR of 20% was used to estimate rice husk generation. A collection efficiency (CE) of 100% was applied in the calculation to represent the total amount of rice husk associated with rice production. Thus, the calculation does not account for losses during collection, handling, or transportation. Rice husk availability was calculated using the following equation:

$$RH = CE \times HGR \times RP \quad (1)$$

Where RH is rice husk potential (tons), CE is collection efficiency (%), HGR is the *husk-to-grain ratio (%)*, and RP is rice production (tons). The energy potential was then calculated based on the calorific value of rice husk [9]:

$$EPRH = RH \times CVRH \quad (2)$$

Where EPRH is the energy potential of rice husk (MJ/year) and CVRH is the calorific value of rice husk (MJ/kg). The resulting energy was converted into electricity using 1 kWh = 3.6 MJ and adjusted using an 80% plant capacity factor.

To analyze the economic value added, the Modified Hayami Method developed by Hidayat et al. [10] was applied. The method was modified by using monetary values and an annual production period as the basis of calculation, instead of the quantity of raw materials and output per production process. This adjustment allows the method to be applied to electricity production. The analysis included value added, value-added ratio, processing margin, other input contributions, and business profit from rice husk utilization as biomass power plant fuel. The contribution of other input costs and business profit was calculated based on their respective proportions of the processing margin. A value-added ratio of less than 15% was categorized as low, 15–40% as medium, and above 40% as high.

III. Results and Discussion

A. Rice Husk Potential in South Sumatra Province

Rice husk potential was estimated based on rice production in South Sumatra Province during 2023–2025. The development of rice production is presented in Table 1.

Table 1 Harvested Area and Rice Production in South Sumatra Province, 2023–2025

Year	Harvested Area (ha)	Rice Production (tons)
2023	504,143.03	2,832,773.92
2024	521,092.21	2,909,411.67
2025	636,316.00	3,627,022.00
Average	553,850.41	3,123,069.20

Source: BPS-Statistics Indonesia, South Sumatra Province.

Based on Table 1, the average rice production in South Sumatra Province during 2023–2025 reached 3,123,069.20 tons of dry unhusked rice. Using an HGR of 20% and a collection efficiency of 100%, the amount of rice husk associated with this rice production was estimated as follows:

$$\begin{aligned} RH &= CE \times HGR \times RP \\ &= 100\% \times 20\% \times 3{,}123{,}069.20 \\ &= 624{,}613.84 \text{ tons/year} \end{aligned}$$

The calculation resulted in 624,613.84 tons of rice husk per year. This amount represents the rice husk generated from the average rice production in South Sumatra during 2023–2025.

B. Electricity Generation Potential from Rice Husk

The estimated rice husk availability of 624,613.84 tons, equivalent to 624,613,839.33 kg, was used to calculate its energy potential based on a calorific value of 13.44 MJ/kg. The calculation was as follows:

$$\begin{aligned} EPRH &= RH \times CVRH \\ &= 624{,}613{,}839.33 \text{ kg} \times 13.44 \text{ MJ/kg} \\ &= 8{,}394{,}810{,}000.64 \text{ MJ/year} \end{aligned}$$

The resulting energy was then converted into kWh:

$$\begin{aligned} EE &= \frac{8{,}394{,}810{,}000.64}{3.6} \\ &= 2{,}331{,}891{,}666.84 \text{ kWh/year} \\ &\quad \text{or } 2{,}331.89 \text{ GWh/year} \end{aligned}$$

Using a plant capacity factor of 80%, electricity generation was calculated as follows:

$$\begin{aligned} EE &= 2{,}331.89 \times 80\% \\ &= 1{,}865.51 \text{ GWh/year} \end{aligned}$$

The results indicate that rice husk in South Sumatra could generate 1,865.51 GWh of electricity per year. This amount was compared with the average annual electricity sold in South Sumatra during 2023–2025, which was 6,595.43 GWh per year [11]. Thus, electricity generated from rice husk could contribute 28.28% of the average annual electricity demand in South Sumatra Province.

This contribution shows that rice husk can play an important role in supporting renewable electricity gen-

eration in South Sumatra. The availability of rice production and the existing implementation of a rice husk-fired biomass power plant indicate opportunities for further development of biomass-based energy in the province [5][12].

C. Value Added from Rice Husk Processing as Biomass Power Plant FuelH

Value-added analysis was conducted to determine the increase in the economic value of rice husk after it was processed into electricity [7]. The calculation used the Modified Hayami Method with monetary values and an annual production period as the basis of analysis.

Table 2 Value Added from Rice Husk Processing as Biomass Power Plant Fuel in South Sumatra Province

No.	Variable	Result
1	Fuel purchase price (US$/kWh)	0.00184
2	Electricity selling price (US$/kWh)	0.11220
3	Total value added per kWh of output (US$)	0.11036
I	Output, Input, and Price	
4a	Sales output volume (kWh/year)	1,865,513,333.48
4b	Sales value of output (US$)	209,310,596
5	Main raw material (US$)	3,435,635
6	Direct labor (man-days)	23,400
7	Conversion factor	60.92
8	Direct labor coefficient (US$/man-day)	8,945
9	Direct labor wages (US$/year)	10,898,427
II	Revenue and Value Added	
10a	Other production input costs (US$/year)	89,078,262
10b	Other operational input costs (US$/year)	5,363,351
11a	Value added (US$/year)	111,433,349
11b	Value-added ratio (%)	53%
III	Returns to Production Factors	
12	Processing margin (US$)	205,874,961
12a	Contribution of other input costs (%)	46%
12b	Business profit (%)	54%

The electricity selling price used in the value-added analysis was US$0.11220/kWh. This price was obtained by applying the location factor for the Sumatra region to the electricity purchase price for biomass power plants. The fuel purchase price for rice husk was US$0.00184/kWh. The difference between the electricity selling price and the fuel purchase price was US$0.11036/kWh.

In Section I, the sales value of output was obtained by multiplying the sales output volume by the electricity selling price per kWh. With an output volume of 1,865,513,333.48 kWh per year, the resulting sales value was US$209,310,596 per year. The value of the main raw material was US$3,435,635, while direct labor amounted to 23,400 man-days. The conversion factor was 60.92, and the direct labor coefficient was US$8,945 per man-day.

In Section II, other production input costs include expenses that support the production process, such as annual investment costs and fixed operation and maintenance (O&M) costs. These costs amounted to US$89,078,262 per year. Other operational input costs, including variable O&M costs, amounted to US$5,363,351 per year.

Value added was obtained by subtracting the value of the main raw material, other production input costs, and other operational input costs from the sales value of output. The value added generated from rice husk processing reached US$111,433,349 per year. The value-added ratio was 53%, indicating a high value-added category because it exceeded 40%. This result indicates that rice husk processing can substantially increase the economic value of an agricultural residue. Previous studies have also demonstrated the economic feasibility of rice husk-based energy systems, particularly when the available feedstock is sufficient to support continuous operation of rice-milling facilities [3][12].

Section III presents the processing margin obtained from rice husk processing as biomass power plant fuel. The margin represents the difference between the sales value of output and the cost of the main raw material. The processing margin reached US$205,874,961. Of this amount, 46% was allocated to other input costs, while 54% represented business profit. The relatively large share of business profit indicates that rice husk utilization can generate substantial economic returns when the residue is converted into electricity. This finding is consistent with previous studies reporting positive economic benefits from rice husk-based electricity generation and highlighting the importance of sufficient feedstock availability and appropriate system design [12][13]. In addition, the utilization of rice husk and its by-products can create further economic value within a circular economy framework [14].

IV. Conclusions

South Sumatra Province has considerable potential to utilize rice husk as fuel for biomass power generation. The average rice production during 2023–2025 was 3,123,069.20 tons of dry unhusked rice, generating an estimated 624,613.84 tons of rice husk per year using a husk-to-grain ratio of 20%. This amount could generate 2,331.89 GWh of electricity annually. With an 80% plant capacity factor, electricity generation reaches 1,865.51 GWh per year, equivalent to 28.28% of the average electricity demand in South Sumatra Province.

The utilization of rice husk as biomass power plant fuel also generates economic value. The annual sales value of electricity reached US$209,310,596, while value added amounted to US$111,433,349, with a value-added ratio of 53%, placing it in the high value-added category. The processing margin reached

US$205,874,961, of which 54% represented business profit and 46% was allocated to other input costs.

The utilization of rice husk as biomass power plant fuel can therefore provide an alternative for managing rice milling residues in South Sumatra. In addition to generating electricity, this utilization increases the economic value of rice husk and supports the development of biomass-based renewable energy.

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The Performance Effects of Innovation Diversification under Different Levels of R&D Intensity: Evidence from Japanese Listed Firms

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Abstract—
This study examines the relationship between innovation diversification and firm value using panel data on Japanese listed firms from 2000 to 2022. Innovation diversification is measured by the breadth of International Patent Classification (IPC) classes covered by firms' patent portfolios, while firm value is measured by Tobin's Q. Fixed-effects estimates provide suggestive evidence of an inverted U-shaped relationship, indicating that moderate innovation diversification may be associated with higher firm value, whereas the benefits diminish as diversification increases. However, the nonlinear relationship becomes statistically insignificant after accounting for firm-value persistence and potential endogeneity using System GMM. The results further show that R&D intensity is negatively associated with firm value in the fixed-effects models, while its moderating effects on the diversification–value relationship are statistically insignificant. Overall, the findings suggest that greater technological breadth does not necessarily translate into higher firm value and highlight the importance of considering both innovation diversification and R&D commitment when evaluating firms' innovation strategies.

Keywords— Innovation diversification; Firm value; R&D intensity

I. Introduction

Innovation is widely recognized as an important source of firm competitiveness and long-term value creation. Firms invest in research and development (R&D), accumulate technological knowledge, and develop intellectual property to strengthen their competitive positions and create future growth opportunities. From the knowledge-based view of the firm, technological knowledge constitutes a strategically important resource, and firms differ in their abilities to integrate and exploit such knowledge [1]. The economic value of innovation therefore depends not only on the amount of innovative activity but also on how firms organize and utilize their technological knowledge.

While conventional innovation measures such as R&D expenditure and patent counts primarily capture the quantity or intensity of innovation, firms may also differ substantially in the breadth of technological fields in which they innovate. A firm whose patents are concentrated in a narrow technological domain possesses a different knowledge portfolio from one whose innovative activities span multiple technological fields, even when the two firms generate a similar number of patents. Patent classification information therefore provides a useful means of identifying the technological scope of firms' innovative activities [2]. In this study, innovation diversification refers to the breadth of technological fields represented in a firm's patent portfolio and is measured by the number of distinct International Patent Classification (IPC) classes.

Innovation diversification may generate both benefits and costs. A broader technological portfolio can expand a firm's knowledge base, facilitate knowledge recombination across technological domains, and create opportunities for developing new products and technologies. García-Vega finds that innovation diversification promotes innovative activity [5], while previous patent-based studies show that the diversity and configuration of technological portfolios are associated with innovation and firm performance [4], [7], [9]. However, greater technological breadth may also disperse limited resources, increase coordination and integration costs, and weaken technological specialization. Consistent with this trade-off, Chen et al. report a negative relationship between Innovation diversification and market-based performance, including Tobin's Q [8]. These competing benefits and costs suggest that the relationship between innovation diversification and firm value may be nonlinear rather than simply positive or negative.

An important factor that may condition this relationship is R&D intensity. Maintaining innovative activities across multiple technological fields requires resources to develop, integrate, and exploit heterogeneous technological knowledge. Firms with greater R&D commitment may have stronger capacity to sustain multiple technological activities and exploit complementarities across different knowledge domains. In contrast, when R&D resources are relatively limited, Innovation diversification may spread those resources across too many fields, reducing technological depth and increasing coordination costs. Accordingly, the value implications of innovation diversification may depend not only on the extent of technological breadth but also on the resources committed to R&D. This suggests that innovation diversification and R&D intensity should be considered jointly rather than as independent dimensions of innovation strategy.

The Japanese context provides a particularly relevant setting for examining these relationships. Japanese firms have historically accumulated substantial technological capabilities through sustained R&D and patenting activ-

ities. Suzuki and Kodama show that Innovation diversity can contribute to persistent innovation and product diversification among Japanese firms [3], while Nagaoka demonstrates that R&D activities are associated with the market value of Japanese firms [6]. More recently, Matsumoto et al. examine Innovation diversification and enterprise value among Japanese listed firms and find that the dispersion of technological activities across multiple areas may adversely affect enterprise value [10]. These findings indicate that technological breadth is economically relevant for Japanese firms, while also suggesting that greater diversification does not necessarily generate greater firm value.

Despite the growing literature on technological diversification, relatively less attention has been devoted to whether its relationship with firm value is nonlinear and whether this relationship depends on firms' R&D commitment. Existing studies indicate that technological diversification can create opportunities for knowledge recombination but can also impose resource-allocation and coordination costs [7], [9]. These competing mechanisms imply that moderate diversification may generate benefits, whereas excessive diversification may reduce them. Moreover, the balance between these benefits and costs may differ according to firms' R&D intensity. Examining Innovation diversification without considering both its potential nonlinearity and firms' R&D commitment may therefore conceal important differences in its performance implications.

Accordingly, this study examines the relationship between innovation diversification and firm value using panel data on Japanese listed firms over the period 2000–2022. Innovation diversification is measured by the breadth of IPC classes represented in firms' patent portfolios, while firm value is measured by Tobin's Q. The empirical analysis first examines the linear and nonlinear effects of innovation diversification using fixed-effects models. It then employs a dynamic System GMM specification to account for the persistence of firm value and potential endogeneity. Finally, the analysis investigates whether R&D intensity moderates the relationship between innovation diversification and firm value.

This study contributes to the literature in two respects. First, it extends research on innovation and firm performance by focusing on the breadth of firms' technological portfolios and explicitly considering a potential nonlinear relationship between innovation diversification and firm value. Second, it provides a conditional perspective by examining whether R&D intensity moderates this relationship. In doing so, the study provides evidence on how technological breadth and R&D commitment jointly relate to the market-based performance of Japanese listed firms.

The rest of the paper is organized as follows. Section II describes the data sources, empirical models, and variable definitions. Section III presents and discusses the empirical results, and Section IV concludes the paper.

II. Data sources, empirical model setup and variable description

A. Data sources

To investigate the relationship between innovation diversification and firm value, we construct a longitudinal dataset of publicly listed Japanese firms over the period 2000–2022. The sample covers nine industries: electronic machinery and equipment, precision instruments, other manufacturing sectors, automobiles, shipbuilding, machinery, transportation equipment, pharmaceuticals, and telecommunications. The two largest industry groups are electronic machinery and equipment (32.52%) and machinery (28.70%). After matching the required variables and accounting for the lag structure used in the empirical analysis, the final estimation sample consists of 13,374 firm-year observations.

The variables used in this study are drawn from two sources. Firm-level financial and ownership variables, including Tobin's Q, R&D intensity, number of employees, capital intensity, and foreign ownership, are obtained from a global stock market and economic database. Patent-related information is manually collected from the Japan Patent Office's patent search system. Innovation diversification is measured as the natural logarithm of one plus the number of distinct International Patent Classification (IPC) classes covered by each firm's patent portfolio.

B. Empirical Model and Variable Definitions

This study employs fixed-effects panel regression models to examine the relationship between innovation diversification and firm value. Firm value is measured by Tobin's Q (TQ), while innovation diversification (DIV) is measured as the natural logarithm of one plus the number of distinct International Patent Classification (IPC) classes covered by a firm's patent portfolio. The linear specification is first estimated using DIV alone, after which the squared term of DIV is introduced to examine a potential nonlinear relationship. R&D intensity (RDS) is incorporated to capture firms' R&D commitment and is further used to examine whether it moderates the diversification–value relationship. The models control for firm size (SIZE), capital intensity (CAP), and foreign ownership (FOR). Firm and year fixed effects are included to account for time-invariant firm heterogeneity and common time-specific shocks. All explanatory variables are lagged by one year to mitigate potential simultaneity concerns.

The baseline empirical model is specified as follows:

$$\mathrm{TQ}_{it} = \alpha + \beta_1 \mathrm{DIV}_{it\text{-}1} + \beta_2 \mathrm{DIV}^2_{it-1} + \beta_3 RDS_{it-1} + \lambda X_{it-1} + \mu_i + \mathrm{T}_t + \varepsilon_{it} \quad \ldots\ldots\ldots\ldots (1)$$

where TQ_{it} represents the firm value of firm i in year t; $\mathrm{DIV}_{it\text{-}1}$ and DIV^2_{it-1} capture the linear and nonlinear effects of innovation diversification, respectively; and RDS_{it-1} denotes R&D intensity. $\mathrm{X}_{i,t-1}$ is a vector of firm-level control variables, including SIZE, CAP, and

FOR. Firm fixed effects and year fixed effects are represented by μ_i and λ_t, respectively, and ε_{it} is the error term. Standard errors are clustered at the firm level. A positive coefficient on DIV combined with a negative coefficient on DIV² would provide evidence consistent with an inverted U-shaped relationship between innovation diversification and firm value.

Because firm value may exhibit persistence over time and innovation decisions may be endogenous to firm performance, a dynamic panel specification is further estimated by incorporating lagged Tobin's Q. The dynamic model is specified as follows:

$$TQ_{it} = \alpha + \rho TQ_{it-1} + \beta_1 DIV_{it-1} + \beta_2 DIV_{it-1}^2 + \beta_3 RDS_{it-1} + \lambda X_{it-1} + \mu_i + T_t + \varepsilon_{it} \quad \ldots\ldots\ldots\ldots (2)$$

The dynamic model is estimated to use the two-step System GMM estimator to account for the persistence of firm value and potential endogeneity. The instrument matrix is collapsed to limit instrument proliferation. The Arellano–Bond tests for first- and second-order serial correlation and the Hansen test of over-identifying restrictions are used to assess the adequacy of the model specification and the validity of the instruments.

Finally, to investigate whether R&D intensity moderates the relationship between innovation diversification and firm value, the baseline specification is extended by interacting RDS with both the linear and squared terms of DIV:

$$TQ_{it} = \alpha + \beta_1 DIV_{it-1} + \beta_2 DIV_{it-1}^2 + \beta_3 RDS_{it-1} + \beta_4 (DIV \times RDS)_{it-1} + \beta_5 (DIV^2 \times RDS)_{it-1} + \lambda X_{it-1} + \mu_i + T_t + \varepsilon_{it} \quad \ldots\ldots\ldots\ldots (3)$$

The coefficients on the interaction terms, β_4 and β_5, indicate whether R&D intensity alters the linear and nonlinear components of the relationship between innovation diversification and firm value. Detailed definitions and descriptive statistics for all variables are reported in Table 1.

Table 1. Variable Definitions and Descriptive Statistics

Variable	Definition	Mean	S.D.
TQ	Market value relative to asset value	0.732	0.755
DIV	Log of one plus the number of IPC classes covered by the firm's patents	1.762	1.038
RDS	R&D expenditure relative to sales	0.064	0.209
SIZE	Log of the number of employees	7.448	1.766
CAP	Log of the capital–labor ratio	10.461	0.689
FOR	Foreign ownership ratio	0.242	0.273

Note: The sample covers firm-year observations from 2000 to 2022. TQ and RDS are winsorized at the 1st and 99th percentiles to mitigate the influence of extreme values. All explanatory variables are lagged by one year in the regression analysis.

III. Results and Discussion

A. Innovation Diversification and Firm Value

Table 2 reports the relationship between innovation diversification and firm value. Model (1) presents the linear fixed-effects estimates. The coefficient on DIV is positive but statistically insignificant, providing no evidence of a significant linear relationship between innovation diversification and Tobin's Q. R&D intensity (RDS), however, is negatively and significantly associated with firm value.

Model (2) introduces the squared term of innovation diversification to examine potential nonlinearity. The coefficient on DIV is positive and significant at the 10% level (0.0667), whereas the coefficient on DIV² is negative and significant at the 10% level (−0.0216). This pattern provides suggestive evidence of an inverted U-shaped relationship between innovation diversification and firm value. The results imply that expanding the technological scope of innovation may initially be associated with higher firm value, potentially through greater opportunities for knowledge recombination and technological complementarities. Beyond a certain level, however, further diversification may generate increasing coordination and integration costs, thereby diminishing these benefits.

Model (3) further accounts for the persistence of firm value and potential endogeneity using the two-step System GMM estimator. Lagged Tobin's Q is positive and highly significant (0.8695), indicating strong persistence in firm value over time. Once this dynamic effect is taken into account, however, the coefficients on DIV and DIV² are no longer statistically significant. The diagnostic tests generally support the validity of the model specification: the AR(2) test does not reject the null of no second-order serial correlation at the 5% level (p = 0.054), and the Hansen test does not reject the validity of the instruments (p = 0.904).

Table 2. Innovation Diversification and Firm Value

Variables	(1) Linear FE	(2) Quadratic FE	(3) SGMM
Lagged TQ			0.8695***
DIV	0.0102	0.0667*	0.1062
DIV²		−0.0216*	0.0166
RDS	−0.8448***	−0.8450***	−0.9115
SIZE	−0.0065	−0.0054	−0.0777**
CAP	0.0412	0.0425	0.0441
FOR	0.0394	0.0390	0.1312**
Within R²	0.1327	0.1333	—

Notes: Models (1) and (2) are estimated using firm fixed-effects regressions with standard errors clustered at the firm level. Model (3) is estimated using the two-step System GMM estimator with corrected robust standard errors. All explanatory variables are lagged by one year. Firm and year fixed effects are included in Models (1) and (2), while year effects are included in Model (3). The System GMM model uses 37 collapsed instruments; the p-values of the AR(1), AR(2), and Hansen tests are 0.000, 0.054, and 0.904, respectively. *** p < 0.01, ** p < 0.05, * p < 0.10.

Overall, the fixed-effects estimates provide suggestive evidence of an inverted U-shaped relationship between innovation diversification and firm value. However, the nonlinear relationship becomes statistically insignificant in the dynamic specification, indicating that the result is sensitive to the treatment of firm-value persistence and potential endogeneity.

B. The Role of R&D Intensity

Table 3 further examines whether R&D intensity moderates the relationship between innovation diversification and firm value. After incorporating the interaction terms, the coefficient on DIV remains positive and significant (0.0790, $p < 0.05$), while the coefficient on DIV^2 remains negative and significant (−0.0288, $p < 0.05$). This pattern is consistent with the nonlinear relationship identified in the fixed-effects results reported in Table 2.

However, neither the interaction between DIV and RDS nor that between DIV^2 and RDS is statistically significant. These results provide no significant evidence that R&D intensity moderates the nonlinear relationship between innovation diversification and firm value. In contrast, RDS itself remains negatively and significantly associated with subsequent firm value, suggesting that greater R&D intensity does not necessarily translate into higher market valuation in the short run.

Table 3. The Moderating Role of R&D Intensity

Variables	Coefficient	Robust S.E.
DIV	0.0790**	0.0365
DIV^2	−0.0288**	0.0134
RDS	−0.8336***	0.1944
DIV × RDS	−0.2521	0.2304
DIV^2 × RDS	0.1640	0.1581
SIZE	−0.0047	0.0434
CAP	0.0442	0.0432
FOR	0.0389	0.0573
Within R^2	0.1337	

Notes: The dependent variable is Tobin's Q. All explanatory variables are lagged by one year. Firm and year fixed effects are included. Robust standard errors clustered at the firm level are reported. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

IV. Conclusions

This study examines the relationship between innovation diversification and firm value using panel data on Japanese listed firms from 2000 to 2022. By considering both the linear and nonlinear effects of innovation diversification, the study provides a more nuanced understanding of how the breadth of firms' innovation activities is associated with market valuation.

The fixed-effects results provide suggestive evidence of an inverted U-shaped relationship between innovation diversification and Tobin's Q. Moderate technological diversification may be associated with higher firm value by facilitating knowledge recombination and technological complementarities, whereas excessive diversification may reduce these benefits because of increasing coordination and integration costs. However, after accounting for the strong persistence of firm value and potential endogeneity using System GMM, the nonlinear relationship becomes statistically insignificant. The evidence for an inverted U-shaped relationship should therefore be interpreted with caution. In addition, although R&D intensity is negatively associated with firm value in the fixed-effects models, there is no significant evidence that it moderates the relationship between innovation diversification and firm value.

Overall, the findings suggest that expanding the technological scope of innovation does not necessarily translate into higher firm value. Rather, the value implications of innovation diversification appear to depend on the extent of diversification and are sensitive to the empirical specification. These results highlight the importance of considering the breadth of technological activities and firms' R&D commitment when evaluating the value implications of innovation strategies.

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Innovation without Expansion: Patents and Firm Performance in Taiwan's Electronics Industry

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Abstract—
This study examines whether different types of patents have heterogeneous effects on operational efficiency and firm expansion using an unbalanced panel of publicly listed electronics firms in Taiwan from 2010 to 2025. Fixed-effects panel regression models are employed to control for unobserved firm heterogeneity. Firm performance is evaluated using labor productivity as a measure of operational efficiency and employment growth, sales growth, and asset growth as measures of firm expansion. The empirical results reveal substantial differences across patent types and performance dimensions. Invention patents are positively and significantly associated with labor productivity but negatively and significantly associated with employment, sales, and asset growth, suggesting that technology-oriented innovation is primarily associated with operational efficiency rather than firm expansion. In contrast, utility model and design patents exhibit relatively limited economic effects, with no significant relationship with labor productivity, sales growth, or asset growth and only a negative association with employment growth. Overall, the findings suggest that the economic value of innovation depends on both the type of innovation and the dimension of firm performance considered.

Keywords— Patent types; Firm performance; Taiwan electronics industry

I. Introduction

Innovation has long been regarded as an important source of firm competitiveness and productivity growth. Firms invest in research and development (R&D) and intellectual property with the expectation that innovation will strengthen technological capabilities and improve economic performance. Previous studies have documented a close relationship between R&D, innovation, and productivity [1–3], while patents have become a widely used indicator of innovation output. However, patents differ considerably in their technological and economic value, suggesting that aggregate patent counts may not fully capture the economic consequences of innovation [4,5].

More importantly, innovation may affect different dimensions of firm performance in different ways. Technological innovation can improve production processes, facilitate automation, reduce costs, and enable firms to use existing resources more efficiently. Such improvements may increase productivity without necessarily leading to proportional increases in employment, sales, or productive assets. Previous studies have shown that the growth effects of innovation vary considerably across firms and over time [6,7]. Harrison et al. [8] further show that innovation can generate both labor-displacement effects and output-related employment gains. These findings suggest that operational efficiency and firm expansion should be considered distinct outcomes of innovation. This raises a fundamental question: Does innovation make firms more efficient, larger, or both?

This issue is particularly relevant to Taiwan's electronics industry, a mature and technology-intensive sector with a strong global position in semiconductor manufacturing, IC design, electronic components, and information and communication technology. Recent developments in artificial intelligence, 5G communications, high-performance computing, and global supply-chain restructuring have further increased the importance of technological innovation and operational efficiency. Previous studies have documented the importance of innovation in this industry. Chen et al. [9] find that scientific linkages embodied in patents are positively associated with the productivity of Taiwanese electronics firms, while Aw and Lee [10] report a positive relationship between R&D investment and labor-augmenting productivity. Nevertheless, whether the benefits of innovation extend beyond productivity improvement to broader firm expansion remains less clear.

Another important consideration is the heterogeneous nature of innovation. Invention patents generally represent more technology-oriented innovation, whereas utility model and design patents tend to reflect incremental improvements in product functionality, structure, or appearance. Kim et al. [11] show that patents and utility models can play different roles in technological development and learning. Recent evidence also suggests that design innovation can contribute to firm performance through distinct channels [12,13]. Treating different patent types as a homogeneous measure of innovation may therefore conceal important differences in their economic effects.

Against this background, this study examines the effects of different patent types on firm performance using an unbalanced panel of publicly listed electronics firms in Taiwan from 2010 to 2025. The analysis distinguishes invention patents from utility model and design patents and evaluates firm performance from two complementary perspectives. Labor productivity measures operational efficiency, while employment growth, sales growth, and asset growth capture different dimensions

of firm expansion. Fixed-effects panel regression models with firm and year fixed effects are employed to control for unobserved firm heterogeneity and common time-specific shocks.

This study contributes to the literature by simultaneously distinguishing between different patent types and different dimensions of firm performance. Rather than assuming that innovation uniformly promotes firm growth, the analysis examines whether its economic effects are reflected primarily in greater efficiency, broader firm expansion, or both. This distinction provides a more comprehensive understanding of the economic value of innovation in a mature technology intensive industry.

The rest of the paper is organized as follows. Section II describes the data sources, empirical model, and variable definitions. Section III presents and discusses the empirical results, and Section IV concludes the paper.

II. Data sources, empirical model setup and variable description

A. Data sources

This study employs an unbalanced panel dataset of publicly listed electronics firms in Taiwan from 2010 to 2025. Patent data were manually collected from the Taiwan Intellectual Property Office (TIPO) and classified into invention, utility model, and design patents. Firm-level financial information and firm characteristics were obtained from the Taiwan Economic Journal (TEJ) database. Patent records were matched with firm-level data by firm and year. After excluding observations with missing information, the final sample consists of 397 firms and 4,932 firm-year observations. The sample includes firms from eight major electronics industry categories classified by the Taiwan Stock Exchange (TWSE), with electronic parts and components accounting for the largest share (23.69%), followed by computer and peripheral equipment (18.48%), semiconductor (15.94%), optoelectronics (14.30%), and other electronics-related industries.

B. Empirical Model and Variable Definitions

This study employs fixed-effects panel regression models to examine the effects of different patent types on firm performance. Firm performance is evaluated in terms of operational efficiency, measured by labor productivity, and firm expansion, measured by employment, sales, and asset growth. Invention patents are used to represent technology-oriented innovation, while utility model and design patents represent relatively incremental innovation. The two patent measures are estimated separately to capture potential heterogeneity in their relationships with firm performance. All models control for firm characteristics and include firm and year fixed effects to account for unobserved firm heterogeneity and common time-specific shocks.

The baseline empirical model is specified as follows:

$$\mathrm{PF}_{it} = \alpha + \beta PAT_{it} + \lambda X_{it} + \mu_i + \mathrm{T}_t + \varepsilon_{it} \quad (1)$$

where PF_{it} denotes one of the four dependent variables for firm i in year t, including labor productivity (LP), employment growth (GR_EMP), sales growth (GR_NS), and asset growth (GR_A). PAT_{it} represents either invention patents (PATINV) or utility model and design patents (PATUD). X_{it} is a vector of control variables, including firm size (SIZE), firm age (AGE), capital intensity (CAP), advertising expenditure (lnAD), export ratio (EXPR), and foreign ownership (FORER). u_i denotes firm fixed effects, T_t represents year fixed effects, and ε_{it} is the random error term.

Table 1 presents the variable definitions and descriptive statistics. The sample firms exhibit substantial variation in innovation activities and firm characteristics. On average, firms hold 21.33 invention patents and 2.28 utility model and design patents, with large standard deviations reflecting considerable heterogeneity in patenting activities across firms. The average firm is approximately 28 years old, and the mean export ratio is 0.744, reflecting the strong export orientation of Taiwan's electronics industry. The average foreign ownership ratio is 0.146. The descriptive statistics also reveal considerable variation in labor productivity and the three measures of firm expansion—employment, sales, and asset growth. Firm size, capital intensity, and advertising expenditure are included as additional firm-level characteristics in the subsequent regression analysis.

Table 1.
Variable Definitions and Descriptive Statistics

Variable	Definition	Mean	S.D.
LP	Log of net sales per employee	8.910	1.173
GR_EMP	Employment growth rate	0.060	0.456
GR_NS	Sales growth rate	0.010	0.261
GR_A	Asset growth rate (%)	6.929	22.169
PATINV	Number of invention patents	21.332	113.085
PATUD	Number of utility model and design patents	2.280	9.631
SIZE	Log of number of employees	6.858	1.617
AGE	Firm age in years	28.121	11.321
CAP	Log of capital–labor ratio	7.498	1.023
lnAD	Log of advertising expenditure	12.348	2.091
EXPR	Ratio of exports to sales	0.744	0.285
FORER	Foreign ownership ratio	0.146	0.170

Note: All variables are calculated based on firm-year observations over the sample period from 2010 to 2025.

III. Results and discussion

A. Effects of Invention Patents

Table 2 and Table 3 report the estimation results of the fixed-effects panel regression models examining the

effects of different patent types on firm performance. Table 2 presents the estimation results for invention patents, while Table 3 reports the corresponding results for utility model and design patents. To capture different dimensions of firm performance, this study evaluates firms from two complementary perspectives. Labor productivity is employed to measure operational efficiency, whereas employment growth, sales growth, and asset growth are used to represent firm expansion.

Table 2 reports the fixed-effects estimation results for the relationship between invention patents and firm performance. A clear contrast emerges between operational efficiency and firm expansion. In Model (1), the coefficient on invention patents (PATINV) is positive and statistically significant at the 1% level (0.039), indicating that greater invention patenting activity is associated with higher labor productivity. This finding suggests that technology-oriented innovation may be associated with greater operational efficiency, potentially reflecting knowledge accumulation, technological upgrading, process improvement, and more efficient use of existing production resources. The result is consistent with previous evidence linking technological innovation to productivity improvement [2,9,10].

In contrast, invention patents are negatively and significantly associated with all three measures of firm expansion. The coefficient on PATINV is −0.036 for employment growth, −1.324 for sales growth, and −1.038 for asset growth. The negative relationship with employment growth may be consistent with labor-saving technological change, whereby productivity-enhancing innovation reduces the need for proportional increases in labor input. More importantly, the negative associations with sales and asset growth suggest that the higher productivity associated with invention-based innovation does not necessarily translate into short-term expansion in market scale or productive capacity. Firms may instead use technological innovation to improve the utilization of their existing resources rather than expand their organizational scale. Taken together, these results indicate that invention-based innovation is associated with higher productive efficiency but lower rates of firm expansion. Thus, technological innovation may make firms more efficient without necessarily making them larger.

The control variables also reveal several notable patterns. Firm size (SIZE) is negatively associated with labor productivity but positively associated with employment, sales, and asset growth, whereas firm age (AGE) is negatively and significantly associated with all four performance measures, indicating weaker productivity and growth performance among older firms. Capital intensity (CAP) is positively associated with labor productivity and asset growth but negatively related to employment growth, a pattern consistent with greater production efficiency and lower reliance on labor input. Advertising expenditure (lnAD) is positively related to labor productivity and sales growth but negatively associated with employment growth. Export intensity (EXPR) has a positive and significant association only with labor productivity. Foreign ownership (FORER) is positively associated with labor productivity, sales growth, and asset growth but negatively associated with employment growth. Overall, these results suggest that capital investment, market-oriented activities, export participation, and foreign ownership are associated with different dimensions of firm efficiency and expansion.

