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Fermented lettuce waste as an organic nutritional supplement of synthetic fertilizer in hydroponic production of Archivel lettuce

Resíduos de alface fermentados como suplemento nutricional orgânico ao fertilizante sintético na produção hidropônica de alface Archivel

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ABSTRACT

Lettuce productivity grown hydroponically increases, but the plant quality is lower than conventional because of the absence of organic compounds. Lettuce waste is an organic material contributing 15–20% of the total weight of the plant and has the potential to be used as liquid organic fertilizer (LF). The objective of the study was to evaluate the effect of lettuce waste as an organic nutritional supplement on lettuce growth and development in a hydroponic system. Different quantities of lettuce waste were fermented in liquid-enriched oxygenation nanobubbles for 22 days. LF at 0.5-2% was incorporated into the AB-mix fertilizer, and their effect on the morphophysiological characters of Archivel lettuce was evaluated. Organic supplementation in synthetic fertilizer effectively increased Archivel lettuce growth in hydroponic cultivation. Organic fertilizer at 1.5% supplementation in AB-mic mixtures increased biological fresh weight by 28.03% over AB-mix, representing by plant height, canopy diameter, leaf number, and area, the quantity of photosynthetic pigments, and vitamin C in leaves improvement. Lettuce waste has the potential to be utilized in the organic hydroponics of lettuce; nevertheless, further investigation is needed to limit the unfavorable excess of ionic presentation in oxygenation nanobubbles fermented biomass.

Index terms: Romaine; bio-based nutrition; crop-residue; soilless; plant-food.

RESUMO

A produtividade da alface cultivada hidroponicamente aumenta, mas a qualidade da planta é inferior à convencional devido a ausência de compostos orgânicos. O desperdício de alface é um material orgânico que contribui com 15 a 20% do peso total da planta e tem o potencial de ser utilizado como fertilizante orgânico líquido (LF). O objetivo do estudo foi avaliar o efeito do resíduo de alface como um suplemento nutricional orgânico no crescimento e desenvolvimento da alface em um sistema hidropônico. Diferentes quantidades de resíduos de alface foram fermentadas em nanobolhas de oxigenação líquida enriquecida por 22 dias. LF em 0,5-2% foram incorporados ao fertilizante AB-mix e avaliou-se seu efeito nas características morfofisiológicas da alface Archivel. A suplementação de fertilizante orgânico a 1,5% nas misturas AB-mic aumentou o peso fresco biológico em 28,03% em relação à mistura AB, representando melhorias na altura das plantas, diâmetro da copa, número de folhas e área, na quantidade de pigmentos fotossintéticos e na vitamina C nas folhas. O desperdício de alface tem o potencial de ser utilizado na hidroponia orgânica de alface; no entanto, mais investigações são necessárias para limitar o excesso desfavorável de apresentação iônica na biomassa fermentada de nanobolhas de oxigênio.

Termos para indexação: Romaine; nutrição à base de bioprodutos; resíduos de culturas; sem solo; alimento vegetal.

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Introduction

The exponential growth of the human population is leading to an increasing demand for food and water. Consumers seek safe and nutritious foods to enhance physical performance, lower disease risks, and extend life. Lettuce is one of the most commonly consumed leafy vegetables worldwide due to its organoleptic and nutraceutical properties (Shi & Gu, 2022). Lettuce has a crunchy texture and a more pungent sweet taste (Hayes et al., 2018). It is low in calories (10 kcal [60 kJ]/100 g, FW), fat, and sodium (Kim et al., 2016). Lettuce contains fiber (1.1 g/100 g, FW), vitamin A (166 µg/100 g, FW), folate or vitamin B9 (73 µg/100 g, FW), vitamin C (4 mg/100 g, FW), vitamin K (24 µg/100 g), iron (Fe), calcium (Ca), potassium (K), and secondary metabolites such as phenolic compounds and carotenoids (Mampholo et al., 2016; Santos et al., 2014). Studies have shown that it can improve health, prevent and treat cancer and cardiovascular diseases (Sepehri & Parvizi, 2022), have anti-free radical and anti-inflammatory properties (Kim et al., 2016), and reduce oxidative damage, Alzheimer's, and diabetes (Naseem & Ismail, 2022).

Romaine lettuce (*Lactuca sativa* var. longifolia) is widely cultivated as consumer preferences increase. The use of high rates of agrochemicals heavily supports modern agriculture. Lettuce production commonly use fertilizer to produce a satisfactory yield (Hossain & Ryu, 2017). Synthetic fertilizer has simplicity, precision, fast, reproducible effects, and ease of dissolution. Its application enhances crop productivity by replenishing essential nutrients in the growth medium, supporting plant growth, and maximizing agricultural yields (Asadu et al., 2024). However, since global awareness and food safety have become major concerns, there is an urgent need for a significant shift in food production and agricultural practices (Herrero et al., 2023; Islam et al., 2021), leading to a combination of synthetic and organic fertilizer application (Ahmed et al., 2021; Chowdhury et al., 2024; Hossain & Ryu, 2017; Kebalo et al., 2024).

