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Design and Implementation of a Controlled Environment Chamber to Accelerate Germination of Slow-Germinating Lettuce Seeds using Trade-off Analysis in Villegas Organiks and Hobby Farm

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Abstract

Agriculture in the Philippines faces challenges from unpredictable weather, which hampers seed germination and crop establishment. This study, “Design and Implementation of a Controlled Environment Chamber to Accelerate Germination of Slow-Germinating Lettuce Seeds Using Trade-Off Analysis in Villegas Organiks and Hobby Farm,” aimed to develop a germination chamber that maintains optimal conditions for lettuce seed growth. Key environmental parameters, temperature, humidity, light intensity, oxygen, and water level, were monitored and controlled. Data were collected through observations, interviews, and environmental monitoring at Villegas Organiks and Hobby Farm in Malvar, Batangas. Findings revealed that the farm’s current germination setup, reliant on ambient conditions, led to inconsistent results, extending germination to 25 days versus the optimal 7–10 days. Multiple chamber designs were evaluated using trade-off analysis methods, including Standard Weighted Sum, Maximin and Minimax Criteria, Imprecise Designer Ranking Table, and Analytic Hierarchy Process (AHP). Design 2 was selected with a performance score of 4.21 based on cost, usability, safety, and material availability. The final prototype featured an Arduino-based control system with DHT22 temperature-humidity sensors, BH1750 light sensor, red LED lighting, humidifier, and ventilation system. The chamber maintained optimal conditions (18°C–22°C, 50%–70% RH, 12–16 µmol/m²/s), achieving an 89.52% germination rate by Day 9, compared to 30–40% using traditional methods. Usability evaluation received a “Very Satisfactory” mean rating of 4.38. The study demonstrates that the chamber accelerates lettuce germination and offers a sustainable solution for smallholder farms. Expansion to other crops, integration of data logging/IoT, and enhanced interface accessibility are recommended to further support farm productivity and resilience.

Keywords
Controlled environment chamber, lettuce germination, trade-off analysis, smallholder farms, agricultural innovation

1. Introduction
Unpredictable climate patterns continue to pose serious challenges to agriculture worldwide. Extreme weather events such as drought, prolonged rainfall, and temperature fluctuations disrupt farming operations, particularly during early crop development. According to Zhang et al. (2021), low temperatures can significantly inhibit seed germination and reduce plant growth and yield. These conditions are often associated with the El Niño Southern Oscillation, which is expected to occur more frequently and may place small farms in tropical regions such as the Philippines at greater risk. Aside from climate stress, intrinsic seed dormancy and slow germination rates also affect crop production. Baskin and Baskin (2020) emphasized that understanding and managing seed dormancy is essential for successful plant propagation. Seed germination depends on environmental factors such as temperature, humidity, light, oxygen, water availability, and soil moisture. Studies show that seeds germinate best within specific environmental ranges; for instance, Khaeim et al. (2022) found that maize seeds germinate best at temperatures between 20°C and 35°C, while excessive or insufficient moisture negatively affects growth. To address these challenges, this study proposes the development of a solar-powered controlled germination chamber equipped with sensors and actuators for real-time monitoring and automatic environmental control. Advances in microcontroller and IoT technologies have made such systems more affordable for small farms. As demonstrated by Prasetyo et al. (2024), low-cost sensors can effectively monitor plant conditions in precision agriculture systems. The system will be implemented at Villegas Organiks and Hobby Farm in Malvar, Batangas, where inconsistent germination caused by unstable environmental conditions affects vegetable production. Using decision-making tools such as the Analytic Hierarchy Process will help determine the most suitable chamber design based on cost, functionality, usability, and durability. This innovation aims to improve germination efficiency, reduce resource waste, and support sustainable agricultural production.

2. Problem Formulation
Despite modern technology, many small-scale farms still use traditional seed germination methods with minimal environmental control. At Villegas Organiks and Hobby Farm (VOHo Farm), seeds are germinated in trays or nursery beds exposed to ambient conditions. This has resulted in inconsistent germination, with lettuce seeds taking 21–25 days instead of the usual 7–10 days, and only 30–40% germinating successfully after 11 days. Environmental monitoring showed temperatures of 26–36°C, high moisture, and variable light—far from optimal levels of 18–22°C, stable moisture, and consistent light.

