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Research Article

Mainstreaming Low-Cost Hydroponics Using Fermented Plant Juice for Sustainable Lettuce Production in Urban Farming

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ABSTRACT

This study investigated the viability of a low-cost hydroponic system for food security in the Zamboanga Peninsula, employing a mixed-methods approach. The research assessed the acceptability, growth performance, and economic feasibility of hydroponic lettuce production using locally sourced organic inputs, specifically Fermented Plant Juice (FPJ). Hydroponics is seen as beneficial for addressing space limitations and improving food security in the region, though adoption is hindered by limited technical knowledge, material access, and capital. Estrosa and Olmetie lettuce varieties showed optimal performance. Nitrate levels in Estrosa and Green Wave were undetectable, and while Olmetie and Invicta absorbed more nitrate with FPJ, all levels remained within international safety limits. Cadmium was not detected. Recommendations for the Zamboanga Peninsula include agricultural modernization through technical training, start-up assistance, material accessibility, and R&D support. Public awareness campaigns for low-cost hydroponics using FPJ, crop diversification, farmer engagement, and urban/peri-urban adoption incentives are also suggested. Growers are advised to prioritize Estrosa and Green Wave for lower nitrate uptake and ensure correct FPJ preparation.

Keywords: *Mainstreaming low-cost hydroponics, Fermented plant juice, Sustainable lettuce production, Urban farming*

Background

Global food security is challenged by conventional farming limitations and increasing urban populations, with Philippine urban and peri-urban areas experiencing reduced food production due to land conversion, leading to food insecurity. Hydroponic systems, a soil-less method, offer a viable solution for localized food production, enabling year-round cultivation, water conservation, and reduced chemical

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use. While the Philippines supports hydroponics through initiatives like the National Urban and Peri-urban Agriculture Program (NUPAP), adoption is limited by barriers including high start-up costs, lack of technical know-how, and concerns about nutrient solution affordability. The development of low-cost hydroponic systems using locally available materials such as Fermented Plant Juice (FPJ) is emerging as a promising alternative.

While numerous studies have validated the efficacy of fermented plant juices (FPJ) in traditional, soil-based crop production systems, limited attention has been directed towards understanding its application within hydroponic environments. The study further aims to investigate the practicability of applying Fermented Plant Juices (FPJ) within hydroponic systems to enhance lettuce cultivation. This exploration seeks to offer insights into alternative, more sustainable approaches to lettuce production, aligning with evolving consumer preferences for healthier and environmentally friendly food options.

This study addressed food safety concerns related to nitrate and cadmium accumulation in lettuce, which is often consumed raw and accumulates these substances from intensive fertilization or contaminated environments. Nitrates can convert to nitrites in the body, linked to health issues, while cadmium is a toxic heavy metal classified as a human carcinogen. The dissertation proposes integrating low-cost hydroponics in the Zamboanga Peninsula through a multi-method approach. This involves a quantitative survey on hydroponics acceptability, an experimental study comparing lettuce growth and yield with different nutrient solutions (analyzing cadmium and nitrate levels), and stakeholder discussions to mainstream hydroponics. The research aims to support UN Sustainable Development Goals by providing scientific evidence for scalable, cost-effective, and safe food production systems, examining technical, social, economic, and policy dimensions.

Objectives of the Study

This dissertation sought to study the challenges and prospects of mainstreaming an innovative low-cost hydroponic technology among farmers in Zamboanga Peninsula during the calendar year 2024.

The study specifically aims to:

1. assess the acceptability and adaptability of innovative low-cost hydroponics among urban and peri-urban communities in the Zamboanga Peninsula.
2. identify the effects of different nutrient hydroponic solutions, including Fermented Plant Juice (FPJ), on the horticultural characteristics, yield performance, and profitability of selected leafy lettuce varieties produced under hydroponic systems.
3. determine the cadmium and nitrate concentrations in harvested lettuce.
4. elaborate the qualitative perspective on mainstreaming hydroponics through focus group discussion.
5. formulate policy recommendations for the institutionalization of hydroponic technology as a strategy for agricultural modernization and a tool for addressing the United Nations Sustainable Development Goals (SDGs) in urban and peri-urban areas in the Zamboanga Peninsula

Methods

The study employed mixed-methods design that integrated three complementary approaches namely: survey, cultivar experiment or planting trial in the greenhouse and focus group discussion (FGD). Further, the study employed a Convergent Parallel Mixed-Methods Design (Creswell & Plano Clark, 2018). The study was conducted in Zamboanga Peninsula with an established greenhouse which served as experimental laboratory within the property of the Department of Agriculture Regional Field Unit 9 located at Lenienza, Pagadian City. The experiment on the cultivars of lettuce using low-cost hydroponic system was conducted from July to October 2024 and thereafter, data were gathered on lettuce samples. The survey interview was conducted in Pagadian City, Dipolog and Dapitan City, Ipil, Zamboanga Sibugay and Zamboanga City. Prior to the conduct of the experiment, between May to July, The Focused Group Discussion (FGD) sessions were conducted in Dipolog City in September 2024. This was followed by an online interview using Zoom online platform conducted in October, 2024.

The experiment employed a factorial research design in a Completely Randomized Design (CRD) setup to determine the effects of different types of nutrient hydroponic solutions and lettuce varieties on growth characteristics, yield performance, economic returns and cadmium and nitrate concentrations.

A total of 317 respondents participated to the survey interview which was facilitated and administered by the researcher. The study employed purposive sampling technique. In coordination with the Department of Agriculture-National Urban and Peri-urban Agriculture Program (NUPAP), all participants of the DA-FOIX's Roll-out Training on Vegetable Productions in Urban Settings coming from Zamboanga del Norte (Dipolog and Dapitan Cities and other urban/peri-urban), Zamboanga Sibugay (Ipil and neighboring barangays); Zamboanga City, Basilan City, and Zamboanga del Sur (Pagadian City, Dumalinao, Molave and other urban and peri-urban communities) were invited to answer the survey questionnaire and were interviewed during the NUPAP Roll-out training conference conducted in the region.

The study used seeds of Lettuce (Lactuca Sativa L), germinated inside the greenhouse structure with these specifications (10 x 6 x 12 meters) with UV film roofing (200 um) and 40-60 shade from nearby trees in the property. It has germinated 300 seed to each of the four (4) varieties of lettuce: Olmetie, Invicta, Estrosa and Green Wave. Likewise, the experiment used 60 plastic hydroponic boxes as experiment units, on two elevated tables inside the greenhouse, 840 hydroponic cups, 4 pieces of big water containers, pails, coco peat, water resources, water quality meter/tester, and measuring tools (ruler/caliper and digital weighing scale). Water solutions are enriched with prepared fermented plant juice, commercial NHS and mixed of the latter and the FPJ at varying levels. Finally, the experiment site with a total area of 60 square meters was accommodated.

The experiment was laid out in a 4 X 5 Factorial arranged in Complete Randomize (CRD), where Factor A, represents the varieties of lettuce. The nutrient hydroponic solutions with 5 types/formula will serve as Factor B. The experiment has twenty (20) treatments each replicated three (3) times. This design allows for the simultaneous investigation of the independent effects of FPJ and synthetic NHS and lettuce varieties, as well as potential interactions between these factors. As indicated:

Factor A: Lettuce Loose Leaf Varieties

- Variety 1: Olmetie Batavia Lettuce
- Variety 2: Invicta Rz
- Variety 3: Estrosa
- Variety 4: Green Wave

Factor B: Synthetic-based and FPJ-based Nutrient Solutions

- Level 1: Commercial NHS
- Level 2: 25% FPJ Nutrient Solution and 75% Commercial NHS
- Level 3: 50% FPJ Nutrient Solution and 50% Commercial NHS
- Level 4: 75% FPJ Nutrient Solution and 25% Commercial NHS
- Level 5: FPJ-based Nutrient Solution (100% FPJ)

The treatments and treatment combinations are presented in Table 1.