Table 2.
Effects of Invention Patents on Firm Performance

Vars	(1) LP	(2) GR_EMP	(3) GR_NS	(4) GR_A
PATINV	0.039***	-0.036***	-1.324**	-1.038**
SIZE	-0.783***	0.241***	1.683**	0.950*
AGE	-0.018***	-0.016***	-2.017***	-0.760***
CAP	0.043***	-0.032**	0.653	1.989***
lnAD	0.221***	-0.022**	1.289**	0.395
EXPR	0.330***	0.058	-4.128	-0.736
FORER	0.735***	-0.309***	18.943***	18.860***
Within R^2	0.717	0.281	0.124	0.063

Note: All models include firm and year fixed effects. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

B. Effects of Utility Model and Design Patents

Table 3 presents the fixed-effects estimation results for utility model and design patents (PATUD). In contrast to invention patents, utility model and design patents exhibit relatively limited relationships with firm performance. The coefficient on PATUD is negative but statistically insignificant for labor productivity (−0.007), indicating no significant association between these relatively incremental forms of innovation and operational efficiency. Similarly, the coefficients for sales growth (−0.215) and asset growth (−0.606) are negative but statistically insignificant, providing no evidence of a significant relationship between utility model and design patents and these dimensions of firm expansion.

Employment growth is the only performance measure significantly associated with PATUD. The estimated coefficient is −0.025 and statistically significant at the 5% level, indicating a negative association between utility model and design patenting and employment growth. This finding may reflect labor-saving adjustments associated with incremental innovation. However, the absence of a significant association with labor productivity provides limited support for a labor-saving interpretation.

The estimated coefficients of the control variables are generally consistent with those reported in Table 2, suggesting stable relationships between firm characteristics and performance across the two patent specifications. Overall, the results suggest that utility model and design patents exhibit relatively limited associations with both

operational efficiency and firm expansion, with the exception of their negative association with employment growth.

Table 3.
Effects of Utility Model and Design Patents on Firm Performance

Vars	(5) LP	(6) GR_EMP	(7) GR_NS	(8) GR_A
PATUD	-0.007	-0.025**	-0.215	-0.606
SIZE	-0.778***	0.239***	1.575**	0.893*
AGE	-0.015***	-0.017***	-2.090***	-0.799***
CAP	0.042***	-0.032**	0.685	2.011***
lnAD	0.221***	-0.022**	1.275**	0.377
EXPR	0.343***	0.050	-4.527	-1.000
FORER	0.756***	-0.330***	18.268***	18.362***
Within R^2	0.716	0.279	0.123	0.062

Note: All models include firm and year fixed effects. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Taken together, the results reveal substantial heterogeneity in the relationships between different patent types and firm performance. Invention patents are positively associated with labor productivity but negatively associated with employment, sales, and asset growth, suggesting that technology-oriented innovation is more closely associated with operational efficiency than with firm expansion. In contrast, utility model and design patents exhibit relatively limited associations with firm performance, with no significant relationship with labor productivity, sales growth, or asset growth and only a negative association with employment growth. These findings suggest that innovation does not necessarily translate into firm expansion and that its economic consequences depend on the type of innovation. In the context of Taiwan's mature technology-intensive electronics industry, invention-based innovation appears to be more closely associated with greater operational efficiency than with continuous expansion of firm scale.

IV. Conclusions

This study examines the relationships between different types of patents and two dimensions of firm performance—operational efficiency and firm expansion—using panel data on publicly listed electronics firms in Taiwan from 2010 to 2025. The results reveal substantial heterogeneity across patent types and dimensions of firm performance. Invention patents are positively associated with labor productivity but negatively associated with employment, sales, and asset growth, suggesting that technology-oriented innovation is more closely associated with operational efficiency than with firm expansion. In contrast, utility model and design patents exhibit relatively limited associations with firm performance, with no significant relationship with labor productivity, sales growth, or asset growth and only a negative association with employment growth.

These findings highlight the importance of distinguishing both the type of innovation and the dimension of firm performance when evaluating the economic value of patents. Innovation should not be assumed to generate uniform improvements across all aspects of firm performance. In the context of Taiwan's electronics industry, technological innovation appears to be more closely associated with productivity improvement than with continuous expansion of firm scale.

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Effects of Cross-Boundary Learning in Depopulated Local Communities on Corporate Employees: An Exploratory Study of Employee Engagement

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Abstract—**Cross-boundary learning, in which corporate employees encounter different values and cultures outside their organizations, has attracted growing attention. This study initially focused on effects on employee engagement and exploratorily examined how cross-boundary learning in depopulated local communities influences corporate employees' perceptions and attitudes toward work. Six two-day, one-night programs conducted in depopulated areas of Mie Prefecture were analyzed using five-point-scale ratings and open-ended responses. The results identified multidirectional insights and intentions, including renewed recognition of the meaning and purpose of one's own work and organizational purpose, as well as attachment to local communities, greater personal relevance of local issues, and perceived opportunities to contribute to local communities. Job crafting intention received highly positive responses, whereas its perceived feasibility and employee engagement did not show the same pattern. These exploratory findings suggest that job crafting intention may serve as a more proximal indicator of the effects of cross-boundary learning itself in depopulated local communities. Future research should focus on job crafting intention and examine its formation process quantitatively and qualitatively.**

***Keywords*—Cross-boundary learning, Job crafting, Organizational purpose, Employee engagement, Depopulated local communities**

I. Introduction

As population decline and industrial restructuring continue to change the environment surrounding companies, it has become increasingly important for employees to acquire new perspectives and proactively apply them to their work and business activities. Against the backdrop of the spread of remote work, cross-boundary learning - in which employees cross organizational boundaries and encounter different values and cultures - has attracted attention as one approach to human resource development. In particular, crossing into depopulated local communities, which differ markedly from everyday workplaces, may provide opportunities for employees to reconsider their work and ways of working.

Cross-boundary learning has been conceptualized as learning through which individuals acquire new perspectives by crossing the boundaries of their organizations and everyday work environments and engaging with people and work settings characterized by different values and practices [1]. Research on pro bono activities by corporate employees has also pointed to a relationship between cross-boundary experiences and job crafting [2]. However, it remains insufficiently understood how exposure in depopulated local communities to nature, livelihood-related work perspectives and cultures adapted to local environments, and pressing local challenges affects corporate employees.

Accordingly, this exploratory study examines how cross-boundary experiences in depopulated local communities influence participants' perceptions and attitudes toward work. At the outset, an initial conceptual model was developed in which cross-boundary experiences promote renewed recognition of the meaning and purpose of one's own work and organizational purpose, with alignment between the two leading to job crafting and ultimately employee engagement [3] (Fig. 1). Using this model as a guide, the study aimed to identify not only changes anticipated by the model but also changes that emerged beyond it.

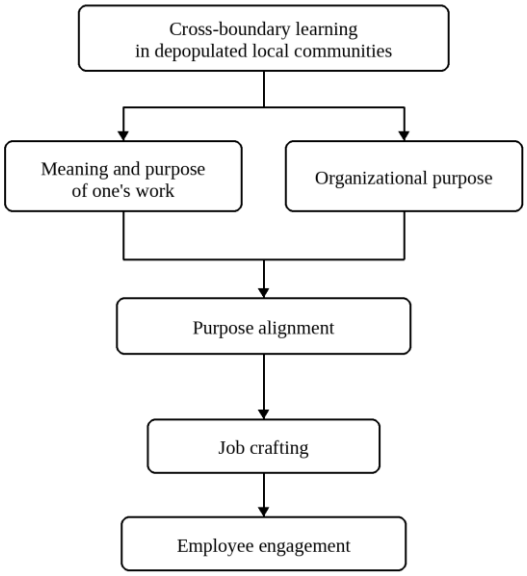


Fig. 1. Initial conceptual model.

II. Methods

This study analyzed six two-day, one-night cross-boundary learning programs conducted in depopulated local communities in Mie Prefecture. Participants were primarily corporate employees. Each program combined direct exposure to nature, livelihood-related work perspectives and cultures adapted to local environments, and pressing local challenges with dialogue and reflection among participants. Table 1 summarizes the programs analyzed.

Table 1. Overview of the Cross-Boundary Learning Programs Analyzed

Program	Date	Setting	n	Main activities
A	Jun. 13–14, 2026	Misugi	6	Shrine cleanup; forestry experience; Albergo Diffuso initiative
B	Jan. 23–24, 2026	Misugi	8	Forest mindfulness; forestry experience; interaction with a hotel owner using fermentation-generated hot water
C	Nov. 19–20, 2025	Owase	8	Evacuation mapping and tsunami drill with residents; shelter cleanup
D	Feb. 1–2, 2025	Misugi	7	Forest therapy; forestry experience; career reflection
E	Sep. 12–13, 2024	Shima	7	Beach cleanup; interaction with a young entrepreneur revitalizing an abandoned pearl farm
F	Aug. 7–8, 2024	Owase	8	Wildlife-prevention fencing on abandoned farmland; vacant-house observation

Note: Participants were primarily corporate employees; three freelancers and one university faculty member were also included.

After each program, participants completed a questionnaire consisting of five-point-scale items, mainly informed by the initial conceptual model, and open-ended questions. Because questionnaire items were progressively added or revised as the programs were implemented, the number of respondents varied across measures. For quantitative data, ratings of 4 or 5 on the five-point scale were classified as positive responses. Open-ended responses were also exploratorily categorized to identify changes not captured by the initial conceptual model, in addition to confirming correspondence with that model. The directions toward which participants' insights and intentions were oriented were then organized. Statements considered relevant to job crafting were additionally extracted and examined for potential correspondence with Task, Relational, and Cognitive Crafting [4].

III. Results

Five-point-scale ratings showed positive responses on multiple measures, including renewed recognition of the meaning and purpose of one's work and of organizational purpose, attachment to and willingness to contribute to the local community, and the personal relevance of local community issues (Table 2). Job crafting intention (wanting to apply insights to one's work) received positive responses from 100% (14/14) of respondents, whereas perceived feasibility of job crafting (believing that the insights could actually be applied to one's work) received 75% (33/44), and employee engagement (feeling motivated to contribute beyond what is normally expected) received 83% (30/36). Because the number of respondents differed across measures, these percentages cannot be directly compared.

Table 2. Major Quantitative Findings

Measure	**Positive responses, % (n/N)**
Renewed recognition of meaning and purpose of one's work	81.8% (36/44)
Renewed recognition of organizational purpose	70.0% (21/30)
Personal-organizational purpose alignment	58.3% (21/36)
Job crafting intention	100.0% (14/14)
Perceived feasibility of job crafting	75.0% (33/44)
Employee engagement	83.3% (30/36)
Pride in one's organization	86.4% (19/22)
Attachment to and willingness to contribute to the local community	100.0% (29/29)
Personal relevance of local community issues	95.5% (42/44)
Perceived opportunity to contribute to the local community	86.4% (19/22)
Intention to expand work-related relationships	90.9% (20/22)

Note: Positive responses represent ratings of 4 or 5 on a five-point scale. N varies across measures because questionnaire items were added or refined across programs.

Across programs, open-ended responses showed changes corresponding to the initial model, including encounters with different values and work perspectives and reconsideration of personal and organizational purpose and their connection. At the same time, changes not fully anticipated in the initial model were also identified, including attachment to local communities, greater personal relevance of local issues, and perceived opportunities to contribute to local communities. Qualitative changes that were difficult to capture through the five-point scales also showed that insights and intentions were directed toward multiple domains: one's own values and way of life, one's work and the company's business, involvement in and contribution to local communities, and reconsideration of the relationship between the company and the local community through the individual. Thus, insights and intentions arising from cross-boundary experiences emerged in multiple directions involving the self, local community, company, and company-community relationships (Table 3).

Table 3. Key Qualitative Findings and Directions of Change

Qualitative finding	Direction of change	Representative statement
Awareness of one's own state	Self	I became aware of how tense I usually am at work and found a clearer way to mentally reset myself.
Reconsideration of one's view of work	Self / Work	I began to question whether working solely for productivity truly leads to a richer and happier life.
Reinterpretation of organizational purpose	Company / Work	By interpreting each element of the company's philosophy in my own way, I felt that I could connect it to greater meaning in my daily work.
Attachment and willingness for continued involvement	Local community	I would like to introduce the community's attractions to my family and friends, visit again with them, and help through volunteer activities.
Recognition of the personal relevance of local community issues	Self / Local community	I had regarded local community problems as someone else's issues, but realized that similar problems exist in my own community. This made me think about how I should engage with my own community.
Recognition of opportunities to contribute	Local community / Work	I could contribute by supporting the introduction of emergency communication systems and promoting disaster communication services at local events.
Reconsideration of company-community relationships	Company / Local community	I realized that by using the remote-work arrangements encouraged by my company, it may be possible to better understand the community and build a mutually beneficial relationship between the company and the community.
Intention to apply cross-boundary learning to work	Work	I intend to note citizens' needs and ideas from daily life and incorporate them into my proposals.
Perceived constraints on implementation	Work	It would be difficult to put this into practice in my current assignment.

Note: Representative statements were shortened for presentation while preserving their original meaning. Directions indicate the primary target(s) toward which participants' reflections or intentions were oriented.

Because perceived feasibility of job crafting showed a lower proportion of positive responses than job crafting intention, individual-level ratings were examined together with open-ended responses. One respondent acknowledged the value of community-based activities but rated feasibility low, stating that they did not see how such activities related to their daily business. By contrast, respondents who rated feasibility high described intentions to translate insights gained in the local community into concrete proposals or initiatives for the company and into their own daily work. In addition, some respondents rated perceived feasibility of job crafting low, stating that implementation would be difficult in their current assignment. Among these respondents, renewed recognition of organizational purpose was also observed in cases with high employee engagement ratings.

Statements considered relevant to job crafting included intentions and orientations that could correspond to Task Crafting, such as changing work content, scope, or methods; Relational Crafting, such as changing work-related relationships; and Cognitive Crafting, such as reconstructing the meaning or interpretation of work.

IV. Discussion

Although the sample was limited, job crafting intention received highly positive responses, whereas perceived feasibility of job crafting did not show the same pattern. Individual-level examination of open-ended responses together with five-point-scale ratings also indicates that the intention to apply insights from cross-boundary experiences to work should be distinguished from the perception that such changes can actually be implemented in one's work. This suggests that, relative to perceived feasibility, job crafting intention may serve as a

more proximal indicator of the effects of cross-boundary learning itself in depopulated local communities.

Insights and intentions arising from cross-boundary learning in depopulated local communities emerged in multiple directions - not only toward work and the company, but also toward the self, the local community, and reconsideration of company-community relationships through the individual. These may constitute important learning outcomes for participants. From the perspective of corporate human resource development, however, not all of these outcomes necessarily feed back directly into work or the organization. It may therefore be important to reinterpret diverse insights and intentions in relation to work after participants return to their workplaces.

In this regard, renewed recognition of organizational purpose may, in addition to its position in the initial conceptual model, serve as one possible axis through which multidirectional insights and intentions are reinterpreted in relation to one's own work, the company, and the relationship between the company and the local community. For example, post-program reflection that encourages participants to consider the relationships among insights and intentions gained in the local community, their own work, and organizational purpose may help reconnect such multidirectional insights and intentions to work. This possibility should be examined in future research.

At the same time, attachment to local communities, greater personal relevance of local issues, and perceived opportunities to contribute suggest that job crafting intention may not be fully explained by personal-organizational purpose alignment alone. Future research should examine the formation process of job crafting intention in light of prior research [5] linking hands-on, overview, and beyond-routine experiences with awareness of social contribution and job crafting. In addition, because some respondents rated perceived feasibility of job crafting low while employee engagement was high, these two measures may provide supplementary perspectives for understanding, at the individual level, the context in which job crafting intention is formed.

This study is limited by its small sample, non-identical questionnaire items across programs, and the absence of pre-post comparisons and sufficient measurement of changes in job crafting intention and actual behavior. Future research should standardize the measures and combine pre-post quantitative assessment with qualitative inquiry, with particular attention to the formation process of job crafting intention. Based on these exploratory findings, Fig. 2 presents a provisional conceptual model incorporating multidirectional relationships among the individual, company, and local community, reconnection to work through organizational purpose as one possible axis, job crafting intention, and conditions for implementation.

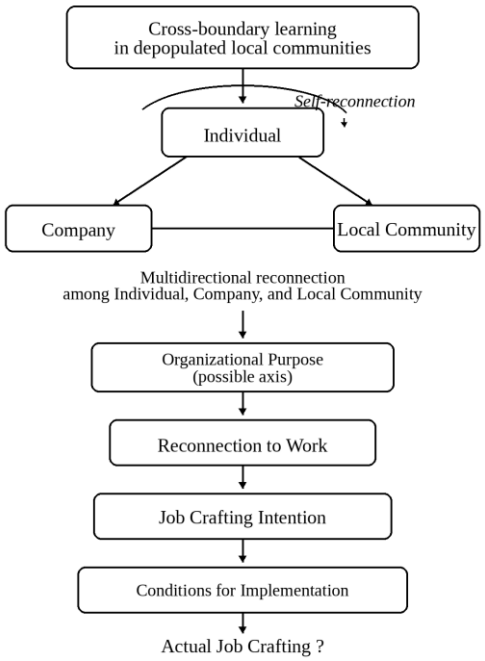


Fig. 2. Provisional conceptual model emerging from the exploratory findings.

V. Conclusions

This study identified multidirectional insights and intentions among corporate employees participating in cross-boundary learning in depopulated local communities, including renewed recognition of the meaning and purpose of one's own work and organizational purpose, attachment to local communities, greater personal relevance of local issues, and perceived opportunities to contribute. The study began as an exploratory investigation initially focused on effects on employee engagement; however, the analysis suggests that job crafting intention may serve as a more proximal indicator of the effects of cross-boundary learning itself in depopulated local communities. Future research should focus on job crafting intention and examine its formation process using both quantitative and qualitative approaches.

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An Exploratory Case Study on the Knowledge Creation Process in a Non-Profit Organization.

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Abstract— **Social Welfare Councils (SWCs) in Japan face a severe management challenge: organizational resources are disproportionately consumed by statutory services like long-term care insurance. This weakens their incubation function for discovering and resolving emerging community issues, trapping many in a vicious cycle of stagnation. This exploratory case study investigates the new project development process within an SWC to identify organizational structures that facilitate knowledge creation. Focusing on the successful launch of a "Hospital/Facility Admission Support Project," a semi-structured interview was conducted with the key staff member (Staff A) who spearheaded the initiative. The narrative was analyzed using Ikujiro Nonaka's SECI model and the concept of *Ba* (shared context).**

The findings suggest that development process can be interpreted through the four modes of the SECI model: acquiring tacit knowledge through shared field experiences (Socialization); crystallizing explicit missions in informal dialogue spaces (Externalization); systematizing the project through managerial negotiations (Combination); and routinizing operations to accumulate practical know-how (Internalization). The study highlights the crucial roles of Staff A as a "knowledge activist" and their supervisor (Staff B) as a "boundary spanner". However, although this case exhibited a sequence consistent with the SECI process, staff now face increasing routine workloads that may constrain subsequent knowledge creation. The paper concludes that non-profit organizations must address the innovator's dilemma and organizational ambidexterity by strategically allocating resources and sustaining *Ba* to maintain continuous innovation.

Keywords— Social Welfare Council, Knowledge Creation, SECI Model, Non-profit Organization

I. Introduction

Social Welfare Councils (SWCs), which are non-profit organizations dedicated to promoting community welfare in Japan, currently face a management challenge: their organizational resources are disproportionately consumed by statutory services such as long-term care insurance, making it difficult to initiate new projects. The weakening of their inherent incubation function to solve community issues through such projects could affect the sustainability of local communities.

This study is an exploratory case study that focuses on the process from an individual employee's discovery of a community issue to its formalization to examine organizational structures that facilitate knowledge creation—a process not fully elucidated in the context of non-profit organizations. In this paper, a semi-structured interview was conducted with Staff A, who launched a unique new project at the X City SWC, and the narrative was analyzed and interpreted using the framework of Ikujiro Nonaka's Knowledge Creation Theory.

II. Background and problem statement

In Japan, the externalization of family functions has rapidly progressed due to shrinking household sizes and the trend toward nuclear families. The Long-Term Care Insurance system, introduced in 2000, institutionalized welfare for the elderly, delivering it as a service based on contracts with providers. This shift created an institutional market backed by stable financial resources, namely insurance premiums and taxes.

During the early stages of this system, when the provision of public welfare services was immature, SWCs played a crucial role on a national scale. SWCs, non-profit organizations present in almost every prefecture and municipality, possess dual characteristics: they function as intermediary support organizations backing welfare service providers and volunteers, and as regional welfare practitioners aiming to discover and resolve emerging community needs. In the 2000s, many municipal SWCs launched statutory long-term care services (e.g., day care services) and disability welfare services, thereby generating significant revenue.

Today, however, as the institutional system has matured and the number of service providers has increased, revenues have declined, and 60% of SWCs are operating at a deficit [1]. Despite this severe financial situation, SWCs are required to develop and implement projects aimed at solving community issues. Today, against this background, this study aims to examine organizational structures and mechanisms conducive to knowledge creation by focusing on the development process of new projects aimed at resolving community issues within SWCs.

III. Methodology

This study analyzed the development process of a new project, the "Hospital/Facility Admission Support Project," implemented by the X City SWC, using the framework of Ikujiro Nonaka's Knowledge Creation Theory, specifically the SECI model and the concept of *Ba* (shared context) [2]. The author conducted a semi-structured interview lasting approximately 90 minutes in

July 2026 with Staff A, the central figure who spearheaded the project. The primary interview questions focused on the formalization process leading up to implementation, including the initial trigger for conceiving the project, the process of sharing and articulating the awareness of the issues with colleagues, the practical steps taken toward formalization, and the reactions of staff and stakeholders. Finally, the gathered narrative was chronologically reconstructed, and the knowledge conversion at each phase was interpreted using the SECI model and *Ba* as analytical concepts (Table1).

A. Theoretical Framework

Knowledge creation theory is frequently utilized in academic and practical analyses of for-profit enterprises, but its application to non-profit organizations remains scarce. However, this study posits that the theory is exceptionally well-suited for analyzing non-profit organizations, which share values with the community and operate deeply rooted within it. This is supported by Nonaka et al. (2008) [3], who argue that the utilitarian hypothesis of economics—which assumes that an individual firm's pursuit of profit maximization for shareholder interests inherently achieves the "good" and happiness of society as a whole—now requires revision; instead, they explain the theory of the firm as an entity that continuously learns and evolves through proactive interaction with its environment.

The core of Nonaka et al.'s knowledge creation theory consists of the "SECI model" (Fig. 1) and the concept of Ba. In this theory, it is explained that new knowledge is created through continuous mutual conversion between "tacit knowledge," which is obtained through individual experiences such as physical sensations and emotions, and "explicit knowledge," which is articulated into data or language. This process consists of four modes (SECI): "Socialization" (sharing tacit knowledge), "Externalization" (articulating tacit knowledge into explicit knowledge), "Combination" (systematizing explicit knowledge), and "Internalization" (embodying explicit knowledge as tacit knowledge through practice); as these modes unfold in a spiral, organizational knowledge expands. Furthermore, the shared context or space for interaction that drives this SECI model is called Ba. Ba includes physical, virtual, and mental spaces, functioning as an essential foundation that generates the energy for knowledge creation.

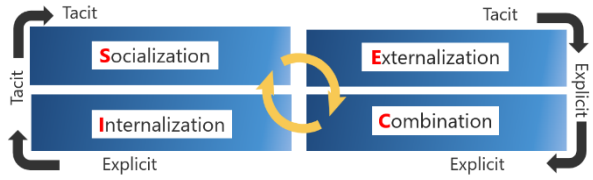


Fig. 1 SECI Model (Source: Adapted from Nonaka, Toyama and Konno (2000) [4])

B. Case Overview

The X City SWC independently developed and implemented the "Hospital/Facility Admission Support Project" to assist residents who are estranged from relatives and lack guarantors, a situation that otherwise prevents them from being admitted to hospitals or welfare facilities. Simply put, this project allows the SWC to mediate between the individual and the hospital or facility, assuming a role equivalent to a guarantor. In reality, the individuals were not the only ones struggling. From the perspective of hospitals and facilities, when dealing with individuals without guarantors, there were significant concerns regarding the inability to obtain surgical consent and the uncertainty of patients' ability to pay. Consequently, consultations regarding these difficult situations were frequently directed to local welfare commissioners, leaving them caught in the middle. This project was established to resolve these community issues that could not be solved through casework alone and were difficult to address through existing statutory systems and frameworks.

IV. Results

Staff A's statements were organized into Table 1 using the concepts of SECI and *Ba*.

A. Socialization

Socialization is the process of sharing individual tacit knowledge among multiple people to create new tacit knowledge. Its methodological key is empathy through shared experiences (Nonaka et al., 2010). Staff A accompanied local welfare commissioners and co-experienced the front lines of life consultations with residents. During this time, Staff A also witnessed a resident being defrauded of money. Staff A considered that there were other similar cases (troubles) besides this resident and began to perceive it as a community issue. In other words, through shared experiences in the field, Staff A acquired tacit knowledge in the form of a strong awareness of issues that had not yet been visualized or articulated in the community.

B. Externalization

Externalization is the process where tacit knowledge accumulated within an individual is expressed into specific explicit knowledge through language or images, developing into collective knowledge. Its methodology is described as "the pursuit of essence through dialogue," where the creation of concepts using metaphors is crucial. Staff A intentionally set up spaces for dialogue (e.g., after-work drinking parties, lunch meetings, birthday parties) with colleagues from the Community Welfare Division of the X City SWC. These informal spaces created by Staff A were environments for free discussion where colleagues offered unreserved opinions, generating a lively atmosphere. There, Staff A shared tacit knowledge based on personal experiences,

Table 1: Interview Analysis Table (Source: Compiled by the author)

SECI	Ba	Key Episodes	Theoretical perspective
Socialization	The sites where local issues are arising.	Together with welfare commissioners, one experiences situations where local residents' rights are being violated and acquires tacit knowledge.	Knowledge Activist (Staff A)
Externalization	After-hours drinking gatherings, lunch meetings, and birthday parties.	Articulate tacit knowledge in alignment with the mission and share explicit knowledge with colleagues.	Knowledge Activist (Staff A)
Combination	Negotiations with SWC executives and city authorities.	Create operational manuals and forms while negotiating with parties both inside and outside the organization to secure support.	Boundary Spanner (Staff B)
Internalization	Daily tasks at the office and on-site (in the community).	The new business becomes routine, and new practical know-how accumulates.	-

discussed the possibility of formalization, and further shared their own vision of the SWC's mission—"To become an SWC that the community relies on"—as a driving goal to promote knowledge creation.

C. Combination

Combination is the process of converting abstract explicit knowledge into higher-order, systematized explicit knowledge at the organizational level, which must be conducted based on a specific purpose (Nonaka et al., 2010). The staff of the X City SWC advanced preparations for modeling the new project by creating operational manuals and forms while referring to existing projects. Furthermore, Staff B, Staff A's supervisor (Manager of the Community Welfare Division), played the role of negotiator by explaining the new project to SWC executives and X City officials, securing their approval for formalization.

D. Internalization

Internalization is the mode where explicit knowledge is reabsorbed into individuals as tacit knowledge and accumulated as new knowledge. Explicit knowledge created and shared within the organization is consciously converted into personal tacit knowledge through actions at this stage (Nonaka et al., 2010). At the X City SWC, after the model project was officially launched as a formal project, daily operations were established as organizational routines with clearly defined roles. Through field practices, specialized insights and skills accumulated among the staff. Moreover, not only within the X City SWC but also among related organizations benefiting from the new project, the SWC became recognized, with people saying, "For payments, go to the SWC".

V. Implications and Discussion

Important implications were drawn from these results. First, Staff A appears to have functioned as a "knowledge activist" (1). This includes discovering community issues by accompanying welfare commissioners, intentionally organizing drinking parties and lunch meetings to share those insights and the mission within the Community Welfare Division, and advancing preparations for formalization by transferring the know-how of existing projects to the new project.

Second, not only Staff A but also Staff B played an important role, and appears to have functioned as a "boundary spanner" (2). Staff B, while grasping Staff A's actions as a supervisor, explained and negotiated with SWC executives and city officials, laying the groundwork for formalization. It can be said that Staff B promoted combination by linking the explicit knowledge created in the Community Welfare Division to the knowledge of the entire organization.

Third, the observed project development process can be interpreted as exhibiting the four modes of the SECI model. However, no clear movement toward a subsequent cycle was identified. A new organizational structural issue has emerged where staff are overwhelmed by the operations of the new project and cannot direct their attention to further new project development. Figure 2 summarizes the chronological knowledge creation process observed in this case, including the constraint on initiating a subsequent cycle.

VI. Conclusion and Future Directions

This paper clarified the new project development process in an SWC from the perspective of Staff A. In this case, it can be interpreted that each phase of the SECI model manifested, along with the existence of *Ba* where staff can discuss freely. Furthermore, it was suggested that Staff A, as a knowledge activist, and Staff B, as a boundary spanner, played crucial roles in realizing the SECI process.

However, examinations regarding management issues—such as developing human resources capable of taking action like Staff A and Staff B, the driving force to continuously sustain successive cycles of knowledge, and funding methods to sustain the project—have not been sufficiently conducted. Once the new project was formally established and routinized, significant administrative resources were diverted to its maintenance and operation. Consequently, it is inferred that the time and resources available for exploratory activities necessary for Staff A to function as a knowledge activist, along with the *Ba* for free dialogue, may have been reduced. Furthermore, not only Staff A but the current staff are

now overwhelmed by the execution of the project, leaving them unable to direct their attention toward discovering new community issues. Ultimately, this suggests the emergence of an organizational dilemma in which the success of one knowledge creation cycle structurally inhibits the initiation of the next. These identified challenges can be connected to discussions on the innovator's dilemma [5]and organizational ambidexterity [6], making them highly significant for considering the management of non-profit organizations.

Therefore, future research aims to more specifically understand the knowledge creation process in non-profit organizations by conducting surveys not only with Staff A but also with stakeholders such as Staff B, colleagues in the Community Welfare Division, city officials, and project users.



Fig. 2 Chronological Knowledge Creation Process in the X City SWC Case (Source: Compiled by the author)

Note

(1)A "knowledge activist" is defined as a catalyst for knowledge creation who coordinates initiatives, provides direction, and connects individuals within the organization (von Krogh, Ichijo, & Nonaka, 2000) [7].
(2)A "boundary spanner" refers to an individual who links the organization's internal network to external sources of information and resources, facilitating cross-boundary communication and negotiation (Tushman & Scanlan, 1981) [8].

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Exploring "Omotenashi" Through Sukiyaki: Toward Its Essence

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Abstract— **The relationship between "Omotenashi" and hospitality remains unclear in previous studies; some argue that the two share a common foundation, yet they are connected only by a thin thread. This study examines how sukiyaki, a representative Japanese communal dish, embodies the essence of "Omotenashi." Drawing on historical and cultural sources, "Omotenashi" is compared with hospitality to clarify its distinctive characteristics. Historical analysis shows that motenasu originally meant "to intentionally take a particular attitude toward someone," without implying the entertainment of guests or the serving of food. The senses of hosting and lavishly entertaining guests developed gradually from the Kamakura and Muromachi periods onward and were not the original concept. Previous studies indicate that chisou (feasting) and kyouou (entertaining with food) should be understood not as the essence of "Omotenashi" itself, but as means of cultivating a meaningful encounter between people. Japanese-English dictionaries also show that "Omotenashi" has four aspects—hospitality, welcome, care, and entertainment—that cannot be expressed with a single English word. Against this background, sukiyaki offers an ideal case for examining "Omotenashi." While its cooking methods and styles have changed historically, the practice of cooking and eating together has remained consistent. During the meal, diners naturally focus their attention on the nabe bugyou -the person responsible for cooking- who not only prepares the dish but also facilitates conversation and shapes the atmosphere of the gathering. Through this process, diners shift from receivers of service to active participants in a shared experience. A similar practice is observed at the restaurant Kakiya, where staff prepare sukiyaki while explaining its history and method, encouraging discussion and gradually creating a sense of unity between host and guest. The findings suggest that the significance of sukiyaki lies not merely in providing high-quality food, but in creating a memorable interpersonal experience. In line with recent discussions of "Omotenashi" as a relational practice, this study argues that chisou and kyoou function as means rather than ends. The essence of "Omotenashi," therefore, lies not in providing hospitality through food itself, but in building meaningful human relationships through discussion, shared experience, and communal dining.**

Keywords— hospitality, sukiyaki, communal dining, building relationships

I. INTRODUCTION

Previous studies offer no clear common understanding of the similarities and differences between "Omotenashi" and hospitality; the distinction remains unclear. Some state that, although the two share a common foundation, they are connected only by a thin thread. One element constituting the essence of "Omotenashi" is chisou (feasting). The expression "eating rice from the same pot" has long signified the depth of a relationship. The Nihon Shoki records that companions once "rubbed shoulders and elbows together, ate together, and shared the same food," describing how eating together brought hearts into a bond.

This study focuses on sukiyaki as a symbol of shared dining, asking which elements of "Omotenashi" it embodies. By comparing and referencing hospitality, this study reviews the related literature on the "Omotenashi" as seen in sukiyaki, and aims to approach its essence.

II. THE ORIGIN AND CHANGE OF "OMOTENASHI"

A. Motenasu and the Meaning of Hospitality

First, what is hospitality? The Super Anchor English-Japanese Dictionary defines it as "kind treatment, a warm welcome." Tracing the origin of the Japanese term "Omotenashi," however, shows that it did not originally carry this meaning of warm welcome.

According to a dictionary of classical Japanese, motenasu is a synthetic word of "mote" ("to hold") and "nasu" ("to do"): to hold something and to do something with it. In modern explanations, the "something held" is understood as (1) whatever is most fitting to the situation, or (2) sincerity. While the "something done" is (1) to please the other person, or (2) to build a good relationship. Over time "mote" lost its original sense of "holdings" and became a prefix enhancing the following verb (as moteasobu, or motehayasu). "Nasu" means "to treat in a certain way" or "to put into effect." Motenasu thus originally meant "to take a certain attitude toward someone on purpose" or "to manage a situation somehow"—it carried no sense of warm welcome.

The tenth-century tale Ochikubo Monogatari contains the phrase “sugenaku nomi motenashi” ("treated only coldly"). Motenashi thus could describe a cold reception, with no sense of food or drink. A related term, "arujimouke," means "to act as host and feast a guest." Because this "mouke" overlaps with the "making" in motenasu, it has two meanings: (1) preparation, and (2) hospitality through a meal. Motenasu is also written "kyousu," literally "to feast and welcome a person." But when referring generally to how a guest is treated, we do not use "kyousu," because motenashi is not limited to food and drink.

In modern dictionaries, Koujien (2018) defines motenashi as "connecting, grooming, conduct, attitude, feasting," and Daijirin (2019) as "the treatment of a guest, the manner of behaving toward a guest, a feast served to a guest." Even these modern definitions add no value beyond treatment—such as "thinking of the other person"—and feasting appears only at the end. This is

because these long-established dictionaries preserve the term's original weight.

The Shin Meikai Kokugo Jiten defines motenashi as "to attend to a guest wholeheartedly," or, more narrowly, "to serve tea, sweets, or a meal with sincerity." There is no sense of anticipating a guest's unspoken wishes, but it includes "wholeheartedly," and also includes serving food. On this point, Kumakura's [1] observation on ichigo ichi-e ("one time, one meeting") is sharp: each encounter between people is unique and irreplaceable, and everything—including chisou—is merely a tool for making the encounter wonderful. Chisou is thus a means of motenashi, not its end.