Food production in a healthy way is one of the most challenging societal and scientific issues today in the era of synthetic fertilizers and pesticides in agricultural production. In terms of safety and health, the integrated nutrient management system is an alternative way to reduce the use of synthetic fertilizer by combining with organic materials such as manures, crop residues, and composts (Chojnacka et al., 2020; Chowdhury et al., 2024; Santos-Naressi et al., 2022; Siddiqui et al., 2023). The benefit of a combination can improve the use efficiency of recommended synthetic fertilizer, reduce its cost (Abedi, Alemzadeh, & Kazemeini, 2010), reduce heavy metal contamination (Tombarkiewicz et al., 2022) and healthier products (Alneyadi et al., 2024). Bio-based fertilizers (BBFs), derived from livestock wastes, crop residues, manures, or unmarketable farm produce, are widely used in the production of vegetables and produce new chemicals or circulation minerals, allowing macro- and micronutrients available to be uptake. This system effectively contributes to sustainability and circularity while minimizing the environmental impact of agriculture (Chojnacka et al., 2020; Kebalo et al., 2024; Zajac et al., 2018).

Crop residues or plant-derived waste in a large amount are generated annually from agricultural activities that have presented a major source of carbohydrates, lipids, proteins, minerals, vitamins, aromatic compounds, dyes, other phytochemicals and biostimulant. Plant-based biostimulants can improve nutritional efficiency and promote plant growth under abiotic stress conditions, reducing the need for synthetic chemicals (Asif et al., 2023). Since plants have unique physical properties and chemical compositions, fermented biomass should contain unique carbon, nitrogen, vitamins, minerals, and other trace elements (Jin et al., 2018; Kamm & Kamm, 2004). Aerobic fermentation occurs in the presence of oxygen and has been used to break down compounds to make them available for plant uptake (Samtiya et al., 2021). Aerobic fermentation is usually a more intense process than anaerobic fermentation. However, oxygen limitation is a major problem in aerobic fermentation since oxygen has a low solubility in water. Application of nanobubbles (NB) that have high stability oxygenation in liquids (Ebina et al., 2013) could increase aerobic fermentation. However, there was a lack of information on lettuce waste fermentation-enriched oxygenation NB. The objective of the study was to evaluate organic fertilizer generated from fermented lettuce waste-enriched oxygenation NB as a nutritional supplement into synthetic fertilizer on lettuce growth and development in a hydroponic system.

Material and Methods

Growth condition and plant materials

The experiment was conducted at the Zijhi Farm Research Center, Batu City, East Java, Indonesia (7°50’54.3”S 112°32’51.7”E; elevation of 920 m above sea level). During the production cycle, the air temperature outside the greenhouse ranged between 21 and 34 °C (day), and inside the greenhouse was between 25 and 41 °C. In comparison, the relative humidity was in the range of 40 to 89% (Figure 1). Seeds of the Archivel variety (RZ 41-428) were planted into pot trays filled with commercial cocopeat substrates from local production. Growth mediums were fertilized with AB-mix and kept in a dark room at 25 °C until seed germination. Germinated and healthy seedlings were then moved onto fixed benches in the greenhouse for further seedling growth. After 26 days of incubation, seedlings were planted in gullies using a nutrient film technique (NFT) hydroponic system.

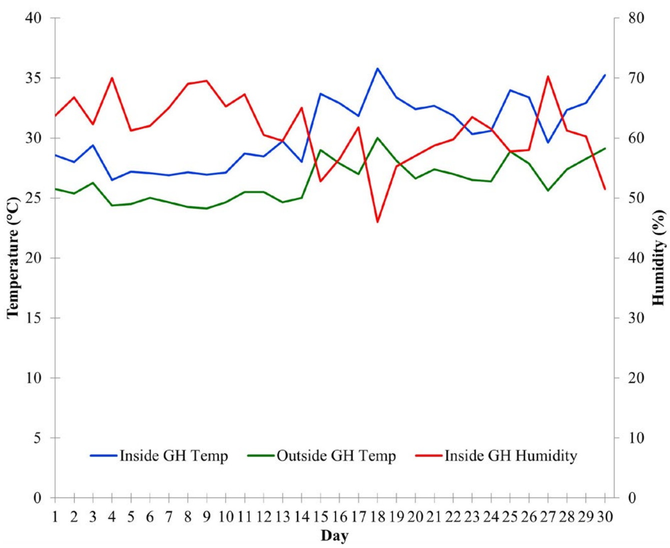

Figure 1: Daily inside, outside the greenhouse (GH) temperature, and inside the GH humidity throughout the production cycle.