Environmental factors strongly influence germination. Abayechaw and Wulchafo (2020) reported that seed physiological activities such as water imbibition, enzyme activation, and radicle emergence are sensitive to environmental variability. Baskin and Baskin (2020) emphasized that consistent moisture is crucial for metabolism, while Chu et al. (2022) showed that non-optimal temperatures reduce germination in cool-season crops like lettuce.

Automated environmental control systems have proven effective in regulating temperature, humidity, and soil moisture (Bhujel et al. 2020; Jamroen et al. 2024), enhancing crop performance. However, existing systems are mainly designed for greenhouses or laboratories and often require complex infrastructure or high energy use.

This study aims to design and evaluate a solar-powered automated seed germination chamber that stabilizes environmental conditions while remaining cost-effective for small-scale farms, improving lettuce germination through controlled temperature, humidity, light intensity, and soil moisture.

3. Literature Review
Seed germination is highly influenced by environmental factors such as temperature, humidity, light, oxygen, and water availability (Abayechaw and Wulchafo 2022). Lettuce seeds, in particular, often show uneven germination when exposed to fluctuating ambient conditions, leading to reduced crop uniformity and lower overall yield (Chu et al. 2022). Ghaleb et al. (2022) emphasized that proper control of these environmental factors significantly improves both germination rate and seedling vigor. Similarly, Wei et al. (2024) highlighted that slow-germinating lettuce seeds require optimized conditions to reduce the time to germination and ensure uniform early development, which is crucial for small-scale farms seeking efficiency.

Controlled environment chambers have been shown to effectively regulate key parameters such as temperature, humidity, light intensity, and ventilation, providing an optimal environment for seed germination (Andhare et al. 2025). Huang et al. (2024) noted that precise control of these parameters accelerates germination and enhances early seedling growth. Additionally, Dai et al. (2024) developed systems where controlled lighting improved photosynthesis and biomass accumulation in lettuce seedlings, resulting in healthier and more uniform growth. Austria et al. (2023) demonstrated that IoT-based monitoring allows real-time adjustments of environmental conditions, further improving germination outcomes. Mansoor et al. (2025) highlighted that automation reduces labor requirements and improves operational efficiency in controlled environments.

Optimal light intensity also supports photosynthesis and overall growth in lettuce (Zhou et al. 2022). However, thermoinhibition can occur when temperatures exceed the optimal range, negatively affecting germination and seedling vigor (Wei et al. 2024). Khaeim et al. (2022) further highlighted that consistent temperature and adequate water availability are crucial for uniform seedling establishment.

Trade-off analysis provides a systematic approach for balancing performance, cost, and resource use in controlled systems. Anderson and Zachary (2023) applied minimax decision rules to optimize operational planning under uncertainty, while Jamroen et al. (2024) emphasized energy-efficient temperature control in greenhouse environments. Wang et al. (2025) evaluated PV-assisted drying chambers for seed processing, and Basas et al. (2024) highlighted practical approaches for developing cost-effective small-scale germination systems suitable for local farms.

4. Methods

This study employed a mixed-methods research design to evaluate the performance of a controlled environment chamber developed to accelerate the germination of slow-germinating lettuce seeds. The research followed a Design and Development Research (DDR) approach, which involved the stages of problem identification, system design, prototype development, fabrication, and system evaluation.

The study was conducted at Villegas Organiks and Hobby Farm (VOHo) in Malvar, Batangas, where observations and interviews with farm personnel were first conducted to identify challenges in the existing seed germination practices. Environmental monitoring was also performed to establish baseline conditions affecting germination.

Trade-off analysis was used to determine the most suitable design configuration of the germination chamber. Several design alternatives were evaluated based on criteria such as functionality, efficiency, cost, and practicality. The selected design integrated sensors and control components to regulate environmental parameters critical to seed germination, including temperature, humidity, and light intensity.

The chamber was fabricated and assembled using the selected components, followed by system integration and functionality testing. Experimental testing was conducted by manually sowing lettuce seeds in seed trays, which were then placed inside the germination chamber. The system maintained controlled environmental conditions to support germination.

Environmental parameters were monitored throughout the testing period using instruments such as a lux meter, thermometer-hygrometer, and anemometer. Observations were conducted to record germination progress and seedling development. The collected data were used to evaluate the chamber's effectiveness in improving germination performance and providing a controlled environment suitable for lettuce seed germination.

5. Data Collection

Data were collected through site observation, environmental monitoring, and experimental testing. Initial data gathering involved interviews with farm personnel and observations of the farm's current seed germination practices to identify factors contributing to slow germination.