On the origin of the term, then, neither “Omotenashi” nor motenasu originally meant warm welcome or entertainment with food. According to Yasuda [2], the sense of entertainment with food dates from the Kamakura period, and generous treatment dates from the Muromachi period; later usages increasingly took on these senses, yet chisou and kyouou remain, finally, means rather than ends.

B. "Omotenashi" in Japanese-English and English Dictionaries

Next, this study examines "Omotenashi" in Japanese-English and English-English dictionaries, hypothesizing that both an altruistic aspect and a feasting aspect will appear. In English dictionaries, hospitality is defined as the friendly reception and entertainment of guests, visitors, or strangers by the Oxford English Dictionary. And by the Longman Dictionary, it is defined as kindness and friendly behavior toward visitors. Adding generous and thoughtful before hospitality is thought to bring it closer to "Omotenashi". Generous means forgiving and selfless (Oxford English Dictionary). And thoughtful means considerate and caring toward others (Cambridge English Dictionary). On the other hand, adding friendly to "Omotenashi" is thought to bring it closer to hospitality.

Based on Japanese-English dictionaries, four aspects of "Omotenashi" can be identified: (1) hospitality—warm heart, brother’s love ; (2) reception/welcome—greeting; (3) treatment/care—looking after; and (4) entertaining—feasting. Aspects (3) and (4) most often involve food and drink; (2) and (4) carry a strong sense of invitation; and (1), (2), and (4) carry a strong sense of acting for the other's sake. Sukiyaki includes aspects (1), (2), and (3) while directly embodying (4). These findings support the hypothesis that "Omotenashi" involves both an aspect of consideration for the other person and an aspect involving food and drink.

This is not to say hospitality lacks these aspects (2), (3), (4). Hattori [3] argues hospitality cannot be expressed by a single Japanese word, it has many aspects, such as zousa, okamai, shouban, aiso, and ikkon, in addition to "Omotenashi." "Omotenashi," too, has four aspects, and this study proceeds from that perspective.

III. SUKIYAKI

Although "Omotenashi" does not necessarily include the meaning of warm welcome or entertaining with food, it is commonly regarded as containing these elements. This study therefore particularly examines "Omotenashi" including the aspect of feasting. Sukiyaki is taken up as a concrete example of "Omotenashi." Because it is regareded as a symbol of feasting dish that directly expresses entertaining while also embodying several elements of "Omotenashi" by welcoming, attending to, and sharing a meal with fellow diners.

A. Origin

Four theories are commonly proposed for the origin of the name: (1) the dish was grilled on top of a suki, a farming tool; (2) thinly sliced meat was called sukimi, so it was called suki-yaki; (3) sukiyaki means one grills (yaku) favorite (suki) ingredients as one likes(suki); and (4) it was a festival dish written with the celebratory characters for kotobuki.

Regarding (1): a suki was a hand-held tool, and a heka a similar tool used with oxen. Farming households had oxen for cultivation, and an overworked ox became unusable within a few years. Even at a time when eating meat was officially prohibited (Emperor Tenmu issued the ban in 675, and Emperor Meiji publicly ate and encouraged meat in 1872), it is easy to imagine such animals being grilled on a suki. This theory is based on the reasoning that "it must be grilled because it is called sukiyaki." This is favored in the Kansai region. In contrast, the Kantou theory holds that sukiyaki evolved from gyuunabe (beef pot).

Regarding (2): before thin-slicing techniques developed, meat was cut into large lumps and cooked with miso—called gyuunabe in Kantou—while the dish with thinly hand-sliced meat was called sukiyaki. Kanagaki Robun's Aguranabe records a customer ordering "the finest raw beef, made into sukiyaki, for four." This suggests that thin-sliced beef was eaten with wasabi and soy sauce.

Regarding (3): this is the most widely accepted theory. Although sukiyaki has no fixed ingredients, a 1986 survey by the Department of Food and Nutrition at Sonoda Gakuen Women's University [4] found that beef and negi (Welsh onion) were used in every case in spite of other ingredients chosen. Variants without beef are called torisuki (chicken) or sakanasuki (fish) because sukiyaki otherwise suggests beef. Negi was favored for masking odors before refrigerator existed, and it was essentially the only suitable vegetable available when sukiyaki was first grilled on a suki (negi dates from the Nara period, while onion and Chinese cabbage spread only from the Meiji period).

Regarding (4): sukiyaki was originally an everyday dish in both Kantou and Kansai. As cattle breeders improved their stock and competed to produce finely marbled beef, the dish gradually became upscale. At the 1935 National Livestock Exhibition, a Matsusaka cow

named Michi won the top prize of 180 yen; at the 2002 Matsusaka Beef Cattle Show, a cow named Yoshitoyo won the excellence award and sold for 50 million yen. In this way, Matsusaka beef became the foremost of Japan's three great wagyu brands, and sukiyaki in particular turned it into a tourism resource in Mie Prefecture, drawing travelers who come specifically to eat it.

Gathering around a shared pot, seasoning within the pot itself, and the sense of luxury conveyed by sugar's sweetness also turned sukiyaki into a special-occasion dish. Kawarazaki et al. [4] note that sukiyaki, even amid today's trend toward instant convenience, gives no impression of lazy cooking for one's family, even though preparation mainly involves cutting ingredients—a feast for a celebratory day.

B. Historical Development

The 1923 Great Kantou Earthquake caused major destruction to about 500 gyuuya and gyuunabe restaurants in Tokyo. After that, sukiyaki entered from Kansai and united with local practice, producing the prototype of the Kantou style (simmered in a sweet-and-salty warishita sauce). The Kansai style (grilled with sugar and soy sauce) has changed little in method, though seasonings, vegetables, and the order of adding them have each been refined.

The two styles were born independently and developed while influencing one another. Early versions used only negi and miso to mask odors. Over time, additional vegetables, mushrooms, tofu, and shirataki noodles were added, improving nutritional balance, and seasoning shifted from miso to soy sauce. Gradual improvement continued until sukiyaki reached essentially its present form by the 1960s.

C. The "Omotenashi" Perspective

Mukasa [5] observes that "the nabe bugyou (the person in charge of the pot) encourages the meal; enjoyment increases with the tea-ceremony-like awareness of ichiza konryuu, building a single gathering together." And further notes, "There is a clear, elegant boundary between the one who cooks and the one who eats, and yet the two become one."

In other one-pot dishes such as shabu-shabu or mizutaki, seasoning is not done within the pot itself. A nabe bugyou may be present, but their role is limited to judging the best timing to eat. The nabe bugyou has an important role (sometimes called sarashi): one person cooks and serves in front of the group. In restaurants this is generally a staff member. In sukiyaki, every movement of adding beef and seasoning draws everyone's attention, uniting all present. The nabe bugyou thus acts not only as cook but also as an entertainer who gets the gathering excited and leads it toward unity—, this study argues, this is the reason why sukiyaki embodies "Omotenashi."

IV. SUKIYAKI AT KAKIYA

As a practice showing how sukiyaki embodies the constituent elements of "Omotenashi," particularly its aspect of feasting, this study introduces the practice of Kakiya. Kakiya is a wagyu restaurant in Yokkaichi City, Mie Prefecture, where the author serves as the okami(the madam of a Japanese restaurant). Kakiya does not simply serve sukiyaki. Its staff take on the role of nabe bugyou using a distinctive method, explain the dish's history and cooking style, and shape the dining experience through discussion with guests. Because this entire sequence—cooking, serving, and conversation—is practiced as "Omotenashi," the restaurant is a suitable subject for this analysis.

Kakiya's leading dish is sukiyaki. The restaurant is particular about its cooking method, grilling everything in five distinct stages(each using a different vegetable under the beef rather than simply repeating the same ingredients).

In the first stage, only negi is used, with beef spread on top and grilled using as little warishita as possible; the second uses onion, the third shiitake mushroom together with grilled tofu, and the fourth mitsuba—always a single vegetable at a time. In the fifth and final stage, beef alone is quickly cooked shabu-shabu-style in a lot of warishita. To finish, the warishita, now infused with the flavor of beef and vegetables, is fully absorbed into shirataki noodles. And they are grilled to the end like yakisoba, maintaining the emphasis on grilling throughout.

Each vegetable has its own ideal moment of cooking to eat, judged individually. After each stage the flame is turned off and the pot emptied completely before the next stage begins.

Because of this distinctive method, the role of nabe bugyou is always taken on by restaurant staff. Nabebugyou talks about the history of sukiyaki and its cooking style, while cooking, drawing guests into conversation, and gradually building a state that host and guest become one.

V. CONCLUSION

This study has examined the essence of "Omotenashi" through comparison with hospitality and a case study of sukiyaki. “Omotenashi has four aspects , ①hospitality, ②recception/welcome,③treatment/care, and④entertain. The findings suggest that "Omotenashi" can be understood not only as a spirit of consideration for others, but as a practice in which provider and recipient build a relationship and form a sense of unity through food and drink.

What matters most in practice is exactly judging whether a guest wishes to converse with staff—offering humor while carefully watching for reactions to build a sense of correct distance. Even a person who avoids conversing with strangers may find comfort in discussion with someone who feels familiar. Takano [6] describes

this as feeling "like visiting the home of an old friend"; the key lies in how such a relationship is built. When discussion leads to shared understanding and empathy, there is neither imposition nor unwelcome interference. Parry's [7] argument that "good will alone is not enough" points not to a one-directional act from provider to receiver, but to both "creating and enjoying the occasion together." Mayeroff [8] also states that caring "is not something external to either the one who cares or the one who is cared for," and that the two become "one with the other."

As Nagaishi [9] states, a basic expectation of good flavor is fundamental for any food, yet a mere sense of "deliciousness" does not necessarily produce a memorable experience. Matsuda, head of Wadakin—the originator of Matsusaka beef—also cites sukiyaki's distinguishing characteristic aspect as being "memorable" in a way kaiseki cuisine is not. Mukasa [5] similarly states, "I cannot think of another dish that reaches the heart as sukiyaki does," adding that when people gather around sukiyaki, they simply feel the happiness of being alive. Sukiyaki is thus characterized not merely by the dish itself, but by the experience shared on the occasion, which is what remains in memory. Although sukiyaki may appear to embody "Omotenashi" through luxury, its essence lies in relationship-building. Quantitative extravagance is not the essence. Even with a lower grade of beef, an enjoyable space and time remain, and if additional extravagance is layered on top, it becomes a dish representative of Japan. It is because a relationship is built that the experience becomes memorable. Accordingly, Kumakura's [1] observation makes clear that chisou and kyouou in "Omotenashi" are tools—that is, means—for building relationships, and that relationship-building itself is the essence of "Omotenashi."

Honge [10] states that once a sense of unity is achieved, "the price no longer matters so much." This indicates a relationship over monetary value. Through a form of motenashi offered only in that particular place, the aim becomes connecting with the guest as far removed from money as possible. "Omotenashi," in other words, is not simply the provision of "things" such as food or service, but the creation of a shared experience, and further, a shared story, between provider and receiver.

It should be noted that this study is based on a single case, Kakiya, and comparative verification with other sukiyaki restaurants remains a task for future research.

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Numerical simulation of the heat transfer characteristics of serpentine heat exchangers for localized temperature control in greenhouse cultivation

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Abstract— **The objective of this research is to develop technologies for efficiently controlling the thermal environment around crops in greenhouse cultivation, with the aim of improving agricultural productivity and increasing farmers' income. In greenhouse cultivation, temperature control is crucial for consistently producing high-quality crops. However, conventional air conditioning systems have the drawback of high energy consumption because they heat and cool the entire facility. Therefore, a localized temperature control technology that heats and cools only the area surrounding the crops is proposed. Prior to the experiment, the heat transfer characteristics of serpentine heat exchangers installed near the crops for local air temperature control are evaluated by numerical simulation. In this study, two-dimensional unsteady analysis was used to predict the temperature distribution between serpentine heat exchangers under cooling and heating conditions. In addition, the transition time required to reach a steady state was evaluated for both the cooling and heating conditions.**

As a result, it was confirmed that the surface temperature of the heat exchangers govern the temperature variation in the entire computational domain. It was also shown that natural convection, arising from the temperature difference between the heat exchanger surface and the ambient air, affects the time required to reach a steady state.

Keywords— numerical simulation, greenhouse cultivation, heat exchanger, air heat transfer, energy saving

I. Introduction

In recent years, there has been a demand for the stable production of high-quality and high-value crops. Greenhouse cultivation is popular method for the stable production of high-quality crops, as it allows for the appropriate control of the growing environment. On the other hand, in greenhouse cultivation, energy consumption by air-conditioning systems is substantial, and results in rising cultivation costs [1]. In particular, it is necessary to heat during the day and cool at night for crops such as strawberries and cucumbers. Consequently, it results in increased energy consumption for air conditioning.

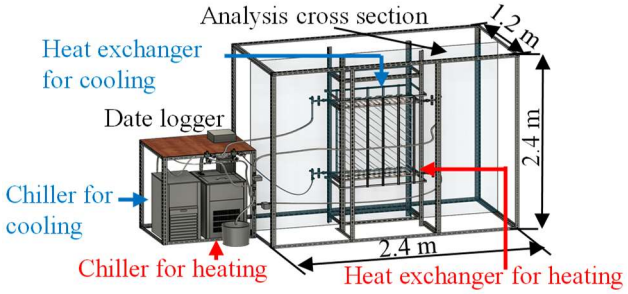
To address these challenges, localized temperature control technology targeting only near the crops is attracting attention. Localized temperature control heats and cools only the necessary areas, rather than the entire greenhouse. Therefore, significant reductions in energy consumption are expected compared to conventional air conditioning systems [2]. Wai et al. have experimentally evaluated the temperature distribution and heat transfer characteristics around a heat exchanger of local temperature control [3]. However, the characteristics associated with cyclically varying the temperature by combining cooling and heating have not yet been fully investigated. To design an efficient air conditioning system, it is important to understand the heat transfer characteristics between the heat exchangers.

This study aims to develop a local temperature control technology using heating and cooling serpentine heat exchangers. As the first step, the temperature distributions around the cooling and heating heat exchangers were predicted through numerical simulation. Two-dimensional unsteady-state analysis was conducted to evaluate the transient temperature distribution and the transition time required to reach the steady-state. The results of this study contribute to the design of cultivation environments that enable appropriate temperature field and energy saving for crop cultivation.

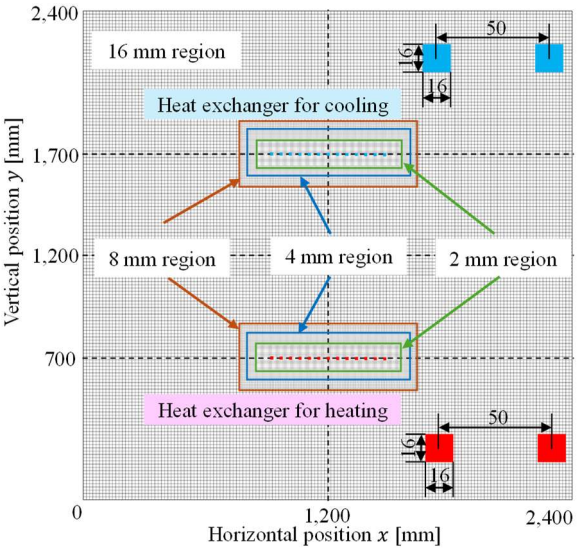
II. Experimental

A. Numerical simulation model

In this study, a two-dimensional unsteady-state model was developed to predict the heat transfer field as a preliminary step. Figure 1 shows the numerical simulation model used in this study. Figure 1(a) shows an overview of the cultivation area used for the analysis, and Figure 1(b) shows the computational domain. The cooling heat exchanger was positioned at y = 1,700 mm, and the heating heat exchanger at y = 700 mm. For each heat exchanger, 13 copper tubes were arranged at 50 mm intervals within the range of x = 800 to 1,600 mm. The heat exchanger was treated as a 16 mm square. A non-uniform mesh was used, with a spacing of 2 mm near the heat exchanger and a stepwise increase to 16 mm away from the heat exchanger.



(a) Overview of the cultivation area



(b) Computational domain

Fig. 1 Numerical simulation model.

Table 1 shows the simulation conditions. Tables 1(a), (b), and (c) show the heat exchanger specifications, air properties, mesh details, and parameters, respectively. Copper was used as the material for the heat exchanger.

Table 1 Simulation conditions.

(a) Heat exchanger specifications, air properties [4] [5]

	Value	Remarks
Computational domain	2,400 mm × 2,400 mm	
Heat exchanger geometry	16 mm × 16 mm	Square model
Number of square pipes	13 pieces	50 mm interval
Air density ρ_{air}	1.2 kg/m^3	20 °C
Specific heat at constant pressure c_p	1,005 J/(kg·K)	Air
Thermal conductivity k_{air}	0.026 W/(m·K)	Air
Kinematic viscosity ν	1.51×10^{-5} m^2/s	Air
Volumetric expansion coefficient β	3.41×10^{-3} 1/K	
Thermal conductivity k_{cu}	398 W/(m·K)	Copper

(b) Mesh details

Area	Mesh size	Remarks
Near the heat exchanger	2 mm	x = 848 ~ 1,552 mm y = 640 ~ 760 mm y = 1,640 ~ 1,760 mm
Surrounding area	4 mm	x = 800 ~ 1,600 mm y = 592 ~ 816 mm y = 1,584 ~ 1,824 mm
Intermediate area	8 mm	x = 768 ~ 1,632 mm y = 544 ~ 864 mm y = 1,536 ~ 1,856 mm
Outer area	16 mm	

(c) Simulation parameters

	Cooling conditions	Heating conditions
Active heat exchanger position	y = 1,700 mm	y = 700 mm
Inactive heat exchanger position	y = 700 mm	y = 1,700 mm
Heat exchanger surface temperature $T_{cu,ac}$	0, 5, 10, 15 °C	30, 40, 50, 60 °C
Time step Δt	0.002 s	0.002 s

B. Governing equation

In this study, air was treated as an incompressible fluid, and the Boussinesq approximation was applied for buoyancy force. The governing equations were the energy equation, the two-dimensional equation of momentum with natural convection, and the continuity equation. The equations used are shown in equations (1) – (4), respectively.

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + S_T \quad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho_{air}}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \quad (2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho_{air}}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + g\beta\left(T - T_{ref}\right) \quad (3)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (4)$$

where, T is air temperature [°C]; t is time [s]; u and v are velocities in the x and y directions, respectively [m/s]; S_T is the flux balance in each computational cell [K/s]; ρ_{air} is air density [kg/m^3]; c_p is the specific heat of air at constant pressure [J/(kg·K)]; k is the thermal conductivity of air [W/(m·K)]; p is pressure [Pa]; ν is the kinematic viscosity of air [m^2/s]; g is gravitational acceleration [m/s^2]; β is the volumetric expansion coefficient of air [1/K]; and T_{ref} is the reference temperature [°C].

C. Boundary conditions

Table 2 shows the boundary conditions used in the simulation and the equations applied to each boundary.

Table 2 Boundary conditions.

Boundary	Temperature conditions	Speed/pressure conditions
Top/Side	T = 20 ℃ Isothermal wall	$u = v = 0$ $\frac{\partial p}{\partial n} = 0$
Bottom surface	$\frac{\partial T}{\partial n} = 0$ Adiabatic condition	$u = v = 0$ $\frac{\partial p}{\partial n} = 0$
Active heat exchanger	$T_{cu,ac} = T_{target}$ Isothermal wall	$u = v = 0$ $\frac{\partial p}{\partial n} = 0$
Inactive heat exchanger	$\frac{\partial T}{\partial n} = 0$ Adiabatic condition	$u = v = 0$ $\frac{\partial p}{\partial n} = 0$

D. Data Analysis

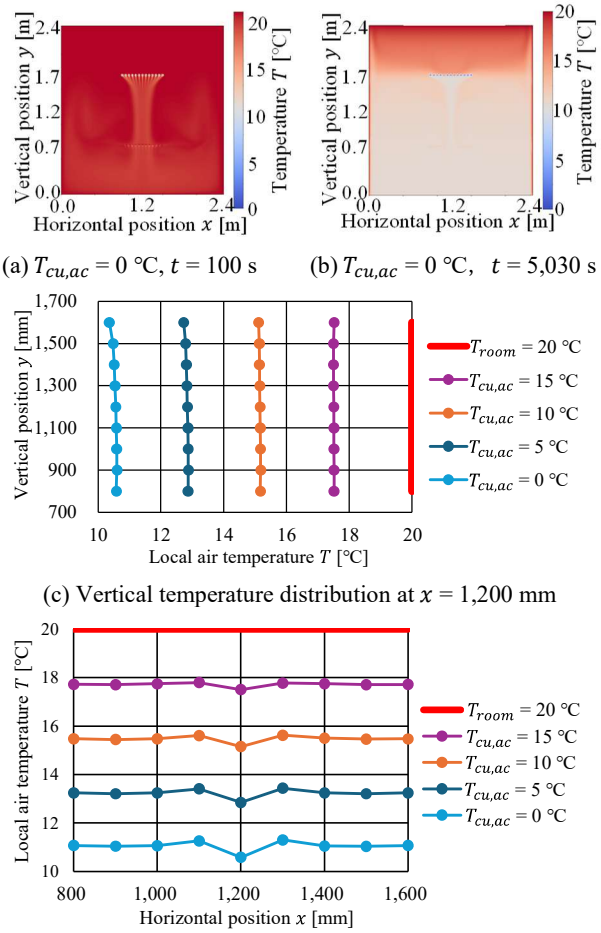
In this study, the finite volume method was used as the analysis method. The forward Euler method was used for the time term, the upwind scheme for the advection term, and the central difference method for the diffusion term. Table 3 shows the detailed conditions for the numerical analysis.

Table 3 Details of numerical analysis.

	Details
Analysis method	Finite volume method
Time term	Forward Euler method
Advection term	Upwind difference method
Diffusion term	Central difference method
Steady-state criterion	Less than 0.05 ℃ over 10 minutes

III. Results and Discussion

The air temperature distribution in the vicinity of the heat exchanger will be analyzed. Figure 2 shows the temperature distribution at various cooling conditions under steady state. Figures 2 (a) and (b) show color maps at $T_{cu,ac}$ = 0 ℃ and t = 100 s, $T_{cu,ac}$ = 0 ℃ and t = 5,030 s, respectively. Figure 2 (c) shows the vertical temperature distribution of the heat exchangers at x = 1,200 mm, while Figure 2 (d) shows the horizontal temperature distribution at y = 1,200 mm. Regarding the vertical temperature distribution, no significant temperature differences were observed; the temperature distribution was uniform at all measurement points. This is because the cooled air flowed downward, and the vertical temperature difference was mitigated because of mixing with the surrounding air. Regarding the horizontal temperature distribution, a slight drop in temperature was observed near the center. This is due to natural convection around the heat exchanger; air was replenished from both the left and right sides. As a result, a local temperature change occurred in the vicinity of x = 1,200 mm.



(a) $T_{cu,ac}$ = 0 ℃, t = 100 s (b) $T_{cu,ac}$ = 0 ℃, t = 5,030 s

(c) Vertical temperature distribution at x = 1,200 mm

(d) Horizontal temperature distribution at y = 1,200 mm

Fig. 2 Temperature distribution under cooling conditions.

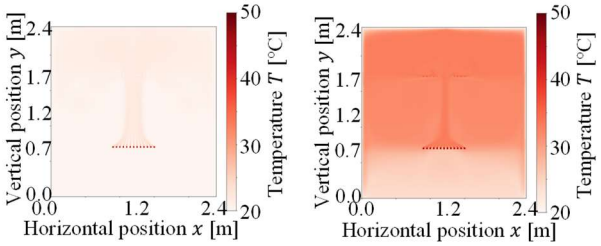
Table 4 shows the time required to reach a steady state under cooling condition. The time to reach steady state did not change monotonically with the surface temperature of the operating cooling heat exchanger; it was longest at $T_{cu,ac}$ = 5 ℃ and shortest at $T_{cu,ac}$ = 15 ℃. This means that the greater the temperature difference between the surface temperature and the ambient air temperature, the greater the buoyancy becomes. As a result, the downward flow of cooling air become strong. Therefore, at $T_{cu,ac}$ = 0 ℃, it is considered that the cooling air spread more easily within the region compared to the $T_{cu,ac}$ = 5 ℃ condition, resulting in a faster transition to the steady state.

Table 4 Time to reach steady state at each heat exchanger temperature.

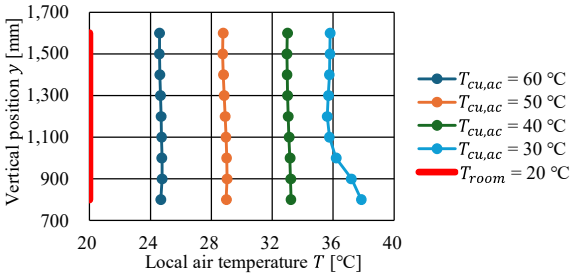
Heat exchanger surface temperature	0 ℃	5 ℃	10 ℃	15 ℃
Time to reach steady state	5,030 s	5,380 s	4,280 s	3,740 s

Figure 3 shows the temperature distribution under the steady state in the computational domain when the lower heat exchanger is heated and the upper heat exchanger is inactive. Figures 3 (a) and (b) show color maps at $T_{cu,ac}$ = 50 ℃ for t = 100 s and t = 3,910 s, respectively.

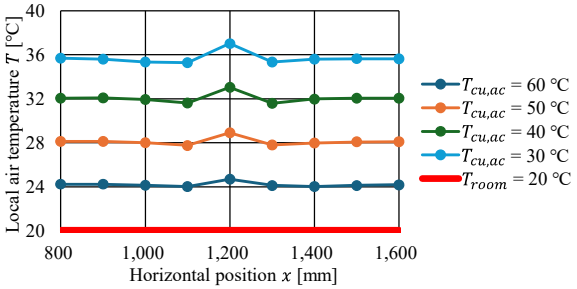
Figure 3 (c) shows the vertical temperature distribution at x = 1,200 mm, and Figure 3 (d) shows the horizontal temperature distribution at y = 1,200 mm. From the comparison of the vertical temperature distributions at $T_{cu,ac}$ = 30 ℃, 40 ℃, and 50 ℃, the temperature difference along the height was small. This results in a uniform temperature distribution at all measurement points. On the other hand, the lower measurement points near the heat exchanger at $T_{cu,ac}$ = 60 ℃, the temperature become higher compared to the temperature farther away from it. This is due to the increased temperature difference between the heat exchanger and the ambient air, which caused the localized heating near the heat exchanger. Furthermore, regarding the horizontal temperature distribution, no significant overall temperature differences were observed. However, a slight temperature increase was occurred near the center. This is due to the upward flow due to buoyancy force near the center of the heat exchanger. Therefore, the local air temperature increased in the vicinity of x = 1,200 mm.



(a) $T_{cu,ac}$ = 50 ℃, t = 100 s (b) $T_{cu,ac}$ = 50 ℃, t = 3,910 s



(c) Vertical temperature distribution at x = 1,200 mm



(d) Horizontal temperature distribution at y = 1,200 mm

Fig. 3 Temperature distribution under heating conditions.

Table 5 shows the time required to reach a steady state under heating condition. Under the various heating conditions, monotonic trend does not occur. The time was shortest at $T_{cu,ac}$ = 40 ℃ condition and longest at $T_{cu,ac}$ = 60 ℃. As the heat exchanger temperature rises the buoyancy force stronger. Thereby it intensified the upward flow of heated air. Therefore, it is considered that warm air spread more easily at $T_{cu,ac}$ = 40 ℃ than at $T_{cu,ac}$ = 30 ℃. It results in a faster transition to reach the steady state.

Table 5 Time to reach steady state at each heat exchanger temperature.

Heat exchanger surface temperature	30 ℃	40 ℃	50 ℃	60 ℃
Time to reach steady state	3,960 s	3,390 s	3,910 s	4,380 s

IV. Conclusions

This study evaluated the temperature field between serpentine heat exchangers using two-dimensional unsteady numerical analysis. The vertical and horizontal temperature differences between the heat exchangers were small, which is 0.2 ℃ or less. However, in the horizontal direction, local temperature changes were observed near the center, where downward or upward flow was driven by the buoyancy force. Furthermore, the time required to reach a steady state did not change monotonically with the heat exchanger temperature. This is due to the buoyancy force resulting from temperature differences and the manner in which cold and warm air spread due to natural convection.

Acknowledgment

We would like to express our deep gratitude to the Graduate School of Engineering at Mie University for their support in conducting this research.

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Evaluation of soil temperature distribution around heat exchangers installed for crop root zones thermal control

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Abstract— **The objective of this study is to develop a technology for efficiently controlling the thermal environment of the crop root zone and reducing the energy costs. As the fundamental research, numerical simulations of the local soil temperature distribution around a heat exchanger installed near the plant root zone was conducted and the soil's heat transfer characteristics was evaluated.**

The heat transfer characteristics of soil depend significantly on soil moisture content. Furthermore, the layout of the heat exchanger directly affects the temperature distribution in the soil. Therefore, to appropriately control the root-zone temperature, it is important to understand the effects of soil moisture content and heat exchanger arrangement on soil temperature distribution.

In the numerical simulation, the soil temperature distribution around the heat exchanger was calculated using the two-dimensional unsteady heat conduction equation and the finite volume method. Soil moisture content and heat exchanger arrangement were set as analysis conditions, and their effects on soil temperature distribution were analyzed.

As a result, it was shown that the heat propagates further as the soil moisture content increases. Furthermore, it was quantitatively shown that the heat transfer area subject to temperature changes from the initial state varies depending on the soil temperature distribution by the heat exchanger arrangement.

Keywords - plant cultivation, root zone, heat exchanger, numerical simulation, soil temperature distribution

I. Introduction

In the agricultural sector, there is a need to simultaneously achieve a stable food supply, higher quality, and energy-efficient cultivation. Plant factories and greenhouse cultivation have been introduced to achieve these objectives. However, due to climate change and rising energy costs, it has been reported that greenhouse climate control accounts for 70–80% of total energy consumption during cultivation [1]. Therefore, in addition to conventional air-conditioning control, localized temperature control technology targeting the plant root zone was focused. It was hypothesized that the entire plant body would be warmed or cooled by the absorption of warm or cold water. Soil temperature in the plant root zone directly affects germination, nutrient uptake, and yield. Effectively controlling soil temperature in the plant root zone to establish an optimal cultivation environment is expected to lead to significant energy savings on the air-conditioning side [2].

In recent years, several research have been conducted on localized temperature control systems that include the plant root zone. Kim H. Y. et al. have reported that a localized temperature control system, including the root zone, contributes to the greenhouse microclimate and energy savings [3]. To support localized temperature control, it is important to understand the soil temperature distribution around a heat exchanger installed in the soil. In particular, soil water content is a crucial factor in root-zone temperature control because it significantly affects soil thermal conductivity. Furthermore, the arrangement of the heat exchanger, corresponding to the root distribution of the plants, directly affects the temperature distribution in the soil.

This study aims to clarify the effects of soil moisture content and heat exchanger arrangement on the soil temperature distribution by numerical simulations based on the unsteady heat conduction equation. These research findings are expected to contribute to enhancing the root-zone temperature control and designing energy-efficient cultivation environments.

II. Numerical Method

A. Numerical simulation model

A two-dimensional unsteady heat conduction model was developed to predict the soil temperature distribution around a heat exchanger installed in the soil. Figure 1 shows the domain for the numerical simulation. The analysis domain is a two-dimensional plane with a width of 300 mm and a height of 285 mm, with the heat exchanger positioned in the center. Hot or cold water is supplied to the heat exchanger from a chiller. This paper evaluates the case of heating soil.

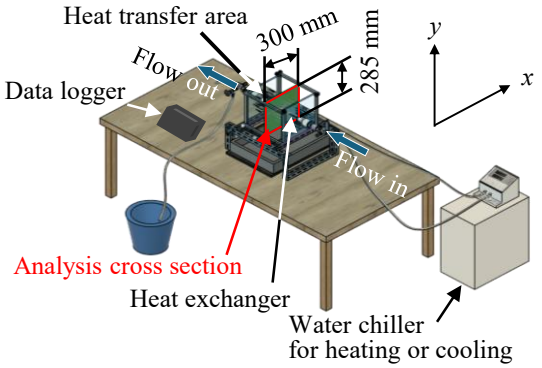


Fig. 1 Numerical simulation domain.

B. Analysis Parameters

In the numerical simulations, sand was used as the soil, and soil moisture content was varied. Regarding the heat exchanger arrangement, a single-tube configuration was addressed first, followed by the two-tube and four-tube configurations. The effects of soil moisture content and heat exchanger arrangement on soil temperature distribution were evaluated. The specifications of the heat exchanger and the classification of soil moisture content are shown in Tables 1 and 2, respectively. For the single and two-tube configurations, 1-inch pipes were used. The two and four tubes arrangements were configured so that the heat transfer surface area of the tubes remained the same.

Table 1 Heat exchanger specifications.

	Single tube	2 tubes	4 tubes
Length L	300 mm		
Inner diameter d	25 mm (1 in)		11 mm (3/8 in)
Outer diameter D	34 mm		17 mm
Total outside surface area A_o	0.032 m^2	0.064 m^2	
Material	Polyvinyl chloride (PVC)		
Thermal conductivity k_p	0.19 W/(m·K)		

Table 2 Classification of soil moisture content [4].

Soil type	Moisture content w [%]	Thermal conductivity k_s [W/(m·K)]	Density ρ_s [kg/m^3]	Specific heat c_{ps} [J/(kg·K)]
Sand	0	0.25	1,400	750
	5	0.80	1,700	800
	10	1.50	1,800	850
	15	2.20	1,900	900
	40	2.80	2,000	950

C. Governing equation

In this study, the two-dimensional unsteady heat conduction equation (1) was used to analyze the temperature distribution in the soil.

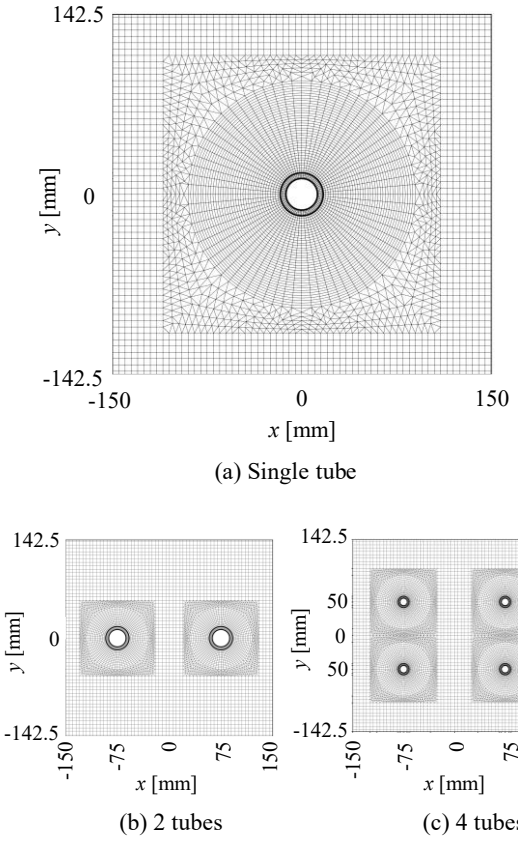
$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \tag{1}$$

where, T [°C] is temperature, t [s] is time, x [m] and y [m] are coordinates in the respective directions, and α [m²/s] is thermal diffusivity. And,

$$\alpha = k_s/(\rho_s c_{ps}). \tag{2}$$

D. Analysis grid

Single-tube, two-tube, and four-tube configurations were set up for the analysis models. The analysis grids for each condition are shown in Figure 2. To illustrate the details of the analysis grid, the case of a single tube is shown on a larger scale, but the computational domain is identical for all three cases.