Liquid organic and synthetic fertilizer

Organic fertilizer was generated from unmarketable baby romaine lettuce. The waste of leaves and stems of baby romaine was quantified at 2 (LF-1), 4 (LF-2), 6 (LF-3), and 8 kg (LF-4) and fermented in 8 liters of sterilized water-enriched NB, and 22 mg L^{-1} dissolved oxygen (DO) in addition of 50 ml (v/v) effective microorganism (EM4; SLP, EMRO Licence). An NB generator and an oxygen concentrator generated the NB and DO in liquid. After 22 days of fermentation in the dark condition, an equal volume of the organic liquid fertilizers was added to the liquid AB-mix (Pratama, Ardie, & Sukma, 2023), resulting in a final nutrition concentration of 0.5% (LF-1), 1% (LF-2), 1.5% (LF-3), and 2% organic fertilizer in AB-mix (LF-4) and AB-mix (LF-0). The pH and nutrition concentration were measured daily and kept within the range of 5.5–5.7 and 600 ppm, along with production.

Plant characters measurement

The lettuce plants were harvested after 56 days of transplanting. Samples were collected to determine plant height, leaf size, and fresh and dry leaf mass. The plant height was measured from the lowest stem to the tip of the lettuce leaves. Individual leaf length and width were measured and calculated by 0.66 as correction factors, and total leaves per plant were counted. The chlorophyll-a (chl-a) and b (chl-b) and carotenoids were extracted from leaves using 95% ethanol. The mixtures were homogenized and centrifuged at 10,000 rpm for 15 minutes. The supernatant was diluted ten times and observed using UV-Vis spectrophotometer at 664 nm, 649 nm, and 470 nm and calculated based on Lichtenthaler (1987). Vitamin C was determined using the iodometric method. Individual samples were added to the iodine solution until the color turned blue. The amount of iodine solution needed to change color is then used in the calculation formula in a mg $100g^{-1}$ unit.

Experimental setup, data collection, and statistical analysis

The experiments followed a completely randomized design with five replications. The data of the plant height, diameter of the canopy, leaf number and leaf areas, biological fresh weight, biological dry weight, shoot and root dry weight, chlorophyll-a and -b, carotenoid content, and vitamin C were analyzed by a normality test (Jarque-Bera test) and a one-way ANOVA. The mean values were compared using the Tukey test at a 5% error probability. The data was also subjected to principal component analysis (PCA) and hierarchical clustering using XLStat 2019 software.

Results and Discussion

The organic fertilizer-derived fermented lettuce waste-enriched oxygenation NB had a significant effect ($p<0.05$) on the morphophysiological characters of Archivel lettuce cultivated hydroponically NFT system. Generally, organic fertilizers increased plant height, canopy diameter, leaf areas, biological fresh and dry weight, shoot, and root dry weight, but not leaf number (Table 1; Figure 2). Moreover, organic fertilizers have considerably increased the photosynthetic pigments concentration. Organic fertilizer improved vitamin C concentrations but not significantly (Table 2).

Organic fertilizer (LF-3) is superior to other treatments in the production cycle. The administration of 1.5% organic fertilizer improved 3.99% plant height (15.4-18.6 cm), reduced 1.7% leaf number (42-44 leaf $plant^{-1}$), and improved 13.20% leaf areas (3192.62-3594.61 cm^2 $plant^{-1}$), compared to AB-mix, which have 15.2-17 cm of individual plant height, 41-45 leaf $plant^{-1}$, and 2445.14-3567.66 cm^2 individual leaf areas.

Organic fertilizer treatments of 0.5%, 1.0%, and 2.0% LF resulted in significantly lower plant height, leaf number, and leaf area when compared to the AB mix. Higher mean values of leaf number and leaf area indicate biological fresh weight. The results showed that the mean leaf numbers for LF-3 and control treatments were not significantly different. Interestingly, other organic fertilizer treatments (LF-1, LF2, and LF-4) reduce plant height, canopy diameter, leaf number and area, biological fresh and dry weight, and shoot and root dry weight. This shows that the variations in plant growth stimulation may have been caused by the concentration of nutrients in the organic solution mixed with synthetic fertilizer.

Figure 3 shows that LF-3 promoted Archivel growth more effectively during the production cycle than other treatments. Interestingly, 1.5% organic fertilizer was shown to be more effective in stimulating Archivel growth in the early stages of the production cycle at 33 days, resulting in a greater LF-3 growth rate of 5.35 g day-1.