Environmental monitoring was conducted to measure temperature, humidity, light intensity, and airflow using instruments including a lux meter, thermometer-hygrometer, and anemometer. These measurements established baseline environmental conditions within the greenhouse environment.

During the experimental phase, lettuce seeds were manually sown in seed trays and placed inside the controlled environment chamber. Observations were conducted throughout the germination period to record germination results and seedling development. The collected data were analyzed to determine the effectiveness of the developed chamber in accelerating the germination of lettuce seeds.

6. Results and Discussion

The experimental results were analyzed to assess the effectiveness of the proposed solar-powered controlled environment germination chamber in improving lettuce seed germination. The performance of the developed system was compared with traditional germination practices at Villegas Organiks and Hobby Farm (VOHo Farm). Quantitative analysis provided an objective assessment of the impact of environmental control on seed germination.

Key Performance Indicators such as germination rate, time to germinate, environmental stability, and overall system performance were evaluated to determine the chamber's effectiveness. The data revealed observable patterns in germination performance, indicating that stabilizing environmental conditions improved seed outcomes.

Graphical representations were used to visualize trends during the experiment, providing clear comparisons between conventional and controlled germination methods. These graphs illustrated the relationship between environmental stability and germination performance.
Statistical validation confirmed that the improvements observed were due to the system's environmental control mechanisms rather than natural variability, ensuring the reliability of results.

By integrating quantitative analysis, graphical interpretation, and statistical validation, the study demonstrates that stabilizing environmental parameters enhances germination conditions and system performance. The findings provide empirical evidence that the solar-powered controlled environment germination chamber is an effective and practical solution for improving seed germination efficiency in small-scale agricultural applications.

6.1 Numerical Results

Table 1 shows the differences between the recommended conditions for lettuce seed germination and the actual environmental parameters observed during the monitoring period at Villegas Organiks and Hobby Farm.

Table. 1. Optimal and observed condition of lettuce seed

LETTUCE SEED								
Optimal Days to Germinate: 7-10 Days					Usual Germination (VOHo): 21-25 Days			
Parameters	Optimal Condition	Observed Condition						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Temp. (°C)	18-22	26.9 - 29.6	28.6 - 36.1	27.6 - 32	25.5 - 29.3	29 - 34	29 - 32	28 - 32.3
Humidity (%)	50%-70%	82-90	65- 83	83- 86	72 - 91	82 - 87	79 - 84	78 - 85
Water Level	150 mL	Not Precisely Measured	Not Precisely Measured	Not Precisely Measured	Not Precisely Measured	Not Precisely Measured	Not Precisely Measured	Not Precisely Measured
Light Intensity (lx)	12-16 mol/m²/s	0- 5,642	0- 7802	0- 6,114	0- 13,007	0- 9,857	0- 12,088	0- 11,802

The table highlights significant variations in temperature, humidity, light exposure, and water availability, indicating that the seeds were consistently exposed to non-optimal conditions. Temperature readings frequently exceeded the recommended range of 18–22°C, while humidity and water levels fluctuated beyond the ideal thresholds necessary for proper seed metabolism and enzyme activation. Light exposure also varied due to natural environmental factors, which may have contributed to uneven germination and slower seed development.

These deviations from optimal conditions are critical because lettuce seeds are highly sensitive to environmental fluctuations. Excessive or insufficient moisture can delay germination or reduce seed vigor, while inconsistent temperatures can cause thermoinhibition and affect the uniformity of sprouting. Variability in light intensity can also impact photosynthesis in early seedlings, further limiting growth and overall health.

Table 2. Lettuce seed germination (traditional method)

Day	Number of Seed Sown	Number of Fully Germinated Seeds	Cumulative Germinated Seeds	Cumulative Germination (%)
1-16	208	0	0	0.00%
17	208	11	11	5.29%
18	208	19	30	14.42%
19	208	29	59	28.37%
20	208	23	82	39.42%
21	208	18	100	48.08%
22	208	12	112	53.85%
23	208	9	121	58.17%
24	208	11	132	63.46%
25	208	7	139	66.83%
26	208	5	144	69.23%
Total	208	---	144 Seeds Fully Germinated	64 Seeds Did Not Germinate (30.77%)

Table 2 shows germination data of 208 lettuce seeds observed over a 26-day period reveal a slow initial phase followed by a gradual but consistent progression once germination began. For the first sixteen (16) days, no visible germination occurred, indicating that the seeds were still in their dormant stage or undergoing physiological preparation for sprouting. This extended dormancy may have been influenced by suboptimal environmental conditions such as low soil temperature, insufficient moisture, or limited oxygen availability, factors that can delay the metabolic activation necessary for germination. During this stage, the seeds were most likely absorbing water and activating enzymes essential for breaking dormancy and initiating cell division.