(a) Single tube

(b) 2 tubes (c) 4 tubes

Fig. 2 Computational grid.

E. Boundary conditions

The boundary conditions used for the simulation are shown in Table 3.

Table 3 Boundary conditions.

Boundary	Conditions	Mathematical formula
Heat exchanger inner surface	Constant temperature boundary	$T = T_w = 50$ °C
Heat exchanger outer surface	Material interface	$-k_p \left.\frac{\partial T}{\partial n}\right\|_{os} = -k_s \left.\frac{\partial T}{\partial n}\right\|_{ss}$
Case top surface	Constant temperature boundary	$T = T_{room} = 20$ °C
Case side surfaces	Symmetry boundary	$\frac{\partial T}{\partial x} = 0$
Case bottom surface	Adiabatic boundary	$\frac{\partial T}{\partial y} = 0$

In the table, T_w [°C] is the fluid temperature flowing into the heat exchanger, T_{room} [°C] is the room temperature, $\left.\frac{\partial T}{\partial n}\right|_{os}$ [K/m] and $\left.\frac{\partial T}{\partial n}\right|_{ss}$ [K/m] are the temperature gradient in the normal direction at the outer surface of the heat exchanger and at the soil-side heat transfer interface, respectively.

F. Numerical Analysis Methods

In this study, the finite volume method (FVM) was used as the numerical analysis method. In the FVM, the time evolution of the temperature distribution is determined sequentially by discretizing the heat balance in each subdivided computational cell. This method was employed in this study because it is suitable for the analysis of two-dimensional domains and allows for the analysis of different heat exchanger configurations. Table 4 also shows the details of the numerical analysis methods.

Table 4 Numerical analysis methods.

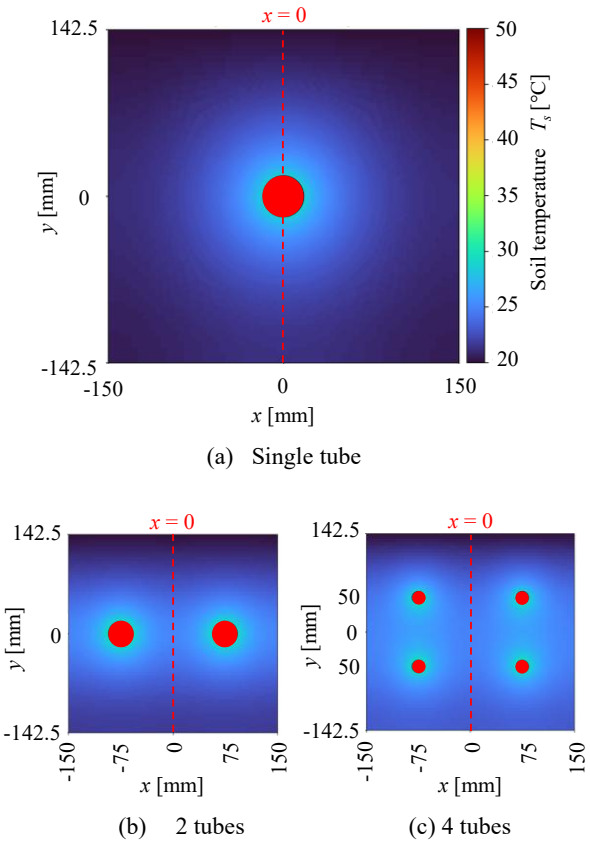
	Remarks
Dimension	Two dimensional
Discretization method	Finite volume method (FVM)
Time integration	Explicit method
Time step	Δt = 0.05 s
Analysis time	t = 0 - 3,600 s

III. Results and Discussion

First, the soil temperature distribution in the vicinity of the heat exchanger is analyzed. Soil temperature distributions resulting from differences in moisture content were compared for single-tube, double-tube, and four-tube configurations. Next, the effect of heat exchanger arrangement on heat transfer area was evaluated.

A. Effect of soil moisture content on temperature distribution

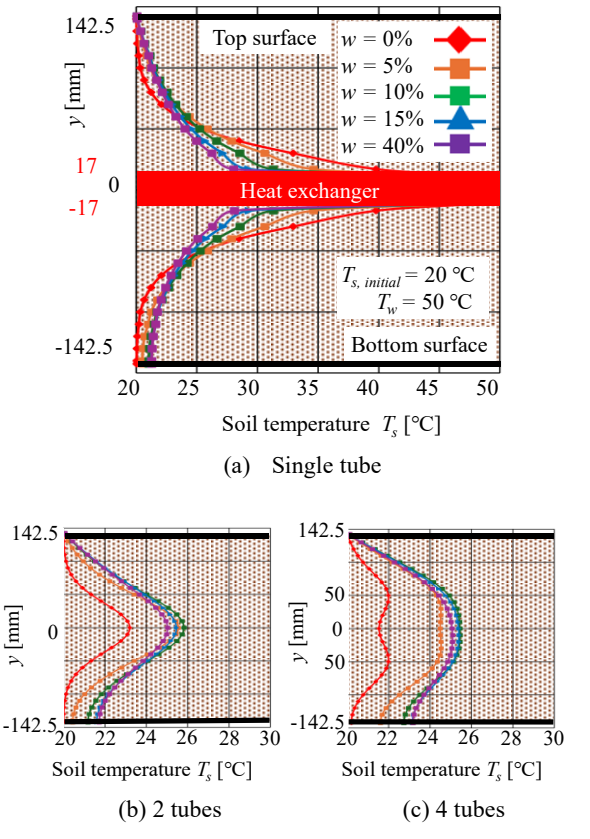
Figure 3 shows the temperature distribution around the tube at a moisture content of w = 40% as a representative condition. A temperature rise is observed around the tube. Figure 4 shows the soil temperature distribution one hour after the start of heating at different moisture contents. The temperature distribution shows the values at x = 0 in Figure 3. As soil moisture content increases, the thermal conductivity of the soil increases. As a result, the heat transfer area expands. This is because the porosities within the soil are filled with water, which has a higher thermal conductivity than air.



(a) Single tube

(b) 2 tubes (c) 4 tubes

Fig. 3 Temperature distributions (w = 40%).



(a) Single tube

(b) 2 tubes (c) 4 tubes

Fig. 4 Temperature distribution at different soil moisture contents (x = 0).

B. Effect of heat exchanger arrangement on heat transfer area

The heat transfer area of the heat exchanger was quantitatively evaluated. The condition under which the magnitude of the change in soil cell temperature T_s exceeds 5% (= 21.5 °C) of the temperature difference between the initial soil temperature $T_{S,\,\mathrm{initial}}$ (= 20 °C) and the fluid temperature T_w (= 50 °C) was defined by the following equation.

$$\frac{T_s - T_{s,\,initial}}{T_w - T_{s,\,initial}} \geq 0.05 \qquad (3)$$

The heat transfer area satisfying this condition was defined as $A_{affected}$. Based on this, the effect of heat exchanger arrangement on the heat transfer area was quantitatively evaluated. Figure 5 shows an example of calculating the heat transfer area for the single-tube. The white line indicates the boundary of the heat transfer area defined by Equation (3). Table 5 also shows the heat transfer area at each moisture content.

Comparing the results for a single-tube configuration and a two-tube configuration where the heat transfer area of the heat exchanger is doubled, the heat transfer area of the two-tube configuration is approximately twice as large. It is considered that, with the interval of two-tube arrangement used in this calculation, there is no interference between heat transfer areas resulting from the use of two tubes.

Comparing the two-tube and four-tube arrangements with identical outer heat transfer surface areas, the four-tube arrangement results in the heat transfer area being distributed around each tube, as shown in Figs. 3(b) and (c). Therefore, the heat transfer area at a moisture content of $w = 0\%$ is larger than that of the two-tube arrangement. Similar results are observed even at $w \geq 5\%$, although the difference is smaller. Furthermore, as the moisture content increased from 0% to 40%, the heat transfer area increased by approximately 2.0 times in the two-tube arrangement. On the other hand, with the four-tube configuration, it increased by approximately 1.4 times.

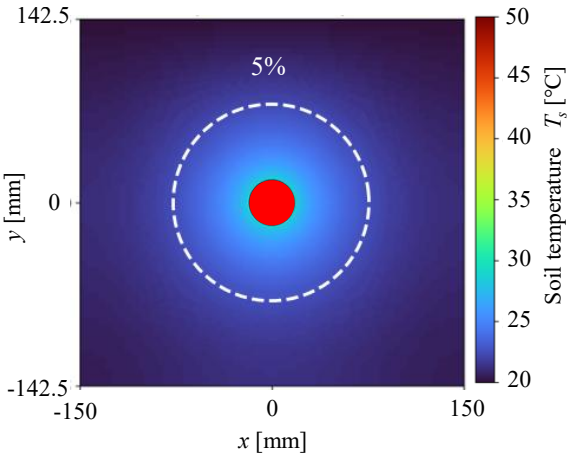


Fig. 5 Heat transfer area. (Example: single tube, w = 40%).

Table 5 Heat transfer area $A_{affected}$ [m^2].

Moisture content w [%]	Single tube	2 tubes	4 tubes
0	0.017	0.037	0.056
5	0.027	0.053	0.076
10	0.033	0.064	0.077
15	0.035	0.072	0.077
40	0.036	0.073	0.078

IV. Conclusions

In this study, the effects of soil moisture content and heat exchanger arrangement on soil temperature distribution were investigated by numerical analysis. It was quantitatively shown that an increase in soil moisture content increases the soil's thermal conductivity, allowing heat transfer area spreads wider area. It was also shown that the soil temperature distribution by the heat exchanger arrangement differs. This study provided fundamental insights for examining heat exchanger arrangements suitable for the root zone geometry of the plants.

Acknowledgment

The author would like to express their gratitude to the Graduate School of Engineering, Mie University for conducting this research.

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Influence of channel surface characteristics on compressor oil behavior and heat transfer in a CO_2 evaporator and its visualization

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Abstract— **This study evaluates the heat transfer performance of the evaporator, a key component of the refrigeration system, with the aim of improving the energy efficiency of low-temperature refrigeration units used to maintain the freshness of marine products. As part of the fundamental research, the effects of the surface roughness of the refrigerant flow path in the evaporator and the lubricating oil mixed with the refrigerant on heat transfer characteristics are evaluated.**

Heat transfer in the refrigerant flow path depends significantly on the oil film by compressor oil (lubricating oil) mixed into the refrigerant. Compressor oil adhering to the heat transfer surface acts as thermal resistance and prevents heat transfer. Furthermore, the surface roughness of the refrigerant flow path directly affects oil film formation and the flow pattern of the refrigerant. Therefore, to enhance evaporator performance, it is important to understand the effects of oil concentration and the surface characteristics of the refrigerant flow path on heat transfer properties.

In this study, experiments were conducted in which CO_2 refrigerant flowed through a horizontal channel (inner diameter: 4.5 mm, length: 300 mm) of an evaporator. Here, the oil flow behavior was visualized and heat transfer in the channel while varying the oil concentration was analyzed. As a result, the behavior of the oil film adhering to the channel walls and the oil clumps passing through the flow channel were visualized. It was also shown that the heat transfer coefficient decreases sharply when oil is mixed in. Furthermore, the influence of surface roughness on heat transfer characteristics was suggested. Understanding the behavior of the oil and its effects is expected to support in the design of refrigerant flow paths in evaporators.

Keywords— CO_2 refrigerant, heat transfer, evaporator, compressor oil, surface roughness

I. Introduction

To mitigate global warming, it is desirable to use low-environmental-impact refrigerants in refrigeration systems. This study focused on CO_2 as a refrigerant. CO_2 is a refrigerant with a global warming potential (GWP) of 1 that is tasteless, odorless, non-toxic, and non-flammable [1]. CO_2 is also used as a refrigerant in low-temperature refrigeration systems because it can provide cooling down to -40 °C at an evaporator refrigerant pressure of approximately 1 MPa-abs.

Hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs), which have been used since the 1970s, have come to be recognized as ozone-depleting refrigerants. Consequently, the Montreal Protocol was adopted in 1987, and efforts to reduce production and consumption have been pursued globally [2]. Subsequently, hydrofluorocarbons (HFCs) have been used as refrigerants. However, due to its high persistence in the atmosphere, it is a major cause of global warming [3]. For these reasons, eco-friendly natural refrigerants are attracting attention.

On the other hand, from the perspective of energy conservation, there is a demand for higher performance refrigeration unit. A refrigeration unit consists of four main components: a compressor, a condenser, an expansion valve, and an evaporator. Among these, a low-performance evaporator increases the compressor load, leading to higher energy consumption by the refrigeration system [4]. Therefore, increasing the efficiency of the evaporator is important.

Compressor oil is used for the operation of the compressor. This oil circulates through the flow paths of the refrigeration unit together with the refrigerant. A problem arises in that the heat transfer coefficient decreases significantly when this oil adheres to the walls of the refrigerant flow paths in the evaporator. Several studies have been conducted on the reduction in heat transfer coefficient associated with oil contamination during in-tube refrigerant boiling. For example, Katsuta et al. measured the heat transfer coefficient of CO_2 refrigerant mixed with compressor oil in a horizontal stainless-steel pipe [5]. As a result, it has been shown that the heat transfer coefficient decreases due to the inclusion of a very small amount of compressor oil (0.05–0.08 wt%). In addition, J. Keeni et al. evaluated the effect of oil concentration on evaporator heat transfer and visualized oil behavior [6, 7].

Therefore, this study aims to obtain fundamental knowledge for enhancing heat transfer in the evaporators of CO_2 refrigeration systems. The effects of flow-path surface roughness on the flow behavior of compressor oil and the heat transfer characteristics of the evaporator were evaluated. The results of this study are expected to clarify the effects of oil contamination, thereby contributing to the design of highly efficient evaporator flow paths and the energy conservation of refrigeration systems.

II. Experimental

A. Experimental setup

Figure 1 shows a schematic diagram of the test section used in this experiment. The test section consists of a horizontal flow implementing actual refrigerant flow, with an inner channel diameter of 4.5 mm and a flow path length of 300 mm. The flow path is divided into ten sections along the direction of heat flow to prevent axial heat conduction. A cartridge heater is installed on the back of the flow channel to maintain a constant flow channel wall temperature.

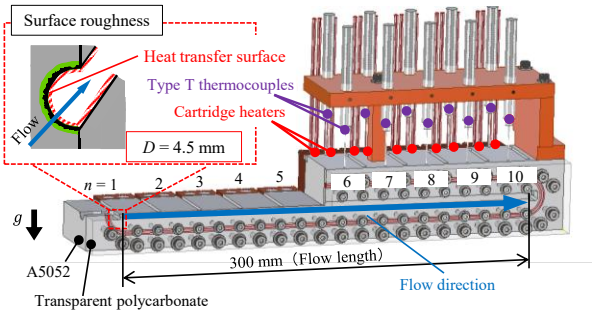
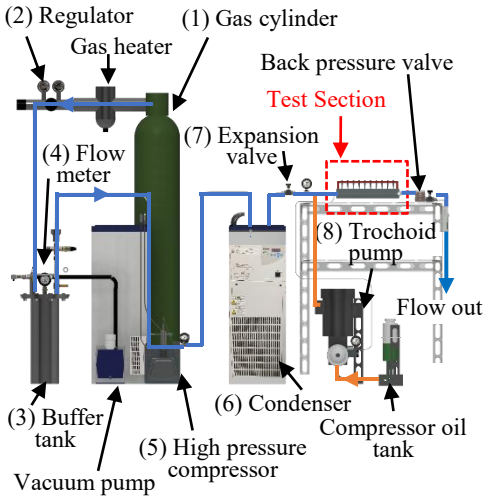
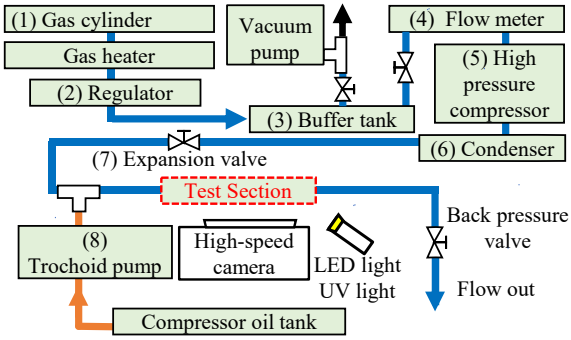


Fig. 1 Overview of the test section.

Figure 2 shows an overview of the experimental setup. Figure 2(a) shows an external view of the experimental apparatus, and Figure 2(b) shows a schematic diagram of the apparatus. This is a blow-down type system. The experimental setup consists of (1) a CO_2 gas cylinder, (2) a pressure-reducing valve (regulator), (3) a buffer tank, (4) a flow meter, (5) a high-pressure compressor, (6) a condenser, (7) an expansion valve, and (8) a trochoid pump.



(a) Overview of the experimental apparatus



(b) Schematic diagram of experimental apparatus

Fig. 2 Experimental setup.

B. Experimental methods

In this experiment, CO_2 refrigerant at approximately -35 °C is introduced into the test section. Figure 3 shows the *p-h* diagram (pressure-enthalpy diagram) for the CO_2 refrigerant. The liquid refrigerant condensed by the condenser is cooled to 1.2 MPa-abs (evaporation temperature of approximately -35 °C) by the expansion valve. After that, the refrigerant flows into the evaporator. Inside the evaporator, the pressure and temperature of the refrigerant remain constant. The refrigerant vaporized within the evaporator is discharged.

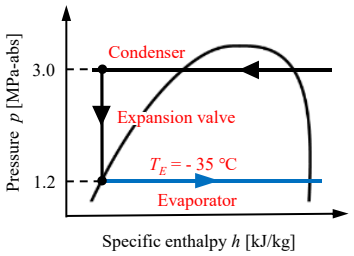
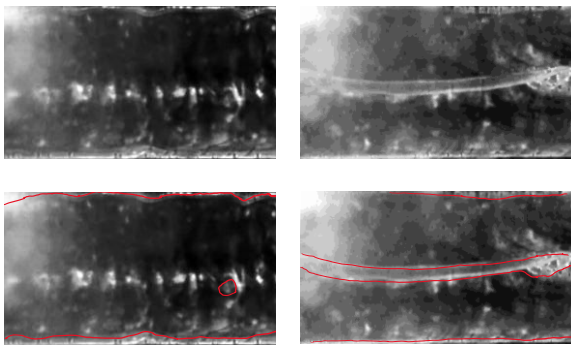


Fig. 3 *p-h* diagram for CO_2 refrigerant.

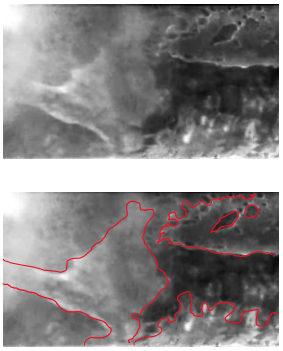
III. Results and Discussion

A. Visualization of refrigerant flow

Figure 4 shows an example of a visualized image of CO_2 refrigerant mixed with compressor oil flowing through an evaporator tube. The channel wall surface is rough. As shown in Figures 4(a) through (c), it was observed that the oil flowed as particles, a band-like pattern, and clumps. The upper figures show the screenshot of the oil film formation captured from the video. The lower figures present the highlight of the oil film formation as particles, a band-like pattern, and clumps. It was observed that the oil flowed changing its shape because the oil viscosity increased due to the low evaporation temperature. In addition, it was confirmed that an oil film was formed on the wall surface.



(a) Particulate (b) Band-shaped



(c) Clumped state

Fig. 4 Visualization of an oil-containing refrigerant flow (Mass flux G = 119.7 kg/(m^2・s), Evaporation temperature T_E = -34.8 °C, Oil concentration b = 10.1 wt%, Wall temp. T_{nW} = -0.3 °C, Section n = 9, Quality x = 0.93).

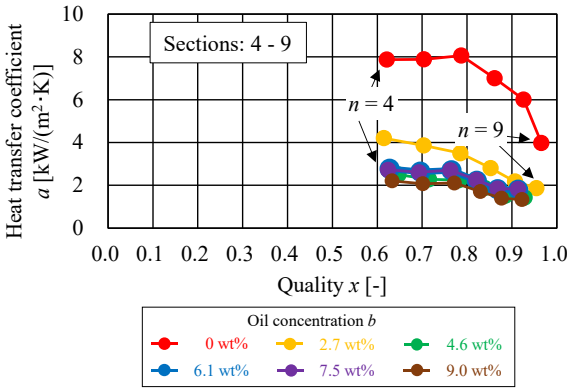
B. Heat transfer coefficient

Figure 5 shows the effect of oil concentration on the heat transfer of the evaporator. It was found that the heat transfer coefficient drops sharply when even a small amount of oil is mixed in. It is considered that the oil shown in Fig. 4 adheres to the wall surface as an oil film, acting as a thermal resistance. Furthermore, the heat transfer coefficient decreases as the oil concentration increases. This is because, as the oil concentration increases, the oil film thickness increases and the thermal resistance rises. It is presumed that the surface roughness of the flow path contributes to the formation of this oil film.

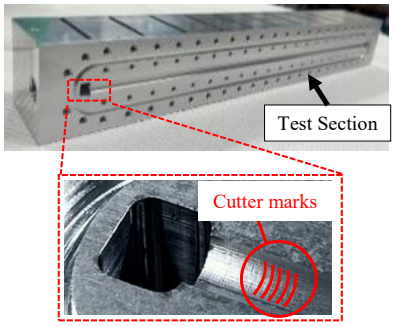
Figure 5(b) shows the surface characteristics of the flow channel. Since the test flow channel was made using a milling machine, cutter marks from the end mill remain. It is thought that oil stagnates there, forming a thicker oil film compared to a smooth surface. Therefore, it is important to understand the surface roughness of the flow path and the state of oil film formation.

C. Method for evaluating the effect of surface roughness on heat transfer

A method is proposed to evaluate the effect of flow-path surface roughness on flow and heat transfer. Figure 6 shows the surface roughness measurement method using a surface tester. A stylus-type surface roughness tester is used to measure the semicircular cross-section. The measurement position is the center of the semicircular cross-section, and the evaluation length is the total flow path length of 300 mm. The measuring jig is fixed to the test section, and the surface tester is moved to several locations along the flow direction to perform measurements. Since the measurement range at a single location is a few millimeters, the surface roughness Ra is determined by calculating the arithmetic mean of the results obtained from measurements at several locations.



(a) Heat transfer coefficient



(b) Surface roughness

Fig. 5 Effect of oil concentration on evaporator heat transfer coefficient (Mass flus G= 108.1-120.7 kg/(m^2・s), Evaporation temperature T_E = -32.9 ～ -37.9 °C, Oil concentration b = 0 ～ 9.0 wt%, Wall temp. T_{nW} = -4.0 ～ -24.7 °C).

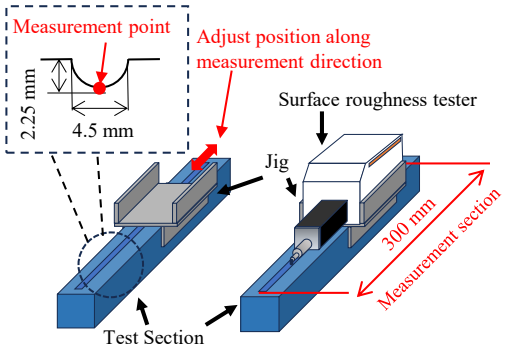


Fig. 6 Surface roughness measurement method.

D. *Expected Results*

Table 1 shows the experimental conditions for comparing the results. The experimental conditions are the same as those used to obtain the results shown in Figure 5. Regarding the surface roughness, the current surface processed with a milling machine (Rough) and the polished surface (Smooth) was compared.

Table 1 Experimental conditions.

Evaporation temperature T_E	-35 ℃
Mass flux G	120 kg/(m^2·s)
Compressor oil concentration b	0, 5, 10 wt%
Surface roughness Ra	Smooth, Rough (Before polishing)

Figure 7 shows the predicted relationship between refrigerant quality and heat transfer coefficient for different surface roughness. As the surface roughness of the flow path becomes smoother, the oil film thins and thermal resistance decreases, leading to a predicted increase in the heat transfer coefficient. However, at an oil concentration of $b = 0$ wt%, although changes in the velocity boundary layer due to surface roughness occur, no significant increase in the heat transfer coefficient is predicted.

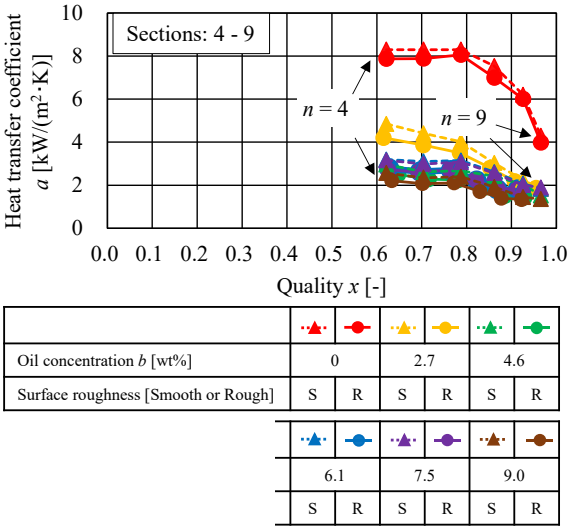


Fig. 7 Prediction of refrigerant quality and heat transfer coefficient at different surface roughness.

IV. Conclusions

This study investigated the relationship between lubricating oil, a factor inhibiting heat transfer in CO_2 refrigeration system evaporators, and tube wall roughness. First, the flow state was visualized by introducing lubricating oil to refrigerant. Furthermore, it was shown that the heat transfer coefficient decreases sharply due to the thermal resistance of lubricating oil. The influence of oil film thickness due to surface roughness was suggested as one of the factors contributing to the reduction in the heat transfer coefficient. Furthermore, a method for measuring the surface roughness of heat transfer tubes was presented, along with predictions of heat transfer based on the resulting effects. The results of this study are expected to contribute to the optimal design of high-efficiency evaporators that prevent oil retention. Furthermore, increasing the efficiency of the refrigeration unit contributes to reducing the refrigerant circulation flow rate in units and to saving the energy consumption of the refrigeration system.

Acknowledgment

We would like to express their gratitude to the Graduate School of Engineering, Mie University for conducting this research.

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Experimental investigation on heat transfer characteristics and flow visualization of CO_2 refrigerant in microchannels

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Abstract— **The objective of this study is to visualize the flow behavior and investigate the heat transfer characteristics of a CO_2 refrigerant mixed with compressor oil as it flows through microchannels. In this paper, as the first stage of the research objective, CO_2 refrigerant was flowed through a microchannel to evaluate the heat transfer coefficient during the evaporation process.**

It is generally known that reducing the size of the groove inner tube surface of an evaporator increases the heat transfer area and improves the heat transfer coefficient per unit of projected area. Here, groove is called as microchannel. However, in actual refrigeration systems, the oil mixes with the refrigerant and circulates through the equipment. Consequently, the oil acts as a thermal resistance and prevents heat transfer. Therefore, it is important to clarify the heat transfer characteristics of the refrigerant with oil.

This study evaluates the heat transfer characteristics and visualization of CO_2 refrigerant flowing through the microchannels of an evaporator, prior to assessing the effects of oil contamination.

Keywords— CO_2 refrigerant, microchannel, compressor oil, heat transfer, flow visualization

I. Introduction

In recent years, power consumption in the refrigeration sector has been increasing due to the increasing number of the cold chain [1]. There is a demand for reducing CO_2 emissions associated with rising electricity consumption. Hence, higher-performance refrigeration units are necessary. Refrigerants are used as heat transport media in refrigeration equipment. Natural refrigerants with low global warming potential (GWP) are attracting attention from the perspective of preventing global warming and ozone layer depletion [2]. Among them, CO_2 is non-toxic and non-flammable. Furthermore, since it can be cooled to approximately -40°C at an absolute pressure of around 1 MPa, it is suitable as a refrigerant for freezing systems.

A refrigeration unit consists of four main components that are a compressor, a condenser, an expansion valve, and an evaporator. This study focused on improving the heat transfer performance of the evaporator. One specific method is to introduce the small grooves on the inner tube surface of the heat exchanger. Reducing the groove dimension increases the inner tube surface area. As a result, it is considered that the heat transfer coefficient per unit of projected area increases. However, in actual refrigeration systems, oil mixes with the refrigerant and circulates through the equipment.

When oil mixes with the refrigerant, an oil film forms on the walls of the flow path. As a result, it has been reported that the heat transfer coefficient decreases. Caobin Dang et al. investigated the flow boiling heat transfer of CO_2 mixed with lubricating oil in horizontal smooth tubes with inner diameters of 2, 4, and 6 mm [3]. When the lubricating oil concentration was varied between 0.5% and 5%, the heat transfer coefficient dropped to less than half the value observed without oil contamination. While research has been conducted on the heat transfer characteristics of CO_2 refrigerant mixed with oil, there have been few studies utilizing microchannels with a hydraulic diameter of 1 mm or less.

This study aimed to investigate the heat transfer characteristics and visualize the flow patterns of a CO_2 refrigerant mixed with compressor oil as it flows through microchannels. Prior to evaluating the effects of oil contamination, heat transfer characteristics of CO_2 refrigerant only flowing through the microchannels of an evaporator will be evaluated.

II. Experimental

A. Experimental setup

Figure 1 shows overview of the test section used in this study. The flow direction of the CO_2 refrigerant is vertically upward. The flow path consists of rectangular grooves, each with a total length of 300 mm, a width of 0.8 mm, and a height of 0.8 mm, comprising eight microchannels. The flow channel is divided into 15 sections and is thermally insulated in the flow direction. In addition, to achieve isothermal wall conditions, the cartridge heaters were placed behind the flow channel.

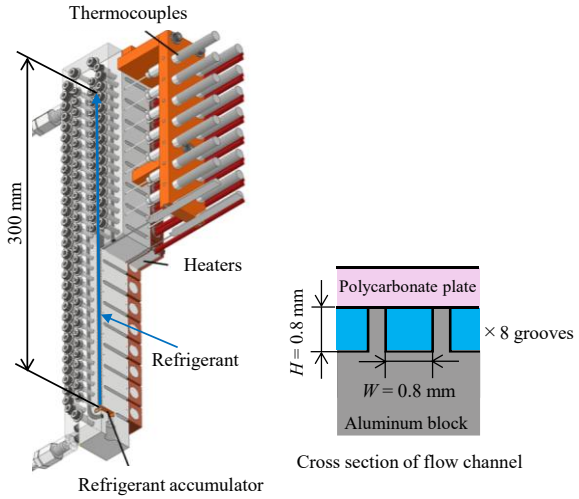
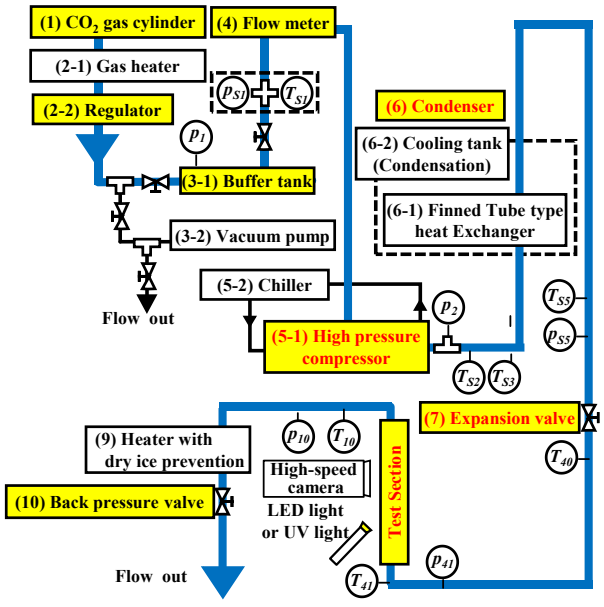
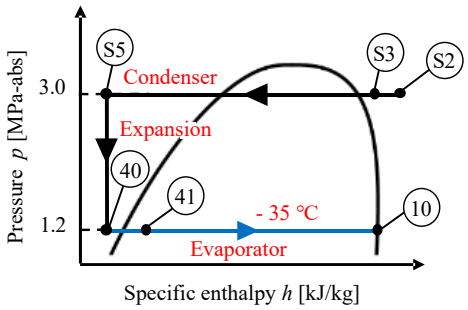


Fig. 1 Overview of test section.

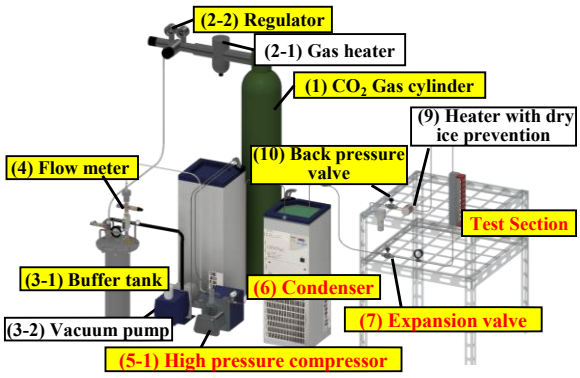
Figure 2 shows an overview of the experimental apparatus. This apparatus employs a blow-down method. Figure 2(a) shows the layout of the experimental apparatus. The apparatus consists of (1) a CO_2 gas cylinder, (2-2) a regulator, (3-1) a buffer tank, (4) a flow meter, (5-1) a high-pressure compressor, (6) a condenser, (7) an expansion valve, and (10) a back-pressure valve. In this experiment, the CO_2 refrigerant is depressurized by an expansion valve and cooled to 1.2 MPa-abs (approximately -35 °C) through adiabatic expansion valve. Figure 2(b) shows the *p-h* diagram for the CO_2 refrigerant corresponding to Figure 2(a). Figure 2(c) shows an overall view of the experimental apparatus.



(a) Overview of the experimental apparatus



(b) *p-h* diagram for CO_2 refrigerant



(c) Schematic diagram of the experimental system

Fig. 2 Experimental apparatus and *p-h* diagram.

B. Visualization method

This study also focuses on the visualization of the flow state of CO_2 refrigerant. Figure 3 shows the test section and the position of the visualization camera. The test section is divided into 15 sections along the flow direction to prevent heat conduction. The behavior of the CO_2 refrigerant and oil is observed using a high-speed camera. A video was recorded with the visualization range centered on each interval (n = 1 to 15).

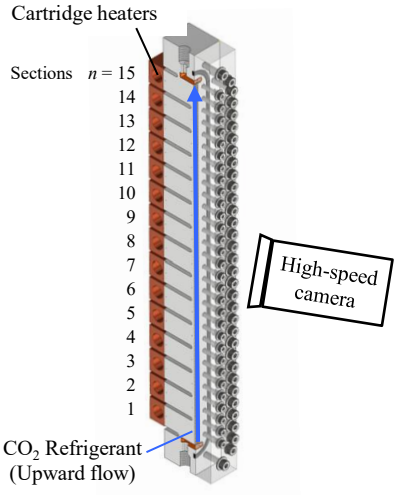


Fig. 3 Detail of the test section and visualization points.