Table 1. Treatment and treatment combinations of the study

Varieties of Lettuce	Hydroponic Nutrient Solution	Treatment Combinations (Codes)	Treatments
Olmetie Batavia Lettuce (A_1)	• Commercial NHS (B_1)	A_1B_1	T_1
	• 25% FPJ Nutrient Solution and 75% Commercial NHS (B_2)	A_1B_2	T_2
	• 50% FPJ Nutrient Solution and 50% Commercial NHS (B_3)	A_1B_3	T_3
	• 75% FPJ Nutrient Solution and 25% Commercial NHS (B_4)	A_1B_4	T_4
	• 100% FPJ) (B_5)	A_1B_5	T_5

Varieties of Lettuce	Hydroponic Nutrient Solution	Treatment Combinations (Codes)	Treatments
Invicta Rz (A_2)	• Commercial NHS (B_1)	A_2B_1	T_6
	• 25% FPJ Nutrient Solution and 75% Commercial NHS (B_2)	A_2B_2	T_7
	• 50% FPJ Nutrient Solution and 50% Commercial NHS (B_3)	A_2B_3	T_8
	• 75% FPJ Nutrient Solution and 25% Commercial NHS (B_4)	A_2B_4	T_9
	• 100% FPJ) (B_5)	A_2B_5	T_{10}
Estrosa (A_3)	• Commercial NHS (B_1)	A_3B_1	T_{11}
	• 25% FPJ Nutrient Solution and 75% Commercial NHS (B_2)	A_3B_2	T_{12}
	• 50% FPJ Nutrient Solution and 50% Commercial NHS (B_3)	A_3B_3	T_{13}
	• 75% FPJ Nutrient Solution and 25% Commercial NHS (B_4)	A_3B_4	T_{14}
	• 100% FPJ (B_5)	A_3B_5	T_{15}
Green Wave (A_4)	• Commercial NHS (B_1)	A_4B_1	T_{16}
	• 25% FPJ Nutrient Solution & 75% Commercial NHS (B_2)	A_4B_2	T_{17}
	• 50% FPJ Nutrient Solution and 50% Commercial NHS (B_3)	A_4B_3	T_{18}
	• 75% FPJ Nutrient Solution and 25% Commercial NHS (B_4)	A_4B_4	T_{19}
	• 100% FPJ (B_5)	A_4B_5	T_{20}

The respondents of the FGD in Zamboanga Peninsula (Region 9) comprise farmers, gardeners, and urban/peri-urban residents, including DepEd teachers. Farmers, likely experienced in traditional methods, are interested in hydroponics as a sustainable alternative, offering insights into its potential in rural settings. Gardeners, with smaller-scale cultivation experience, are expected to show interest in hydroponics to enhance gardening techniques and yields, providing perspectives on community and household demand. Urban and peri-urban residents, facing limited arable land, see hydroponics as a solution for urban farming, contributing to food security and environmental sustainability in space-constrained areas. Collectively, these diverse respondents offer a comprehensive view of the need and demand for innovative, low-cost hydroponic systems across various settings in ZamPen.

A structured survey questionnaire was developed by the researcher, encompassing Likert and Liker-type scale questions to gather data on demographic profile of the respondents, their level of awareness and/or knowlegde of hydroponics, perception on practicability, usefulness, relevance, acceptability and sustabinbility of hydroponics and level of interest to adopt this innovation.

The planting materials used consisted of certified lettuce seeds of four (4) varieties, namely Olmetie, Invicta (Batavia), Estrosa and Green Wave, procured from accredited seed suppliers. The hydroponic system was set up using the “Kratky Method” container-based (hydroponic box) units with a capacity of 16 liters served as nutrient reservoirs. All these hydroponic box were settled in constructed low-cost greenhouse using bamboo poles, UV film, garden nets.

In this study, cadmium and nitrate concentrations in fresh lettuce were analyzed to assess food safety compliance and potential health risks, especially in relation to the use of different nutrient solutions.

Data gathered from the survey of the study were analyzed using a descriptive statistic, tailored to the nature of the variables in each part of the study. The specific analysis tools include software such as SPSS (Statistical Package for the Social Sciences).

Data from the experiment were subjected to factorial two-way ANOVA in determining the differences among the samples and post-hoc test (HSD) using Starr software.

Qualitatively, the data from the FGD and the online interview are analyzed using thematic analysis and through IBM-MAXQDA software.

Results and Discussion

Acceptability and adaptability of hydroponic lettuce production among urban and peri-urban communities in the Zamboanga Peninsula

A survey of participants in the National Urban and Peri-urban Agriculture Program (NUPAP) in Zamboanga Peninsula explored awareness of hydroponic lettuce production using Fermented Plant Juice (FPJ) as an organic nutrient solution. This awareness is crucial for policymakers at the Department of Agriculture to assess the acceptability and adaptability of this technology, particularly in urban and peri-urban areas facing space and land-use limitations. The study highlights the importance of such initiatives in meeting the high demand for sustainable food production driven by a growing population. Thus this study supports the argument that urban agriculture supports sustainable good supply and ensure food security in cities (Gunapala, et al., 2025).

This study surveyed participants to understand their perception and awareness of hydroponics, including operational, setup, and labor costs, perceived health benefits, and new technologies. The findings, presented in a detailed table, highlight participants' knowledge and perceptions of hydroponics and the use of FPJ as a nutrient solution. This information serves as a backgrounder for assessing the acceptability and adaptability of hydroponic agriculture for lettuce production as a sustainable strategy for participants and interested parties in the region.

Table 2. Respondents' Level of Awareness on Hydroponics

Question Statement	Weighted Mean	Adjectival Equivalent
1. Are you aware that some crops like lettuce can be grown in soil-less system?	3.84	Moderately Aware
2. Are you aware that there are farmers in ZamPen who are growing lettuce through hydroponics?	3.18	Aware
3. Are you aware of the current trends and innovations in hydroponic farm industry?	3.36	Aware
4. Are you aware of the positive impact of hydroponic farming (e.g., water conservation, reduced use of pesticides, etc.)?	3.56	Moderately Aware
5. To what extent are you aware of the advantages of growing lettuce in hydroponic systems?	3.02	Aware
6. To what extent are you aware of the challenges associated with hydroponic systems?	3.16	Aware
7. How familiar are you with government policies or incentives supporting the adoption of hydroponics in agriculture?	2.94	Aware
Total	23.00	
Grand Mean	3.29	Aware

Legend: 1.0-1.80 = NOT Aware at all; 1.81-2.60=Somewhat Aware; 2.61-3.40= Aware; 3.41-4.20= Moderately Aware; 4.21-5.0= Fully Aware

The potential for growing crops like lettuce in a soilless system and the advantages of hydroponic farming in terms of water saving and lower pesticide use were both moderately understood by the participating farmers. This awareness among NUPAP participants, a Department of Agriculture program, is attributed to official introductions through seminars, trainings, and workshops in Zamboanga Peninsula, where resource persons informed attendees of hydroponics' benefits. This result also echoed in a study which purportedly claimed that urban agriculture, plant-based foods and food nanotechnology hold a great potential in building sustainable agri-food system (Qu, Xiao, Upadhyay, & Luo, 2024).

The farmer participants stated that they were "aware" of producing lettuce hydroponically, of the latest developments and trends in the hydroponic sector, of the benefits of growing lettuce, and of the difficulties that farmers faced while using the systems.

Participants recognize the financial and technical challenges of hydroponic farming, a perception likely shaped by their familiarity with common industrial-scale projects in urban and peri-urban areas. Despite these hurdles, the study suggests that properly mainstreamed hydroponics, particularly ground-based systems, holds promise for supplying society with affordable and sustainable produce. This connected to the study that established that ground-based hydroponics has more yields than indoor ones or rooftops or vertical spaces (Payen, et al., 2022).

Table 3. Respondents' Level of Knowledge about Hydroponics

Question Statement	Weighted Mean	Adjectival Equivalent
1. Different types of hydroponics (e.g., NFT, DWC, etc.)	1.28	NO Knowledge at all
2. Preparing and managing nutrient solutions for hydroponic systems	1.54	NO Knowledge at all
3. Maintaining proper pH levels in hydroponic nutrient solutions	1.36	NO Knowledge at all
4. Managing electrical conductivity or total dissolved solids (TDS) in hydroponic solution	1.27	NO Knowledge at all
5. Impact of temperature on hydroponic plant growth and ability to control it	1.28	NO Knowledge at all
6. Knowledge of growing lettuce in a hydroponic system	1.59	NO Knowledge at all
7. Monitoring hydroponic system parameters for optimal plant growth	1.61	NO Knowledge at all
8. Knowledge of different growing mediums in hydroponics	1.68	NO Knowledge at all
9. Knowledge of plant nutrition requirements in hydroponic cultivation	1.58	NO Knowledge at all
10. Overall knowledge of hydroponics	1.79	NO Knowledge at all
Grand Total	14.98	
Mean	1.50	NO Knowledge at all

Legend: 1.0-1.80 = No Knowledge at all; 1.81-2.60=Somewhat Knowledgeable; 2.61-3.40= Knowledgeable; 3.41-4.20= Moderately Knowledgeable; 4.21-5.0= Very Knowledgeable

According to the survey, participants had significant gaps in their understanding of hydroponics systems. The majority reflected "No Knowledge" indicating a lack of technical awareness, especially with regard to system types such as NFT and DWC, as well as the preparation and maintenance of nutrient solutions, pH levels, and EC/TDS. Similar gaps were found in knowledge regarding how temperature affects the growth of hydroponic plants. The participants also showed somewhat higher but still limited awareness of growing media and plant nutrition requirements.