Visible germination first occurred on Day 17, with 11 seeds (5.29%) emerging, signaling the start of the germination phase. The rate of germination accelerated significantly over the next few days, particularly between Days 18 and 20, when a total of 71 new seedlings emerged. Specifically, 19 seeds germinated on Day 18, followed by 29 seeds on Day 19, bringing the cumulative total to 59 seeds (28.37%). An additional 23 seeds sprouted on Day 20, increasing the cumulative germination to 82 seeds (39.42%). This three-day period marked the peak of germination activity, suggesting that environmental conditions such as temperature and moisture may have temporarily reached optimal levels for lettuce seed germination.

After Day 20, the rate of germination began to decline, indicating that most viable seeds had already sprouted, while the remaining ones were slower or non-viable. On Day 21, 18 new seedlings appeared, raising the total to 100 (48.08%), followed by 12 new sprouts on Day 22, bringing the total to 112 (53.85%). A few additional seeds germinated during the final days, with 9 on Day 23, 11 on Day 24, 7 on Day 25, and 5 on Day 26. By the end of the 26-day observation period, the cumulative total reached 144 germinated seeds, equivalent to a germination rate of 69.23%.

Table 3. Summary of results using trade-off analysis techniques

Trade-off Analysis Technique	Design 1	Design 2	Design 3
Standard Weighted Mean	3.09	4.21	3.01
Maximin	3.09	4.05	2.35
Minimax	1.85	0	2.15
Imprecise Designer Ranking Table	3.12	4.17	3.07
Analytic Hierarchy Process	0.14	0.44	0.42

Table 3 presents the results from the different trade-off analysis techniques, Standard Weighted Mean, Maximin, Minimax, Imprecise Designer Ranking, and Analytic Hierarchy Process (AHP), show that Design 2 consistently performs the best among all alternatives. It has the highest scores in Standard Weighted Mean (4.21), Maximin (4.05), and Imprecise Designer Ranking (4.17), indicating strong performance and reliability across all criteria. In the Minimax method, Design 2 obtained a value of 0, meaning it has no regret and is the most stable and risk-free choice under uncertainty. Similarly, the AHP score (0.44) confirms that Design 2 is the most preferred option overall, balancing key factors such as cost, portability, usability, safety, durability, maintainability, and material availability. The consistency of Design 2's performance across multiple evaluation methods demonstrates its robustness and suitability for real-world implementation. These results provide a clear and well-supported recommendation, reinforcing confidence in selecting Design 2 as the optimal solution for the controlled environment germination chamber.

Table 4. Germination performance per chamber layer

	Upper Middle (2nd layer)	lower Middle (3rd layer)	Bottom (4th layer)	Top (1st layer)
Total seeds	105	105	105	105
Germinated seeds	93	102	96	81
Ungerminated seeds	12	3	9	24
Germination rate (%)	88.57%	97.14%	91.43%	77.14%
Germination period (days)	7	7	7	7

Table 4 evaluates germination uniformity across vertical layers of the chamber to assess airflow, light distribution, and environmental consistency. Each layer contained 105 seeds, ensuring a fair and controlled comparison across layers. Upper Middle (2nd layer) recorded the highest number of germinated seeds (102) and the lowest ungerminated count (3). The bottom layer (4th layer) showed the lowest germination performance, with only 81 germinated seeds and 24 ungerminated. This variation suggests that light intensity, airflow, or humidity distribution may be less optimal at the bottom layer, possibly due to reduced ventilation or shading effects. These findings emphasize the importance of strategic airflow design in controlled environment chambers, as proper ventilation not only maintains uniform temperature but also supports optimal germination and crop development by preventing localized heat accumulation and improving air exchange.

In addition, Reed et al. (2022) showed how high temperatures affect seed quality. Their recommendations on seed priming and breeding for vigor support the need to control light, humidity, and temperature for uniform germination. Furthermore, the observed differences among vertical layers highlight the importance of spatial monitoring within controlled environment systems. Even when overall germination performance is high, small gradients in microclimatic factors such as light penetration, air velocity, and moisture retention can lead to uneven seed responses. All layers completed germination within 7 days, indicating that despite differences in percentage, the chamber still maintains consistent germination timing throughout. While the chamber demonstrates high overall effectiveness, this table identifies opportunities for design optimization, particularly in improving environmental uniformity at the bottom layer. These insights are valuable for future system refinement and validation.