This favorable benefit of 1.5% organic fertilizer in AB-mix persisted throughout the production cycle, reaching its peak growth rate of 9.11 g day-1 at 49 days of cultivation before declining. BFW peaked at 191.35 g plant-1 during a 56-day production cycle, 28.03% greater than the control. BDW improved similarly to BFW, which was 26.82% higher than control.

Compared to 0.5, 1, and 2% organic fertilizer supplementation, this study found that 1.5% organic fertilizer was a favorable psychochemical condition for promoting Archivel growth. Organic fertilizer-induced growth was also demonstrated by active root growth. All dry weights of root portions produced from organic fertilizer treatments improved from 39.11 to 68.23% over the control (Table 1). The results showed that organic fertilizers completely altered RDW, although there was no difference between organic fertilizer treatments.

Organic-based fertilizer was reported on lettuce compared to synthetic fertilizer, which resulted in the growth promotion of plant height and leaf number in a shorter cultivation period. Synthetic fertilizer was dominant at the end of cultivation compared to solely organic fertilizer-derived fish (Ahmed et al., 2021), and so from fruits and vegetables (Siddiqui et al., 2023). Combined organic waste from animals and synthetics was claimed to have improved the development of the iceberg (Santos-Naressi et al., 2022). Using fish farming water for lettuce fertigation resulted in a remarkable increase of over 26% in commercial productivity compared to using healthy water for irrigation alone (Silva et al., 2023). The lettuce cultivated with mineral and organomineral fertilizers exhibited the highest yield of physical characteristics directly linked to the superior nitrogen content in their leaves (Monteiro et al., 2024). Organic hydroponics has been used in lettuce (Chowdhury et al., 2024).

In most cases, using organic fertilizers is difficult because the nutrient release rate may not match the plant's nutrient demands, necessitating continuous adjustment of the hydroponic system and substrate media to increase microbial activity and obtain the optimum decomposition of organic materials for the plant to uptake (Burnett et al., 2016; Treadwell et al., 2007). This challenge will limit the grower's ability to manage the nutrient supply for the plants properly, and their use may result in the accumulation of salts (Ahmed et al., 2021). However, fermentation before utilizing plant waste may degrade complex compounds to simple substances and increase mineral availability from the complex (Samtiya et al., 2021). In this study, oxygenation NB-assisted fermentation of LT-3 produced ammonium, nitrate, P, and K at 233.10, 234.18, 177.61, and 197.90 mg L^{-1}, respectively. Aerobic fermentation accelerated the breakdown process. Introducing NB into liquid phases has solved the problem of low oxygen availability. Nanobubbles are microscopic gas bubbles in liquids that are less than 200 nm in diameter and possess various distinct physical features. Long-term stability in water and highly efficient gas solubility resulted in the supersaturation of oxygen gas in water (Ebina et al., 2013). Ion minerals derived from lettuce waste and other simple organic compounds enriched by synthetic fertilizer are represented by AB-mix mixtures.

A recent study revealed that organic fertilizer-derived lettuce plants play a significant role in regulating plant growth. Adding organic fertilizer to synthetic fertilizer composition improved Archivel's physiological characteristics, as seen by higher levels of vitamin C, chlorophyll-a, -b, and carotenoid content. The mean vitamin C levels in Archivel peaked at 28.16 mg $100g^{-1}$ fresh material, 45.5% greater than the 1.5% organic fertilizer in AB-mix. However, 2% organic fertilizer lowered vitamin C by 18.2% compared to AB-mix (Table 2). The results confirmed that organic fertilizer treatment improved the quality of photosynthetic pigments. In general, organic fertilizer treatments boosted chlorophyll-a content more than chlorophyll-b. Adding 0.5% raised chlorophyll-a by 61%; however, increasing the amount of organic fertilizer decreased stimulation values. Many studies found that bio-based fertilizers from various sources boosted plant growth in diverse ways.

Organic fertilizer at 1% enhanced chlorophyll-a by 45.3%. Adding 0.5% organic fertilizer to nutrition boosted chlorophyll-b levels to 10.81 µg mL^{-1}, 81.6% higher than the control. However, the increased organic fertilizer concentrations lowered chlorophyll-b content. In contrast to the vegetative enhancement provided by LF-3, overall chlorophyll content was lowest in LF-3. Organic fertilizers at 0.5, 1, and 2% enhanced chlorophyll concentration over the control, reaching a peak of 18.48 µg mL^{-1} with 0.5% supplementation (LF-1). Organic fertilizer treatments had the most positive impact on carotenoid pigments. Organic fertilizer treatments raised carotenoid pigment in leaves by 56.6-170.3% compared to control, with peaks at 0.98, 0.93, and 0.91 µg mL^{-1} for LF-4, LF-2, and LF-1, respectively, but not significantly. In fact, the mineral composition of the nutrition solution significantly impacted the chlorophyll and carotenoid content of lettuce leaves (Machado et al., 2020; Moncada, Miceli, & Vetrano 2021), as this study found.