C. Experimental conditions

Table 1 shows the experimental conditions. Evaluations were conducted for an evaporation temperature of T_E = -35°C and mass fluxes of G = 190 kg/(m²·s) and 230 kg/(m²·s).

Table 1 Experimental conditions.

Evaporation temperature T_E [°C]	-35
Mass flux G [kg/(m²·s)]	190, 230

D. Calculation method for heat transfer coefficient

In this study, the heat transfer coefficient was calculated using thermocouples inserted into each of the 15 sections of the test section. Figure 4 shows a schematic diagram of the heat transfer in each section.

The heat flux q_{nA} for an arbitrary section n was calculated using Newton's law of cooling (Eq. (1)) and Fourier's law (Eq. (2)). Furthermore, assuming that there is no heat exchange with the surroundings and that all heat passing through each section is transferred to the refrigerant, Eq. (3) is derived from the heat balance relationship.

$$q_{nR} = a(T_{nW} - T_{nR}) \tag{1}$$

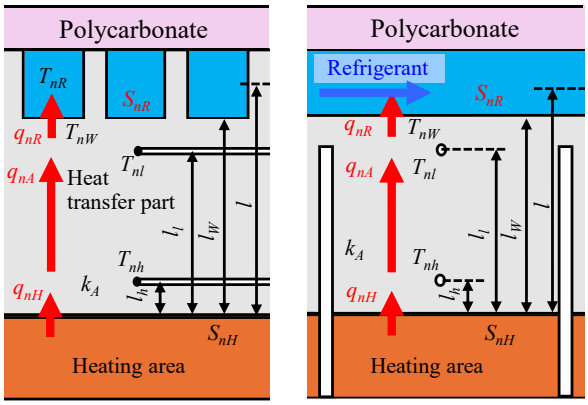
$$q_{nA} = k_A \frac{T_{nh} - T_{nl}}{l_l - l_h} \tag{2}$$

$$S_{nH} q_{nH} = S_{nH} q_{nA} = S_{nR} q_{nR} \tag{3}$$

From Eqs. (1) to (3), the refrigerant heat transfer coefficient a is expressed by Eq. (4). Note that the heat transfer wall temperature, T_{nW}, is difficult to measure. Therefore, T_{nW} was determined using Eq. (5) via extrapolation from the temperature gradient between two points, T_{nh} and T_{nl}, in the heat transfer section.

$$a = \frac{S_{nH}}{S_{nR}(T_{nW} - T_{nR})} q_{nA} = \frac{k_A S_{nH}}{S_{nR}(T_{nW} - T_{nR})} \frac{T_{nh} - T_{nl}}{l_l - l_h} \tag{4}$$

$$T_{nW} = \frac{T_{nl} - T_{nh}}{l_l - l_h}(l - l_h) + T_{nh} \tag{5}$$



(a) Cross sectional view (b) Longitudinal view

a : Heat transfer coefficient [W/(m²·K)]
k_A : Thermal conductivity of heat transfer section (= 140 [W/(m·K)])
l : Heat transfer surface thickness [m]
l_h : Distance from heater to high temperature thermos couple [m]
l_l : Distance from heater to low temperature thermos couple [m]
q_{nA} : Heat flux through the heat transfer section [W/m²]
q_{nH} : Heat transfer coefficient from the heater [W/m²]
q_{nR} : Heat flux to the refrigerant [W/m²]
S_{nH} : Contact area between heater and heat transfer section [m²]
S_{nR} : Contact area between refrigerant and heat transfer surface [m²]
T_{nR} : Refrigerant temperature [K]
T_{nW} : Wall surface temperature [K]
T_{nh} : Heater side temperature measuring by thermos couple [K]
T_{nl} : Flow side temperature measuring by thermocouple [K]

Fig. 4 Schematic diagram of heat transfer in the test section.

III. Results and Discussion

Figure 5 shows the heat transfer coefficients from sections 4 to 13. Sections 1 through 3 and sections 14 and 15 were excluded from the evaluation due to significant heat loss at the inlet and outlet. Figure 5 confirms that the heat transfer coefficient decreases at qualities of x = 0.7 and higher. It is considered that dry-out is occurring in this region. It was also confirmed that the heat transfer coefficient increases with an increase in mass flux. This suggests that the refrigerant liquid film on the heat transfer surface becomes thin as the mass flux increases.

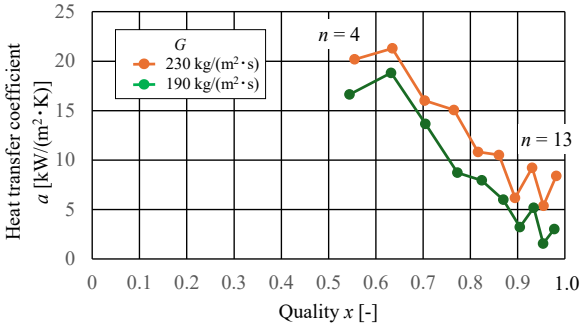


Fig. 5 Results of heat transfer coefficient.

Figure 6 shows the theoretical heat transfer mode and heat transfer coefficient for vertical upward flow. In Figure 6, the heat transfer coefficient drops sharply when dry-out occurs, whereas in Figure 5, it decreases gradually. This is because of the failure to maintain isothermal wall conditions and heat dissipation to the surroundings. Setting more precise experimental conditions is required.

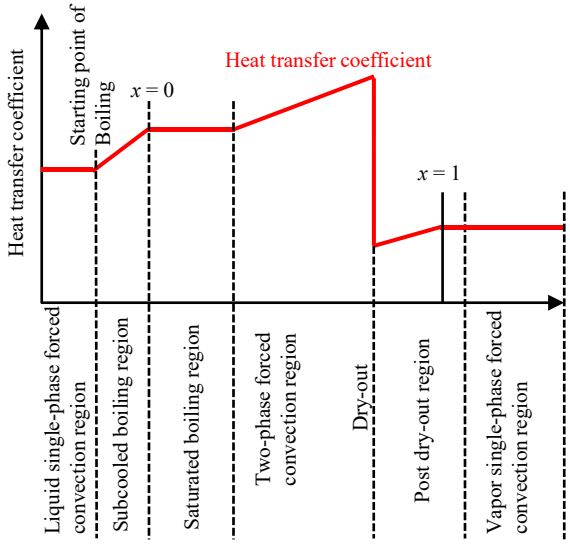


Fig. 6 Heat transfer regimes and heat transfer coefficient distribution in vertical upward flow [4].

IV. Conclusions

This study evaluated the heat transfer coefficient of CO_2 refrigerant in microchannels. Based on the heat transfer coefficient results, it was confirmed that the heat transfer coefficient decreases at qualities of $x = 0.7$ and higher. The occurrence of dry-out was inferred as a contributing factor. It was also confirmed that the heat transfer coefficient increases as the mass flux increases. This indicated that the refrigerant liquid film on the heat transfer surface becomes thin when the mass flux increases. To investigate the effect of the experimental conditions on the heat transfer characteristics, visualization of the gas-liquid two-phase flow of CO_2 refrigerant in microchannels is essential. Furthermore, setting more precisely experimental conditions is important for investigating the refrigerant heat transfer characteristics in microchannels.

Acknowwedgemnt

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Experimental evaluation of Hypochlorous Acid production characteristics and bubble behavior in a flow-type electrolysis device

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Abstract— **In recent years, the importance of safe and stable disinfection technologies has been increasing in the fields of drinking water treatment and infection prevention. Hypochlorous acid has high bactericidal activity and can be produced by the electrolysis of sodium chloride solution. For this reason, hypochlorous acid is widely used, particularly in water treatment and the medical field. There are two methods of generation that are flow-type and batch-type. However, flow-type electrolysis device is usually utilized because it allows for the continuous supply of electrolyte solution. On the other hand, the generated concentration and efficiency of hypochlorous acid depend significantly on operating conditions such as the applied current density, the input flow rate and so on. In particular, gas bubbles generated near the electrode plates during electrolysis reduce the effective reaction area on the electrode surface and act as a factor that prevents chemical reactions. The effect of this bubble behavior on hypochlorous acid generation characteristics has not been fully investigated.**

This study investigated the effect of applied current density on hypochlorous acid generation characteristics in a flow-type electrolytic device. Furthermore, using a high-speed camera, bubble behavior during hypochlorous acid generation was visualized and the relationship between bubble behavior and hypochlorous acid generation characteristics was analyzed. The results of this study are expected to contribute to the realization of technology for the high-concentration and high-efficiency generation of hypochlorous acid using a flow-type electrolysis device.

Keywords— hypochlorous acid, bubble, applied current density, inlet flow rate, NaCl solution, flow-type electrolysis

I. Introduction

Disinfection technology is of great importance in the fields of drinking water treatment and infection prevention [1]. Hypochlorous acid (HClO) is widely used due to its high bactericidal activity, low cost, and ease of handling [1, 2]. In recent years, the demand for hypochlorous acid has been increasing because of growing interest in infectious disease control and hygiene management. Therefore, the technology for the stable and efficient generation of hypochlorous acid is attracting attention [2, 3].

Hypochlorous acid can be produced by the electrolysis of sodium chloride (NaCl) solution. There are two methods of generation that are the continuous-flow method and the batch method. In this study, a flow-type electrolysis device was employed. Flow-type electrolysis devices are expected to maintain stable production conditions through the continuous supply of electrolyte. Therefore, it is considered to have an advantage in applications involving mass production as well [4]. On the other hand, its performance depends significantly on operating conditions such as supply flow rate and applied current density. Therefore, the optimization of operating conditions taking these factors into account is a key challenge [5]. In particular, gas bubbles generated during electrolysis are considered to reduce the reaction area on the electrode surface and prevent chemical reactions. However, the influence of bubble behavior resulting from variations in operating conditions on the concentration, generation efficiency, and total yield of hypochlorous acid has not yet been fully investigated.

Therefore, this study aims to clarify the effects of current density on bubble behavior and hypochlorous acid generation characteristics in a flow-type electrolytic device. Generation characteristics are evaluated based on three parameters which are generation concentration, generation efficiency, and total amount. In addition, the influence of bubble behavior on generation characteristics is examined by evaluating the behavior of bubbles under various operating conditions.

II. Experimental

A. Principle of hypochlorous acid generation

Available chlorine is a general term for chlorine that exhibits bactericidal activity. Available chlorine includes both free chlorine and combined chlorine. HClO exhibits the strongest bactericidal activity among free chlorine species [6].

To generate HClO, it is necessary to add a chloride to the water as an electrolysis aid. In this study, NaCl is used as an electrolysis-assisting substance because it is safe and easy to handle.

Figure 1 shows the formation process of HClO.

NaCl dissociates into chloride ions (Cl^-) and sodium ions (Na^+) in water.

$$NaCl \rightarrow Na^+ + Cl^- \quad (1)$$

At the anode, water (H_2O) is decomposed into oxygen (O_2) and hydrogen ions (H^+) through an oxidation reaction. Cl^- is also oxidized to produce Cl_2. The principal reactions at the anode are as follows.

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (2)$$

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (3)$$

The reaction producing Cl_2 proceeds preferentially

over the water decomposition reaction because Cl^- is a halide ion. Most of the generated Cl_2 is released externally as a gas, but a portion dissolves in water to form HClO.

$$Cl_2 + H_2O \rightarrow HClO + H^+ + Cl^- \quad (4)$$

Meanwhile, at the cathode, electrons are transferred to water through a reduction reaction, producing hydrogen (H_2) and hydroxide ions (OH^-).

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (5)$$

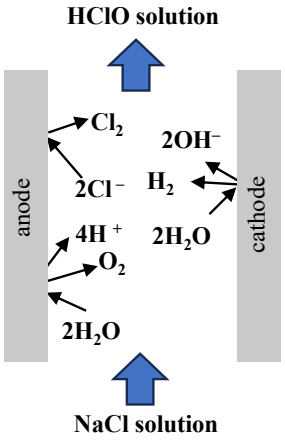


Fig. 1 Formation process of HClO.

B. Experimental Apparatus

Figure 2 shows a schematic diagram of the experimental apparatus. The experimental apparatus consists of the electrolysis apparatus (test section), a tubing pump, a power supply, a digital multimeter for measuring current and voltage, and beakers for sampling and drainage. The NaCl solution is supplied to the electrolysis unit by a tubing pump. Hypochlorous acid is generated through electrolysis in the device. The generated liquid is collected by a beaker for inspection.

Figure 3 shows the electrolysis apparatus (test section). Acrylic, which is resistant to hypochlorous acid, was used for the main body of the apparatus. Electrodes consisting of a titanium substrate with a platinum coating were used. The spacing between the electrode plates is adjusted using Teflon spacers. A flow-straightening section was provided at the inlet of the electrolysis unit to ensure the uniform flow of the electrolyte solution between the electrodes. In addition, an observation window was provided at the top of the electrolysis unit to observe the bubble flow.

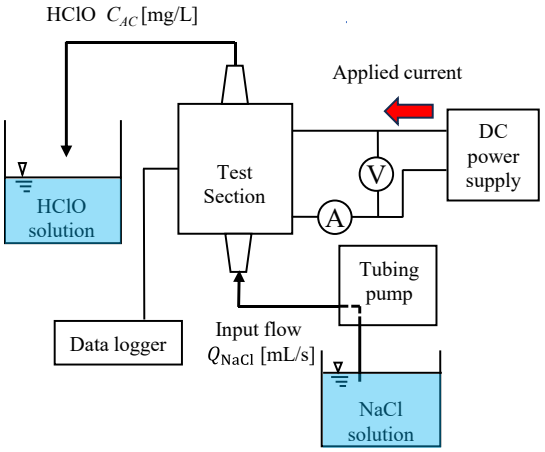


Fig. 2 Schematic diagram of the experimental setup.

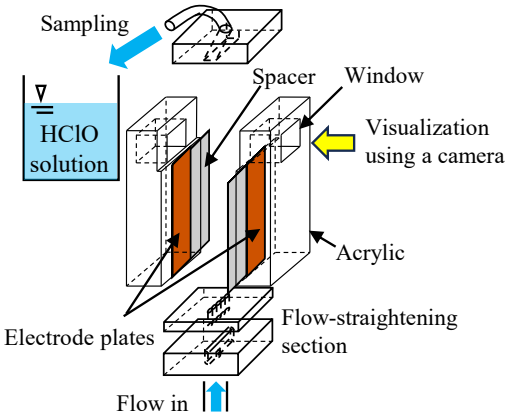


Fig. 3 Schematic diagram of the electrolysis apparatus.

C. Experimental Conditions

Table 1 shows the experimental conditions in this study. The highest values for all evaluation parameters were obtained at an NaCl concentration of C_{NaCl} = 50,000 mg/L in the previous experiments. Therefore, this experiment was conducted at an NaCl concentration of C_{NaCl} = 50,000 mg/L. The dimensions of the electrode plates in the flow-type electrolysis apparatus were set to 50 mm in width and 100 mm in height, with an inter-electrode spacing of 5.0 mm. The titanium electrode plates were coated with platinum to a thickness of 50 μm. In the experiment, the applied current density was varied to see the conditions of bubble generation.

Table 1 Experimental conditions.

Input flow Q_{NaCl}	0.101 mL/s
NaCl Concentration C_{NaCl}	50,000 mg/L
Current density I_S	400, 800, 1,200, 1,600 A/m^2
Electrode plate size	W50 mm × H100 mm
Electrode plate	Titanium with 50 μm Platinum coating
Electrode plate spacing d	5 mm

D. Evaluation Method

A residual chlorine meter based on spectrophotometry using DPD (diethyl-p-phenylenediamine) reagent was used to measure the effective chlorine concentration. The effective chlorine concentration in the generated solution is high, significantly exceeding the measurement range of the residual chlorine meter. Therefore, the collected samples were diluted with purified water and adjusted to a measurable concentration range. After measurement, the actual effective chlorine concentration was calculated by multiplying the obtained measured value by the dilution factor.

Production efficiency, η_{AC} , is calculated from the ratio of the production rate to the amount of electron supplied. It was calculated using the following equation.

$$\eta_{AC} = \frac{2 \times C_{AC} \times Q_{\mathrm{NaCl}} \times F}{M_{AC} \times I_S \times S} \times 10^{-6} \qquad (6)$$

where, C_{AC} is HClO concentration produced [mg/L], Q_{NaCl} is input flow rate [mL/s], $F = 9.65\times10^4$ is Faraday constant [C/mol], M_{AC} is HClO molecular weight [kg/kmol], and I_S is current density [A/m^2].

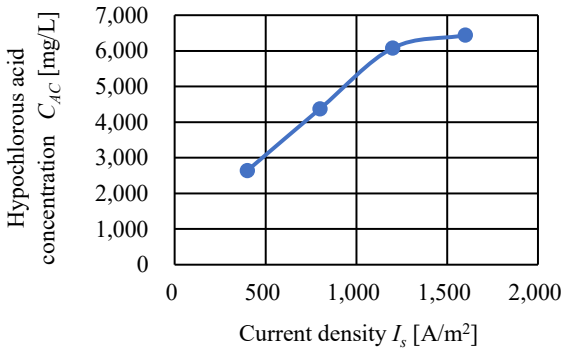
The production rate of available chlorine was evaluated as the amount generated per unit time, estimated from the product of the available chlorine concentration in the generated solution and the flow rate of the NaCl solution.

The amount of available chlorine generated, P_{AC} [mg/s], was calculated using the following equation.

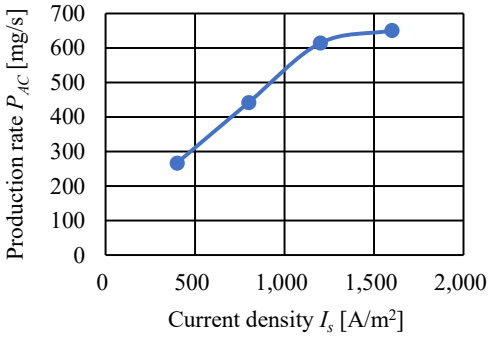
$$P_{AC} = C_{AC} \times Q_{\mathrm{NaCl}} \qquad (7)$$

III. Results and Discussion

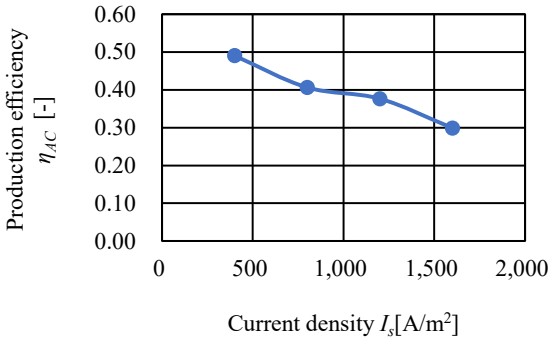
In this study, the effect of applied current density on hypochlorous acid generation was evaluated. First, experiments were conducted by keeping the input flow rate constant while varying the current density supplied to the electrode plates. Figure 4 shows the experimental results. Figures 4(a)–(c) present the effective chlorine concentration, production rate, and production efficiency, respectively.



(a) Effective chlorine concentration



(b) Production rate



(c) Production efficiency

Fig. 4 Effective chlorine concentration, production rate, and generation efficiency versus current density.

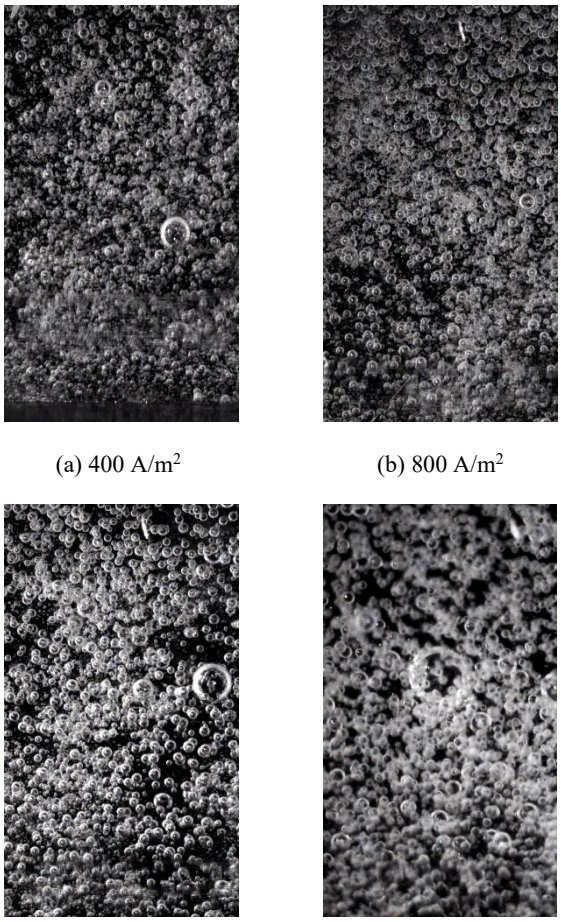
As shown in Figures 4(a) and (b), the concentration and the production rate increase with increasing current density. This is considered to be due to an increase in the amount of chloride ion (Cl^-) reaction resulting from the acceleration of the electrode reaction.

However, when the current density exceeded approximately 1,200 A/m², the rate of the concentration and production rate decreased. Under high current density conditions, the consumption rate of Cl^- at the electrode surface increases. Therefore, it is considered that the supply of Cl^- from the solution to the electrode surface becomes insufficient.

Additionally, side reactions may occur under high current density conditions. For example, a portion of the current is consumed by oxygen evolution. Furthermore, bubbles generated at the electrode surface may inhibit the reaction. In addition, a rise in the solution temperature due to the electric current is also possible. The rise in temperature may have accelerated the decomposition of hypochlorous acid.

Production efficiency decreased as current density increased. This is thought to be partly due to the increased consumption rate of Cl^-. If the consumption of Cl^- increases, the supply of Cl^- to the electrode surface may become insufficient. As a result, it is considered that the proportion of the input current utilized for the intended reaction decreased.

Next, visualization experiments were conducted to observe the bubbles during the generation process. Figure 5 shows the results obtained when the current density was varied.



(a) 400 A/m^2 (b) 800 A/m^2

(c) 1,200 A/m^2 (d) 1,600 A/m^2

Fig. 5 Visualization image of bubbles.

From Figures 5(a) and (b), a tendency for the number of bubbles to increase with increasing current density was observed. In addition, changes in bubble size and distribution were observed as the current density increased. Under high current density conditions of I_S = 1,600 A/m², vigorous bubble behavior was observed that differed from that seen at I_S = 1,200 A/m². From this, it was found that under high current density conditions, bubble size and distribution became non-uniform, and bubble behavior became complex. Furthermore, such changes in bubbles may affect chemical reaction and contribute to a reduction in production efficiency.

IV. Conclusions

This study aimed to investigate the characteristics of hypochlorous acid generation in a flow-type electrolytic device. The generation characteristics of hypochlorous acid resulting from changes in current density were evaluated. It was also shown that bubble behavior changes with variations in current density. It is desirable to further investigate the relationship between the conditions for hypochlorous acid generation and bubble behavior by expanding the range of experimental conditions.

Acknowledgment

We would like to express our deep gratitude to the Graduate School of Engineering at Mie University for their support in conducting this research.

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Latest Status of Japanese-Style Vegetable Production and Distribution in Indonesia: A Case Study of OKIAGARU Farm in West Java

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Abstract— **The transfer of agricultural knowledge across countries involves not only production technology but also the adaptation of management practices, quality standards, and market relationships to local conditions. This study examines the development of Japanese-influenced vegetable production and distribution at OKIAGARU Farm in Cianjur, West Java, Indonesia. Specifically, it investigates how Japanese-style production and quality-management practices have been adapted to Indonesian farming conditions and how marketing and institutional arrangements influence the sustainability of the model. A case-study approach was employed using field observation, semi-structured interviews, secondary information, and a comparative farmer survey framework. The planned survey covers 60 vegetable farmers, consisting of 30 farmers associated with OKIAGARU and 30 non-OKIAGARU farmers. Preliminary field observations indicate that Japanese influence extends beyond cultivation techniques to production planning, quality management, harvesting, sorting and grading, and market-oriented production. OKIAGARU also developed higher-value marketing channels. From 2010 to 2018, vegetables were supplied to restaurant and specialty-market customers, including Yoshinoya, Sushi Tei, and Cosmo, while supplies to AEON were developed during 2015–2018. However, the relationship with AEON was discontinued from 2019. Field information suggests that deferred payment arrangements and the resulting cash-flow considerations were important factors in this decision. The case demonstrates that product quality can facilitate entry into modern markets, but sustainable participation also depends on institutional and financial arrangements compatible with small-scale agricultural enterprises. Japanese-style vegetable farming in Indonesia should therefore be understood as a process of selective adaptation integrating technology, farmer learning, quality management, institutional arrangements, and market coordination.**

Keywords— Japanese-style agriculture; knowledge transfer; vegetable farming; modern retail; smallholders; Indonesia

I. Introduction

Vegetable production plays an important role in Indonesia's horticultural sector by providing income opportunities for rural households and supplying increasingly diversified urban food markets. However, a large proportion of vegetable production remains dependent on small-scale producers who face difficulties in consistently meeting the requirements of higher-value markets. The expansion of supermarkets, restaurants, hotels, and other modern food outlets has created opportunities for farmers to access these markets, but participation requires more than production capacity [1]. Product consistency, grading, packaging, infrastructure, production planning, and coordination with buyers are increasingly important [2][3]. Previous research found that small-scale farmers participating in supermarket channels differed from those using traditional channels in terms of irrigation, packaging and storage facilities, education, and infrastructure, while supermarket participation was associated with improved farmer income [2].

Producer organizations can further facilitate this transition by strengthening farmer–buyer collaboration, improving farmers' ability to meet quality requirements, and developing appropriate contractual and organizational arrangements [4]. Thus, participation in modern markets involves both technical and institutional challenges. Japan provides an interesting reference for production–market coordination, as Japanese agricultural development has emphasized the transfer of production knowledge, technical skills, and market-oriented practices through agricultural technology transfer and extension systems [5][6]. MAFF regularly provides supply-and-demand guidelines and monitors production, shipment, and market conditions, highlighting the importance of coordinating production timing, product quality, expected demand, and distribution.

However, the transfer of agricultural knowledge should not be understood as a direct replication of the original farming system, as the effectiveness and sustainability of technology transfer depend on local conditions, institutional arrangements, and stakeholder participation [5][6]. Differences in climate, farm size, labor availability, input systems, consumer preferences, and market institutions require such knowledge to be adapted to local conditions. OKIAGARU Farm in Cianjur, West Java, provides a relevant case for examining this process. Previous studies have identified product availability, direct distribution, packaging, cooperation, and Good Agricultural Practices as important aspects of OKIAGARU's development and quality-oriented production.

Against this background, this study examines how Japanese-style production and quality-management practices are adapted to Indonesian farming conditions and how marketing relationships and institutional arrangements have influenced the development and sustainability of OKIAGARU's vegetable distribution. Accordingly, the study aims to: (1) identify Japanese-influenced production and quality-management practices adopted by OKIAGARU farmers; (2) examine the

evolution of production and marketing channels, particularly relationships with restaurant and modern-retail buyers; and (3) assess the opportunities and constraints affecting the sustainability of the OKIAGARU model.

II. Materials and Methods

A. Study Area and Research Approach

The research was conducted at OKIAGARU Farm in Cianjur Regency, West Java, Indonesia. Cianjur is an important horticultural production area, and OKIAGARU represents a particularly rele-vant case because of its experience in producing differentiated vegetables and developing relation-ships with restaurant and modern-retail markets.

The study applies a case-study approach com-bined with a comparative farmer survey. The case study is intended to reconstruct the process through which Japanese agricultural knowledge has been introduced, interpreted, and adapted, while the comparative survey is designed to identify differ-ences between farmers associated with OKIAGARU and farmers operating outside the organization.

Descriptive statistics, frequencies, and percentages will be used to characterize production and marketing practices. Categorical differences between OKIAGARU and non-OKIAGARU farmers will be examined using chi-square or Fisher's exact tests where appropriate. Continuous variables, including farm size, yield, price, production cost, and income, will be compared using independent-samples t-tests when statistical assumptions are satisfied.

As the comparative farmer survey is ongoing, the quantitative values presented in this preliminary paper are used to indicate the expected comparative pattern derived from initial field observations and will subsequently be replaced by verified survey results.

B. Data Collection

Primary data were collected through field observations and semi-structured interviews with key actors. Field observations focused on production facilities, crop management, cultivation practices, harvesting, quality management, and the organization of vegetable production and marketing. Semi-structured interviews were conducted to obtain information on the historical development of OKIAGARU, Japanese agricultural influence, production management, buyer relationships, and changes in marketing channels.

The quantitative component of the study is designed to include 60 vegetable farmers, comprising 30 OKIAGARU farmers and 30 non-OKIAGARU farmers operating under comparable local conditions. The questionnaire covers farmer characteristics, production planning, cultivation practices, quality management, harvesting, sorting and grading, buyer coordination, marketing channels, production performance, selling prices, production costs, and farm income.

C. Analytical Framework

The conceptual pathway examined in this study is as follows: **Japanese Agricultural Experience → Knowledge Transfer → Local Adaptation → Production and Quality Improvement → Access to Higher-Value Markets → Institutional and Financial Conditions → Sustainable Market Participation.**

Descriptive statistics, frequencies, and percentages will be used to characterize production and marketing practices. Categorical differences between OKIAGARU and non-OKIAGARU farmers will be examined using chi-square or Fisher's exact tests, where appropriate. Continuous variables, including farm size, yield, selling price, production costs, and farm income, will be compared using independent-samples t-tests when the statistical assumptions are satisfied.

As the comparative farmer survey is still ongoing, the quantitative values presented in this preliminary paper are intended to illustrate the expected comparative patterns based on initial field observations. These preliminary estimates will subsequently be replaced with verified results from the completed farmer survey.

III. Results and Discussion

A. Transfer and Adaptation of Japanese-Style Farming Practices

Field observations indicate that Japanese influ-ence at OKIAGARU extends beyond the transfer of particular cultivation techniques. More importantly, it involves a shift from a predominantly production-oriented approach toward a production-and-market-oriented management system.

Several elements are evident. First, production is increasingly planned according to expected market requirements rather than simply according to what farmers are capable of growing. Second, greater attention is given to harvesting time and product consistency. Third, sorting and grading become important components of post-harvest management. Finally, production decisions are more closely coordinated with buyer requirements.

This approach is conceptually consistent with the Japanese emphasis on matching vegetable production and shipment with expected demand. MAFF's vegetable supply-and-demand guidelines explicitly promote production according to demand and pro-vide information on production, shipment, market arrivals, and price expectations.

However, the practices observed in Cianjur can-not simply be characterized as the replication of Japanese agriculture. They have been selectively modified according to local climatic conditions, smallholder resources, available labor, farm size, input access, and the characteristics of Indonesian markets.

Thus, the principal transfer is not merely technology, but also management knowledge, quality consciousness, production discipline, and market orientation [6].

Table 1 Preliminary comparison of production and marketing practices

Indicator	OKIAGARU Farmers (%)	Non-OKIAGARU Farmers (%)
Production planning based on market demand	83.30	46.70
Regular quality control	86.70	50.00
Sorting and grading before marketing	80.00	43.30
Production coordinated with buyers	76.70	36.70
Access to organized/higher-value markets	73.30	30.00

Note: The percentages presented in Table 1 are preliminary estimates based on the expected pattern derived from field observations.

The preliminary pattern suggests that the most important difference between the groups may lie in the organization of production in relation to mar-kets, rather than in cultivation technology alone [4][7]. OKIAGARU farmers appear more likely to connect production planning with market demand, apply systematic quality management, sort and grade products, communicate with buyers, and access organized markets.

This interpretation is consistent with previous research, which found that producer organizations can facilitate smallholder participation in modern retail by strengthening collaboration with buyers and improving farmers' ability to meet quality requirements [4].

B. Evolution of Vegetable Marketing and Distribution

The development of OKIAGARU can be understood through the evolution of its marketing relationships. The farm expanded beyond conventional vegetable marketing by establishing relationships with restaurant, specialty-market, and modern-retail buyers. Based on field information, the development of its marketing and distribution can be broadly described across three periods. From 2010 to 2018, OKIAGARU supplied vegetables to several buyers, including Yoshinoya, Sushi Tei, and Cosmo. These relationships represented an important development in the farm's marketing channels, as restaurant and specialty-market customers required greater attention to product specifications, consistency, and supply reliability.

From 2015 to 2018, OKIAGARU further expanded its marketing channels by supplying vegetables to AEON in Jakarta. This expansion represented an important achievement in gaining access to the modern retail market. Participation in modern retail requires producers to meet requirements related to product quality, handling, continuity of supply, and commercial coordination [2][7]. Previous research on OKIAGARU conducted in 2019 also highlighted product, distribution, availability, packaging, and cooperation as important components of its marketing strategy [9]. More broadly, evidence from Indonesia indicates that participation in supermarket channels can provide income opportunities for small-scale vegetable producers, although access to these channels depends on production assets and market capabilities [2].

Since 2019, OKIAGARU has no longer supplied vegetables to AEON. Based on information obtained through field interviews, the deferred payment arrangement was an important consideration in the discontinuation of this relationship. This issue is particularly relevant to vegetable farming because production requires continuous working capital. Farmers and suppliers must finance seeds, production inputs, labor, harvesting, packaging, transportation, and subsequent production cycles. When payment is received only after an extended settlement period, suppliers must continue financing these activities while waiting for revenue from previously delivered products. Such payment arrangements can therefore place additional pressure on the working capital of small-scale agricultural enterprises [8].

The experience of OKIAGARU illustrates that access to higher-value markets does not necessarily guarantee sustainable market participation. Although a farmer organization may have sufficient technical capacity and product quality to enter modern retail markets, maintaining such relationships may remain challenging when financial and contractual arrangements are not compatible with its working-capital capacity. Thus, sustainable market participation depends not only on product quality and technical capabilities but also on appropriate payment systems, contractual arrangements, and buyer–supplier relationships.

C. Technology Is Only One Part of the Story

The OKIAGARU case suggests that the sustainability of international agricultural knowledge transfer should be considered as a sequence of interrelated processes:

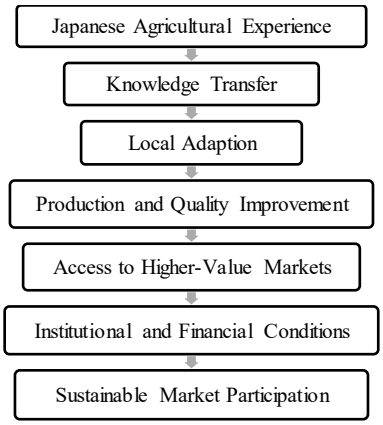


Fig. 1 Conceptual Framework of Japanese-Style Agricultural Knowledge Transfer and Sustainable Market Participation.

The OKIAGARU case suggests that the sustainability of international agricultural knowledge transfer should be understood as a sequence of interrelated processes.

