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# Agronomic and Physiological Responses of Sweet Potato to Moringa Leaf–seaweed Liquid Organic Fertilizer in Coastal Soil

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author HH curated the data, conducted the formal analysis and investigation, developed the methodology, and wrote the original draft. Author FF conceptualized the study, acquired the funding, supervised the research, administered the project, and reviewed and edited the manuscript. Authors ZM and NS conceptualized the study, acquired the funding, supervised the research, and reviewed and edited the manuscript. Author SS, CH and WW supervised the research and reviewed and edited the manuscript. All authors read and approved the final manuscript.*

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## Abstract

**Aims:** To determine the physiological and agronomic responses of sweet potato plants to the application of liquid organic fertiliser (LOF) prepared from moringa leaves and seaweed, and to identify the best moringa leaf-seaweed LOF combination for sweet potato growth and yield in coastal soil.
**Study Design:** Completely randomised block design.

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Place and Duration of Study: The research was conducted over two growing seasons, from August to November 2022 and from January to April 2023, on coastal land in Bengkulu Tengah, Indonesia.
**Methodology:** Two consecutive field experiments were conducted in 2022 and 2023. The treatments were LOF1 = 100% flowering moringa leaves, LOF2 = 100% non-flowering moringa leaves, LOF3 = 100% seaweed, LOF4 = 50% seaweed + 50% flowering moringa leaves, LOF5 = 50% seaweed + 50% non-flowering moringa leaves, and LOF6 = 50% seaweed + 25% flowering moringa leaves + 25% non-flowering moringa leaves.
Results: Pooled data from the two-year experiments indicated that LOF prepared from 100% flowering moringa leaves was more effective in increasing chlorophyll a and carotenoid contents, whereas LOF prepared from 50% seaweed + 50% non-flowering moringa leaves was more effective in increasing proline content. However, the treatments did not affect chlorophyll b, total chlorophyll, tuber sweetness, nitrogen uptake, phosphorus uptake, potassium uptake, leaf greenness, fresh plant weight, dry plant weight, number of tubers per plant, or tuber weight per plot.
**Conclusion:** The results suggest that moringa leaf- and seaweed-based LOF can influence selected physiological responses of sweet potato grown in coastal soil, although its effect on agronomic yield was not significant under the conditions of this study.

*Keywords: Sweet potato; liquid organic fertiliser; moringa leaf; seaweed; coastal soil; liquid organic fertiliser formulation; chlorophyll a; carotenoids; proline; physiological response*

## 1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a tuberous crop with a high carbohydrate content and is considered an alternative food crop because it provides energy, vitamins and minerals (Ochieng, 2019). Sweet potato production is primarily conducted in highland areas; however, highland farmland is becoming increasingly limited because of land conversion to non-agricultural uses and the growing demand for various vegetables, including organic vegetables. This situation requires the use of alternative lowland areas for sweet potato cultivation, including coastal land. Coastal land is often characterised by Entisols (Ma'ruf, 2018). Land use has a significant impact on coastal ecosystems, including salinity, tidal processes, water stress and waterlogging, which may contribute to unstable agricultural practices (Stuart, 2010). Coastal land can be utilised through production technologies that enable crops to adapt to new environments.

Organic vegetable farming on coastal land may provide an alternative production area, particularly for sweet potato cultivation. Demand for organic plant products is increasing because of growing public awareness of the negative effects of synthetic fertilisers and pesticides, as well as their adverse environmental impacts (Singh et al., 2017). Organic crop production requires organic fertilisers, which may be supplied as solid organic fertiliser (SOF) or liquid organic fertiliser (LOF). The addition of LOF in organic vegetable production is necessary because SOF takes a longer time to release nutrients, whereas LOF can provide nutrients more rapidly. Several advantages of LOF include its practical use, shorter production period (2-3 weeks) and faster absorption into the soil, allowing released nutrients to be absorbed more quickly by plants (Pratama & Triyanto, 2020). In coastal areas, the number of leaves, leaf length, leaf greenness, fresh canopy weight, plant weight, fresh root weight and dry root weight of organically produced sweet corn were similar to those of conventionally produced sweet corn (Haryuni et al., 2021). The nutrient characteristics of liquid organic fertiliser can differ according to fermentation duration and source material, indicating that locally prepared LOF formulations require specific evaluation before crop application (Febryani et al., 2023).