Table 1: Organic fertilizer-derived nanobubble fermented lettuce waste in synthetic fertilizer affected the plant height (PH), the diameter of the canopy (CD), leaf number (LN) and areas (LA), biological fresh weight (BFW), and dry weight (BDW), shoot (SDW), and root dry weight (RDW) of morphophysiological characteristics of Archivel lettuce grown hydroponic NFT system.

Organic fertilizer	PH (cm)	CD (cm)	LN	LA (cm^2)	BFW (g)	BDW (g)	SDW (g)	RDW (g)
LF-0	16.06±0.17a	23.41±0.33b	43.50±1.73a	3050.21±516.05b	149.45±16.37b	7.01±0.66b	5.81±0.58b	1.20±0.23b
LF-1 (0.5%)	14.55±0.62b	22.02±0.61c	36.25±1.26b	2176.46±153.76c	125.97±6.41c	6.55±0.39bc	4.53±0.43c	2.0±0.30a
LF-2 (1.0%)	13.75±1.01a	20.14±0.91d	36.25±1.26b	1968.23±146.99c	102.01±12.58d	5.9±0.80c	4.32±0.69c	1.67±0.32a
LF-3 (1.5%)	16.7±0.73a	24.82±0.89a	42.75±0.96a	3452.80±178.46a	191.35±9.51a	8.89±0.38a	7.01±0.36a	1.89±0.11a
LF-4 (2.0%)	14.52±0.41b	21.94±0.49c	37.25±2.22b	2015.38±100.07c	105.95±5.38d	6.14±0.43c	4.18±0.21c	1.96±0.26a
Pr > F	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.000
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Means± standard deviations followed by the same letter in the column do not differ at 5% probability using the Tukey test. LF-0 (AB-mix), LF-1 (0.5%), LF-2 (1.0%), LF-3 (1.5%), LF-4 (2.0% organic fertilizer in AB-mix).

Figure 2: Pictorial representation of biological fresh weight of the lettuce variety 'Archivel' grown for 56 days in an NFT hydroponic system fertilized with a AB-mix (LF-0) or with organic fertilizer derived nanobubble fermented lettuce waste (LF); LF-0 (AB-mix), LF-1 (0.5%), LF-2 (1.0%), LF-3 (1.5%), LF-4 (2.0% organic fertilizer in AB-mix). Bars = 10 cm.

Table 2: Organic fertilizer derived from lettuce waste and synthetic fertilizer affected the chlorophyll a (chl-a), b (chl-b), total chlorophyll (total chl), carotenoid (car) and vitamin C of Archivel lettuce grown in a hydroponic NFT system.

Organic fertilizer	Chl-a ($\mu g\ mL^{-1}$)	Chl-b ($\mu g\ mL^{-1}$)	Total chl ($\mu g\ mL^{-1}$)	Car ($\mu g\ mL^{-1}$)	Vitamin C ($mg\ 100\ g^{-1}$)
LF-0	4.76±1.36bc	5.95±1.18 b	10.71±2.51bc	0.36±0.17b	19.36±9.64a
LF-1 (0.5%)	7.66±1.23a	10.81±6.50a	18.48±6.54a	0.91±0.56a	22.88±7.87a
LF-2 (1.0%)	6.92±2.24ab	5.20±1.25b	12.12±3.45bc	0.93±0.37a	23.00±7.67a
LF-3 (1.5%)	3.76±0.74c	2.67±1.00b	6.43±1.58c	0.57±0.17ab	28.16±14.46a
LF-4 (2.0%)	7.47±2.92a	5.74±3.47b	13.20±6.02ab	0.98±0.49a	15.84±3.94a
Pr > F	0.010	0.020	0.007	0.008	0.339
Significant	Yes	Yes	Yes	yes	No

Means± standard deviations followed by the same letter in the column do not differ at 5% probability using the Tukey test. LF-0 (AB-mix), LF-1 (0.5%), LF-2 (1.0%), LF-3 (1.5%), LF-4 (2.0% organic fertilizer in AB-mix).