The first four stages primarily concern knowledge acquisition, production capabilities, and local adaptation. Farmers learn new ways of organizing production and adapt these practices to local conditions. Improvements in product quality and consistency can subsequently facilitate access to restaurants, specialty outlets, and modern retail markets.

However, the transition from market access to sustainable market participation requires additional conditions. These include the ability to meet quality requirements, appropriate payment terms, sufficient working capital, suitable contractual arrangements, trust, and effective buyer–supplier relationships [8]. Thus, successful entry into a higher-value market does not necessarily ensure that the market relationship can be maintained over time.

This finding is consistent with the value-chain upgrading perspective. Linking Indonesian smallholders with modern retail markets requires improvements not only in product quality but also in network relationships and governance structures [2]. Similarly, the OKIAGARU case indicates that improvements in production and quality capabilities need to be accompanied by supportive institutional and financial arrangements [2][4].

The experience of OKIAGARU therefore leads to a central proposition of this study: quality opens the market, but institutional arrangements determine whether the relationship can be sustained.

This distinction has broader implications for the international transfer of agricultural models. A technically successful farming system may not achieve institutional or economic sustainability unless local market arrangements develop alongside production capabilities. Therefore, sustainable agricultural knowledge transfer requires not only the adaptation of production practices but also the development of appropriate market, financial, and institutional conditions.

IV. Conclusions

This study provides four preliminary conclusions.

1. Japanese agricultural knowledge transfer extends beyond production technology. In the OKIAGARU case, Japanese influence can be observed in production planning, quality management, harvesting, sorting and grading, and the stronger integration of production decisions with market requirements.
2. Japanese agricultural practices are selectively adapted rather than directly replicated. Farmers oprate within different climatic, socioeconomic, labor, farm size, and market environments. The resulting model should therefore be understood as a locally adapted system influenced by Japanese agricultural experience.
3. Third, OKIAGARU demonstrated its ability to develop higher-value marketing channels, including restaurant, specialty, and modernretail markets. Its experience indicates that smallholder based vegetable systems can move toward more demanding markets when production capa-bility, quality management, and buyer coordina-tion improve.
4. Fourth, modern-market participation cannot be sustained by product quality alone. The ex-perience with deferred payment arrangements il-lustrates the importance of payment systems, working capital, contractual arrangements, and workable buyer–supplier relationships.

The main implication is that sustainable Japa-nese-style vegetable farming in Indonesia requires the integration of technology, farmer learning, local adaptation, institutional support, and appro-priate market arrangements. The forthcoming comparative survey of 30 OKIAGARU and 30 non-OKIAGARU farmers will provide quantitative evi-dence to validate these preliminary findings and examine whether participation is associated with measurable differences in production planning, quality management, market access, productivity, prices, and farm income

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Effects of cricket powder (*Acheta domesticus*) on growth performance, immune response, and gene expression of Nile tilapia biofloc culture-based system

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Abstract - The present study evaluated the effects of dietary cricket (*Acheta domesticus*) powder on growth performance, innate immunity, and gene expression in juvenile Nile tilapia (Oreochromis niloticus) cultured under biofloc conditions. Fish (initial weight, approximately 14.9 g) were randomly distributed among five dietary treatments containing cricket powder at 0 (CP0), 25 (CP25), 75 (CP75), 150 (CP150), or 225 (CP225) g kg^{-1} diet, with three replicate tanks per treatment and 20 fish per tank, and fed for 8 weeks. Growth performance was significantly affected by dietary treatment ($P < 0.05$), with CP150 producing the highest final weight, weight gain, and specific growth rate, whereas feed conversion ratio and survival were unaffected. Skin mucus and serum lysozyme and peroxidase activities were significantly enhanced by cricket powder supplementation, with the strongest responses generally observed at CP75–CP150. Similarly, CP75–CP150 markedly upregulated the expression of immune- and stress-related genes, including hsp70, il-8, tlr7, and trf2, in the head kidney, whereas expression generally declined at CP225. Intestinal expression of the growth- and appetite-related genes igf1, igf2, and galanin was also enhanced at intermediate inclusion levels, while ghrelin showed its highest expression at CP75. Collectively, these findings demonstrate that moderate dietary inclusion of A. domesticus powder, particularly 75–150 g kg^{-1}, can support growth, enhance mucosal and systemic innate immunity, and modulate growth- and immune-related molecular responses in Nile tilapia cultured under biofloc conditions. Excessive inclusion at 225 g kg^{-1} provided no additional benefit and generally attenuated these responses.

Keywords— *Acheta domesticus*, biofloc technology, insect protein, innate immunity, *Oreochromis niloticus*

I. Introduction

Aquaculture has become an increasingly important component of the global food production system, providing high-quality animal protein, essential nutrients, employment, and income while contributing substantially to global food and nutrition security (Bagheri and Gholamhosseini, 2026). With capture fisheries remaining relatively stable and the demand for aquatic foods continuing to increase, aquaculture is expected to play an even greater role in meeting future food requirements (Mequanent et al., 2026). Nevertheless, the rapid expansion and intensification of aquaculture are accompanied by several challenges, including increasing feed costs, competition for conventional feed ingredients, environmental impacts, disease outbreaks, and the need to improve resource-use efficiency (Ruben et al., 2025). Feed is particularly important because it represents one of the largest operating costs in intensive aquaculture, with dietary protein accounting for a substantial proportion of feed expenditure (Hua et al., 2019). Fish meal has traditionally been regarded as a high-quality protein source because of its favorable amino acid profile, high digestibility, and palatability; however, its limited availability, fluctuating price, and concerns regarding the sustainable use of marine resources have stimulated efforts to identify alternative protein sources (Tignani et al., 2024). Therefore, the development of nutritionally adequate, economically viable, and environmentally sustainable feed ingredients is essential for supporting the continued growth of aquaculture.

Insect-derived ingredients have emerged as promising alternative protein sources for aquafeeds because insects can efficiently convert organic resources into nutrient-rich biomass and generally contain high concentrations of protein, essential amino acids, lipids, minerals, and bioactive compounds (Fantatto et al., 2024). Several insect species, including black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*), and house cricket (*Acheta domesticus*), have been investigated as partial or complete substitutes for conventional dietary protein sources in aquaculture (Quang Tran et al., 2022). Among these, *A. domesticus* is particularly attractive because of its relatively high protein content, favorable amino acid composition, and availability from established commercial farming systems (Oliveira et al., 2026). In addition to supplying nutrients, cricket-derived ingredients contain chitin and other biologically active components that may influence digestive function, antioxidant capacity, immune responses, and host metabolism (Stull et al., 2018). Previous studies have demonstrated that appropriate inclusion of insect meals can support growth and feed utilization in several cultured fish species; however, responses vary considerably depending on insect species, processing method, dietary inclusion level, fish species, and culture conditions (Abdolmanafi et al., 2025; Suryadi et al., 2025). Excessive inclusion may also reduce nutrient utilization because of factors such as chitin content or imbalances introduced into the formulated diet. Consequently, determining suitable dietary inclusion levels of cricket powder and evaluating its effects beyond conventional growth parameters are important for establishing its practical value as an alternative feed ingredient for aquaculture.

Nile tilapia (*Oreochromis niloticus*) is one of the most widely cultured freshwater fish species worldwide because of its rapid growth, omnivorous feeding habit, adaptability to diverse production environments, and capacity to utilize a broad range of dietary ingredients (Wen et al., 2027). These characteristics make Nile tilapia a suitable model for evaluating alternative protein

sources such as insect-derived ingredients (Elegbede et al., 2026). At the same time, biofloc technology (BFT) has gained increasing attention as an intensive culture strategy for tilapia because it promotes the conversion of dissolved nitrogenous wastes into microbial biomass through manipulation of the carbon-to-nitrogen ratio (Lovejan et al., 2026). The resulting bioflocs can contribute supplementary nutrients to fish while improving nutrient recycling and reducing water exchange requirements (Rai et al., 2025). The simultaneous use of BFT and alternative feed ingredients may therefore provide complementary opportunities to improve the sustainability and resource efficiency of tilapia production (Emerenciano et al., 2025). Nevertheless, information regarding the responses of Nile tilapia to graded levels of dietary A. domesticus powder under biofloc conditions remains limited, particularly with respect to the integration of growth, mucosal and systemic immunity, and molecular responses. Therefore, the present study evaluated dietary cricket powder at 0, 25, 75, 150, and 225 g kg^{-1} in juvenile Nile tilapia cultured in a biofloc system for 8 weeks. The effects were assessed through growth performance, feed utilization, serum and skin mucus immune responses, and the expression of genes associated with growth regulation, immunity, and antioxidant defense, with the aim of identifying an appropriate dietary inclusion level for biofloc-based Nile tilapia production.

II. Experimental

A. Preparation of cricket powder

Cricket (*Acheta domesticus*) powder was obtained in a ready-to-use powdered form from a local cricket farm in Khon Kaen, Thailand. Upon receipt, the powder was stored in sealed containers under dry conditions until preparation of the experimental diets.

B. Experimental design

Five experimental diets were formulated based on the basal formulation described by Van Doan et al. (2026), with graded levels of cricket (*Acheta domesticus*) powder incorporated as the test ingredient. The ingredient composition and inclusion levels of the experimental diets are presented in Table 1. All diets were formulated to provide approximately 30% crude protein and comparable lipid and energy contents, thereby minimizing nutritional variation among treatments other than that associated with the graded inclusion of cricket powder. The target dietary crude protein level was selected based on our previous study demonstrating that approximately 30% crude protein adequately supports the growth of juvenile Nile tilapia under comparable experimental conditions (Hussien et al., 2025). Accordingly, the experimental diets were formulated to be approximately isoproteic, isolipidic, and isoenergetic.

All dry ingredients were weighed according to the respective formulations and thoroughly mixed to ensure uniform distribution. Oil and water were subsequently added, and the mixture was blended until a homogeneous dough was obtained. The dough was then processed through an extruder (Siam Farm Services Co., Ltd., Lampang, Thailand) to produce 2-mm pellets. The resulting pellets were air-dried, packed in sealed plastic bags, and stored at 4 °C until use.

Table 1 Feed ingredients and proximate composition of the experimental diets

Ingredients (g kg^{-1})	CP0	CP25	CP75	CP150	CP225
Fish meal	250	225	175	100	25
Corn meal	100	100	120	150	0
Soybean meal	350	350	356	360	388
Wheat flour	115	125	114	130	150
Rice bran	150	129	105	37	0
Cricket powder	0	25	75	150	225
Binder	0	10	20	35	164
Soybean oil	0	1	0	3	13
Premix	25	25	25	25	25
Vitamin C	10	10	10	10	10
Total	1000	1000	1000	1000	1000

C. *Trial fish, fish management, and water quality*

A total of 300 healthy juvenile Nile tilapia (*Oreochromis niloticus*) was obtained from the Chiang Mai Aquatic Development Farm, Chiang Mai, Thailand. Before initiation of the feeding trial, the fish were acclimated to the experimental conditions for 14 days. During acclimation, fish were fed a commercial diet (CP9951; Charoen Pokphand Foods Public Company Limited, Thailand) twice daily at 08:00 and 16:00 h at approximately 4% of body weight per day. According to the manufacturer's specifications, the commercial diet contained approximately 30% crude protein, 3% crude lipid, and ≤8% crude fiber. Fish were maintained in continuously aerated 150-L glass tanks under controlled indoor conditions throughout the acclimation and experimental periods.

Following acclimation, the fish were randomly assigned to five dietary treatments in a completely randomized design, with three replicate tanks per treatment and 20 fish per tank. Each tank served as an independent experimental unit. The five experimental diets contained cricket (*Acheta domesticus*) powder at 0, 25, 75, 150, and 225 g kg^{-1} diet and were designated CP0, CP25, CP75, CP150, and CP225, respectively. The corresponding initial body weights were 14.87 ± 0.10, 14.88 ± 0.03, 14.88 ± 0.08, 14.90 ± 0.00, and 14.87 ± 0.03 g for the CP0, CP25, CP75, CP150, and CP225 groups, respectively. The close similarity in initial body weight among treatments ensured comparable starting conditions across the experimental groups.

Fish were fed their respective experimental diets twice daily at 08:00 and 16:00 h at a daily feeding rate equivalent to 4% of tank biomass for 8 weeks. To account for changes in biomass during the feeding period, all fish in each tank were collectively weighed at 15-day intervals, and the daily feed ration was adjusted accordingly. Continuous aeration was provided to all tanks throughout the experiment to maintain adequate dissolved oxygen and promote biofloc suspension. At the

completion of the 8-week feeding trial, fish were sampled for determination of growth performance, immune responses, and antioxidant- and immune-related gene expression.

Water quality was monitored throughout the experimental period to maintain conditions suitable for Nile tilapia and biofloc culture. Water temperature, dissolved oxygen (DO), pH, and total ammonia nitrogen (TAN) were measured twice daily at 08:30 and 16:30 h. Temperature, DO, and pH were determined using a multiparameter meter (HI98196, Hanna Instruments, Romania), whereas TAN was measured using a high-range ammonia photometer (HI96733, Hanna Instruments, Romania). Biofloc volume was determined using an Imhoff cone according to the method described by Avnimelech and Kochba (2009). Approximately 5% of the total water volume was replaced weekly to maintain stable water quality and biofloc system performance. Throughout the feeding trial, mean water temperature, pH, dissolved oxygen, and TAN were 27.8 ± 0.68 °C, 8.03 ± 0.56, 5.27 ± 0.12 mg L^{-1}, and 0.18 ± 0.03 mg L^{-1}, respectively.

D. Biofloc formation and management

The biofloc system was established three weeks before the start of the feeding trial following the freshwater biofloc protocol described by Van Doan et al. (2026), with modifications based on (Dey et al., 2026). Briefly, each 150-L experimental tank was filled with dechlorinated freshwater and supplied with continuous aeration to facilitate microbial growth and maintain the developing biofloc in suspension. Biofloc formation was initiated by adding 1 g of commercial probiotic (PondPlus®, Bayer, Germany), 2 g of commercial fish feed, 5 g of molasses, 5 g of dolomite, and 400 g of salt to each tank. The probiotic was used as a microbial inoculum and was subsequently supplemented at 1 g $tank^{-1}$ every 15 days during the feeding trial to support microbial community establishment and biofloc maintenance. Commercial feed provided an initial source of organic nitrogen, whereas molasses served as the external carbon source. Dolomite was added to support alkalinity and pH stability. Salt was applied only during the initial biofloc maturation period and was not routinely supplemented during the subsequent feeding trial.

Throughout the experimental period, the carbon-to-nitrogen (C) ratio was maintained at approximately 15:1 by the addition of molasses containing approximately 40% carbon, following the heterotrophic biofloc approach described by Avnimelech and Kochba (2009). Molasses was added approximately 2 h after feeding, with the required amount calculated according to dietary nitrogen input, estimated nitrogen excretion, and residual inorganic nitrogen in the culture water, following the approach of Cardona et al. (2016). The same carbon-management procedure was applied uniformly across all experimental tanks to minimize variation in biofloc conditions among dietary treatments.

Biofloc development was monitored throughout the maturation and experimental periods, and continuous aeration was maintained to ensure adequate oxygenation and suspension of microbial aggregates. Fish were introduced into the experimental tanks after the three-week maturation period, when visible and stable biofloc aggregates had become established. Biofloc conditions were subsequently maintained throughout the 8-week feeding trial using the same management protocol across all dietary treatments.

E. Growth performance

At the end of the 8-week feeding trial, fish were deprived of feed for 24 h to minimize the influence of gut contents on body weight measurements. All fish were subsequently counted and individually weighed to determine final body weight and survival. Growth performance and feed utilization indices were calculated according to Helal et al. (2024) using the following equations: Weight gain (WG, g) = Final body weight (g) − Initial body weight (g); Specific growth rate (SGR, % day^{-1}) = 100 × [ln(final body weight) − ln(initial body weight)] / Experimental duration (days); Feed conversion ratio (FCR) = Total dry feed intake (g) / Total wet weight gain (g); Survival rate (SR, %) = 100 × Final number of fish / Initial number of fish

Growth and feed utilization data were calculated for each replicate tank, with the tank considered the experimental unit for subsequent statistical analysis.

F. Immune response analysis

F.1 Sample collection

At the end of the feeding trial, three fish were randomly selected from each replicate tank for collection of skin mucus and blood samples. Prior to sampling, fish were anesthetized with clove oil (5 mL L^{-1}) and subsequently euthanized under deep anesthesia in accordance with the guidelines approved by the Chiang Mai University Animal Care and Use Committee (CMU-AASCUC). All sampling procedures were conducted carefully to minimize handling stress and animal suffering.

Skin mucus was collected following the procedure described by Cordero et al. (2016), with minor modifications. Each anesthetized fish was individually placed in a polyethylene bag containing 10 mL of 50 mM NaCl solution, and the body surface was gently massaged in a head-to-tail direction for approximately 1 min to facilitate mucus release. The resulting mucus suspension was transferred into a 15-mL centrifuge tube and centrifuged at 1,500 × g for 10 min at 4 °C. The supernatant was carefully recovered, aliquoted into sterile microcentrifuge tubes, and stored at −80 °C until analysis.

Blood collection was performed according to previously described procedures (Bavia et al., 2024), with minor modifications. Approximately 1 mL of blood was withdrawn from the caudal vein of each fish using a sterile 1-mL syringe and transferred immediately into a sterile microcentrifuge tube without anticoagulant. Samples were allowed to clot at room temperature for approximately 1 h and subsequently maintained at 4 °C until centrifugation. Serum was separated by centrifugation at 1,500 × g for 5 min at 4 °C, carefully collected, and stored at −80 °C until immunological analyses.

F.2 Lysozyme and peroxidase activities

Lysozyme activity in serum and skin mucus was determined using a turbidimetric assay based on the method of (Parry et al., 1965), with modifications described by Van Doan et al. (2026). Briefly, 100 µL of skin mucus or 25 µL of undiluted serum was dispensed in triplicate into a 96-well microplate. Subsequently, 175 µL of *Micrococcus lysodeikticus* suspension (0.3 mg mL^{-1} in 0.1 M citrate–phosphate buffer, pH 5.8) was added to each well. Following rapid mixing, the decrease in turbidity was monitored at 540 nm and 25 °C using a microplate reader, with absorbance recorded at 30-s intervals for 5 min. A standard curve was constructed using hen egg-white lysozyme (0–20 µg mL^{-1}; Sigma-Aldrich, USA), and lysozyme activity was calculated from the standard curve and expressed as µg mL^{-1}.

Peroxidase activity in serum and skin mucus was determined according to Quade and Roth (1997). Briefly, 5 µL of each sample was added in triplicate to a 96-well flat-bottom microplate and mixed with 45 µL of Ca^{2+}- and Mg^{2+}-free Hank's balanced salt solution (HBSS). Subsequently, 100 µL of substrate solution containing 3,3´,5,5´-tetramethylbenzidine (TMB) and H_2O_2 was added to initiate the reaction. The substrate solution was prepared using 40 mL of distilled water, 10 mL of 30% H_2O_2, and one TMB tablet (Sigma-Aldrich, USA). The reaction was terminated by adding 50 µL of 2 M H_2SO_4, after which absorbance was measured at 450 nm using a microplate reader. Blank wells containing all reagents except serum or mucus were used for background correction. Peroxidase activity was expressed as U mg^{-1}, with one unit defined as the amount of enzyme producing an absorbance change of 1.0 under the specified assay conditions.

G. Gene expression analysis

G.1 Tissue collection, RNA extraction, and cDNA synthesis

At the end of the 8-week feeding trial, six fish from each dietary treatment were randomly selected for gene expression analysis. Fish were deeply anesthetized with clove oil prior to tissue collection, and head kidney samples were aseptically excised. The expression of genes associated with growth and appetite regulation (ghrelin, galanin, ef-α, and npy-α), immune response (il-1β, mhc ii-α, nfκb, and tnf-α), and antioxidant defense (hsp70, gpx, and nrf2) was subsequently evaluated.

Approximately 25–50 mg of head kidney tissue from each fish was immediately transferred into a sterile microcentrifuge tube containing 500 µL of TRIzol reagent (Invitrogen, USA) and stored at −80 °C until RNA extraction. Total RNA was extracted using the PureLink™ RNA Mini Kit (Invitrogen, USA) according to the manufacturer's instructions. RNA concentration and purity were assessed using a NanoDrop™ One spectrophotometer (Thermo Scientific, Wilmington, USA). Subsequently, 1 µg of total RNA was reverse-transcribed into first-strand complementary DNA (cDNA) using the iScript™ cDNA Synthesis Kit (Bio-Rad, USA) following the manufacturer's protocol.

The head kidney was selected because it represents a major hematopoietic and immune organ in teleost fish and is involved in the integration of immune, endocrine, and physiological responses.

G.2 Quantitative real-time PCR

Quantitative real-time PCR was performed using a CFX Connect™ Real-Time PCR Detection System (Bio-Rad, USA) following the procedure described by Van Doan et al. (2026), with minor modifications. Each reaction was conducted in a final volume of 10 µL containing 2 µL of cDNA template (250 ng), 2 µL of gene-specific primer mixture (4 µM), 5 µL of 2× Universal SYBR Green Supermix (Bio-Rad, USA), and 1 µL of DNase-free water.

The amplification program consisted of an initial denaturation at 95 °C for 30 s, followed by 40 cycles of denaturation at 95 °C for 15 s and annealing/extension at 60 °C for 30 s. Following amplification, melt-curve analysis was performed to verify the specificity of the PCR products, with sequential steps at 95 °C for 15 s, 60 °C for 60 s, and 95 °C for 15 s. All reactions were performed in triplicate.

Relative transcript abundance was determined using the $2^{\wedge-\Delta\Delta Ct}$ method (Livak and Schmittgen, 2001). β-actin was used as the reference gene for normalization after confirming that its expression remained stable across the experimental treatments. Relative expression values for each target gene were calculated from comparative threshold cycle (Ct) values and expressed relative to the control treatment.

H. Statistical analysis

Data were initially examined for normality using the Kolmogorov–Smirnov test and for homogeneity of variance before statistical comparisons. Percentage data were subjected to arcsine square-root transformation when necessary to satisfy the assumptions of parametric analysis; however, untransformed values are presented in the tables and figures to facilitate interpretation. Differences among dietary treatments were evaluated using one-way analysis of variance (ANOVA). When a significant treatment effect was detected, means were compared using Duncan's multiple range test. The experimental tank was considered the statistical unit for growth performance and other tank-level measurements. All statistical analyses were performed using SAS software (SAS, 2003). Data are presented as mean ± standard error (SE), unless otherwise specified, and statistical significance was accepted at $P < 0.05$.

III. Results and Discussion

The effects of dietary cricket (*Acheta domesticus*) powder supplementation on the growth performance, feed utilization, and survival of Nile tilapia cultured under biofloc conditions are presented in Table 2. Initial body weight was comparable among all dietary treatments, ranging from 14.87 to 14.90 g. Dietary cricket powder significantly influenced final weight (FW),

weight gain (WG), and specific growth rate (SGR) ($P < 0.05$).

Fish fed the CP150 diet exhibited the highest FW (95.70 ± 0.23 g) and WG (80.80 ± 0.29 g), with both values being significantly higher than those recorded in the CP0 and CP225 groups ($P < 0.05$). However, the CP150 group did not differ significantly from the CP25 and CP75 groups for FW or WG. Fish receiving CP75 also showed relatively high FW (93.37 ± 2.25 g) and WG (78.48 ± 2.24 g), whereas the lowest values for both parameters were observed in fish fed the highest cricket powder inclusion level (CP225; 88.33 ± 3.83 and 72.47 ± 3.84 g, respectively).

A similar response was observed for SGR. The highest SGR was recorded in the CP150 group (3.10 ± 0.01% day^{-1}), which was significantly higher than that of the CP225 group (2.97 ± 0.07% day^{-1}; $P < 0.05$), but did not differ significantly from CP0, CP25, or CP75. In contrast, FCR was not significantly affected by dietary cricket powder inclusion, with values ranging from 1.03 ± 0.07 to 1.08 ± 0.05. Survival rate was likewise unaffected by dietary treatment, remaining high across all groups (90.00–96.67%).

Dietary cricket (*Acheta domesticus*) powder significantly influenced the growth performance of Nile tilapia cultured under biofloc conditions, with the most favorable responses observed at moderate inclusion levels. Fish fed CP150 exhibited the highest final weight, weight gain, and SGR, although these responses were generally comparable with those of CP25 and CP75, whereas growth declined at CP225; in contrast, FCR and survival remained unaffected across treatments. These findings suggest a non-linear response to cricket powder, with moderate inclusion supporting better growth than the highest level tested. Similar responses have been reported in tilapia: field cricket (*Gryllus bimaculatus*) meal could replace up to 50% of fishmeal in hybrid red tilapia without compromising growth or feed utilization, whereas higher replacement levels reduced performance (Hanan et al., 2022). In Nile tilapia fry, Perera, A. and Bhujel, R. (2021)likewise reported improved growth and feed utilization with increasing field cricket meal replacement up to approximately 80%, followed by reduced performance at complete replacement. Studies using *A. domesticus* specifically have also demonstrated that its suitability depends strongly on dietary inclusion level (Perera, A.D. and Bhujel, R.C., 2021). Differences among studies may reflect fish species and developmental stage, insect species and age, processing conditions, dietary formulation, and the proportion of conventional protein replaced; notably, the developmental stage of *A. domesticus* can substantially affect its protein, lipid, chitin, and protein-digestibility characteristics. The favorable growth at moderate inclusion levels may therefore be related to the nutritional contribution of cricket protein and other nutrients, whereas the reduced response at CP225 could partly reflect increased chitin intake or changes in nutrient and amino acid availability. High dietary chitin has been associated with reduced protein digestibility and growth in tilapia, although this mechanism was not directly examined in the present study (Eggink et al., 2022). The biofloc environment may additionally have provided supplementary microbial nutrients, contributing to efficient feed utilization across treatments. Notably, the improved growth at CP75–CP150 coincided with enhanced expression of igf1, igf2, and galanin in the present study, suggesting that moderate cricket powder inclusion may support growth through both nutritional and growth-regulatory mechanisms.

Table 2 Growth performances and feed utilization of the Nile tilapia fed different levels of dietary insect powder (CP). Different letter in a row denotes significant difference ($P<0.05$). Values are presented as the mean ± SE.

	CP0	CP25	CP75	CP150	CP225
IW (g)	14.87 ± 0.10	14.88 ± 0.03	14.88 ± 0.08	14.90 ± 0.00	14.87 ± 0.03
FW (g)	91.60 ± 1.31^{bc}	91.97 ± 1.35^{abc}	93.37 ± 2.25^{ab}	95.70 ± 0.23^{a}	88.33 ± 3.83^{c}
WG (g)	76.73 ± 1.23^{bc}	77.08 ± 1.32^{abc}	78.48 ± 2.24^{ab}	80.80 ± 0.29^{a}	72.47 ± 3.84^{c}
SGR	3.03 ± 0.02^{ab}	3.03 ± 0.02^{ab}	3.06 ± 0.04^{ab}	3.10 ± 0.01^{a}	2.97 ± 0.07^{b}
FCR	1.08 ± 0.01	1.08 ± 0.05	1.03 ± 0.07	1.06 ± 0.02	1.07 ± 0.03
SR (%)	96.67 ± 5.77	96.67 ± 5.77	96.67 ± 5.77	96.67 ± 5.77	90.00 ± 5.00

Data assigned with different letter denote significant difference in a row ($P < 0.05$). IW = Initial weight (g); WG = Weight gain (g); SGR = Specific growth rate (%); FCR = Feed conversion ratio; SR = Survival rate (%).

The effects of dietary cricket (*Acheta domesticus*) powder on skin mucus immune parameters of Nile tilapia after the 8-week feeding trial are presented in Table 3. Dietary cricket powder significantly affected both skin mucus lysozyme activity (SMLA) and skin mucus peroxidase activity (SMPA) ($P < 0.05$).

Skin mucus lysozyme activity was significantly enhanced by dietary cricket powder supplementation. Fish fed the CP75 and CP150 diets exhibited the highest SMLA values (1.98 ± 0.08 and 1.83 ± 0.09 μg mL^{-1}, respectively), with no significant difference between these two treatments ($P > 0.05$). Both groups showed significantly higher lysozyme activity than the CP0, CP25, and CP225 groups ($P < 0.05$). The CP25 and CP225 groups exhibited intermediate values of 1.77 ± 0.04 and 1.64 ± 0.09 μg mL^{-1}, respectively, which were significantly higher than that of the control group (0.86 ± 0.06 μg mL^{-1}).

Skin mucus peroxidase activity also differed significantly among dietary treatments ($P < 0.05$). According to the superscript groupings reported in Table 3, the CP25 group (0.27 ± 0.08 μg mL^{-1}) differed significantly from all other treatments. The CP75, CP150, and CP225 groups, with values of 0.37 ± 0.06, 0.39 ± 0.07, and 0.24 ± 0.09 μg mL^{-1}, respectively, did not differ significantly from one another but were significantly higher than the CP0 group (0.19 ± 0.06 μg mL^{-1}).

Table 3 Skin mucus immune parameters of Nile tilapia juveniles fed diets containing graded levels of cricket powder (CP) for 8 weeks. Values are presented as mean ± SE.

	CP0	CP25	CP75	CP150	CP225
SMLA	0.86 ± 0.06^{c}	1.77 ± 0.04^{b}	1.98 ± 0.08^{a}	1.83 ± 0.09^{a}	1.64 ± 0.09^{b}
SMPA	0.19 ± 0.06^{c}	0.27 ± 0.08^{a}	0.37 ± 0.06^{b}	0.39 ± 0.07^{b}	0.24 ± 0.09^{b}

SMLA: Skin mucus lysozyme activity (μg mL^{-1});
SMPA: Skin mucus peroxidase activity (μg mL^{-1}).
Different superscript letters within the same row indicate significant differences among treatments ($P < 0.05$), based on one-way ANOVA followed by Duncan's multiple range test ($n = 9$).

Dietary cricket (*Acheta domesticus*) powder enhanced the skin mucosal immune response of Nile tilapia, as evidenced by increased lysozyme and peroxidase activities, with the most pronounced responses generally observed at moderate inclusion levels, particularly CP75–CP150. This finding supports growing evidence that insect-derived ingredients can exert immunomodulatory effects in fish, including enhancement of mucosal defenses. A recent review identified insect meal as a promising functional ingredient for improving fish mucosal immunity, while meta-analytical evidence indicates that insect-meal supplementation can enhance innate immune responses, including lysozyme activity, although responses vary with inclusion level, fish species, and dietary composition (Chen et al., 2024; Islam et al., 2024). The increased lysozyme activity observed here is particularly relevant because lysozyme is a major component of fish innate mucosal defense, contributing to bacterial lysis and activation of other immune mechanisms (Saurabh and Sahoo, 2008). The immunostimulatory effect of cricket powder may partly be associated with chitin and other bioactive constituents present in the insect exoskeleton, as moderate dietary chitin can stimulate innate immune functions in fish (Loh et al., 2020). However, the absence of a further increase at CP225 suggests a non-linear response, consistent with a recent meta-analysis showing that intermediate insect-meal replacement produced stronger immune responses than very high replacement levels (Chen et al., 2024). Thus, moderate dietary inclusion of *A. domesticus* powder may strengthen the first-line mucosal defense of Nile tilapia through stimulation of lysozyme- and peroxidase-mediated innate immunity, although the specific contribution of chitin or other cricket-derived bioactive compounds requires further investigation.

The effects of dietary cricket (*Acheta domesticus*) powder on the serum immune responses of Nile tilapia after the 8-week feeding period are presented in Table 4. Both serum lysozyme (SL) and serum peroxidase (SP) activities were significantly affected by dietary cricket powder inclusion ($P < 0.05$).

Serum lysozyme activity increased markedly in fish receiving cricket powder compared with the control group. The highest values were recorded in the CP75 and CP150 groups (12.89 ± 0.29 and 11.78 ± 0.44 μg mL^{-1}, respectively), with no significant difference between these treatments ($P > 0.05$). Both groups exhibited significantly higher lysozyme activity than the CP0, CP25, and CP225 groups ($P < 0.05$). Fish fed CP25 and CP225 showed intermediate activities of 10.76 ± 0.25 and 9.75 ± 0.61 μg mL^{-1}, respectively, which were significantly higher than that of the CP0 group (7.61 ± 0.18 μg mL^{-1}).

A similar response pattern was observed for serum peroxidase activity. The highest SP activities were detected in fish fed CP75 (0.45 ± 0.07 μg mL^{-1}) and CP150 (0.41 ± 0.09 μg mL^{-1}), with no significant difference between these treatments ($P > 0.05$). The CP25 and CP225 groups showed intermediate values of 0.38 ± 0.02 and 0.33 ± 0.09 μg mL^{-1}, respectively, whereas the lowest activity was observed in the CP0 group (0.28 ± 0.02 μg mL^{-1}).

Table 4 Serum immune response of Nile tilapia juveniles fed diets containing graded levels of cricket powder (CP) for 8 weeks. Values are presented as mean ± SE.

	CP0	CP25	CP75	CP150	CP225
SL	7.61 ± 0.18^{c}	10.76 ± 0.25^{b}	12.89 ± 0.29^{a}	11.78 ± 0.44^{a}	9.75 ± 0.61^{b}
SP	0.28 ± 0.02^{c}	0.38 ± 0.02^{b}	0.45 ± 0.07^{a}	0.41 ± 0.09^{a}	0.33 ± 0.09^{b}

SL: Serum lysozyme activity (μg mL^{-1});
SP: Serum peroxidase activity (μg mL^{-1});
Different superscript letters within the same row indicate significant differences among treatments ($P < 0.05$), based on one-way ANOVA followed by Duncan's multiple range test ($n = 9$).

Dietary cricket (*Acheta domesticus*) powder significantly enhanced the systemic innate immune response of Nile tilapia, as reflected by increased serum lysozyme and peroxidase activities, with the strongest responses observed at CP75–CP150. Similar immunostimulatory effects of insect-derived ingredients have been reported in fish; for example, superworm (*Zophobas morio*) meal increased lysozyme activity in Nile tilapia, while a recent meta-analysis demonstrated that moderate insect-meal replacement generally elicited stronger innate immune responses than very high replacement levels (Chen et al., 2024). More specifically, dietary house cricket (*A. domesticus*) meal has recently been shown to enhance lysozyme activity in pangasius, supporting the immunomodulatory potential of this cricket species (Ardra et al., 2026). Nevertheless, responses appear to depend on fish species and dietary inclusion level, as cricket meal did not significantly affect serum lysozyme or myeloperoxidase activities in juvenile olive flounder (Jeong et al., 2021). Such differences may arise from variation in insect species, processing methods, dietary formulation, replacement level, fish species, and physiological status. The enhanced serum immune responses observed in the present study may partly be associated with chitin and other bioactive components of cricket powder that can modulate innate immune function; indeed, meta-analytical evidence indicates an overall positive effect of insect meals on fish lysozyme activity (Elieh Ali Komi et al., 2018). The weaker responses at CP225 further suggest a non-linear immunomodulatory effect, whereby moderate cricket powder inclusion may stimulate humoral defenses more effectively than excessive inclusion. Together with the enhanced skin mucus responses, these findings indicate that CP75–CP150 may strengthen both mucosal and systemic innate immunity in Nile tilapia.