Table 5. Summary of system performance comparison

Parameter	Theoretical Computation	Real-time Measurement
System Power(W)	106.545 W	27.62 W
Total Energy Consumption (kWh)	33.699 kWh	15.468 kWh
Total Energy Cost (P)	Php 469.58	~ ₱ 135.258
Battery Runtime (hr)	5.06 hr	19.55 hr

Table 5 compares overall system performance metrics, highlighting a system load of 27.62 W, an operational cost of ₱135.258, and a battery runtime of 5.06 hours under a higher load scenario. The 27.62 W load demonstrates optimized baseline operation, while the 5.06-hour runtime indicates performance under increased demand conditions. Compared to the longer 19.55-hour runtime observed under moderate load, the reduced 5.06-hour duration confirms the inverse relationship between load and battery endurance. The recorded cost of ₱135.258 further emphasizes the economic aspect of system operation. This comparison illustrates that while higher load conditions reduce runtime, the system remains financially sustainable. Overall, the data confirms that the optimized configuration achieves improved efficiency and cost-effectiveness while maintaining acceptable operational endurance.

Table 6. Mann-Whitney U Test Results for Germination Method Comparison

Independent Variable	Test	Hypothesis	Mann-Whitney U Test (W)	Decision Rule ($\alpha = 0.05$)	Decision/ Interpretation
Method (Traditional vs. Chamber)	Mann-Whitney U Test	H_0: $\eta_1 - \eta_2 = 0$ H_1: $\eta_1 - \eta_2 \neq 0$	1275.000	0.000	Since $p = 0.000 < 0.05$, reject H_0. There is a statistically significant difference between the Traditional and Chamber methods, with the Chamber method demonstrating superior performance.

Table 6 shows the results of the Mann-Whitney U test, there is a statistically significant difference between the Traditional method and the Chamber method, as indicated by the p-value of 0.000, which is well below the 0.05 level of significance. This result warrants the rejection of the null hypothesis, which posits no difference in germination performance between the two techniques. In our data, the median germination time for the Traditional method (21.5 days) is substantially higher compared to the Chamber method (6.0 days), reflecting a dramatic acceleration in germination under the controlled environment. The estimated median difference of 16 days, supported by a tight 95% confidence interval ranging from 15 to 17 days, reinforces that the improvement is consistent and not attributable to random variation.

6.2 Validation

Figure 1 shows the validation on the statistical computation in the research. The validation was done by a certified expert, through reviewing the statistical treatment and analysis that was used in the study.

STATISTICIAN CERTIFICATION

I hereby certify that this manuscript titled,

"DESIGN AND IMPLEMENTATION OF A CONTROLLED ENVIRONMENT CHAMBER TO ACCELERATE GERMINATION OF SLOW-GERMINATING LETTUCE SEEDS USING TRADE-OFF ANALYSIS IN VILLEGAS ORGANIKS AND HOBBY FARM"

Prepared by

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has been statistically reviewed by the undersigned.

All data were processed, analyzed and interpreted in an accurate, valid, and reliable manner, and all results were reported clearly and objectively.

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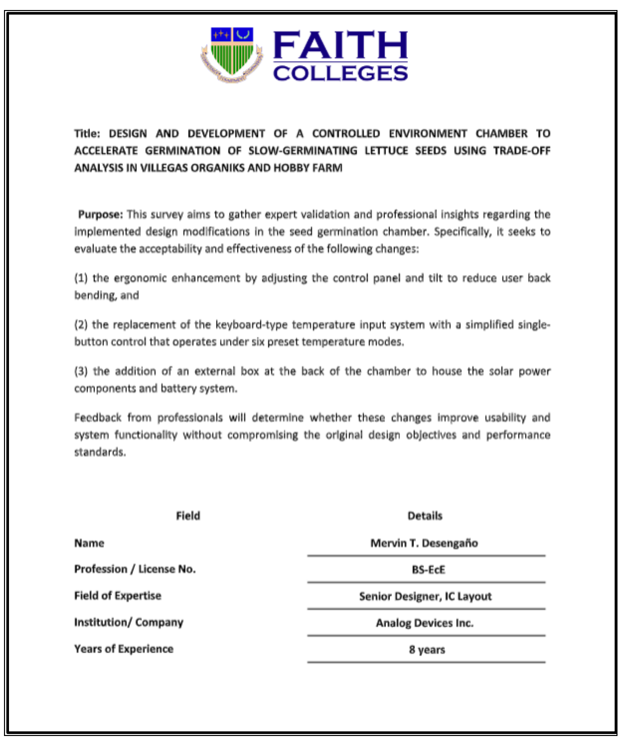
Figure 1. Statistical validation