The participants lack awareness of critical environmental factors that directly influence the success and yield of hydroponic cultivation. There is a substantial educational requirement to enhance public or participant understanding of hydroponics. Addressing these knowledge gaps through targeted educational programs or resources could significantly improve awareness and adoption of hydroponic practices. Focusing on practical applications, system specifics, and environmental controls would be key to fostering a more informed community of hydroponic enthusiasts or practitioners.

Table 4 below presents respondents' level of knowledge of Fermented Plant Juice (FPJ).

Table 4. Respondents' Level of Knowledge of Fermented Plant Juice (FPJ)

Question Statement	Weighted Mean	Adjectival Equivalent
1. Overall knowledge of organic agriculture	2.04	Somewhat Knowledgeable
2. Knowledge of concoctions	1.27	NO Knowledge at all
3. Knowledge of Fermented Plant Juice (FPJ)	1.43	NO Knowledge at all
4. Knowledge of plants recommended for FPJ	1.32	NO Knowledge at all
5. Knowledge of preparing (steps) FPJ	1.41	NO Knowledge at all
6. Knowledge of applying FPJ in growing crops	1.43	NO Knowledge at all
7. Knowledge of applying FPJ in growing lettuce	1.52	NO Knowledge at all
8. Overall knowledge of organic agriculture	2.04	Somewhat Knowledgeable
Weighted Mean Total	12.46	
Grand Mean	1.56	NO Knowledge at all

Legend: 1.0-1.80 = No Knowledge at all; 1.81-2.60=Somewhat Knowledgeable; 2.61-3.40= Knowledgeable; 3.41-4.20= Moderately Knowledgeable; 4.21-5.0= Very Knowledgeable

The results of the analysis show that although participants are somewhat more familiar with organic farming in general, their comprehension is still quite restricted, with mixtures showing the least amount of knowledge, low levels of knowledge exist for fermented plant juice (FPJ), including recommended plants, preparation procedures, and use in crop cultivation. The highest level of familiarity with FPJ's use in lettuce production suggests that its application for popular crops may be recognized.

Table 5. Respondents' Perception of Hydroponics System

	Statements	**Weighted Mean**	**Adjectival Equivalent**
1	I believe that producing lettuce hydroponically can be easily practiced by farmers like me.	3.54	Agree
2	I believe that producing lettuce hydroponically can be easily practiced by households in the urban and peri-urban communities.	3.88	Agree
3	I believe that hydroponics is more economically viable compared to conventional farming methods.	3.54	Agree
4	I believe that hydroponics is more cost-effective compares to traditional soil-based farming methods.	3.76	Agree
5	I believe hydroponics can increase crop yields and thus beneficial	3.79	Agree
6	I believe that hydroponics farming has environmental or resource-related advantages over traditional soil-based farming.	3.96	Agree
7	I believe that hydroponics uses less chemical than soil-based farming.	4.02	Agree

	Statements	Weighted Mean	Adjectival Equivalent
8	I believe hydroponics produces healthier plants and bigger yields.	4.02	Agree
9	I believe hydroponics is relevant to small-scale farmers.	3.29	Neutral
10	I believe hydroponics is relevant to households in the urban and peri-urban communities	3.64	Agree
11	I believe growing lettuce hydroponically has the potential market demand for in the Zamboanga Peninsula	4.10	Agree
12	I believe that hydroponics system of growing lettuce and other crops is acceptable.	3.77	Agree
13	I believe that hydroponics system of growing lettuce and other crops is acceptable by farmers in my community.	4.18	Agree
14	I believe hydroponic technology and resources is adoptable in the city.	3.96	Agree
15	I believe hydroponic technology is reliable.	3.82	Agree
16	I believe hydroponic technology and resources is adoptable in Zamboanga Peninsula.	3.55	Agree
17	Hydroponics is feasible to implement in my farm.	3.66	Agree
18	Hydroponics is feasible to implement in the rural farms.	3.40	Agree
19	Hydroponics is feasible to implement in the urban and peri-urban communities.	3.83	Agree
20	Hydroponics is a sustainable farming method.	3.88	Agree
21	Hydroponics has the potential to help address food security challenges in our region as well as in the whole country.	3.87	Agree
Mean			

Legend: 4.20 – 5.00 = Strongly Agree; 3.40 – 4.19 = Agree; 2.60 – 3.39 = Neutral; 1.80 – 2.59 Disagree; 1.00 – 1.79=Strongly Disagree

The analysis of participant perceptions indicates strong support for hydroponics as an acceptable agricultural technology among farmers and a high potential market demand for hydroponically grown lettuce in the Zamboanga Peninsula. These core beliefs are seen as driving the intent to adapt hydroponics, particularly in urban and peri-urban centers where limited space makes traditional agriculture challenging. Hydroponics is considered adaptable in urban settings offering a sustainable food production solution.

The Zamboanga Peninsula, a region with a diverse agricultural landscape, faces future challenges related to open spaces for production, making mainstreaming hydroponics imperative in urban areas. While both farmers and urban households show openness, urban households exhibit stronger perceptions, possibly due to fewer operational constraints compared to commercial farming. Local government units, cooperatives, and educational institutions are encouraged to promote hydroponic farming through skills training, starter kits, and demonstration projects to bridge knowledge gaps and build confidence.

Despite generally favorable results for relevance, acceptability, adoptability, and sustainability, small-scale farmers expressed some reservation regarding relevance, potentially due to start-up costs or unfamiliarity. Conversely, urban and peri-urban households strongly agree on hydroponics' relevance, supporting its use by hobbyists and families. The system is widely accepted for its adoptability, reliability, and feasibility, with participants recognizing its sustainability and potential to address food security. The positive reception of organic nutrient solutions and perceptions of health benefits, product quality, and environmental impact further suggest receptiveness to such innovations. With adequate technical support, capacity building, and resource access, hydroponic lettuce production has significant potential for sustainable adoption and fostering local food resilience in the Zamboanga Peninsula.

Table 6. Level of interest toward hydroponics and related innovations.

Item Description	Mean	Interpretation
Personal interest in hydroponics	3.46	Moderately Interested
Community farmers' interest	3.46	Moderately Interested
Likelihood to seek further training	3.91	Moderately Interested
Interest to explore hydroponics as a farming method	3.60	Moderately Interested
Producing vegetables hydroponically	3.86	Moderately Interested
Adopting hydroponic technology	3.78	Moderately Interested
Learning low-cost hydroponics systems	3.83	Moderately Interested
Adopting other innovations in farm management	4.04	Moderately Interested

Legend: 1.0-1.80 = NOT Interested at all; 1.81-2.60=Somewhat Interested; 2.61-3.40= Interested; 3.41-4.20= Moderately Interested; 4.21-5.0= Very Interested

Participants displayed moderate interest in hydroponic systems, linked to a lack of practical understanding. While the NUPAP offers information on urban agriculture technologies, including hydroponics, hands-on experience is often absent in trainings. Consequently, participants are likely to seek further training due to a deficit in prior technical knowledge, indicated by a weighted mean of 3.91. A specific focus on hydroponic lettuce or vegetable production also received a high weighted mean of 3.86. This resonated very well to a study done in Jordan among farmers who have established prior knowledge of hydroponics and those who are without prior knowledge of the technology and, to hasten acceptance of the technology, trainings and workshops on the hydroponic technology must be put in place (Shawaqfeh, Altarawneh, Hasan, & Abu Salma, 2024).

Participants in NUPAP trainings and seminars demonstrated an understanding of new farming technologies like hydroponics. However, future training should be more participant-centered and needs-assessment based to promote wider adoption of hydroponic technology in urban and peri-urban areas. Respondents showed consistently high interest in hydroponics and related innovations, with a marked likelihood to seek further training and a strong interest in producing vegetables hydroponically. They displayed keen interest in practical, affordable, and scalable low-cost systems, and the highest interest was in adopting other innovations in farm management, indicating a progressive farming mindset and openness to agricultural advancements.

Factors Influencing the Adaption of Hydroponics

The study results as contained in the succeeding table presented a picture on the factors that may influence the adaption of the hydroponic system in urban and peri-urban centers in Zamboanga Peninsula.

The data were presented with the weighted mean and the corresponding rank as part of the findings of the data from the responses of the participants in the survey.