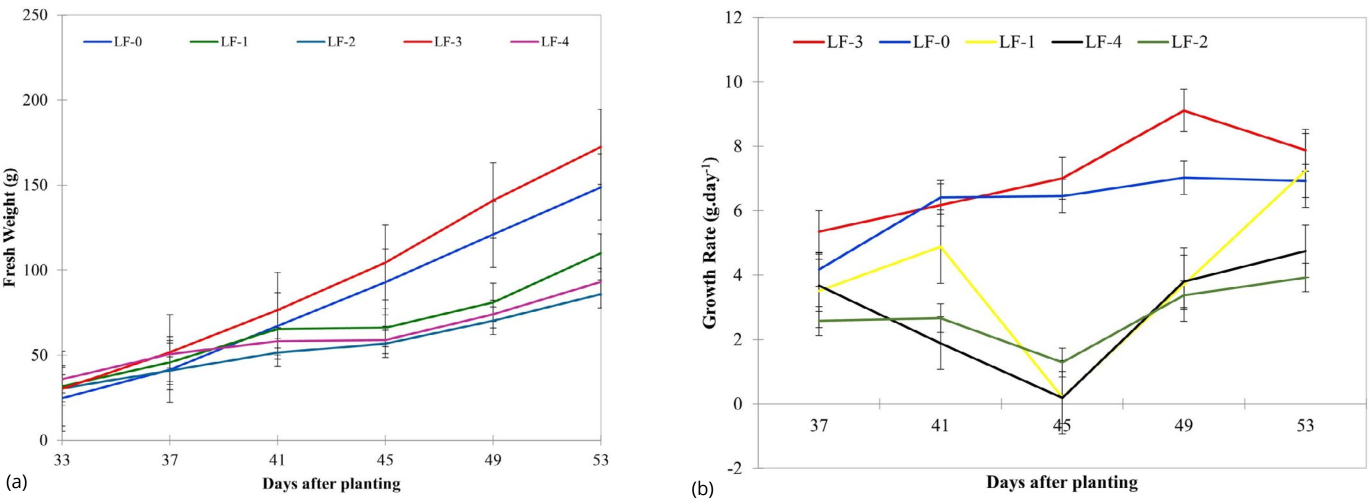

Figure 3: Fresh weight (a) and growth rate (b) of lettuce grown hydroponically, supplemented by liquid organic fertilizer derived nanobubble fermented lettuce waste (LF). LF-0 (AB-mix), LF-1 (0.5%), LF-2 (1.0%), LF-3 (1.5%), LF-4 (2.0% organic fertilizer in AB-mix).

Cluster analysis revealed that organic supplementation in AB mix at 0.5 and 1.5% significantly contributed to morphophysiological improvement in Archivel production. The results indicate three component factors with eigenvalues greater than >1, suggesting a three-factor solution (PC1 = 9.54, PC2 = 1.72, and PC3 = 1.14) with 95.46% cumulative variability (Figure 4). The other small eigenvalue of less than <1 was not utilized to estimate the probable number of contributing source factors. The first principal component (PC1) contains the most significant variance values (73.40%), with dominant PH, BFW, BDW, SDW, CD, LN, and LA variables. The second principal component (PC2) contains the most excellent variance values (13.26%), with dominant variables of BDW, RDW, vitamin C, and carotenoid concentration. The third principal component (PC3) contains the greatest variance values (8.79%), with dominant variables of chlorophyll-b and total chlorophyll (Table 3; Figure 5).

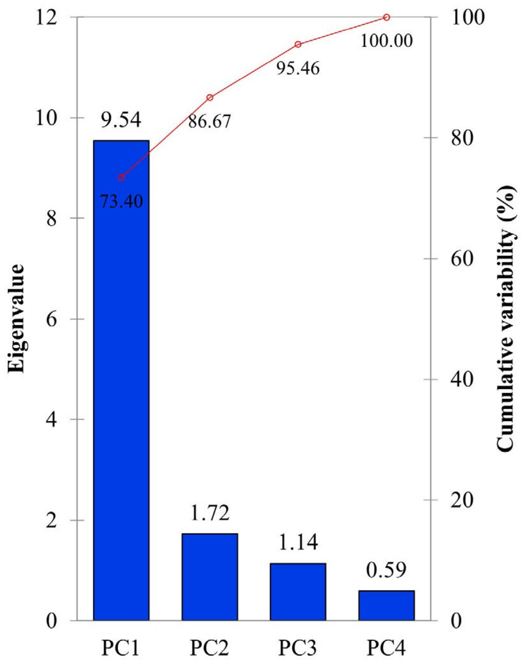

Figure 4: Screen plot for explained eigenvalues and cumulative variability (%) from Principal Component Analysis.

If the factor loading value is more significant than 0.3, the observed variables in PC become the primary determinants of variation. A greater factor loading value indicates that the factors extract adequate variance from the variables (Tavakol & Wetzel, 2020). The correlation study indicated that BFW, BDW, SDW, PH, CD, LN, and LA interact considerably, whereas pigments correlate negatively (Figure 6).