Title: DESIGN AND DEVELOPMENT OF A CONTROLLED ENVIRONMENT CHAMBER TO ACCELERATE GERMINATION OF SLOW-GERMINATING LETTUCE SEEDS USING TRADE-OFF ANALYSIS IN VILLEGAS ORGANIKS AND HOBBY FARM

Purpose: This survey aims to gather expert validation and professional insights regarding the implemented design modifications in the seed germination chamber. Specifically, it seeks to evaluate the acceptability and effectiveness of the following changes:

(1) the ergonomic enhancement by adjusting the control panel and tilt to reduce user back bending, and

(2) the replacement of the keyboard-type temperature input system with a simplified single-button control that operates under six preset temperature modes.

(3) the addition of an external box at the back of the chamber to house the solar power components and battery system.

Feedback from professionals will determine whether these changes improve usability and system functionality without compromising the original design objectives and performance standards.

Field	Details
Name	Mervin T. Desengaño
Profession / License No.	BS-EcE
Field of Expertise	Senior Designer, IC Layout
Institution/ Company	Analog Devices Inc.
Years of Experience	8 years

Figure 2. Expert validation (design)

Figure 2 presents the validation about the implemented design of the prototype and the modification that was made and to be implemented, reviewed and verified by an expert. This section shows the profile of the expert who will validate the implemented design modification in the prototype

FAITH COLLEGES

Instructions: Please rate the statements below based on your professional opinion.
Scale: 5 – Strongly Agree | 4 – Agree | 3 – Neutral | 2 – Disagree | 1 – Strongly Disagree

No.	Statement	1	2	3	4	5
1	The modification to improve the chamber's ergonomics function by reducing the need for bending and lowering back strain.	☐	☐	☐	☐	■
2	The modification aligns with basic ergonomic design standards for workstation height.	☐	☐	☐	■	☐
3	Replacing the keyboard input with a single-button interface is more user-friendly and efficient.	☐	☐	☐	☐	■
4	The 6 preset temperature modes (22°C, 25°C, 28°C, 30°C, 32°C, 35°C) are sufficient for seed germination applications.	☐	☐	☐	■	☐
5	The new control design reduces complexity and potential electrical failure.	☐	☐	☐	☐	■
6	The modifications do not negatively affect the functionality of the chamber.	☐	☐	☐	☐	■
6	The modifications do not negatively affect the functionality of the chamber.	☐	☐	☐	☐	■
7	The simplified control system improves operational reliability and maintenance.	☐	☐	☐	☐	■
8	Overall, I approve the implementation of these design modifications.	☐	☐	☐	☐	■

Figure 3. expert validation (ratings)

Figure 3 shows the rating of the expert regarding the modification in the prototype that will be implemented. It can be seen that the expert strongly agrees on most of the modifications on the design that will be implemented.

FAITH COLLEGES

C. Open-Ended Questions

1. Do you have any recommendations to further improve the chamber's ergonomics or usability?
   Consider adding a small indicator or audible alert when temperature changes between modes. This helps users confirm control actions without visual checking. A detachable or tiltable display may also enhance visibility during operation.
2. Are there any risks or issues that the design team should consider before implementation?
   Ensure that the solar power integration includes proper protection circuits (overcharge, deep discharge, reverse polarity). Also verify thermal insulation to prevent unwanted heat buildup in the control enclosure.
3. Do you have any suggestions regarding the temperature mode selections or control mechanism?
   The preset temperature range is acceptable; however, adding one customizable "manual" mode could allow flexibility for testing non-standard seeds. Additionally, integrating an LED feedback for active mode status would improve user interaction.

D. Validation and Approval

I certify that I have reviewed and validated the proposed modifications and provided feedback based on my professional expertise.

Mervin T. Desengaño — November 06, 2025
Signature over printed name — **Date**

Figure 4. expert validation (approval)

Figure 4 shows the final part of this validation shows the expert's approval, recommendations, suggestions, and risks to take note of for the prototype. Giving some room to improve and what to take caution for.