Table 7. Weighted Mean Scores and Rank of Factors Influencing Hydroponics Adoption

Factor	Weighted Mean	Rank
Affordability	3.19	3rd
Ease of Setup & Maintenance	2.48	4th
Energy Efficiency	3.53	1st
Space Efficiency	3.44	2nd
Water Efficiency	2.33	5th

Participants prioritized energy efficiency, space efficiency, and affordability when considering hydroponic systems. They viewed low-cost, outdoor greenhouse-style setups as an energy-conserving alternative to industrial indoor farms, acknowledging that the study's closed system negated typical energy costs for water transport. Hydroponics' capacity to leverage unconventional spaces within buildings was appreciated for its space efficiency. Affordability was crucial, with participants contrasting the study's economical use of materials like wood and bamboo against the high expenses of urban industrial-scale hydroponics. The findings suggest a growing potential for advanced agricultural research via hydroponics, particularly for younger farmers interested in areas like growing potato tubers in limited spaces with optimized energy, light, and reduced costs, aligning with similar cost-efficient, small-scale systems identified as alternatives to industry-scale ones in other studies.

Experiment Results

A. Growth and Yield

This study assesses the impact of different hydroponic nutrient solutions on the horticultural characteristics and yield of leafy lettuce (Lactuca sativa L.) varieties. The research focuses on key growth parameters like leaf number, leaf area, weight, and overall yield to determine optimal nutrient formulations for enhancing both quality and quantity in controlled hydroponic environments. The findings are intended to guide growers, particularly in urban settings, who are utilizing hydroponics for sustainable food production.

Table 8. Number, length and width of leaves of lettuce varieties applied with different levels of Nutrient Hydroponic Solutions (NHS)

Treatments	1st Cycle			2nd Cycle		
	Number of Leaves	Leaf Length (cm)	Leaf Width (cm)	Number of Leaves	Leaf Length (cm)	Leaf Width (cm)
Varieties						
Olmetie	14^{b}	13.26^{c}	12.24^{a}	14^{b}	11.62^{b}	11.27^{a}
Invicta	12^{c}	17.06^{a}	12.75^{a}	12^{c}	13.72^{a}	11.49^{a}
Estrosa	16^{a}	15.3^{b}	12.87^{a}	16^{a}	13.77^{a}	11.46^{a}
Green Wave	9^{d}	13.06^{c}	8.39^{b}	9^{d}	11.18^{b}	9.18^{b}
F Test A	**	**	**	**	**	**
Levels of Nutrient Hydroponic Solutions (NHS)						
100% Commercial NHS	13	16.01^{a}	12.46	13	13.47	11.42^{ab}
75% Commercial NHS + 25% FPJ	13	15.41^{ab}	11.87	13	12.08	11.59^{a}
50% Commercial NHS + 50% FPJ	13	14.26^{bc}	11.52	13	11.86	10.31^{c}
75% FPJ + 25% Commercial NHS	13	14.40^{bc}	11.12	13	13.06	10.54^{bc}
100% Fermented Plant Juice (FPJ)	13	13.35^{c}	10.85	13	12.42	10.39^{c}
F Test B	Ns	**	ns	ns	ns	*
A x B	Ns	**	**	ns	**	**
CV %	0.1	2.51	5.60			

Means followed by the same letter (s) are not significantly different on the HSD test
*** = Significant at 1% level of probability*
** = significant at 5% level of probability*
ns = not significant

Analysis of four lettuce varieties (Olmetie, Invicta, Estrosa, Green Wave) in hydroponics across two cycles revealed significant genetic differences in growth. Estrosa produced the most leaves, while Green Wave produced the fewest, with variety being a primary driver of leaf number rather than nutrient solutions within the tested ranges. Leaf length and width were significantly influenced by both variety and nutrient treatments. Invicta consistently yielded the longest leaves, and 100% Commercial Nutrient Hydroponic Solution (NHS) produced the longest leaves overall. Combinations of Commercial NHS with Fermented Plant Juice (FPJ) showed potential, with specific ratios (e.g., 75% Commercial NHS + 25% FPJ) demonstrating synergistic effects on leaf width in later cycles.

Interaction Between Varieties and Nutrient Treatments on Growth

The interaction between varieties and nutrient treatments (A × B) was significant at 1% probability level for leaf length and leaf width in the 1st cycle, and for leaf length in the 2nd cycle, indicating that the growth response to nutrient solutions is variety-dependent. This finding corroborates with the research by Samarakoon et al. (2021), who emphasized the genotype × nutrient environment interaction in hydroponic leafy vegetables, suggesting that nutrient formulations should be variety-specific to optimize productivity.

This also echoes the study by Ezzidine et al (2021) which revealed that "The yield of lettuce (kg m−2) grown in ONS was comparable to the yield of lettuce grown in CNS. Except for Mg and Mn, comparable and even higher content of nutritionally minerals were found in the leaves of lettuce grown in organic fertilizer compared to the lettuce grown in conventional fertilizer".

Table 8a. Interaction effects on the length of leaves of lettuce varieties applied with different levels of Nutrient Hydroponic Solutions (NHS) in the 1st and 2nd cycles.

	Levels of Nutrient Hydroponic Solutions (NHS)									
Varieties	**100% Commercial NHS**		**75% Commercial NHS + 25% FPJ**		**50% Commercial NHS + 50% FPJ**		**75% FPJ + 25% Commercial NHS**		**100% Fermented Plant Juice (FPJ)**	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Olmetie	14.85c	12.57c	13.55b	10.79c	12.85c	10.18c	12.85c	12.75b	12.21c	11.81c
Invicta	18.23a	16.19a	17.50a	12.42b	17.31a	11.50b	17.18a	14.60a	15.06a	13.88a
Estrosa	17.47b	13.72b	17.13a	13.74a	14.24b	14.56a	14.61b	14.03a	13.04b	12.82b
Green Wave	13.48d	11.39d	13.48b	13.36c	12.62c	11.18b	12.94	10.85c	13.10b	11.15c

Means followed by the same letter (s) are not significantly different on the HSD test

Table 8a details the interaction effect of lettuce varieties and Nutrient Hydroponic Solutions (NHS) on leaf length across two cropping cycles. Both factors significantly impacted leaf length, with Invicta consistently producing the longest leaves, reaching 18.23 cm in the first cycle and 16.19 cm in the second, particularly at 100% commercial NHS and showing good results with FPJ supplementation. Estrosa also demonstrated adaptability, with notable growth at 50% commercial NHS + 50% FPJ in the second cycle. Olmetie and Green Wave generally had shorter leaves, though Green Wave showed improvement with moderate organic supplementation. Leaf length reductions between cycles may be due to environmental variations or nutrient depletion. These findings align with studies by Chowdhury et al. (2024) on hydroponic systems and Garcia (2022) on fermented plant juice, suggesting that Invicta and Estrosa are suitable for reduced commercial nutrient inputs via FPJ, offering cost-saving sustainable practices for marketability.

Table 8b. Interaction effect of the leaf width (cm) of lettuce varieties applied with different levels of Nutrient Hydroponic Solutions (NHS) in the 2nd cycle

Varieties	**Levels of Nutrient Hydroponic Solutions (NHS)**				
	100% Commercial NHS	75% Commercial NHS + 25% FPJ	50% Commercial NHS + 50% FPJ	75% FPJ + 25% Commercial NHS	100% Fermented Plant Juice (FPJ)
Olmetie	12.27a	11.73b	9.99b	11.28a	11.11a
Invicta	12.02a	12.55a	10.93a	10.77a	11.18a
Estrosa	11.87a	12.80a	11.13a	11.07a	10.45b
Green Wave	9.53b	9.29c	9.20c	9.06b	8.81c

Means followed by the same letter (s) are not significantly different on the HSD test

As shown in Table 8b, the interaction between lettuce variety and the levels of Nutrient Hydroponic Solutions (NHS) during the 2nd cycle indicated significant variations in leaf width. The Olmetie variety attained its widest leaves (12.27 cm) under 100% commercial NHS, followed closely by 75% FPJ + 25% commercial NHS (11.28 cm) and 100% FPJ (11.11 cm). This suggests that while Olmetie benefits most from full commercial nutrient supply, it can still maintain relatively wide leaves under higher FPJ inclusion.

For Invicta, the widest leaves (12.55 cm) were recorded under 75% commercial NHS + 25% FPJ, slightly surpassing the width achieved under 100% commercial NHS (12.02 cm). This indicates that Invicta may respond positively to moderate FPJ supplementation, possibly due to the additional organic metabolites in FPJ that enhance leaf expansion. Estrosa showed a similar trend, with the widest leaves (12.80 cm) under 75% commercial NHS + 25% FPJ, suggesting that partial substitution of commercial solutions with FPJ could enhance leaf development.

In contrast, Green Wave consistently exhibited the narrowest leaves across all treatments, with its highest measurement (9.53 cm) still significantly lower than other varieties. This implies inherent varietal limitations in leaf expansion, regardless of nutrient solution composition.