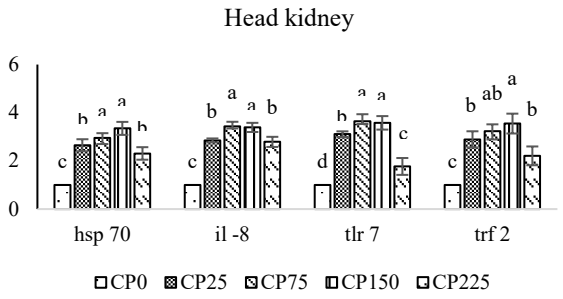


Fig. 1 The figure shows examined immune-related gene expression profiles across all five diets.

Dietary cricket (*Acheta domesticus*) powder significantly modulated the expression of immune- and stress-related genes in the head kidney of Nile tilapia (Fig. 1). Overall, the transcriptional responses showed a dose-dependent pattern, with intermediate cricket powder inclusion levels generally producing greater upregulation than the control and the highest inclusion level.

The expression of hsp70 increased progressively with increasing cricket powder inclusion up to CP150. The highest transcript level was observed in the CP150 group, which was significantly higher than those in the CP0 and CP225 groups ($P < 0.05$), while CP25 and CP75 showed intermediate expression. Similarly, il-8 expression was significantly elevated by dietary cricket powder, with CP75 and CP150 exhibiting the highest expression levels. These groups were significantly higher than CP0, whereas expression declined in the CP225 group.

A pronounced treatment response was also observed for tlr7. Expression increased substantially from CP0 to CP25 and reached the highest levels in the CP75 and CP150 groups, which did not differ significantly from each other. In contrast, tlr7 expression decreased markedly at the highest cricket powder inclusion level (CP225), although it remained above that of the control. The expression pattern of trf2 was broadly similar, increasing with cricket powder supplementation and reaching its highest level in CP150. The CP225 treatment showed lower trf2 expression than CP150.

Dietary cricket (*Acheta domesticus*) powder markedly modulated immune- and stress-related gene expression in the head kidney of Nile tilapia, with the strongest transcriptional responses generally observed at CP75–CP150, whereas expression declined at CP225. The upregulation of hsp70, il-8, and tlr7 suggests that moderate cricket powder inclusion may enhance cellular stress protection and innate immune signaling, consistent with reports that insect-based ingredients can modulate immune-related gene expression and innate defense mechanisms in fish (Abdel-Latif et al., 2020; Henry et al., 2018). In particular, insect-derived chitin and its derivatives have been proposed as important immunomodulatory components capable of interacting with pattern-recognition receptors and stimulating downstream inflammatory and defense pathways (Bouanga et al., 2026; Tor.wattanaphol et al., 2026). Increased tlr7 expression may therefore indicate enhanced recognition and activation of innate immune signaling (Pani et al., 2025), while elevated il-8 expression is consistent with greater chemokine-mediated recruitment and activity of immune cells (Reyes-Cerpa et al., 2012). Similarly, the increased hsp70 expression, particularly at CP150, may reflect enhanced cellular capacity to respond to physiological stress and maintain protein homeostasis. The decline in expression at CP225 indicates that these effects were not proportional to cricket powder inclusion and suggests that excessive inclusion may attenuate the stimulatory response, potentially through changes in nutrient availability or increased intake of poorly digestible chitin. Overall, the transcriptional responses correspond well with the enhanced serum and skin mucus immune parameters observed at CP75–CP150, supporting the

potential of moderate A. domesticus powder inclusion to strengthen innate immune and stress-response pathways in Nile tilapia.

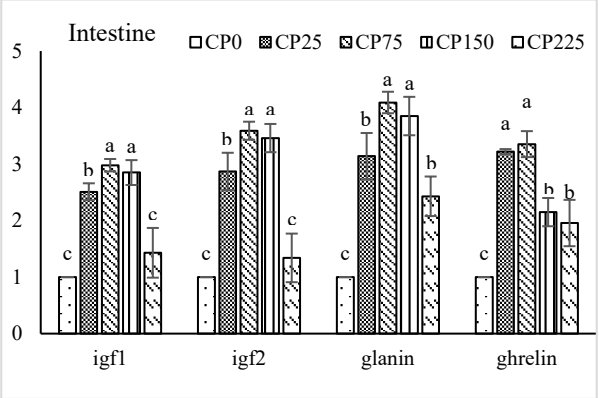


Fig. 2 The figure shows examined growth-related gene expression profiles across all five diets.

The effects of dietary cricket (*Acheta domesticus*) powder on the intestinal expression of growth- and appetite-related genes in Nile tilapia are presented in Fig. 2. Dietary cricket powder significantly influenced the relative expression of igf1, igf2, galanin, and ghrelin ($P < 0.05$), with distinct responses observed among inclusion levels.

The expression of igf1 was elevated in fish receiving intermediate levels of cricket powder, with the highest expression observed in the CP75 group, followed closely by CP150. Both treatments exhibited greater expression than the control, whereas igf1 expression declined markedly in the CP225 group. A comparable pattern was observed for igf2, with the highest transcript abundance recorded in CP75 and CP150, while CP225 exhibited substantially lower expression. For galanin, expression increased markedly in response to cricket powder supplementation, reaching the highest levels in the CP75 and CP150 groups. In contrast, CP225 showed significantly lower galanin expression than the intermediate inclusion groups.

The expression of ghrelin also responded significantly to dietary treatment. The highest transcript level was observed in the CP75 group, whereas expression was significantly reduced in the CP150 and CP225 groups.

Dietary cricket (*Acheta domesticus*) powder significantly modulated intestinal growth- and appetite-related gene expression in Nile tilapia, with igf1, igf2, and galanin generally showing the strongest responses at CP75–CP150, whereas expression declined at CP225. This transcriptional pattern broadly corresponded with the growth results, in which intermediate cricket powder inclusion supported greater weight gain than the highest inclusion level. The response of igf1 is particularly relevant because the GH–IGF axis is a major regulator of somatic growth and nutrient metabolism in fish. A recent study using A. domesticus meal in blue tilapia similarly demonstrated that dietary cricket meal altered the somatotropic axis, with moderate replacement upregulating igf1, whereas higher replacement levels caused downregulation; these changes were associated with differences in growth performance and dietary nutrient balance. Comparable modulation of growth- and appetite-related genes has also been reported with other insect-based diets, including changes in igf1, igf2, and ghrelin expression in zebrafish and sturgeon. The enhanced igf1 and igf2 expression at moderate inclusion levels may therefore reflect improved nutrient availability and activation of growth-regulatory pathways, while increased galanin and ghrelin expression indicates modulation of neuroendocrine pathways involved in appetite and energy homeostasis. However, the decline in these responses at CP225 suggests that excessive cricket powder inclusion may alter nutrient availability or dietary balance, thereby attenuating endocrine signaling. Overall, the coordinated transcriptional responses at CP75–CP150 provide molecular support for the favorable growth observed at moderate cricket powder inclusion, although further studies measuring feed intake, nutrient digestibility, circulating hormones, and tissue-specific protein expression are required to establish the underlying mechanisms.

IV. Conclusions

The present study demonstrates that dietary cricket (Acheta domesticus) powder can be incorporated as a functional feed ingredient for Nile tilapia cultured under biofloc conditions, with responses strongly dependent on inclusion level. Moderate inclusion, particularly at 75–150 g kg^{-1} diet, supported favorable growth performance and enhanced both mucosal and systemic innate immune responses, as evidenced by increased skin mucus and serum lysozyme and peroxidase activities. These physiological responses were further supported by the upregulation of immune- and stress-related genes in the head kidney and growth- and appetite-related genes in the intestine. In contrast, increasing cricket powder to 225 g kg^{-1} provided no additional benefit and generally attenuated growth, immune, and transcriptional responses. Overall, the findings indicate that 75–150 g kg^{-1} dietary A. domesticus powder represents a promising inclusion range for supporting growth and health of Nile tilapia in biofloc systems. Further studies should evaluate nutrient digestibility, intestinal health, disease resistance, and economic feasibility to confirm its practical application in commercial tilapia production.

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Research Trends and Gaps in Court Interpreting Research in Japan: A Systematic Review

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Abstract— **As the foreign population in Japan continues to grow, ensuring accurate and neutral court interpreting plays an increasingly vital role in safeguarding human rights and achieving judicial fairness. This study presents a systematic review of 26 academic papers retrieved from the CiNii Research database using the Japanese keyword "court interpreting(法廷通訳)" to examine publication trends, the languages covered in previous studies, and research topics.**

An analysis of publication trends indicates a notable increase in publications during the 2010s, a trend largely prompted by the introduction of the Lay Judge System (Saiban-in Seido) in 2009, which directed academic attention toward comprehension by ordinary citizens. However, the linguistic distribution shows a certain imbalance, with English and general overviews occupying a major portion of the literature. Despite judicial statistics highlighting a high demand for languages such as Vietnamese and Nepalese, specialized linguistic research focusing on these high-demand languages remains relatively limited.

Regarding research content, institutional issues were the dominant focus of previous studies, particularly interpreter certification, working conditions, and the roles of court interpreters. In contrast, only a few studies have examined specific linguistic phenomena, such as translation errors involving negative interrogative sentences, or emerging technologies such as AI-assisted interpreting.

These findings highlight several areas that deserve greater attention in future research. While institutional issues and English-language interpreting have received considerable attention, greater emphasis could be placed on high-demand languages, specific linguistic phenomena in court interpreting, and the potential application of AI to support interpreting practice. Ultimately, expanding research in these underexplored areas may contribute to improving linguistic support in judicial settings and, more broadly, support the development of multicultural coexistence and social innovation in increasingly diverse local communities.

Keywords— court interpreting, systematic review, research trends, negative interrogative sentences

I. Introduction

In recent years, the number of foreign residents in Japan has continued to increase. According to the latest statistics from the Immigration Services Agency of Japan, the number of foreign residents reached 4,125,395 at the end of 2025. [1] In addition, 18,442 foreign nationals were subject to deportation or departure order procedures in 2025. These figures show that an increasing number of foreign residents are involved in legal procedures in Japan.

This increase has also led to a greater need for language support in the judicial system. According to the Supreme Court of Japan (2026), 4,649 foreign defendants had court interpreters in criminal cases completed at district courts and summary courts in 2024. These defendants came from 81 countries. [2] Accurate and neutral court interpreting is therefore important for protecting the human rights of foreign defendants and ensuring fair trials. [3]

In this study, “court interpreting” mainly refers to interpreting services provided in courts. Court interpreters interpret the statements of foreign defendants into Japanese and the statements of judges, prosecutors, defense attorneys, and witnesses into foreign languages. They therefore play an important role in communication between foreign defendants and other participants in court proceedings. [4]

As of April 1, 2025, Japan had 3,244 registered court interpreters who could provide interpreting in 61 languages. [2] However, the number of court interpreters has been decreasing while the demand for interpreting services is increasing. [5] Japan also does not have a nationwide qualification examination or a unified training system for court interpreters. As a result, the skills and training of interpreters may vary between regions.

Problems related to the quality of court interpreting have also been reported. For example, The *Nihon Keizai Shimbun* reported on October 7, 2024, that a Filipino woman in Matsusaka City was falsely convicted in a drug case because of a translation error in court interpreting at the Tsu District Court. [6] This case shows that translation errors can have serious effects on trial outcomes and may reduce trust in the judicial system.

Based on this background, this study aims to organize and analyze previous studies on court interpreting in Japan and identify their research trends and research challenges. A systematic review was conducted with a focus on the court interpreter system, interpreter training, and problems related to interpreting.

II. Research methods

This study used the CiNii Research database to collect academic papers on court interpreting. The search was conducted in June 2026 using the Japanese keyword “court interpreting(法廷通訳).” A total of 109 papers were identified. After excluding short reports, papers for which the full text was unavailable,

and papers that were not related to the purpose of this study, 26 previous studies were selected for analysis.

These studies were analyzed in terms of publication trends, target languages, research topics, research methods, and research challenges.

III. Results and Discussion

A. Research Trends

The analysis of 26 previous studies showed that the number of studies increased clearly during the 2010s. One important reason was the introduction of the Lay Judge System (Saiban-in Seido) in 2009. As citizens began to participate in criminal trials, the accuracy and objectivity of court interpreting became more important. Researchers therefore began to pay greater attention to the quality and role of court interpreters.

In recent years, research trends have moved toward the development of a more stable court interpreter system and the use of new technologies. In particular, some studies have discussed AI-assisted interpreting using technologies such as large language models, automatic speech recognition, and machine translation. These technologies are not considered replacements for human interpreters. Instead, they are discussed as tools to support interpreters, reduce their workload, and possibly reduce translation errors. [7]

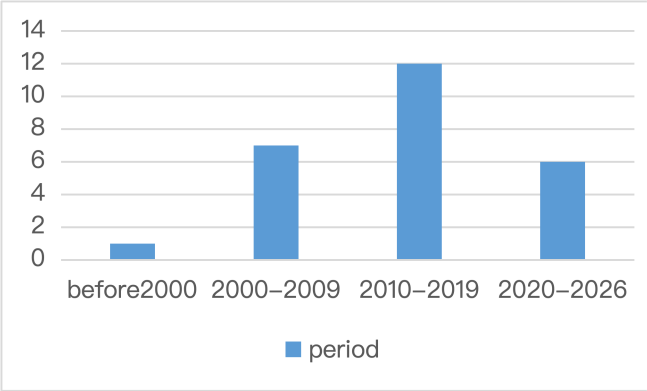


Fig. 1 Publication Trends in Research Papers

B. Research Target Languages

The 26 studies showed a clear imbalance in the languages studied. English was the most common target language, with 12 studies, followed by studies that did not focus on a specific language, with 7 studies. Spanish was studied in 4 papers, Chinese in 3, and Thai, Tagalog, and Korean each in 2. Other languages were covered by only one study each.

This distribution does not fully match the language needs of judicial practice. According to the Supreme Court of Japan (2026), criminal cases requiring interpreters involved defendants from 81 countries. [2] However, no specialized studies were found on Vietnamese or Nepalese, despite the high demand for these languages.

This suggests a gap between practical needs and academic research. Future studies should therefore examine a wider range of languages, especially Asian languages that are increasingly needed in Japanese courts.

C. Research Focus And Research Gap

The analysis of previous studies shows that most research has focused on macro-level and meso-level issues. At the macro-level, 14 studies discussed issues related to the court interpreting system and working environment, such as interpreter certification, working conditions, and support for interpreters. At the meso-level, 11 studies examined communication in court, including the roles of court interpreters and the effects of interpreting on lay judges.

In contrast, only a small number of studies focused on the micro-level analysis of actual language use in court. Among the 26 studies, only two examined specific expressions or sentence structures. One focused on direct and indirect speech, while the other examined the translation of negative interrogative sentences, which can easily cause translation errors. In addition, only one recent study discussed the use of AI tools.

These findings indicate a clear research gap. Previous studies have mainly discussed how to improve the court interpreting system and how court interpreters should perform their roles. However, detailed studies of how specific linguistic structures cause translation errors remain limited. Research on the practical use of AI-assisted interpreting is also still at an early stage. [8]

Future court interpreting research should therefore move beyond general institutional discussions and pay more attention to micro-level linguistic problems. It should also examine the possibilities and limitations of AI-assisted interpreting and develop practical measures to reduce translation errors.

IV. Conclusions

This study systematically reviewed 26 previous studies on court interpreting in Japan using the CiNii Research database. Three main findings were identified.

First, research increased during the 2010s, partly because of the introduction of the Lay Judge System in 2009. Recent research trends have shifted toward improving the court interpreter system and exploring AI-assisted interpreting.

Second, the target languages of previous studies were highly unbalanced. English was the most common target language, while languages with increasing practical demand, such as Vietnamese and Nepalese, received little research attention. This shows a gap between practical needs and academic research.

Third, previous studies mainly focused on macro-level institutional issues and meso-level communication issues. Micro-level research on specific linguistic structures and translation errors remains limited. Research on AI-assisted interpreting is also still limited.

Based on these findings, future research should expand its focus to languages that are highly needed in actual court settings. It should also examine specific linguistic structures that may cause translation errors and explore the possibilities and limitations of AI-assisted interpreting. These research directions may contribute to better language support for foreign defendants and greater fairness in the judicial system.

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Appendix Table 1 Related Research Papers

Year	Author(s)	Journal / Institution	Title	Language(s)	Main Keywords
2026	Chizuko Matsuoka; Qingyang Han	Bulletin of Organization for International Education and Research Mie University	The Potential of AI in Court Interpreting: A Focus on Its Supplementary Role	None specified	AI tools; accuracy; role of interpreters; translation errors
2026	Fumie Michigami; Chisato Murakami	Language Policy	Language Attitudes toward Investigative Interpreting as Seen in YouTube Comments	Tagalog	translation errors; language attitudes; Tagalog; social media
2024	Tomoko Tamura	Interpreting and Translation Studies	An Analysis of “Power Relations” and “Professionalization” in Establishing a Judicial Interpreting System: Implications for Japan Based on Interviews with Court Interpreters in Boston	English	professionalization of court interpreting; qualification system for court interpreters
2023	Sachi Takahata; Shizuka Sakamaki; Naoka Mori; Kahoru Mizuno	Shizuoka University of Art and Culture Court Interpreting Research Group	2022 Survey Report on the Work of Court Interpreters	None specified	reducing interpreter burden; institutional considerations; proposals for improvement; remuneration
2022	Jihyun Kim	Waseda University (Doctoral Dissertation)	Revisiting the Interpreter’s Role in the Bilingual Courtroom: Normative Roles, Users’ Expectations, and the Status Quo of Court Interpreters in Japan	English	role of interpreters; system; shared responsibility
2021	Bencharat Sukaswi	Interpreting and Translation Studies	The Treatment of Direct Speech in Court Interpreting from Japanese into Thai	Thai	treatment of speech styles; translation methods; direct speech; indirect speech
2017	Sachi Takahata; Kahoru Mizuno; Shizuka Sakamaki; Naoka Mori; Mamoru Tsuda	Shizuoka University Court Interpreting Research Group	2017 Survey Report on the Work of Court Interpreters	None specified	reducing interpreter burden; institutional considerations; proposals for improvement; translation errors
2017	Yakov Marshalenko	Nagoya University of Foreign Studies (Doctoral Dissertation)	English as a Lingua Franca: A Study of Language Choice and Interpreting Practice in Criminal Trials Requiring Interpreting	English	—
2017	Yakov E. Marshalenko	Interpreting and Translation Studies	Current Situation and Issues Regarding Relationships between Court Interpreters and the Three Legal Professions	English	qualification system; relationships with the three legal professions
2016	Kahoru Mizuno	Interpreting and Translation Studies	Challenges in Translation in Court Interpreting: A Study of Interpreting Focusing on Negative Interrogative Sentences	Korean; Chinese; English; Tagalog	negative interrogative sentences; translation
2015	Michiyo Ishida	Shizuoka University Educational Research	Accuracy Required in Court Interpreting and Practice in the Field	Korean	cultural differences; accuracy; linguistic equivalence; protection of defendants’ rights
2013	Sachi Takahata; Kahoru Mizuno; Mamoru Tsuda; Shizuka Sakamaki; Naoka Mori	Shizuoka University Court Interpreting Research Group	2012 Survey Report on the Work of Court Interpreters	None specified	reducing interpreter burden; institutional considerations; proposals for improvement; remuneration
2013	Masako Mouri	Research Journal	Court Interpreters from the Perspective of Their Relationships with Clients: A Study of the Court Interpreter’s Position in the Courtroom	None specified	participation framework; footing; communication accommodation theory; gatekeeper
2012	Rika Yoshida	Interpreting and Translation Studies	Court Interpreting and Language Ideology	English; Spanish; Japan	communication theory; metapragmatics; ideology

Year	Author(s)	Journal / Institution	Title	Language(s)	Main Keywords
				ese dialects	
2011	Sachiko Nakamura	*Humanities and Culture*, Bulletin of the Institute of Human Culture, Aichi Gakuin University	Foreign Criminal Cases and Interpreting in Lay Judge Trials: The Expected Role of Court Interpreters and the Reality	English	Lay Judge System; role of interpreters; mock trial
2011	Makiko Mizuno	Journal of Kinjo Gakuin University, Social Sciences	Title unavailable in the source (listed as "2")	English	Lay Judge System; influence on impressions; interpreting gaps
2011	Rika Yoshida	Japanese Language and Society	Courtroom Discourse Practices and Court Interpreting: A Text Woven from Pragmatics and Metapragmatics	Spanish	Lay Judge System; metapragmatics; role of interpreters; mock trial
2010	Makiko Mizuno; Sachiko Nakamura	Journal of Kinjo Gakuin University, Social Sciences	Fatigue and Stress among Court Interpreters in Lay Judge Trials Requiring Interpreting	English	Lay Judge System; mock courtroom; fatigue and stress
2008	Rika Yoshida	Interpreting and Translation Studies	The Footing of Court Interpreters	English	role of interpreters (responsibility); factors that make interpreting difficult
2007	Rika Yoshida	Interpreting Studies	Interpreting Courtroom Interaction: Rethinking the Role of Interpreters	English; Spanish; Persian; Indonesian; Chinese	speech acts; role of interpreters; conduit model; intercultural communication; interaction
2007	Suzumi Nishimatsu	Interpreting Studies	"Court Interpreters" in Japan and the United States	None specified	changes in the legal background and certification systems; institutionalization of the court interpreter certification examination
2006	Sadao Oyama	Interpreting Studies	Court Interpreting from the Perspectives of Trials and Defense Activities	None specified	criminal cases involving foreign nationals; role of interpreters
2005	Hiromi Nagao	*Women's Studies Review*	A Murder Case Involving a Thai Woman: The Reality of Court Interpreters	Thai	role of interpreters; qualification system
2001	Shigeo Akegi	Cultural Science Studies	The Two-Interpreter System in Court Interpreting: A Translation-Theoretical Study	Chinese; English	reducing psychological burden
2001	Yoko Nadamitsu	Intercultural Communication Studies	Problems Faced by Court Interpreters: How Should Cultural Differences Be Understood?	Spanish; English; Chinese; Portuguese	cultural differences; impression formation; accuracy; role of interpreters
1995	Teruhiko Kakuyama	Shudo Law Review	Problems in Court Interpreting and an Educational Program	English	qualification system; bilingual translation; proposals for improvement

Analysis of Transitive and Intransitive Verb Choice in Chinese-Japanese Courtroom Interpreting

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Abstract— **Accurate legal interpreting requires not only propositional accuracy but also careful control of grammatical form. Japanese frequently distinguishes intransitive, transitive, passive, and causative constructions, whereas Chinese often expresses comparable event structures through word order, unmarked result-state clauses, 把(ba-) and 被(bei-)constructions, resultative complements, aspect markers, and context. This pilot study examines whether first-language background is associated with different constructional choices in bidirectional Chinese-Japanese courtroom-style interpreting. Eight bilingual participants, four Japanese-L1 and four Chinese-L1 speakers, completed 12 controlled items. The findings show that both groups preferred state-oriented expressions in result-focused events, while the Chinese-L1 group more often made causation explicit in one critical item. These results suggest that transitivity choice reflects event construal and target-language preferences rather than simple one-to-one transfer.**

Keywords— court interpreting, Chinese-Japanese interpreting, transitivity, agency, responsibility

I. Introduction

Court interpreting is an essential part of multilingual access to justice. In Japan, interpreted communication is used in police interviews, prosecutor interviews, and criminal trials, and previous studies have pointed to continuing concerns about interpreter roles, monitoring, and inaccurate interpretation [1-3]. Small linguistic changes may also affect how testimony is understood [3,4].

Transitivity is particularly relevant to Chinese-Japanese interpreting because the two languages package event structure differently. Japanese has many intransitive-transitive verb pairs, such as aku/akeru (open) and wareru/waru (break), and also uses passive and causative constructions. Chinese often expresses similar meanings through unmarked state clauses, SVO order, ba- and bei-constructions, resultative complements, aspect markers, and contextual inference. Previous work also suggests that event type influences the choice of Japanese intransitive, transitive, and passive forms [5].

These alternatives are not semantically neutral in legal discourse. "The glass broke," "he broke the glass," and "the glass was broken" distribute attention differently across the result, the actor, and the causal relation.

Previous studies have examined courtroom interpreting quality and Japanese transitivity separately. Lee [3] showed that omitted subjects and other inexplicit expressions may create ambiguity in courtroom interpreting, while Sugimura [5] showed that event type influences the choice of Japanese intransitive, transitive, and passive forms. However, little research has examined these two issues together in Chinese-Japanese courtroom interpreting. In particular, it remains unclear whether interpreters with different first-language backgrounds make different grammatical choices when the source allows more than one possible construal, or whether those choices modify agency, causation, intentionality, and linguistic responsibility.

This pilot study therefore asks (1) how Japanese-L1 and Chinese-L1 interpreters differ in construction choice and (2) whether their choices preserve or modify agency, causation, intentionality, and linguistic responsibility. Eight bilingual participants completed a controlled task of 12 independent courtroom-style utterances.

II. Experimental

A. Participants

Eight bilingual participants took part in the pilot study. Four were native speakers of Japanese with advanced Chinese proficiency (HSK 5-6), and four were native speakers of Chinese with advanced Japanese proficiency (JLPT N1). Translation and interpreting experience varied, and the task was not designed as a test of certified professional court interpreters. The groups are referred to as Japanese-L1 (J1-J4) and Chinese-L1 (C1-C4).

Table 1. Participant groups

Group	L2	Background
Japanese-L1	HSK 5-6	Advanced Chinese; experience varied
Chinese-L1	JLPT N1	4-7 years of Japanese study; some written translation experience

B. Materials

The task contained 12 independent courtroom-style utterances: six Japanese-to-Chinese items and six Chinese-to-Japanese items. The materials were adapted from Chinese courtroom discourse and public materials related to the Sun Yang CAS hearing, then simplified to focus on construction choice rather than specialized legal terminology. The items formed six semantic pairs ranging from state descriptions to clearly human-caused events. When participants found an item unclear because some information was implicit or omitted, they were allowed to ask for limited contextual clarification.

Three representative items illustrate the design. Item 8 tested whether an implicit causal relation would be made more explicit: Shinzoku to no kōryū ga sukunaku, hikokunin no shinri jōtai wa ōkiku henka shimashita ka? (With limited contact with relatives, did the defendant's psychological state change greatly?). Item 10 tested treatment of a Japanese passive: Ketsueki sanpuru wa saishūteki ni genba ni nokosareta to iu koto desu ne. (So, the blood sample was finally left at the scene, right?). Item 11 tested explicit human agency: Anata ga tōji, chichioya o tsumazukasete, ano yō na jōtai ni shita no desu ne. (You caused your father to trip and put him in that condition, right?).

Table 2. Stimulus design

Pair	Main event type	Constructional issue
1	No clear agent	Completed event
2	State	Continuing state
3	Resulting state	State vs passive
4	Causal relation	Added causation
5	External intervention	Voice choice
6	Human-caused event	Agent and result

C. Procedure

Before the task, participants were told to imagine that they were working as interpreters in a Japanese courtroom. For Japanese source items, they were instructed to treat the utterance as spoken by a Japanese judge and interpret it for a Chinese-speaking witness. For Chinese source items, they were instructed to treat the utterance as spoken by a Chinese-speaking witness and interpret it for a Japanese judge.

Each source utterance was presented orally in Japanese or Chinese, and participants interpreted it into the other language. If they could not hear the utterance clearly, it was repeated. All test items were independent sentences and did not form a continuous story. If participants considered the meaning of an item ambiguous, they were allowed to ask for clarification. Clarification was provided in the same language as the source item: in Japanese for Japanese source items and in Chinese for Chinese source items.

All interpretations were audio-recorded with the participants' consent and were used as research data. The recordings were subsequently transcribed verbatim. Hesitations, pauses, self-corrections, repetitions, and other features of the participants' actual spoken production were retained in the transcripts.

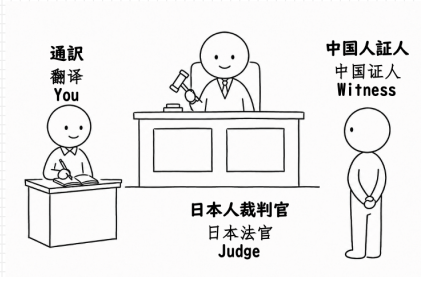


Fig. 1 Role Configuration Shown to Participants Before the Interpreting Task.

D. Coding and Analysis

The analysis focused on two levels. First, the grammatical construction selected in the target language was identified. Second, changes in agency, causation, intentionality, and linguistic responsibility were examined. Added rang/shi or suoyi where the Japanese source did not clearly express causation was treated as stronger causation; added guyi (intentionally) was treated as stronger intentionality. Japanese passives rendered as unmarked Chinese result-state clauses were treated as passive neutralization. Grammatical transitivity and semantic agency were analyzed separately.

Interpreting performance was also reviewed qualitatively using Lee's [6] three criteria: accuracy, target-language quality, and delivery. Because the sample was small and no independent second coding was conducted, the results are reported descriptively rather than with inferential statistics or reliability coefficients.

III. Results and Discussion

A.Japanese-L1 Group

The Japanese-L1 participants tended to use state-oriented expressions when the actor was backgrounded, but more agentive and causative expressions when a human actor was explicit.

1) Passive neutralization. In Item 10, the Japanese passive nokosareta (was left) was rendered by all four participants without Chinese bei. Examples such as xueyang zuizhong liu zai xianchang (the blood sample finally remained at the scene) shifted the focus from an implied external actor to the resulting state. This was coded as passive neutralization.

The propositional outcome was largely preserved, but the grammatical representation of external intervention was reduced. Because an unmarked Chinese result-state clause is natural in this context, this shift was not treated simply as a lexical error. Instead, it was coded as a constructional change that made the resulting state more explicit than the external actor.

2) Added causation. In Item 8, the Japanese source juxtaposed limited family contact and a change in the defendant's psychological state without an explicit causative marker. Most participants kept the two states separate, but one added suoyi (therefore), making the causal relation more explicit and thus strengthening causation.

3) Explicit agency and intentionality. Item 11 explicitly foregrounded "you" as the person who caused the father to trip. Participants generally preserved agency through ba, rang, and nongcheng (cause to become). One participant additionally used guyi (intentionally), which was not present in the source and therefore strengthened intentionality and potentially linguistic responsibility. Another participant produced the non-standard expression gei ni de fuqin diedao. Although

gei is not a standard causative marker in this construction, the following nongcheng still encoded a causal result. Agency and causation were therefore treated as preserved, while the grammatical form itself was treated as non-standard.

4) Transitivity without strong agency. In Item 12, participants mainly used the transitive ushinau (lose). Although grammatically transitive, "lose a job" represents the subject mainly as an affected participant rather than an intentional agent. The Chinese reflexive ziji (self) was also ambiguous, and several participants interpreted the troublemaker and the person losing the job as the same person.

5) Post-interviews. Japanese-L1 participants reported difficulties with culture-related expressions such as 环卫所 (sanitation office), four-character expressions such as 安身立命 (make a living), verb choice, and insufficient context. Some described learning Chinese event structure through patterns such as ba, shi, and jiang. They also found spoken interpreting harder than translation with written text, and rapid production sometimes led to errors. One Japanese-L1 participant with many years of interpreting experience identified Item 12 as ambiguous and noted that it could support multiple interpretations. The participant further explained that excessive clarification may sometimes lead the Japanese or Chinese side to question the appropriateness or faithfulness of the interpretation, adding that they had experienced such questioning on several occasions in the past.

B. Chinese-L1 Group

1) Stable state choice but unstable tense. Item 4 showed a consistent state-focused pattern. All four participants rendered Chinese liangzhe (was still on) with the Japanese intransitive tsuku, using forms such as tsuite iru or tsuite imashita; none used transitive tsukeru or a passive. However, some used present tense where the past was expected, showing stable voice choice but less stable tense marking.

2) Variation in transitivity and voice. Item 9 produced clear competition among 残る (remain), 残す (leave), 残せる (can leave), and 残される (be left). The Chinese liu zai xianchang did not determine one Japanese voice choice, so interpreters selected different event construals. One passive rendition also changed source permission into a completed event, reducing accuracy.

3) Stronger explicit causation. Item 8 showed the clearest group tendency. All four Chinese-L1 participants used shi or rang (cause/make) in their Chinese renditions. The causal relation was therefore more explicit than in the source. One rendition used rang ni juede (make you think), adding an experiencer and partly changing the meaning.

This was the most systematic causation-related pattern in the Chinese-L1 group. The Japanese source placed two situations next to each other without an overt causative marker, whereas the Chinese renditions encoded a cause-result relation grammatically. The shift was therefore analyzed as increased explicitness of causation rather than as a change in grammatical transitivity alone.

4) Explicit agency but unstable event representation. In Item 11, participants generally preserved the human actor with ba or rang. One rendition, ba fuqin bandao le (caused the father to fall), closely matched the source. Others replaced tsumazukaseru (cause to trip) with expressions meaning "remain in that condition" or "lie there." Thus, agency was relatively stable, while lexical and event representation were less stable.

5) Result-focused loss and learning background. In Item 12, participants varied between nakunaru (become lost/disappear), ushinau (lose), and the non-standard passive-like nakusareta. The ambiguity of ziji again influenced reference and causation. Post-interviews also showed difficulty with tense and legal terminology; some participants had studied Japanese transitive and intransitive verbs at school but no longer clearly remembered the rules.

6) Post-interviews. The Chinese-L1 participants reported somewhat different difficulties from the Japanese-L1 participants. They found specialized or context-specific terms difficult to interpret, including 讯问 (interrogation/questioning), 检查官 (inspector/examiner), and 副驾驶 (front passenger seat). They also reported difficulty in selecting corresponding verbs across Chinese and Japanese. One participant further questioned the ambiguity of Item 6, noting that 刀 could be rendered in Japanese as naifu (knife), hōchō(kitchen knife), or katana (blade/sword), and that these lexical choices could lead to different interpretations of the object and potentially different attributions of responsibility.

C. Cross-Group Comparison

The two groups did not show a simple Japanese-L1 = intransitive / Chinese-L1 = transitive contrast. Both groups used state-oriented expressions when the source foregrounded a state rather than an actor. The clearest descriptive group difference appeared in Item 8: only one Japanese-L1 participant explicitly strengthened causation, whereas all four Chinese-L1 participants used shi or rang. In Item 11, both groups generally preserved an explicit human actor, but Japanese-L1 renditions sometimes added intentionality, while Chinese-L1 renditions showed greater lexical instability in representing the caused event. Item 12 further confirmed that grammatical transitivity cannot be equated with semantic agency.

Overall, L1 background interacted with event type, target-language conventions, lexical access, and processing conditions.

These findings partly support previous work showing that event type influences transitivity choice [5]. However, the present data do not support a fixed L1-based preference for one grammatical voice. When an item primarily described a state, participants in both groups tended to preserve that state-focused construal. A clearer group difference emerged when the source allowed the causal relation to remain implicit, suggesting that L1 background may influence how interpreters resolve some underspecified causal relations, while target-language conventions remain important.