7. Conclusion

Based on the analyses and results of the study, the following conclusions were drawn:

1. The existing germination method at VOHo Farm is insufficient for maintaining optimal environmental conditions, resulting in slow, uneven, and inconsistent germination performance.
2. The designed Controlled Environment Seed Germination Chamber successfully maintained temperature, humidity, light intensity, and oxygen levels within optimal ranges required for lettuce germination.
3. Through multi-criteria decision-making tools, Design 2 emerged as the most reliable, efficient, and user-friendly alternative for smallholder farm application.
4. The prototype chamber significantly accelerated germination, achieving 89.52% success within nine days, far superior to the farm's traditional 21–25-day cycle.
5. The chamber's ergonomic interface and automated controls ensure high usability and safety, even for non-technical users.
6. Overall, the system offers a sustainable, energy-efficient, and practical solution for improving germination efficiency in small-scale farming environments.

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Biographies

Melan Dyrene N. Almendras is an Industrial Engineering professional, educator, and researcher dedicated to advancing engineering education, research, and industry collaboration. She currently serves as the Industrial Engineering Coordinator in the Industrial Engineering Department in FAITH Colleges in Tanauan City, Batangas, Philippines where she plays a vital role in overseeing academic programs, student research initiatives, and departmental development. She holds a master's degree in engineering with a specialization in Industrial Engineering and is actively involved in teaching core Industrial Engineering subjects, mentoring students, and facilitating research projects. In her role as coordinator, she manages research supervision, student programs, external affiliations, and curriculum development while ensuring that the department complies with academic and accreditation standards. She is committed to preparing future engineers by integrating real-world applications into the learning process and promoting collaboration with industry partners for internships, research, and professional development opportunities. Her research interests include production systems optimization, production scheduling, quality management, and the integration of Industry 4.0 technologies in manufacturing environments. She is a recognized Associate ASEAN Engineer, demonstrating her commitment to professional excellence and adherence to regional engineering standards. Through research, professional engagement, and academic leadership, she aims to contribute to the advancement of Industrial Engineering practice and strengthen the connection between academia and industry in the ASEAN region.

Engr. Favis Joseph Balinado, PECE, ASEAN Eng. is a Professional Electronics Engineer, ASEAN Engineer, academic administrator, and higher education accreditor with extensive experience in engineering education, research, and institutional quality assurance. He is actively engaged in advancing engineering programs through outcomes-based education, industry collaboration, and strategic academic leadership. As an academic administrator, Engr. Balinado has played a key role in strengthening program development, faculty engagement, and student-centered initiatives that promote excellence in engineering training. His leadership focuses on aligning academic programs with industry needs and global standards, ensuring that graduates are equipped with the competencies necessary for professional practice and technological innovation in a rapidly evolving world. Engr. Balinado also serves as an accreditor for higher education institutions, contributing his expertise in program evaluation, continuous quality improvement, and compliance with national and international accreditation standards. Through this role, he assists institutions in enhancing academic governance, institutional effectiveness, and educational outcomes. His professional and research interests include control systems, renewable energy applications, and the use of intelligent optimization techniques in engineering design. He is particularly interested in applying advanced computational approaches to improve the efficiency and performance of modern power and energy systems. Committed to professional service and academic excellence, Engr. Balinado continues to contribute to the development of future engineers through teaching, research, accreditation work, and leadership within the engineering and higher education communities.

Ryan Sebastian Carandang is a Bachelor of Science in Electrical Engineering (BSEE) student at FAITH Colleges, Tanauan City, Batangas, Philippines. His academic interests include renewable energy systems, electrical design, and the application of electrical engineering technologies in sustainable and efficient power systems. During his studies, he participated in academic projects that explored practical electrical engineering solutions and developed foundational skills in engineering tools such as AutoCAD and lighting design software used for planning and visualization of electrical systems. He completed his undergraduate thesis on the development of a solar-powered controlled environment chamber designed to improve seed germination efficiency and support sustainable agricultural practices. His academic experience reflects his interest in applying engineering knowledge to promote energy efficiency, technological innovation, and environmental sustainability.