The statistical groupings from the HSD test reinforce that the effect of nutrient solution composition is variety-dependent.

Upon closer interpretation, the varieties of Lettuce interaction effect in terms of leaf width showed great potential for a 100% Fermented Plant Juice (FPJ) as nutrient at 11.11a, 11.18a, 10.45b, and 8.81c respectively which are performing at par with the commercial NHS which is very expensive to procure. This data showed that with this difference, the promise brought about by the FPJ as a nutrient solution which is cost-effective because it will not cost so much is a viable alternative to commercial NHS which echoes in the study that claimed that "that lettuce plants grown with organic NS derived from fish waste had lower plant height, leaf number and area, fresh biomass, and stomatal density compared to inorganically grown plants, while the total chlorophyll, chlorophyll a, carotene, phenolic compounds, and flavonoid content as well as antioxidant activity were higher in plants grown in the organic solution compared to the inorganic ones, reflecting the nutritive value of the former. In contrast to N, potassium accumulation was significantly higher in inorganically grown plants compared to those grown in the organic solution. The difference in yield parameters between the two solutions was explained by the availability of mineral nutrients to the plants being lower in the organic solution." (Ahmed, Alnuaimi, Askri, & Tzortzakis, 2021).

However, the findings also suggested that while full commercial NHS promotes uniform leaf width in most varieties, a 75% commercial + 25% FPJ mix may optimize leaf expansion in certain cultivars such as Invicta and Estrosa. This has both economic and sustainability implications, as integrating FPJ reduces reliance on costly synthetic nutrient solutions without markedly reducing morphological quality.

Also, a study on lettuce production through hydroponics using commercially available solutions has revealed that there is no significant difference in its performance (Solis & Gabutan, 2023) and so an option such as the FPJ is a suitable alternative to cut cost and to propagate lettuce in a low-cost hydroponic system.

Table 9. Fresh Weight of different varieties applied with different levels of Nutrient Hydroponic Solutions (NHS)

Treatments	1st Cycle	2nd Cycle
	Fresh Weight (gram)	
Varieties		
Olmetie	36.02[a]	37.28[a]
Invicta	32.09[b]	30.29[b]
Estrosa	37.76[a]	31.05[b]
Green Wave	26.80[c]	25.78[c]
F Test A	**	**
Levels of Nutrient Hydroponic Solutions (NHS)		
100% Commercial NHS	39.13[a]	35.32[a]
75% Commercial NHS + 25% FPJ	34.59[b]	33.09[a]
50% Commercial NHS + 50% FPJ	31.37[b]	31.35[ab]
75% FPJ + 25% Commercial NHS	30.55[b]	28.04[b]
100% Fermented Plant Juice (FPJ)	30.19[b]	27.69[b]
F Test B	**	**
A x B	**	**
CV %	2.00	1.91

Means followed by the same letter (s) are not significantly different on the HSD test
*** = Significant at 1% level of probability*

Fresh weight is a primary yield indicator in leafy vegetable production and a direct measure of biomass accumulation influenced by both genetic and environmental factors, including nutrient availability. Table 9 presents the fresh weight performance of four lettuce varieties subjected to different levels of Nutrient Hydroponic Solutions (NHS) over two cropping cycles.

Across both cropping cycles, the results revealed highly significant varietal differences (F Test A: significant at 1% probability level). In the first cycle, Estrosa produced the highest fresh weight, confirming its superior growth performance among the varieties tested. In the second cycle, Olmetie outperformed the other varieties in terms of fresh weight, although both Estrosa and Olmetie consistently demonstrated superior performance compared to the other varieties across both cycles. Specifically, in the first cycle, Estrosa recorded the highest fresh weight at 37.76 grams, which was statistically comparable to Olmetie at 36.02 grams. Conversely, Green Wave consistently produced the lowest fresh weight at 26.80 grams.

A similar trend was evident in the second cycle, where Olmetie produced the highest fresh weight (37.28 grams), followed closely by Estrosa (31.05 grams). Green Wave remained the least productive variety in terms of fresh biomass. These results affirm the superior and stable performance of Estrosa and Olmetie under the tested nutrient solution levels, making them the more promising varieties for hydroponic lettuce production in urban and peri-urban settings.

The data suggest that lettuce growth in a hydroponic system was primarily influenced by root morphology and nutrient solution flow. Research indicates that a suitable flow rate can mechanically stimulate plants (thigmomorphogenesis), promoting root growth by providing eustress. Enhanced root growth improves nutrient absorption and overall plant development. Conversely, excessive flow rates can be detrimental, causing roots to become compact, reducing surface area, and hindering growth, thereby impacting nutrient uptake and plant health compared to optimal conditions.

The application of different NHS levels also exhibited highly significant effects on fresh weight (F Test B: significant at 1% probability level) in both cycles. In both the 1st and 2nd cycles, the 100% Commercial NHS treatment produced the highest fresh weight (39.13 grams and 35.32 grams, respectively), significantly outperforming other treatments.

Partial replacement of Commercial NHS with Fermented Plant Juice (FPJ) at 25% substitution (75% Commercial NHS + 25% FPJ) resulted in slightly reduced but still competitive fresh weights (34.59 grams in the 1st cycle, 33.09 grams in the 2nd). However, increasing FPJ content beyond 50% led to a progressive decline in fresh weight, with 100% FPJ recording the lowest values (30.19 grams and 27.69 grams, respectively).

This outcome substantiates the findings of (Almeyadi, Almheiri, Tzortzakis, Di Gioia, & Ahmed, 2024) who demonstrated that while plant-based organic nutrient solutions can partially substitute synthetic hydroponic fertilizers, complete replacement significantly reduces yield due to potential nutrient imbalances or insufficiencies in macronutrients critical for leaf biomass development, particularly nitrogen.

The interaction between lettuce varieties and nutrient treatments (A × B) was also found to be highly significant (at 1% probability level) in both cropping cycles. This indicates that the response of each variety to the different NHS levels varied considerably, confirming that nutrient formulation efficacy is genotype-specific.

This finding too support the contention that bio-products as nutrients in hydroponics is a viable option to pursue to allow the technology to be adapted at a low-cost. A study revealed that "demonstrated that the bio-product can serve as an effective and eco-friendly alternative to conventional hydroponic nutrient solutions, especially for organic production. The results highlight the potential of bio-products to support sustainable agricultural practices, reduce dependency on synthetic fertilizers, and improve the quality of crops grown in hydroponic systems." (Vogelmann, Böhmer Júnior, & Tiruneh, 2025)

Table 9a. Interaction effects on the fresh weight of lettuce varieties applied with different levels of Nutrient Hydroponic Solutions (NHS) in the 1st and 2nd cycles.

Varieties	**Levels of Nutrient Hydroponic Solutions (NHS)**									
	100% Commercial NHS		75% Commercial NHS + 25% FPJ		50% Commercial NHS + 50% FPJ		75% FPJ + 25% Commercial NHS		100% Fermented Plant Juice (FPJ)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Olmetie	50.93a	45.29a	40.68a	44.18a	31.24b	39.58a	28.88c	28.98a	28.35c	28.36a
Invicta	35.20c	31.92c	31.58c	30.81b	31.65b	30.20b	31.92b	29.65a	30.09b	28.87a
Estrosa	42.58b	36.82b	38.29b	30.74b	36.38a	29.84b	35.11a	28.81a	36.46a	29.04a
Green Wave	27.82d	27.24d	27.82d	26.64c	26.19c	25.80c	26.30d	24.72b	25.85d	24.48b

Means followed by the same letter (s) are not significantly different on the HSD test

Table 9a specifically, presents the interaction effects of lettuce variety and different levels of Nutrient Hydroponic Solutions (NHS) on fresh weight during the first and second cropping cycles. The results show significant differences, indicating that both varietal characteristics and nutrient solution composition play a major role in determining biomass accumulation.

In the 1st cycle, Olmetie recorded the highest fresh weight (50.93 g) under 100% commercial NHS, significantly outperforming other variety–treatment combinations. Even when supplied with 75% commercial NHS + 25% FPJ (40.68 g), Olmetie maintained a competitive biomass yield. However, reductions were observed as the proportion of FPJ increased, with the lowest weight under 100% FPJ (28.35 g).

Interestingly, in the 2nd cycle, although fresh weights were generally lower across varieties, Olmetie maintained high performance across treatments, with no significant differences detected in several FPJ-inclusive treatments, suggesting adaptability to alternative nutrient sources.