The data obtained from this study indicated that healthy Archivel with small leaf areas is well suited for fresh-cut processing. Small-size leaves might be pack-aged without cutting or trimming operations, enabling faster processing and improving the percentage of usable product by reducing losses due to browning (Martínez-Sánchez et al., 2012). Chlorophyll is known to be rich in vitamins E, A, C, K, and beta-carotene, as well as minerals like Mg, K, Fe, Ca, and essential fatty acids. Its antioxidant properties have been linked to protective effects like anti-carcinogenicity and antimutagenicity (Turkmen et al., 2006).

Table 3: Factor loading based on PCA results.

Variables	PC1	PC2	PC3
PH	0.963	0.000	0.204
BFW	0.955	0.247	0.165
BDW	0.924	0.380	0.032
SDW	0.990	0.125	0.036
RDW	-0.349	0.883	-0.021
Vitamin C	0.540	0.623	-0.078
Chl-a	-0.986	0.093	0.107
Chl-b	-0.627	0.064	0.764
Total chl	-0.821	0.081	0.562
Car	-0.857	0.439	-0.236
CD	0.903	0.146	0.273
LN	0.939	-0.319	0.097
LA	0.992	0.002	0.122

The primary role of ascorbic acid is its function as an antioxidant and scavenger of reactive oxygen species, thereby limiting excessive oxidative stress associated with cell metabolism (Ishikawa & Shigeoka, 2008). Vitamin C (ascorbic acid) has been proven to reduce the risk of coronary heart disease, cancer, and atherosclerosis (Osganian et al., 2003). It is a vital health-promoting compound, and the daily requirement for an adult is 90 mg/d for men and 75 mg/d for women (Frei & Trabe, 2001). In general, lettuce has low vitamin C content; therefore, using organic fertilizer can improve the concentration of vitamins in leaves as a daily dietary need. Organic fertilizers in this study effectively promote the vegetative and reproductive growth and final quality of crops, as previously reported by Liu et al. (2024). Organic hydroponics is a complex method that requires more consideration than traditional hydroponics (Ahmed et al., 2021). Organic sources of nutrients may contain too many constituents (for example, micronutrients) or unneeded constituents (for instance, sodium) that require regular ion-specific monitoring (Burnett et al., 2016). There is an argument that healthy organic produce can only be produced in soil (living systems), whereas hydroponic cultivation systems can produce high-quality crops in more sustainable manners and in places that normally would not be suitable for organic production using soil-based production systems. However, the key components of a productive organic hydroponic system, such as a balanced and stable pH, electrical conductivity (EC) of the nutrient solution, the use of filters, and the presence of adequate microorganisms, have to be regulated (Treadwell et al., 2007), to regulate the negative effect of ionic-derived organic materials.

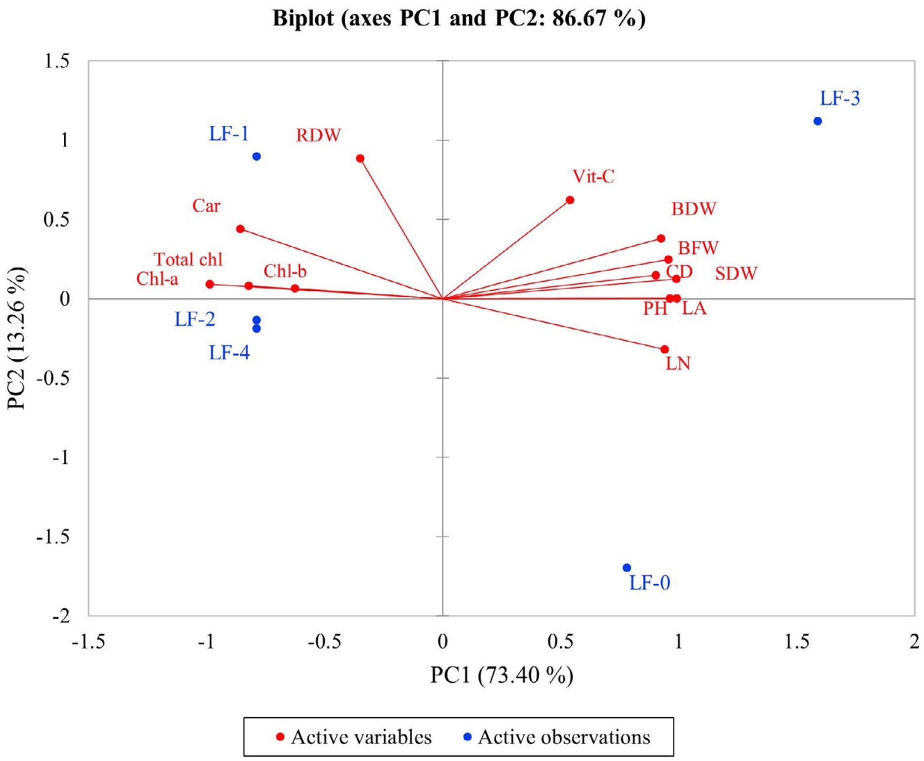

Figure 5: Distribution effect of morphophysiological characteristics of Archivel lettuce grown hydroponic NFT system fertilized by liquid organic fertilizer derived nanobubble fermented lettuce waste (LF). LF-0 (AB-mix), LF-1 (0.5%), LF-2 (1.0%), LF-3 (1.5%), LF-4 (2.0% organic fertilizer in AB-mix).