Ingrid Francheska D. Lantin is a Bachelor of Science in Electrical Engineering (BSEE) student at FAITH Colleges, Tanauan City, Batangas, Philippines. Her academic interests include renewable energy systems, automation, and the application of electrical engineering technologies in sustainable agricultural systems. She has been involved in interdisciplinary research integrating electrical engineering and industrial engineering concepts to address practical engineering challenges. Her current research focuses on the development of a solar-powered controlled environment chamber designed to improve seed germination efficiency and support sustainable agricultural practices. Her work contributes to the exploration of innovative engineering solutions that enhance agricultural productivity, energy efficiency, and environmental sustainability.

Maybelle Em-em D. Magcawas, CLSSYB, SO2, CKP is a 22-year-old student from Lipa City, Batangas, currently pursuing a Bachelor of Science in Industrial Engineering at FAITH Colleges. As a dedicated learner, she is naturally curious and eager to explore new ideas and concepts. Whenever something captures her interest, she takes the initiative to deepen her understanding by seeking knowledge and learning from different experiences. As one of the authors of the study titled "Design and Development of a Controlled Environment Chamber to Accelerate Germination of Slow-Germinating Lettuce Seeds Using Trade-Off Analysis in Villegas Organiks and Hobby Farm," she contributed to the research and development of a system designed to support improved seed germination conditions. Through this experience, she gained exposure to system design, collaboration, and the practical application of engineering concepts. She takes pride in the achievements and experiences she has gained throughout her academic journey. In the future, she aims to pursue a career where she can apply her Industrial Engineering knowledge and skills while building a stable and rewarding professional path.

Vince Aljon V. Manangan, CLSSYB, SO2, CKP is currently pursuing a Bachelor of Science in Industrial Engineering at the First Asia Institute of Technology and Humanities (FAITH Colleges) in Tanauan City, Batangas. His academic journey centers on understanding how systems, processes, and resources can be organized and improved to achieve efficient and effective operations. Through his coursework and academic activities, he has developed a strong interest in operations analysis, systems improvement, and the practical application of industrial engineering tools in solving real-world problems. Throughout his studies, he has cultivated skills in analytical thinking, problem solving, and collaborative work, which are essential in addressing complex operational challenges. He is particularly interested in exploring how engineering principles can be used to support process optimization and enhance productivity in various organizational settings. He is one of the authors of the study titled “Design and Implementation of a Controlled Environment Chamber to Accelerate Germination of Slow-Germinating Lettuce Seeds Using Trade-Off Analysis in Villegas Organiks and Hobby Farm.” As part of the research team, he participated in the development and evaluation of a controlled environment chamber intended to improve germination conditions for lettuce seeds by regulating environmental factors within the system. Vince aims to continue developing his technical knowledge and professional competencies as he prepares to pursue opportunities where he can contribute to improving systems, processes, and operational performance.

Shein Lorain Paler is a Bachelor of Science in Electrical Engineering (BSEE) student at FAITH Colleges, Tanauan City, Batangas, Philippines. Her academic interests include renewable energy systems, electrical power systems, and the application of electrical engineering technologies in sustainable and energy-efficient solutions. Throughout her undergraduate studies, she has been engaged in collaborative academic projects that emphasize the practical application of electrical engineering principles to address real-world engineering challenges. She contributed to the development and implementation of a solar-powered controlled environment chamber designed to enhance seed germination efficiency and support sustainable agricultural practices. Her research focuses on integrating renewable energy technologies with controlled environmental systems to improve agricultural productivity while promoting energy efficiency and environmental sustainability. Her academic work reflects a commitment to advancing innovative engineering solutions that support sustainable development and technological progress.

Eunica Velarde Tuldanes, CLSSYB, SO2, CKP is a fourth-year Bachelor of Science in Industrial Engineering student at FAITH Colleges in Tanauan City, Batangas, Philippines. Her academic training focuses on the application of industrial engineering principles in improving systems, optimizing processes, and enhancing operational efficiency across various fields. Throughout her studies, she has developed strong interests in systems design, process improvement, data-driven decision-making, and operations analysis. As part of her undergraduate research, she contributed to the study titled “Design and Implementation of a Controlled Environment Chamber to Accelerate Germination of Slow-Germinating Lettuce Seeds Using Trade-Off Analysis in Villegas Organiks and Hobby Farm.” The research involved the design, development, and testing of a controlled environment chamber aimed at improving germination conditions through the regulation of environmental parameters such as temperature, humidity, and light intensity. Through this project, she gained practical experience in system design, prototype development, experimental testing, data collection, and performance evaluation. Her research interests include process optimization, systems engineering, operations management, and the application of engineering principles in sustainable and innovative technological solutions that support productivity and efficiency in both industrial and agricultural environments.