Estrosa also exhibited strong performance, particularly under 50% commercial NHS + 50% FPJ in the 1st cycle (36.38 g) and 100% commercial NHS (42.58 g), indicating good flexibility to partial organic supplementation. In contrast, Invicta, which had the highest leaf length in previous tables, did not achieve the highest fresh weight, with its best performance (35.20 g) under full commercial NHS in the 1st cycle. This suggests that morphological advantages (e.g., leaf length) do not always translate directly into greater biomass, as biomass accumulation also depends on leaf thickness, density, and water content (Sambo et al., 2019).

Green Wave consistently recorded the lowest fresh weight across all treatments and cycles, with a maximum of 27.82 g in the 1st cycle under full commercial NHS. This reinforces earlier observations from leaf length and width data that Green Wave's genetic potential for vegetative biomass is inherently lower, regardless of nutrient composition.

Across cycles, fresh weight tended to be lower in the 2nd cycle for most combinations. This decline may be due to environmental variations such as temperature and light intensity inside the greenhouse, nutrient solution temperature effects, or the physiological limits of the reused substrate. The interaction patterns indicate that Olmetie and Estrosa are better candidates for high-yield production when aiming for both commercial NHS efficiency and partial organic integration.

B. Cost and Return of Producing Leafy Varieties of Lettuce Applied with Different Nutrient Hydroponic Solution

The profitability of hydroponic vegetable production systems is highly dependent on both production costs and market returns. In this study, a comprehensive cost and return analysis was conducted to evaluate the economic performance of producing different leafy lettuce varieties under various nutrient hydroponic solution formulations. This analysis aimed to determine which combinations of variety and nutrient management would yield the highest financial returns, thereby providing insights for growers and investors seeking to optimize profitability in hydroponic farming ventures. The following graph presents a summary of the return on investment (ROI) for each treatment combination, highlighting the economic viability of each production setup tested.

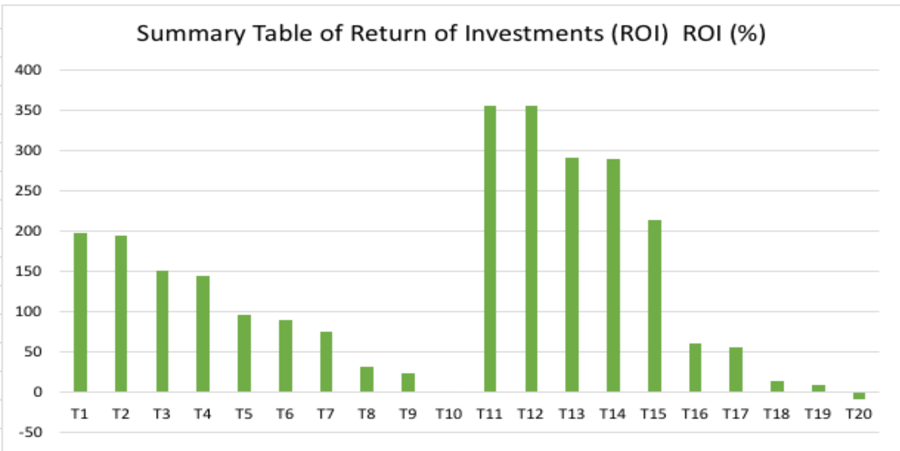

Figure 1. Return of Investment Graph

The graph indicates the Return of Investment (ROI) percentages for twenty different treatments (T1 through T20), demonstrating a wide range of financial outcomes.

The hydroponic lettuce production revealed significant variations in profitability influenced by two major factors: the lettuce variety used (Factor A) and the nutrient hydroponic solution formulation (Factor B). Four lettuce varieties were tested: Olmetie (T1–T5), Invicta (T6–T10), Estrosa (T11–T15), and Green Wave (T16–T20). Alongside this, five nutrient solution formulations were employed, namely: 100% Commercial Nutrient Hydroponic Solution (NHS) for T1, T6, T11, and T16; 75% Commercial NHS mixed with 25% Fermented Plant Juice (FPJ) for T2, T7, T12, and T17; a 50-50 mix for T3, T8, T13, and T18; 25% Commercial NHS with 75% FPJ for T4, T9, T14, and T19; and 100% FPJ for T5, T10, T15, and T20.

The highest ROI observed is 355.91% for T12, closely followed by T11 at 355.63%, indicating significant profitability for these treatments. Conversely, T20 shows a negative ROI of -8.08%, meaning this treatment resulted in a financial loss. The graph further suggests that treatments T11, T12, T13, T14 and T15 are highly effective, while T20 proved to be a losing venture.

The findings showed that the Estrosa variety demonstrated the highest profitability potential, particularly when grown using either 100% Commercial NHS or a 75% NHS and 25% FPJ mixture. Treatment T11 (100% NHS) and T12 (75/25 NHS-FPJ) achieved ROI values of 355.63% and 355.91%, respectively — substantially outperforming all other treatment combinations. This result indicates the strong adaptability of Estrosa to hydroponic systems, coupled with its capacity to respond well to nutrient solutions rich in synthetic commercial formulations, while still maintaining profitability when partially supplemented with organic FPJ. This observation aligns with the findings of Brumfield et al. (2019), who emphasized that variety selection and nutrient management significantly influence the profitability and productivity of hydroponic vegetable production systems.

The Olmetie variety followed as the second most profitable, achieving ROI values of 197.97% and 195.06% for T1 (100% NHS) and T2 (75/25 NHS-FPJ), respectively. However, profitability began to decline as the proportion of FPJ in the nutrient mix increased, with a noticeable drop to 96.64% ROI under T5, which used 100% FPJ. This suggests that while Olmetie can thrive in nutrient-rich solutions, its performance deteriorates when synthetic nutrients are fully replaced by organic alternatives.

On the other hand, the Invicta variety yielded more modest returns. Its highest ROI was 90.71% under T6 (100% NHS), with a steady decline across treatments as FPJ content increased, ultimately dropping to near breakeven levels (0.11%) under T10 (100% FPJ). This demonstrates that Invicta has limited economic suitability in hydroponic systems compared to Olmetie and Estrosa, particularly when using organic or low-synthetic nutrient regimes. The poorest performance was recorded for the Green Wave variety, with its highest ROI at only 61.67% under T16 (100% NHS). Like the other varieties, profitability dropped progressively as the proportion of FPJ increased, ultimately resulting in a financial loss of -8.08% at T20 (100% FPJ).

In summary, the study illustrates that the combined effects of lettuce variety and nutrient formulation considerably affect the financial viability of hydroponic systems. The Estrosa variety, when supplied with 100% Commercial NHS or a 75/25 NHS-FPJ mixture, emerged as the most economically viable combination. The findings also confirm that while partial organic supplementation is feasible, complete replacement of commercial nutrients with FPJ significantly compromises profitability. Future ventures into hydroponic lettuce production should therefore prioritize high-performing varieties like Estrosa, paired with optimized nutrient solution strategies, to maximize economic returns.

C. Cadmium and Nitrate Concentrations and Other Tests

This experiment assessed the safety and nutritional quality of hydroponically grown lettuce by analyzing nutrient concentrations in water solutions (commercial NHS vs. Fermented Plant Juice) and residues in harvested lettuce, specifically nitrates and cadmium. Monitoring these parameters is crucial for food safety compliance and evaluating the environmental sustainability of soilless culture systems, as high nitrates pose health risks and cadmium bio-accumulates. The study aimed to determine if different Nutrient Hydroponic Solutions (NHS) and lettuce varieties resulted in acceptable levels of these elements, aligning with safety thresholds and agronomic standards. Table 10 details the NPK levels in both commercial and FPJ water solutions used in the experiment.

Table 10. NPK levels tested both for commercial and FPJ water solutions used to grow lettuce in the experiment

Parameters	*Unit*	*Commercial NHS*	*FPJ*	*Test Method*
Total Nitrogen	%	0.0716	0.0627	Kjeldahl
Phosphorus as P_2O_5	%	Not Detected	Not Detected	Colorimetry
Potassium as K_2O	%	0.040	0.058	Flame AAS

Nutrient analysis of hydroponic solutions showed variations between commercial and fermented plant juice (FPJ)-based formulations, particularly in nitrogen (N), phosphorus (P), and potassium (K) levels. The commercial solution had slightly higher total nitrogen (0.0716%) compared to the FPJ-based solution (0.0627%), with both being sufficient for leafy crop growth, aligning with optimal hydroponic nitrogen concentrations (50-200 ppm). Both solutions tested "Not Detected" for phosphorus, suggesting potential limitations due to low solubility or extraction inefficiency, consistent with observations of lower phosphorus concentrations in organic liquid fertilizers compared to inorganic ones due to slower breakdown and limited water solubility. This indicates a need for supplementary phosphorus or FPJ formulation optimization for balanced hydroponic nutrition.