From a courtroom-interpreting perspective, these shifts matter because grammatical choices can change how explicitly an actor, causal relation, or intention is represented. This is consistent with Lee's [3] discussion of inexplicit courtroom language, in which interpreters may need to decide whether information left implicit in the source should be made explicit in the target language. The present results therefore suggest that evaluation of legal interpreting should consider not only propositional accuracy but also changes in event construal.

IV. Conclusions

This pilot study examined transitivity-related choices in bidirectional Chinese-Japanese courtroom-style interpreting. The findings indicate that interpreters did not mechanically map Chinese ba/bei structures onto Japanese transitive/passive forms or vice versa. Instead, choices depended strongly on whether an event was construed as a state, an externally caused result, or an explicitly human-caused action. Japanese-L1 participants frequently neutralized a Japanese passive when interpreting into Chinese, while Chinese-L1 participants showed a stronger tendency to make causation explicit in Item 8. Both groups generally preserved explicit human agency, although some renditions strengthened intentionality or changed the specific event meaning. Only two participants asked for clarification when they encountered potentially ambiguous items. Most participants interpreted the sentences according to their own understanding and did not appear to recognize that the ambiguity could influence the linguistic attribution of responsibility.

Because only eight participants were included and coding was conducted by one researcher, the results should be treated as descriptive. Future work should increase the sample, use independent coding, and test whether these linguistic shifts affect listeners' judgments of agency or responsibility. Even so, the present findings show that transitivity choice is a meaningful component of legal interpreting accuracy and should be considered in interpreter training.

Notes

1) The 12 items used in this study were developed on the basis of Sugimura's [5] classification, with particular reference to Categories 5–10. These categories represent human-induced events in which attention is directed to the result of an action.

2) The interpretations produced by the eight participants were transcribed, but are omitted here for reasons of space.

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Appendix

Interpreting Test Items

Pair	Event type	Japanese → Chinese	Chinese → Japanese
1	No clear agent	裁判所に着いたとき、裁判はもう始まっていましたか	我进去的时候，讯问已经结束了。
2	State	部屋に入ったとき、窓は開いていましたか。	我到现场的时候，房间里的灯还亮着。
3	Resulting state	当時、血液サンプルはまだ容器の中に残っていましたか。	当时那把刀还放在副驾驶座上。
4	Causal relation	親族との交流が少なく、被告人の心理状態は大きく変化しましたか。	我发现检查官的资质有问题以后，非常震惊。
5	External intervention	つまり、血液サンプルは最終的に現場に残されたということですね。	最后他们说，血样可以留在现场。
6	Human-caused event	あなたが当時、父親をつまずかせて、あのような状態にしたのですね。	受害人到环卫所吵闹，自己安身立命的工作都丢了。

A Study on Career Education in High Schools

-Focusing on High School Students Who Aspire to Become Teachers-

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Abstract— **IIn an era often referred to as the "100-Year Life" or the "VUCA Era," the concept and research surrounding career education are likely to become increasingly important going forward.In this study, we conducted a survey targeting students aspiring to become teachers.**

Keywords— Education,Career,

I. Introduction

The "High School Career Guidance Handbook" (Ministry of Education, Culture, Sports, Science and Technology, 2011) [(1)] strongly calls for "the promotion of career education that enables each individual to acquire 'life skills,' develop a clear sense of purpose—[omitted]—form a sound work ethic and professional outlook, and become self-reliant as members of society and professionals."

According to Shimomura (2008) [(2)], recent career development theories indicate that the meaning of "deciding" one's career path has changed significantly. He states, "Traditionally, it was sufficient to 'decide' one's career path at a single point in time—upon graduation from school. Today, however, simply 'deciding' at the time of graduation makes it difficult to have prospects for a stable life over the long term after graduation."

In this study, we established Super's "Career Development Theory" and Krumboltz's "Theory of Planned Happenstance" as a framework for developing a career education program. This is because we believed that in school-based career education, it is important to place emphasis not only on pre-established plans but also on how to create "serendipity" through "encounters." Therefore, the author targeted high school students interested in education (including those aspiring to become teachers) with the aim of "intentionally" creating opportunities for "serendipity" for students, thereby offering them an additional option in their career development.

II. Factors contributing to the so-called "teacher shortage"

In recent years, the issue of "teacher shortages" has been covered more frequently in various media outlets, including social media.

According to the Reiwa 7 "Teacher Shortage" Fact-Finding Survey (2026)[(3)], the factors contributing to the so-called teacher shortage include: (1) an increase in the number of young teachers due to expanded hiring resulting from recent mass retirements stemming from the age composition of the teaching workforce, coupled with a rise in the number of teachers taking maternity and paternity leave; (2) the expansion of special education classes and the enhancement of instructional systems to adapt to changes in the educational environment; and (3) in some regions, competition with private companies and the outflow of teachers.

Furthermore, according to the Report on the Results of Initiatives to Enhance the Attractiveness of the Teaching Profession (2022)[(4)], a survey of students (fourth-year undergraduates) enrolled in universities and other institutions offering teacher training programs found that the most common reason—accounting for 55.9%—for not taking teacher training courses aimed at obtaining a teaching license was "a stronger desire to pursue careers outside the teaching profession, such as in the private sector." Another reason cited was "I felt anxious about the workplace environment and actual working conditions based on information obtained from school staff," which accounted for 21.8%.

As this survey indicates, the teacher shortage and the issue of enhancing the appeal of the teaching profession are pressing challenges. In teacher recruitment exams across prefectures, there is a noticeable trend of declining applicant numbers for certain school types and subjects.

To address these challenges, prefectural and municipal boards of education are organizing "projects to enhance the appeal of the teaching profession" and holding seminars centered on the theme of "job satisfaction." However, other challenges identified in this survey include: "① The spread of negative perceptions, such as those circulating on social media through campaigns like '#Teacher's Baton,' and ② the frequent spotlight placed on opinions expressed by students' parents."

The Report on the Results of Initiatives to Enhance the Appeal of the Teaching Profession (2022) states, "Traditionally, teaching was considered a profession with relatively high prestige in society and was attractive to students."

In essence, isn't the teaching profession one that is familiar to children and something they aspire to? While I was enrolled in a graduate program in the College of Education, whenever I had the opportunity to discuss motivations for becoming a teacher with faculty members and friends there, "admiring a teacher I respect" was frequently cited as one of the reasons. There were also those whose motivation stemmed from having parents who were teachers, leading them to want to become teachers themselves.

Therefore, the author conducted a practical investigation using theoretical frameworks to examine how students aspiring to become teachers transform over time, by implementing various initiatives and intentionally creating opportunities for them to think concretely about their career goals.

III. Theory

A. D,E,Super Life-Career Rainbow

Super, a researcher in career psychology, represented a person's life career using the "Life Career Rainbow" model, as shown in the figure. He chose to use the Life Career Rainbow to illustrate his argument that the lifespan, life space, life course, and major life roles are all comprehensively interrelated.

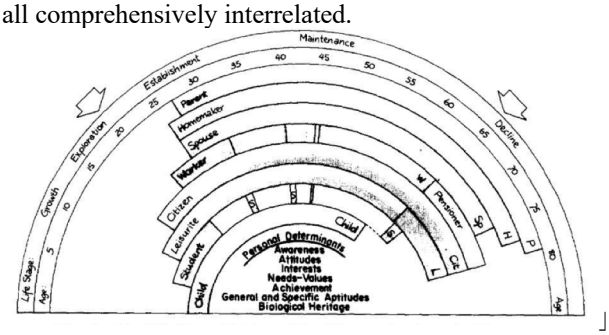


Figure1,D,E,Super(1980)[5], The Life-Career Rainbow

Komikawa (2023) [6]states, "Throughout our lives, we assume various roles: child, learner (student), person enjoying life (leisure-seeker), citizen, worker (laborer), family member (household member), and others. These roles overlap as we age, and the concept of the 'life career rainbow' represents the process of fulfilling them in a balanced manner. Career development refers to an individual's ability to autonomously assume these roles across life stages, and career education is the process of supporting individuals so they can develop their careers."

B. J. D. Krumboltz's "Planned Happenstance Theory"

Like Super, John Krumboltz conducted research on life careers, but he focused on the significance of "chance" in one's career.

Traditional career theories have emphasized the setting of clear goals and plans for achieving them. However, with the rapid pace of social change in recent years, the kind of systematic career planning seen in the past has become increasingly difficult. Consequently, Krumboltz proposed the theory of "planned haphazardness" (Krumboltz, Mitchell, & Levin, 1999)[7], aiming not to simply leave one's career to chance, but to intentionally increase the probability of serendipitous events occurring, thereby harnessing "serendipity" for career development.

The reason Krumboltz focuses on "serendipity" is related to his own career. Krumboltz explains, "I happened to ride my bike down a street I didn't usually take and 'by chance' ran into a friend I hadn't seen since kindergarten. We eventually started playing tennis together, and when I consulted my tennis coach about which major to choose in college—a decision I was struggling with—he recommended psychology, the field he had majored in, so I began studying psychology" (Watanabe, 2022)[6]. His own career is closely tied to this theory.

Subsequently, Krumboltz collected numerous examples similar to his own and, after verifying them, found that chance events were associated with behaviors that led to career opportunities.

According to Krumboltz (1999), traditional career counseling has often focused on "treating" indecisiveness and helping individuals set clear career goals. However, "many unexpected events and contingencies occur every day, making it impossible to accurately predict the future," and "it is foolish to devote one's life to a single path when the environment is constantly changing." Therefore, "refrain from making career decisions"; "rather than deciding your future now, it is far better to keep an open mind while actively seeking opportunities, as fixating too much on a single profession narrows your perspective." Krumboltz advocates "taking action to create new opportunities even when the outcome is uncertain, capitalizing on serendipitous events, keeping your options open at all times, and making the most of whatever life brings."

IV. Research subject and methods

At High School A, as part of the "Comprehensive Inquiry Period" for second-year high school students, a long-term project was carried out in which nine students aspiring to become teachers conducted lessons at an elementary school. During this process, the students collaborated with active teachers to develop lesson plans and interacted with teachers from the types of schools the students hope to work at in the future.

Aprils	Proposal of a "Research Question"
May	Visit to elementary schools (3rd and 5th grades) and classroom observation (1st session)
Jule	Preparation of lesson plans
July	Visit to elementary schools (3rd grade) and classroom observation (2nd session) Collaboration with active elementary school teachers, including exchange activities and lesson plan development (Unplanned Event 1)
August	

September	Creation of teaching aids for use in class
October	Class rehearsal (Unplanned Event #2) ・Classroom instruction at C Elementary School in City B (Actual Lesson)
November	
December	Research Project Presentation (Project Completion)

The terms "Unplanned Events" listed in the schedule were not originally included in the plan formulated by A High School; rather, they were intentionally introduced by the author as "unplanned events."

V. Conclusions

In this study, we aimed to help students expand their future possibilities by implementing a career education program as part of the "Comprehensive Inquiry Time" curriculum in high schools.

The current definition of career education states that "a 'career' is understood as the totality of the sequence and accumulation of experiences through which a person, in the process of fulfilling various roles, discovers the value of those roles and their relationship to the self." However, we currently live in an era of rapid change—often referred to as the "100-Year Life" or the "VUCA era"—where predicting the future and making plans has become difficult. We believe that traditional career education may become less effective in this era of high uncertainty. In high school, for students whose "future path is already clear" before entering college, deciding on a path may seem straightforward; however, for those whose "future path is not yet clear," it may become a "burden."

Given the concerns about uncertainty in the future, I believe it is important to move beyond the traditional "career guidance education"—which focuses solely on statistics such as college acceptance rates—and instead prioritize career education that extends beyond enrollment and graduation.

Therefore, drawing on Krumboltz's "Theory of Planned Happenstance," the author concluded that in school-based career education, it is important to place emphasis not only on pre-established plans but also on how to create "chance encounters" through "encounters."

The results of the practice revealed the following points: ① By "intentionally" creating "chance encounters," we were able to provide students with a diverse range of options and offer a potential path even to students whose future plans were undecided; ② It became clear once again that high school–university partnerships and corporate lectures (special classes) are conducted with the aim of creating opportunities for future career development; while it is unclear which path each student will ultimately choose, these activities serve as "encounters" designed to provide such "opportunities."

Looking back objectively on this practical experience, I believe it was no mere "coincidence" that I was given the opportunity to conduct my practicum at A High School. Furthermore, regarding coincidental events ① and ②, because I made specific proposals, neither the interaction between the student in ① and the practicing elementary school teacher—nor the development of a lesson plan—nor the pre-performance rehearsal in ② actually took place.

concluded that "coincidence" is something that is perceived from an "objective" perspective. While it may be difficult to recognize something as a "coincidence" in the moment, when looking back on one's career later, one can infer that "this event" was a coincidence.

VI. Issue

I will discuss the reflections and challenges regarding Project. My reflections on Project ① I focused too much on the "question," and ② my own lack of proficiency in creating lesson plans.

Regarding①, while the main objective of this teacher project was to gain hands-on experience in the profession of "teaching," I placed too much emphasis on the "question," which resulted in my lesson plans and other materials not turning out as intended. Regarding point ②, I keenly felt my own lack of competence. Although I have previous experience creating lesson plans for middle and high schools, creating lesson plans for elementary school is a completely different matter, and I was acutely aware of my shortcomings. In this project, I was able to use sample lesson plans provided by volunteers as a reference; however, I believe that without them, the project would not have achieved the level of success it did.

③ In a sense, this ended up "reinforcing" the desire to become a teacher among high school students who were already interested in the profession; I believe that if they had had the opportunity to consider options other than teaching, they might have been able to think more deeply about their own futures.

One challenge is the small number of students aspiring to become teachers. This project had only nine participants, which was significantly fewer than I had anticipated. The high school where I conducted this practicum has eight classes of second-year students, so having only nine students from among them is quite a small number. However, a preliminary survey revealed that the reason these nine students aspire to become teachers is largely due to "admiring their elementary and middle school teachers" and "family influence." This time, I participated in a project that is already conducted annually; however, if I were to conduct such a project in the future, I would like to provide a more detailed explanation—including what activities will be carried out—before the project begins, in order to spark the students' interest.

It is likely that the environment surrounding teachers will continue to change day by day. Negative media coverage of teachers—regarding issues such as overtime hours and harassment—shows no signs of abating. However, as a current high school instructor, I find my work deeply rewarding. This stems from the joy of teaching, the students' reactions to me, and seeing them excel during school events. I believe this research will have some significance if, in the future, it can have even a small impact—however modest—on those aspiring to become teachers, those with even a passing interest in teaching, and even those with no interest at all.

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Marriage Intentions in Mie Prefecture in the Context of National Trends in Japan

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Abstract— **This study examines the association between telework and marriage intentions among young unmarried adults in Japan using panel data and hybrid models. Telework availability, rather than telework frequency, was positively associated with women's marriage intentions, while regional differences were observed. The findings highlight the importance of flexible working arrangements for family formation.**

Keywords— Marriage intentions, Telework, Hybrid model, Regional differences, Japan

I. Introduction

Japan has experienced a long-term rise in both non-marriage and delayed marriage. As the young population and the number of births continue to decline, identifying the conditions under which young people wish to marry has become an important issue not only in family sociology and population studies but also in regional policymaking.

Marriage should ultimately be a matter of individual values and personal choice. In Japan, however, marriage and childbearing remain closely linked, and the large majority of births occur within marriage (Hertog & Iwasawa, 2011; Iwasawa, 2017). Understanding the factors that shape marriage intentions is therefore important for examining the social conditions surrounding family formation. From a policy perspective, the objective should not be to encourage marriage itself, but rather to create an environment in which those who wish to marry are able to realize that intention.

Previous research has shown that marriage intentions and marital behavior are associated with individual characteristics such as age, educational attainment, employment status, income, and whether an individual has a romantic partner (Yu & Hara, 2020; Raymo et al., 2021). In particular, economic stability has been shown to be important for men's attitudes toward marriage, whereas women's marriage intentions are associated with their prospects for remaining employed while balancing work and family life (Yu & Kuo, 2017; Yu & Hara, 2020).

Marriage intentions, however, may be influenced not only by individual characteristics but also by broader social conditions, including regional employment opportunities, demographic composition, and transportation infrastructure. Much of the existing literature has focused on national trends or broad comparisons between urban and rural areas, and relatively few studies have situated individual regions within wider national patterns (Takahashi, 2025). Although it is difficult to obtain sufficiently large samples at the prefectural level, examining regional characteristics on the basis of nationwide analyses remains worthwhile.

This study therefore focuses on the Tokai region, which includes Mie Prefecture, and examines its patterns of marriage intentions through comparisons with Japan as a whole and with the Kanto region. Particular attention is paid to telework, which has become increasingly widespread in recent years. The study investigates how both the availability of telework arrangements and the frequency of telework are associated with the marriage intentions of young unmarried adults.

Telework is expected to reduce the burden of commuting and help individuals balance work and personal life. At the same time, frequent telework may reduce opportunities for face-to-face interaction (Graham et al., 2023). The association between telework and marriage intentions may therefore vary according to the frequency of telework and the regional context.

Against this background, this study has three objectives: first, to examine the association between telework and marriage intentions at the national level; second, to compare the Kanto and Tokai regions; and third, to interpret the findings for the Tokai region, including Mie Prefecture, in light of its regional context.

II. Previous research

Research on marriage intentions has shown that young people's attitudes toward marriage are shaped not only by individual values but also by economic and social conditions (Raymo et al., 2021). Across East Asia, delayed marriage and non-marriage have been associated with increasing employment insecurity, rising housing and education costs, and difficulties in balancing work and family life (Raymo et al., 2015). In Japan, stable employment and sufficient income increase the likelihood of marriage, particularly among men, whereas non-regular employment and low income may make marriage more difficult (Esteban-Pretel & Fujimoto, 2022).

The relationship between income, employment status, and marriage intentions is not necessarily straightforward. Some individuals may become less willing to marry because of disadvantaged economic circumstances, while others may retain a desire to marry but assess their chances of realizing that desire as low. Moreover, individuals with strong marriage intentions may be more likely to seek stable employment or make employment decisions with their future married life in mind. It is therefore necessary to exercise caution when

concluding, on the basis of cross-sectional differences between individuals, that employment conditions or income directly generate marriage intentions.

Whether an individual has a romantic partner is also likely to be strongly associated with marriage intentions. However, conventional cross-sectional analyses cannot easily distinguish whether entering a romantic relationship strengthens marriage intentions or whether individuals who already have strong marriage intentions are more likely to form such relationships. To identify the factors associated with marriage intentions, it is therefore necessary to examine not only differences between individuals but also changes occurring within the same individual over time.

Regional conditions also shape marriage and family formation. Regions differ in the size and gender composition of their young populations, industrial structures, employment opportunities, transportation systems, and the extent of migration associated with education and employment. Metropolitan areas tend to offer relatively large young populations and more opportunities to meet potential partners. At the same time, long commuting times and high living costs may make the transition to married life more difficult. In non-metropolitan areas, living and housing costs may be lower, but the outmigration of young people and the limited availability of opportunities to meet potential partners may present significant challenges.

Mie Prefecture includes both areas that are closely connected to the Nagoya metropolitan region and mountainous or coastal areas experiencing substantial population decline. In northern Mie, commuting and travel to schools in Aichi Prefecture are relatively common. In contrast, particularly in southern Mie, some areas face substantial outmigration of young people and significant constraints on mobility. Given this internal diversity, it would be inappropriate to classify marriage intentions in Mie Prefecture simply as either "urban" or "rural."

In recent years, telework has attracted attention as a means of relaxing geographical constraints on employment and increasing the feasibility of living outside major urban areas while coordinating work and personal life. Employment in or movement to a company that permits telework may reduce the burden of commuting and enable individuals to form a more concrete image of their future family life (Tan et al., 2024). For women in particular, the prospect of remaining employed after marriage and childbirth may help sustain their intentions to marry (Yu & Kuo, 2017).

Nevertheless, marriage intentions may not increase linearly with the number of days spent teleworking. Working from home for most of the week may reduce face-to-face interaction with colleagues and increase feelings of social isolation (Graham et al., 2023). In addition, individuals who telework frequently may disproportionately include those with heavy workloads or those employed in particular professional occupations. It is therefore important to distinguish between having access to telework arrangements and actually using telework at a high frequency.

This study employs a hybrid model that separately estimates within-person changes over time and between-person differences. This approach makes it possible to distinguish, for example, between the possibility that individuals with stronger initial marriage intentions are more likely to select employers that permit telework and the possibility that an individual's marriage intentions change after they begin working for an employer that permits telework.

III. Data and methods

This study uses the refresh sample of the Japanese Life Course Panel Survey for the Youth, conducted by the Institute of Social Science at the University of Tokyo. The analytical sample consists of 789 unmarried individuals aged 20–31 who responded to the survey in both 2021 and 2022, yielding a total of 1,578 person-year observations.

The regional analyses focus on the Kanto region—Tokyo, Kanagawa, Saitama, Chiba, Ibaraki, Tochigi, and Gunma Prefectures—and the Tokai region—Aichi, Shizuoka, Gifu, and Mie Prefectures. Respondents who moved between 2021 and 2022 were excluded from the regional analyses. Separate models were estimated for men and women at the national level and for the Kanto and Tokai regions.

The dependent variable is marriage intention. Respondents who answered that they "definitely want to marry" or "would prefer to marry" were coded as 1, while all other respondents were coded as 0. The primary explanatory variables are the availability of telework arrangements and the frequency of telework, categorized as one to four days per week and five or more days per week.

The models control for age, educational attainment, annual income, employment status, company size, working hours, intention to remain employed, coresidence with parents, the presence of a romantic partner, and the desire to have children. Detailed definitions of the variables are omitted because of space constraints.

The analysis employs a hybrid model. This method combines advantages of fixed-effects and random-effects models and enables the simultaneous estimation of within-person changes and between-person differences. It therefore allows the association between changes in telework conditions and marriage intentions to be examined while taking time-invariant individual characteristics into account to some extent.

Because the sample from Mie Prefecture alone is limited, the present study uses the national analysis as its foundation and explores regional characteristics through the results for the Tokai region, which includes Mie Prefecture.

IV. Results

A. National Results

At the national level, beginning to work for an employer that permits telework was positively associated with an increase in marriage intentions. The coefficient for the full sample was 0.192. In the gender-specific analyses, a statistically significant positive association was observed only among women, with a coefficient of 0.251.

This result suggests that, particularly for women, a workplace environment that allows employees to choose flexible working arrangements when necessary may be more closely associated with marriage intentions than the actual frequency of telework.

By contrast, neither teleworking one to four days per week nor teleworking five or more days per week was clearly associated with marriage intentions. At the national level, therefore, the availability of telework as an institutional option may be more important than the number of days on which telework is actually used.

Among the other variables, the desire to have children was consistently and strongly associated with marriage intentions. Respondents with a romantic partner also tended to have stronger marriage intentions. However, changes in whether the same individual had a romantic partner were not clearly associated with changes in marriage intentions.

This finding suggests that having a romantic partner may not itself strengthen marriage intentions. Rather, individuals who already have strong marriage intentions may be more likely to have a romantic partner. Educational attainment, income, employment status, and working hours showed only limited associations with marriage intentions.

The national results suggest that economic and employment conditions may affect the likelihood that individuals are able to realize their desire to marry more strongly than they affect the desire to marry itself.

B. Results for the Kanto Region

The Kanto sample consisted of 564 observations, including 242 observations for men and 322 for women. Working for an employer that permitted telework was not clearly associated with marriage intentions.

Among women, however, teleworking one to four days per week was positively associated with marriage intentions at the 10 percent significance level, with a coefficient of 0.174. No statistically significant association was found for teleworking five or more days per week.

As in the national analysis, the desire to have children was consistently and positively associated with marriage intentions. Among men, longer working hours tended to be associated with weaker marriage intentions, and non-regular employment also showed a negative tendency.

C. Results for the Tokai Region

The Tokai sample consisted of 176 observations, equally divided between men and women, with 88 observations for each group. Individuals working for employers that permitted telework tended to have stronger marriage intentions. A statistically significant positive association was found particularly among women, with a coefficient of 0.366.

Regarding the frequency of telework, teleworking one to four days per week was positively associated with marriage intentions among women, with a coefficient of 0.508. By contrast, teleworking five or more days per week was significantly and negatively associated with marriage intentions among men, with a coefficient of −

Table1. Hybrid Model Estimates of Marriage Intentions

Block	National						Kanto Region						Tokai Region					
	within			between			within			between			within			between		
term	All	Male	Female	All	Male	Female	All	Male	Female	All	Male	Female	All	Male	Female	All	Male	Female
Demographic Characteristics																		
University Degree	—	—	—	−0.004	−0.008	0.001	—	—	—	−0.006	0.072	−0.034	—	—	—	−0.014	−0.046	0.002
	—	—	—	(0.018)	(0.029)	(0.022)	—	—	—	(0.033)	(0.062)	(0.040)	—	—	—	(0.039)	(0.077)	(0.044)
Personal Annual Income	0.035	0.057	−0.005	0.016	0.014	0.018	−0.002	0.084	−0.005	0.016	−0.010	0.014	−0.266	0.079	−0.736†	0.023	0.023	0.069
	(0.049)	(0.063)	(0.072)	(0.011)	(0.015)	(0.019)	(0.069)	(0.078)	(0.117)	(0.015)	(0.021)	(0.029)	(0.197)	(0.163)	(0.397)	(0.039)	(0.050)	(0.047)
Employment Status																		
Non-regular Employment	−0.090	−0.168	−0.044	−0.043	−0.097*	0.005	−0.078	0.06	0.026	−0.031	−0.205†	0.034	−0.309	−0.235	−0.531	−0.074	−0.142	−0.136
	(0.099)	(0.142)	(0.143)	(0.028)	(0.047)	(0.035)	(0.202)	(0.258)	(0.295)	(0.046)	(0.105)	(0.047)	(0.311)	(0.779)	(0.735)	(0.089)	(0.129)	(0.102)
Self-employed / Other	−0.014	−0.016	−0.070	0.03	0.029	0.03	−0.092	−0.131	0.084	0.05	−0.039	0.092	−0.061	0.920†	−1.400*	0.02	0.076	−0.199
	(0.118)	(0.156)	(0.188)	(0.040)	(0.058)	(0.057)	(0.187)	(0.218)	(0.282)	(0.072)	(0.125)	(0.081)	(0.511)	(0.529)	(0.559)	(0.074)	(0.105)	(0.199)
Not Employed	0.056	−0.123	0.249†	−0.025	−0.085	0.028	−0.019	−0.436	0.274	−0.036	−0.055	−0.017	−0.014	—	0.649	−0.339*	−0.502*	−0.216
	(0.108)	(0.170)	(0.145)	(0.051)	(0.071)	(0.068)	(0.202)	(0.348)	(0.242)	(0.089)	(0.127)	(0.129)	(0.561)	—	(0.606)	(0.135)	(0.218)	(0.212)
Working Conditions																		
Working 8+ Hours per Day	−0.031	−0.030	−0.020	0.01	−0.045	0.048	−0.138	−0.505*	0.102	0.011	−0.003	0.029	0.02	0.515	−0.534	−0.118†	−0.244**	−0.237
	(0.080)	(0.121)	(0.114)	(0.034)	(0.049)	(0.052)	(0.139)	(0.200)	(0.203)	(0.053)	(0.088)	(0.074)	(0.235)	(0.393)	(0.586)	(0.062)	(0.091)	(0.142)
Company Size (300+ Employees)	−0.034	−0.014	−0.032	−0.004	−0.005	−0.002	0.05	0.16	−0.016	0.032	−0.013	0.014	−0.013	−0.166	0.235	−0.066	−0.122	−0.029
	(0.072)	(0.105)	(0.106)	(0.021)	(0.033)	(0.027)	(0.137)	(0.185)	(0.205)	(0.034)	(0.058)	(0.045)	(0.193)	(0.189)	(0.396)	(0.049)	(0.083)	(0.055)
Workplace Environment																		
Telework Available	0.192*	0.116	0.251*	−0.004	−0.020	−0.023	0.149	0.129	0.235	−0.020	0.034	−0.095	0.136	0.451	0.208	0.160†	0.074	0.336**
	(0.080)	(0.113)	(0.116)	(0.030)	(0.045)	(0.042)	(0.115)	(0.201)	(0.154)	(0.056)	(0.072)	(0.084)	(0.384)	(0.435)	(0.530)	(0.084)	(0.086)	(0.101)
Telework Frequency																		
Teleworking 5+ Days per Week	−0.058	0.139	−0.125	0.02	0.036	0.026	−0.081	0.126	−0.072	0.016	−0.002	0.075	0.504	−0.201	0.635	−0.223	−1.445***	−0.280†
	(0.194)	(0.312)	(0.237)	(0.047)	(0.075)	(0.062)	(0.260)	(0.391)	(0.362)	(0.076)	(0.105)	(0.111)	(0.421)	(0.423)	(0.481)	(0.185)	(0.254)	(0.151)
Teleworking 1–4 Days per Week	−0.152	−0.096	−0.175	0.041	0.044	0.074	−0.150	−0.101	−0.170	0.036	−0.127	0.174†	0.252	−0.049	−1.225	0.064	0.216	0.508*
	(0.093)	(0.148)	(0.123)	(0.044)	(0.079)	(0.056)	(0.138)	(0.202)	(0.202)	(0.070)	(0.105)	(0.095)	(0.344)	(0.335)	(0.832)	(0.157)	(0.176)	(0.200)
Intention to Continue Working	−0.052	0.019	−0.089	−0.010	−0.005	−0.001	−0.047	−0.001	−0.058	−0.006	0.079	−0.053	−0.338†	0.354	−0.475*	−0.039	−0.089	0.04
	(0.053)	(0.088)	(0.068)	(0.020)	(0.035)	(0.026)	(0.089)	(0.131)	(0.120)	(0.036)	(0.065)	(0.049)	(0.196)	(0.302)	(0.200)	(0.042)	(0.064)	(0.038)
Family and Life Course																		
Living with Parents	−0.099	−0.005	−0.154	−0.018	0.004	−0.045†	0.022	0.419†	−0.203	0.028	0.022	0.005	0.213	0.4	−0.096	−0.058	0.002	−0.046
	(0.082)	(0.146)	(0.099)	(0.019)	(0.032)	(0.027)	(0.166)	(0.229)	(0.200)	(0.033)	(0.054)	(0.048)	(0.275)	(0.315)	(0.527)	(0.044)	(0.082)	(0.052)
Has a Romantic Partner	0.018	0.068	−0.009	0.038*	0.013	0.042*	−0.036	−0.173	0.036	0.096***	0.113*	0.103**	−0.115	−0.579†	0.141	−0.068	−0.040	−0.151†
	(0.072)	(0.132)	(0.087)	(0.017)	(0.031)	(0.021)	(0.146)	(0.258)	(0.185)	(0.027)	(0.045)	(0.033)	(0.187)	(0.343)	(0.265)	(0.048)	(0.073)	(0.079)
Desire to Have Children	0.551***	0.534***	0.560***	0.191***	0.218***	0.178***	0.559***	0.552***	0.547***	0.149**	0.182*	0.088	0.633***	0.626**	0.710***	0.159*	0.242*	0.226*
	(0.038)	(0.059)	(0.052)	(0.028)	(0.047)	(0.038)	(0.062)	(0.081)	(0.098)	(0.048)	(0.084)	(0.061)	(0.133)	(0.203)	(0.195)	(0.071)	(0.105)	(0.091)
Observations	1578	688	890	1578	688	890	564	242	322	564	242	322	176	88	88	176	88	88
Adjusted R^2	0.435	0.440	0.420	0.435	0.440	0.420	0.450	0.478	0.424	0.450	0.478	0.424	0.398	0.366	0.516	0.398	0.366	0.516

† $p < .10$、* $p < .05$、** $p < .01$、*** $p < .001$。

1.445, and also showed a negative tendency among women.

In the Tokai region, moderate telework was therefore positively associated with marriage intentions, whereas high-frequency telework tended to be associated with weaker marriage intentions.

As in the national analysis, the desire to have children was positively associated with marriage intentions. Among women, a stronger intention to remain employed tended to be associated with weaker marriage intentions. Among men, longer working hours tended to be associated with weaker marriage intentions.

Because the sample size for the Tokai region is limited, these results should be interpreted as exploratory findings.

V. Discussion

Because the number of respondents from Mie Prefecture alone is limited, the present study cannot statistically identify characteristics specific to the prefecture. Nevertheless, the results for the Tokai region, which includes Mie Prefecture, provide several implications for understanding marriage and family formation in the region.

First, women in the Tokai region who worked for employers that permitted telework tended to have stronger marriage intentions. Many residents of Mie Prefecture commute not only within the prefecture but also to neighboring areas such as Aichi Prefecture. Flexible working arrangements may therefore reduce the burden of commuting and make it easier for individuals to envision balancing employment and family life.

Telework may consequently be understood not only as part of work-style reform but also as a factor related to the settlement of young people and their family formation.

Second, teleworking one to four days per week was positively associated with women's marriage intentions in the Tokai region, whereas teleworking five or more days per week showed a negative tendency among both men and women. This result suggests that increasing the number of telework days may not in itself be beneficial. Instead, an environment that combines flexible working arrangements with opportunities for face-to-face interaction may be more important.

Third, among the variables other than telework, the desire to have children was most strongly associated with marriage intentions. A stronger intention to remain employed among women and longer working hours among men were negatively associated with marriage intentions.

These findings suggest that young people's marriage intentions are closely connected to their working arrangements and expectations regarding their future lives. They also highlight the importance of creating conditions that support employment stability and the reconciliation of work and family life.

Furthermore, employment conditions and demographic trends differ substantially across areas within Mie Prefecture. Policies should therefore take account of the actual living and working conditions of young people in different parts of the prefecture.

Although this study is exploratory, identifying regional characteristics through comparisons with national trends provides a meaningful basis for considering future policies related to marriage and family formation at the regional level.

VI. Conclusion

Using data from the 2021 and 2022 waves of a panel survey of young adults, this study examined the association between telework and marriage intentions among young unmarried adults in Japan as a whole and in the Kanto and Tokai regions. The analysis employed hybrid models to distinguish within-person changes from between-person differences.

At the national level, working for an employer that permitted telework was positively associated with marriage intentions, particularly among women. In the Tokai region, both the availability of telework arrangements and teleworking one to four days per week were positively associated with women's marriage intentions. By contrast, teleworking five or more days per week showed a negative association or tendency among both men and women.

The desire to have children was consistently and positively associated with marriage intentions across both the national and regional analyses.

These findings suggest that marriage intentions may be associated not so much with the frequency of telework itself as with the availability of an environment in which flexible working arrangements can be selected. The associations also varied by region and gender, highlighting the need to consider regional employment conditions and living environments.

This study has several limitations. First, the analysis is restricted to two survey waves, 2021 and 2022, and therefore cannot adequately capture long-term changes. Second, the sample sizes for the Tokai region and Mie Prefecture are limited, requiring caution in interpreting the results. Third, this study examines marriage intentions rather than actual transitions into marriage.

Future research should use longer-term panel data to examine the transition from marriage intentions to actual marital behavior. It is also necessary to accumulate further data on individual regions, including Mie Prefecture.

The perspective adopted in this study—identifying regional characteristics through comparison with national trends—provides one useful approach to understanding the realities of marriage and family formation at the regional level.

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Due to space limitations, the complete bibliography is provided in the Supplementary References (available on the author's ResearchMap).

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