Variables	PH	BFW	BDW	SDW	RDW	Vit-C	Chl-a	Chl-b	Total chl	Car	CD	LN	LA
PH	**1**	**0.952**	**0.902**	**0.951**	**-0.285**	**0.406**	**-0.913**	**-0.471**	**-0.686**	**-0.850**	**0.978**	**0.938**	**0.979**
BFW		**1**	**0.981**	**0.983**	**-0.122**	**0.662**	**-0.902**	**-0.456**	**-0.671**	**-0.750**	**0.940**	**0.833**	**0.969**
BDW			**1**	**0.961**	0.022	**0.716**	**-0.870**	**-0.535**	**-0.712**	**-0.628**	**0.907**	**0.752**	**0.921**
SDW				**1**	**-0.254**	**0.641**	**-0.966**	**-0.577**	**-0.779**	**-0.809**	**0.905**	**0.889**	**0.988**
RDW					**1**	**0.188**	**0.451**	**0.217**	**0.328**	**0.733**	**-0.098**	**-0.587**	**-0.349**
Vit-C						**1**	**-0.531**	**-0.281**	**-0.404**	**-0.244**	**0.390**	**0.255**	**0.532**
Chl-a							**1**	**0.694**	**0.872**	**0.872**	**-0.822**	**-0.939**	**-0.966**
Chl-b								**1**	**0.957**	**0.367**	**-0.389**	**-0.546**	**-0.528**
Total chl									**1**	**0.599**	**-0.594**	**-0.748**	**-0.746**
Car										**1**	**-0.735**	**-0.957**	**-0.879**
CD											**1**	**0.852**	**0.927**
LN												**1**	**0.943**
LA													**1**

Figure 6: Correlation analysis of morphophysiological characteristics of Archivel lettuce grown hydroponic NFT system fertilized by liquid organic fertilizer derived nanobubble fermented lettuce waste (LF). Values in bold on the correlation diagram are different from 0 with a significant level of alpha = 0.95.

Since organic hydroponics is beneficial in nutritional and phytochemical supplementation biomass recycling and is becoming more expensive relative to inorganic fertilizer, hydroponic production systems with organic inputs may offer the opportunity to grow organic, healthy, fresh vegetables without the use of synthetic inputs in areas where traditional organic cultivation is not possible. Microbial processed organic materials as plant nutrient sources and an organic substrate offered mechanical support to plant roots, as the study revealed better root development. Organic hydroponics has the potential to reduce reliance on chemical fertilizers entirely by using organic-based fertilizers as the primary source of nutrients for crop production. Organic fresh products are valued and establish a positive reputation regarding human health, environmental issues, and sustainable production practices. This investigation confirmed that fertilizer-derived romaine waste improved Archivel lettuce growth and development in hydroponic NFT circumstances, and it has the potential to be used in future organic hydroponic production cycles to develop better food production and sustainability.

Conclusions

Organic fertilizer supplementation in synthetic fertilizer effectively increased Archivel lettuce growth in hydroponic cultivation. Organic fertilizer at 1.5% supplementation in AB-mic mixtures increased biological fresh weight by 28.03% over AB-mix, representing by plant height, canopy diameter, leaf number, and area, the quantity of photosynthetic pigments, and vitamin C in leaves improvement. Lettuce waste has the potential to be utilized in the organic hydroponics of lettuce; nevertheless, further investigation is needed to limit the unfavorable excess of ionic presentation in oxygenation NB fermented biomass.

Author contribution

Conceptual idea: Pujiwati, I.; Rosyidah, A.; Agisimanto, D.; Yulianti, F.; Methodology design: Pujiwati, I.; Rosyidah, A.; Agisimanto, D.; Data collection: Saputra, RB; Pujiwati, I.; Rosyidah, A.; Agisimanto, D.; Yulianti, F.; Data analysis and interpretation: Saputra, RB; Pujiwati, I.; Rosyidah, A.; Agisimanto, D.; Yulianti, F.; and Writing and editing: Pujiwati, I.; Rosyidah, A.; Agisimanto, D.; Yulianti, F.; Saputra, RB.

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