The FPJ-based solution (0.058%) showed a greater potassium concentration than commercial NHS (0.040%), suggesting FPJ's effectiveness in extracting potassium from plant sources. Potassium is vital for plant water balance, stomatal function, and health, with its levels being particularly important in hydroponics for cell turgidity and nutrient transport. The higher potassium content in FPJ indicates its potential as a supplementary or alternative potassium source for nutrient solutions, especially for leafy vegetables with high potassium requirements.

Table 11. Laboratory test results of Cadmium traces in water solutions and growth medium used in growing lettuce of the experiment

Parameters	Unit	Commercial NHS	FPJ	Growing Medium	Test Method
Cadmium	mg/kg	Not Detected	Not Detected	Not Detected	Flame AAS

Traces of Cadmium were not detected in water solutions treated with commercial NHS and FPJ, as shown in Table 11. This absence of cadmium, a toxic heavy metal, in hydroponic nutrient solutions is a positive food safety outcome, aligning with studies by Gupta & Gupta (2021) on plant-based fertilizers and meeting FAO/WHO Codex Alimentarius (2019) recommendations. These findings indicate FPJ's potential as a sustainable hydroponic nutrient source, supporting the UN's Sustainable Development Goals for Zero Hunger and Responsible Consumption and Production.

Table 12. Laboratory test results of Cadmium traces in fresh lettuce samples per treatment.

Parameters	**Unit**	**Sample Treatments**		**Test Method**
Cadmium	mg/kg	T1	Not detected	Flame AAS
		T5	Not detected	

Parameters	Unit	Sample Treatments		Test Method
		T6	Not detected	
		T10	Not detected	
		T11	Not detected	
		T15	Not detected	
		T16	Not detected	
		T20	Not detected	

Analysis of fresh lettuce samples using Flame Atomic Absorption Spectrophotometry (Flame AAS) revealed no detectable cadmium (Cd). This indicates that the hydroponic nutrient solutions and production materials used were free from cadmium contamination, aligning with international food safety standards (Codex Alimentarius 2019 maximum permissible level of 0.2 mg/kg fresh weight for leafy vegetables). These findings are consistent with previous studies demonstrating the safety of hydroponically grown vegetables when using clean water and controlled nutrient solutions. Hydroponics, as a controlled soilless system, significantly reduces the risk of heavy metal contamination compared to open field production, particularly in polluted areas, offering a viable alternative for producing safer vegetables.

Laboratory analysis of nitrate concentrations in fresh lettuce treated with commercial nutrient hydroponic solution (NHS) and fermented plant juice (FPJ) revealed significant variations. The Olmetie variety treated with 100% FPJ (T5) had the highest concentration at 260.90 ppm, followed by the Invicta variety with FPJ (T10) at 206.32 ppm, and Olmetie with 100% NHS (T1) at 28.48 ppm. Other treatments registered below the limit of detection (0.1 ppm). The study indicates that both lettuce variety and nutrient source substantially affect nitrate accumulation; Olmetie and Invicta varieties were highly responsive to FPJ, while Estrosa and Green Wave varieties showed consistently undetectable nitrate levels regardless of the nutrient source. Factors such as delayed harvesting and FPJ application practices might contribute to elevated nitrate. All samples were found to be below the European Commission's maximum residue limits (MRLs) for nitrate, thus considered safe for consumption, underscoring the importance of appropriate nutrient management and variety selection for crop quality.

Table 13. Laboratory test results of Nitrate concentrations in fresh lettuce applied with commercial and fermented plant juice NHS.

Parameter	*Varieties*	*NHS Applied*	*Nitrate as Sodium Nitrate (ppm)*	*Test Method*
Nitrate as Sodium Nitrate	Olmetie (T1)	100% Commercial	28.48	AOAC
	Olmetie (T5)	100% FPJ	260.90	
	Invicta (T6)	100% Commercial	Not detected	
	Invicta (T10)	100% FPJ	206.32	
	Estrosa (T11)	100% Commercial	Not detected	
	Estrosa (T15)	100% FPJ	Not detected	
	Green Wave (T16)	100% Commercial	Not detected	
	Green Wave (T20)	100% FPJ	Not detected	

Not Detected = (LOD=0.0)

C. Focus Group Discussion Insights

The FGD session was conducted in a very cordial, relaxed atmosphere where the participants seated around a rectangular table and were openly sharing their insights and ideas of and about the hydroponics agriculture as a technology and how it can be mainstreamed in the urban and peri-urban areas in the region. It was a gathering of like-minded agricultural enthusiast from the region who represented various government agencies who were active in agricultural programs and projects in the Department of Agriculture, Department of Education, in various Local Government Units in different provinces in the region. It was moderated by the researcher with the guidance of a Qualitative research expert from JH Cerilles State College and it was held in one of the hotels in Dipolog City one afternoon on September 2024. Food and snacks were provided to the participants of the FGD session.

Figure 2. FGD session in Dipolog City

Table 14. Thematic Analysis Results from the Focused Group Discussion Sessions

Themes	Subthemes
ISSUES OF HVCDP POLICY LINKED TO HYDROPONICS	- Types and/or variety of produce to be possibly mainstreamed through hydroponic s technology; - Diversification of Lettuce and other produce; - Access to IEC on HVCDP and hydroponics
POTENTIALS FOR URBAN AND PERI-URBAN, PUBLIC SPACES SUCH AS OFFICES AND SCHOOLS THROUGH THE GULAYAN SA PAARALAN PROGRAM AND NATIONAL URBAN AND PERI-URBAN AGRICULTURE PROGRAM	- Future of food production in urban and peri-urban centers; - Mainstreaming of hydroponic technology in public schools through Gulayan sa Paaralan Program of DepEd; - Provide additional income streams for the public schools; - Addresses hunger and malnutrition among pupils and students; - Addresses UN SDG No. 2 on Hunger;
LACK OF COMMUNITY-LEVEL AWARENESS, EDUCATION AND KNOWLEDGE-SHARING ABOUT HYDROPONICS	- Non-familiarity of the hydroponic technology as a low-cost alternative to traditional farming techniques; - Misconception on the costs of hydroponic gardening; - Misconceptions on the materials to be used for hydroponics (communal versus commercial/industrial) - Lack of understanding on the proper preparation of nutrients and its alternatives such as those found organically and thus, lesser appreciation of the fermented fruit juice (FPJ) as a nutrient that is lowcost compared to commercialized nutrients and substrates;
SUITABILITY OF GREENHOUSE AND SITE SELECTION	- High elevation or low elevation site for hydroponic that maximize plant growth; - Close or open ventilated greenhouses;

Themes	Subthemes
	- Access to DA-based facility for greenhouses (individual farmer versus cooperative) - Employing Kratky or other methods of hydroponic agriculture such as open or close system hydroponics;
POLICY GAPS IN THE DEPARTMENT OF AGRICULTURE	- streamline requirements for the availment of programs that mainstreams hydroponics agriculture in urban and peri-urban areas; - lesser political influence on the process and institutional selection of beneficiaries of the program; - low IEC which resulted into non-acceptance of the hydroponic system in the farming community;
POSTHARVEST FACILITY	- streamline requirements for availment of post-harvest facility to support hydroponic; - logistics from farm to post-harvest-market issues; - Beneficiary identification and mainstreaming of DA-related policies on postharvest facility grant;

The following are the thematic results of the Focused Group Discussion in Dipolog City.

Hydroponic agriculture presents significant potential for urban and peri-urban areas, particularly within public schools, to improve food security, provide nutritious food, and generate revenue for school feeding programs. While hydroponics is recognized within Philippine agricultural programs like the High-Value Crops Development Program (HVCDP) and National Urban and Peri-urban Agriculture Program (NUPAP), its mainstreaming is hindered by policy and program issues, coupled with a lack of access to appropriate information, education, and communication (IEC) materials. Current government support is often lettuce-centric, failing to adequately promote diversification into other leafy greens and herbs. Misconceptions about the cost and technical complexity of hydroponic systems, leading to the perception of it being an elite, capital-intensive practice, also deter adoption.

However, low-cost, do-it-yourself hydroponic setups are feasible, utilizing locally sourced materials like bamboo and upcycled containers, and organic nutrient alternatives such as Fermented Plant Juice (FPJ). A study demonstrated a 60 square meter greenhouse with a capacity for 1000-1200 heads costing PhP25,000.00, with production costs not exceeding PhP5,000.00 per cycle, largely due to the use of FPJ made from readily available kangkong and affordable molasses.

Site selection, greenhouse suitability, and appropriate system types (e.g., Kratky, NFT, deep-water culture) are crucial for success, though access to supported greenhouse facilities is limited. Policy gaps within the Department of Agriculture, including bureaucratic processes, political interference, and weak IEC implementation, contribute to inequitable distribution of assistance and hinder broader adoption. Furthermore, inadequate postharvest handling facilities, such as cold storage and efficient transport logistics, lead to significant product losses, and access to postharvest equipment grants is often limited by political patronage. Streamlining processes and ensuring fair beneficiary identification are essential for supporting hydroponic growers and improving system viability.

Challenges of mainstreaming this innovative low-cost hydroponic technology and using Fermented Plant Juice (FPJ) as nutrient solution

As the researcher embarked on this study and experiment as well as its related activities, challenges were encountered which were likewise documented and addressed successfully. The following tables summarize these challenges, observations and recommended solutions on each of the different aspects during the actual paces of implementing the project.

Table 15. Summary of challenges encountered and Solutions in Constructing the Greenhouse/Growing Shelter.

Challenge	***Observation***	***Recommended Solution***
1. Material Sourcing Delays	Not all these materials are available in the local market, some can be purchase thru on-line, they may take time and difficult to source from, like UV film, bamboo poles, or lumber sticks and inputs	Plan and purchase materials in advance. Identify multiple suppliers for critical materials.
2. Fragility of UV Film	During installation, the material tears easily if not handled carefully.	Hire a team that can do the installation skillfully.
3. Securing Net Screen Walls	Fixing the net screens is difficult, it tends to sag.	The use of tie wires secured the net screen tightly.
4. Labor Management	Insufficient or unskilled labor can lead to delays and errors in construction.	Hire experienced workers
5. Cost Overruns	Unexpected expenses for materials or labor can exceed the budget.	Canvass materials you need and detailed budget plan should be prepared with contingency funds.

Implementation of greenhouse construction faced material sourcing delays for UV films, bamboo, and lumber, necessitating advance planning and multiple supplier identification. The fragility of UV films during installation requires careful handling to prevent tears and waste. Securing net screen walls efficiently involves proper tensioning and tie-wire use. Labor management issues, including insufficient or unskilled workers, can be resolved by hiring experienced personnel. Cost overruns are best managed by comprehensive budgeting and a contingency fund to address unforeseen expenses.

Effective hydroponic lettuce management hinges on addressing critical challenges in seed germination and seedling development. Variability in seed germination rates and times across different lettuce varieties requires meticulous monitoring and adjusted sowing schedules to ensure uniform transplanting readiness. Overcrowding in seedling trays, especially for non-pelleted seeds, necessitates thinning or using appropriately sized trays to prevent competition for resources and potential disease susceptibility. The timing of transplanting is also vital; seedlings should be transplanted when they have 2–3 true leaves, ensuring adequate root and shoot development for optimal nutrient uptake and establishment in the hydroponic system.

Table 16. Summary of challenges encountered and solutions in seedling preparation

Challenge	***Observation***	***Recommended Solution***
1. Seed Germination Variability	The four varieties of lettuce did not germinate simultaneously.	Adjust sowing time to ensure all varieties are ready for transplanting simultaneously.
2. Overcrowding in Trays	Too many seedlings in a tray result to poor seedling development and difficulty to transplant them later.	Sow 2-3 seeds per cell in the seedling trays then thin out.
3. Timing of Transplanting	Incorrect timing of transplanting can result in weakened or overly mature seedlings.	Transplant seedlings only when they have at least 2–3 true leaves.

Table 17. Challenges encountered and Solutions in Preparation of Fermented Plan Juice (FPJ)

Challenge	***Observation***	***Recommended Solution***
1. Mold or Fungal Growth	Mold or fungal contamination can occur if the fermentation environment is not controlled properly.	Ensure proper air circulation during fermentation. Cover the mixture loosely and check regularly for any mold growth.
2. Over Fermentation & Odor	An overly strong smell was observed when harvesting was delayed or fermentation was too much.	Check the smell fermentation regularly and harvest FPJ during optimal fermentation period (usually 7-14 days). Maintain proper ventilation.
3. Storage Issues	The first harvest was stored in a plastic bottle and tightly sealed; however, it eventually exploded and was rendered unusable	Store FPJ in a cool, dark place in airtight containers to preserve its quality and effectiveness.

Preparation and utilization of Fermented Plant Juice (FPJ) present challenges related to mold contamination, odor development, and storage. Mold growth, often due to improper sealing or ventilation of fermentation containers, can be mitigated by ensuring loose covering and regular inspections for microbial balance. Prolonged fermentation or delayed harvesting can lead to unpleasant odors and degraded quality; timely harvesting within 7-14 days and maintaining ventilation are recommended. Storage issues, such as bottle explosions from gas build-up, can be avoided by using durable, slightly vented containers stored in cool, dark environments, or by periodically releasing gases. Effective FPJ management relies on controlled fermentation, precise harvesting, and safe storage to preserve its nutrient content and efficacy in organic farming.

Table 18. Challenges encountered and Solutions in Transplanting:

Challenge	***Observation***	***Recommended Solution***
1. Time-Consuming Process	Transplanting multiple varieties requires sorting and careful handling of seedlings.	Plan activities ahead, allocate sufficient time, and organize seedlings by variety.
2. Maintaining Root Health	Delicate lettuce roots are prone to damage during transplanting into hydroponic cups.	Handle seedlings gently, ensure proper root alignment, and avoid overcrowding in the cups. Prepare buffer.
3. Ensuring Proper Variety Placement	Mixing up varieties in boxes and/or treatments.	Label properly. Double check placements.
4. Environmental Control	Lettuce seedlings are highly sensitive during transplanting. In the first batch, many plants did not survive, necessitating repeated replanting.	Transplant in the afternoon. Prepare buffers.

Transplanting in hydroponic lettuce production presents several operational challenges that can negatively impact plant health, uniformity, and market readiness. These include:

- Labor-intensive sorting and careful handling of multiple lettuce varieties, requiring meticulous identification and placement to avoid delays and experimental schedule compromises. Mitigation strategies involve advance planning, sufficient time allocation, and pre-transplanting organization by variety.

- Damage to delicate, fibrous root systems during transfer to hydroponic cups, leading to transplant shock, reduced vigor, and survival. Gentle handling, proper root alignment, and preparation of buffer seedlings are recommended to minimize root disturbance and early-stage mortality.
- Occasional mixing of lettuce varieties during transfer, which can compromise experimental validity. Prevention requires clear, consistent labeling and double-checking of placements.
- High seedling sensitivity during transplanting, leading to mortality and the need for replanting. Environmental stressors like high temperature, intense light, and low humidity exacerbate transplant shock. Conducting transplanting during cooler periods (afternoon) and preparing buffer seedlings can help mitigate these issues.

Addressing these challenges in time management, root handling, labeling, and environmental control is crucial for improving seedling survival and transplanting efficiency, thereby safeguarding yield and experimental integrity.

Conclusions

Hydroponic lettuce production in the Zamboanga Peninsula is perceived positively by participants, indicating potential for addressing space, food security, and livelihood challenges, particularly in urban areas. While willingness to adopt is high, practical barriers like limited technical knowledge, access to materials, and capital constrain adaptability, necessitating targeted support for implementation. The study also found that lettuce variety selection and nutrient formulation significantly impact growth, yield, and profitability. Estrosa and Olmetie varieties showed superior performance. Nutrient solution at 100% Commercial NHS yielded the best results, with partial substitution (25%) of fermented plant juice (FPJ) maintaining satisfactory growth and economic returns; higher FPJ levels negatively affected yield. Nutrient management should be variety-specific. Nitrate accumulation varied by variety and nutrient source, with Olmetie and Invicta showing higher uptake when treated with FPJ, reaching up to 260.90 ppm. Estrosa and Green Wave consistently showed no detectable nitrate, regardless of treatment, suggesting their suitability for low-nitrate production. All detected nitrate levels were below international safety limits. Cadmium was not detected in any samples, confirming the safety and marketability of the lettuce produced through both organic and inorganic nutrient applications.

Recommendations

The study recommends developing local policies and programs to institutionalize hydroponic farming in ZamPen, including technical training, start-up assistance, material access, R&D support, and urban agriculture integration, aligning with UN SDGs. Key suggestions include information campaigns on low-cost FPJ-based hydroponics, diversifying plant varieties beyond lettuce, involving farmers in addressing challenges for best practices, and incentivizing hydroponics in urban settings for nutritional produce. Lettuce farmers should choose varieties with high nitrate uptake capacity and manage FPJ properly, ensuring no cadmium contamination. Continued monitoring of nitrate and heavy metals, along with training on organic fertilizers, is advised. Future research should examine long-term FPJ effects and hydroponics' integration into Filipino cuisine.

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