Despite the availability of numerous commercial LOFs in the marketplace, organic agricultural production systems have focused on the use of local resources, including weeds found within production areas. The foliar structures of several weeds, such as *Tithonia diversifolia*, *Gliricidia sepium*, *Wedelia trilobata*, *Leucaena leucocephala*, *Chromolaena odorata*, *Calopogonium mucunoides*, *Ageratum conyzoides* and *Eichhornia crassipes*, can serve as nutrient sources in LOF production. With respect to moringa leaves, previous studies showed that moringa leaf LOF increased plant height, tuber weight per planting, stem and leaf weight, and tuber weight of onion (Ihsan et al., 2021), and increased the growth and yield of sticky corn (Junaidi, 2021). In addition, seaweed is a plant resource found in coastal ecosystems and can serve as a source of liquid organic fertiliser because it contains several biostimulating compounds, including carbohydrates, amino acids, phytohormones, osmoprotectants and proteins (Haryuni et al., 2025b). Seaweed LOF acts as a soil moisturiser and does not damage soil structure (Basmal, 2010). Seaweed-based LOF has also been reported to increase plant height, number of leaves and number of branches in red chilli (Yusnaeni et al., 2022). Reports on the use of moringa leaf- and seaweed-based LOF for sweet potato production in lowland areas remain limited. It is therefore necessary to develop moringa leaf- and seaweed-based LOF for sweet potato production in lowland areas. Recent work on *Moringa oleifera* leaf extract has reported its role as a plant-growth enhancer and salt-stress mitigator in tomato seedlings, indicating that crop-specific validation remains necessary when moringa-based preparations are used in different production systems (Abdelhameed et al., 2025). Recent reviews and experimental studies also indicate that seaweed extracts contain bioactive constituents associated with antioxidant regulation, osmolyte accumulation and photosynthetic performance under stress conditions (Amrutha et al., 2025; Hernandez-Herrera et al., 2024). However, yield responses to seaweed extract-based biostimulants can vary according to application strategy, formulation and extraction method, supporting the need for formulation- and site-specific evaluation (Perez-Onate et al., 2026). Therefore, the combined use of flowering and non-flowering moringa leaves with seaweed as LOF remains insufficiently documented for sweet potato under coastal soil conditions. The objective of this study was to determine the physiological response of sweet potato plants to the application of moringa leaf- and seaweed-based liquid organic fertiliser and to determine the best combination of moringa leaf and seaweed organic fertiliser for sweet potato growth and yield in coastal land.

## 2. Materials and Methods

### 2.1 Experimental Design and Treatments

This research was conducted over two growing seasons, from August to November 2022 and from January to April 2023, on coastal land in Bengkulu Tengah, Indonesia [03° 43' 24.8" S and 102° 14' 20.6" E].
The study used a completely randomised block design with three replicates. The treatments were (1) LOF1 = 100% flowering moringa leaves, (2) LOF2 = 100% non-flowering moringa leaves, (3) LOF3 = 100% seaweed, (4) LOF4 = 50% seaweed + 50% flowering moringa leaves, (5) LOF5 = 50% seaweed + 50% non-flowering moringa leaves, and (6) LOF6 = 50% seaweed + 25% flowering moringa leaves + 25% non-flowering moringa leaves.

### 2.2 Production of Liquid Organic Fertilizer

Three types of green biomass, namely flowering moringa leaves, non-flowering moringa leaves and seaweed, were used according to the treatment compositions. For each treatment, 10 kg of biomass was fermented with a mixture of 20 litres of cow urine, 20 litres of EM4 solution (100 ppm) and 50 litres of water in a 150-litre plastic barrel. Each type of green material was replicated three times, and all containers were placed under a roof to avoid direct exposure to sunlight and rain. Incubation was conducted for four weeks.

### 2.3 Planting and Treatment Applications

The planting site was prepared by clearing weeds, ploughing and harrowing the land. Composite soil samples were taken from three points at a depth of 0-20 cm for analysis. The soil samples were then dried, crushed, sieved through a 0.5 mm sieve, and analysed for pH, N, P, K and organic C at the Soil Science Laboratory, Faculty of Agriculture, Universitas Bengkulu.

After soil preparation, planting beds were prepared with a length of 4 m, width of 2 m and height of 0.35 m. The planting beds were separated by 0.5 m within each replication and by 1 m between replications. Each soil bed was fertilised with 10 Mg ha-1 vermicompost one week before planting. Planting was carried out by inserting cuttings into planting holes, with two nodes buried at distances of 0.3 m and 0.75 m. LOF was applied at 2, 3, 4, 5, 6, 7 and 8 weeks after planting at volumes of 25, 50, 75, 100, 125, 175 and 200 mL plant-1, respectively. The application was carried out in the morning by wetting the soil around the plants.

### 2.4 Data Collection and Analysis

Physiological indicators were collected by measuring chlorophyll a, chlorophyll b, total chlorophyll, carotenoid content, proline content, sweetness level and NPK nutrient uptake. The agronomic indicators included leaf greenness, fresh plant weight, dry plant weight, number of tubers per plant, tuber weight per plant, tuber weight per plot and stomatal density. Data from 2022 and 2023 were pooled and analysed using ANOVA at the 5% level. Significant treatment effects were further tested using the 5% Least Significant Difference test, and group comparisons were evaluated using 5% orthogonal contrasts. Rainfall, temperature and humidity data were collected from the Meteorology, Climatology and Geophysical Agency, Bengkulu (ID WMO: 96255).

## 3. Results and Discussion

### 3.1 Environmental Conditions

During the first growing season in 2022, rainfall from August to November was 466 mm, 342 mm, 483 mm and 288 mm, respectively. The average air temperatures were 26.70°C, 26.40°C, 27.10°C and 26.30°C, and the average air humidity values were 85%, 85%, 85% and 86%, respectively. In the second growing season in 2023, rainfall from January to April was 531 mm, 248 mm, 230 mm and 195 mm, respectively. The average air temperatures were 26.30°C, 26.80°C, 27.10°C and 27.40°C, and the average air humidity values were 84%, 83%, 83% and 84%, respectively. Soil analysis indicated that soil pH, N, P, K and organic C were 4.74, 0.2%, 6.0 mg kg-1, 0.15 cmol(+) kg-1 and 3.0%, respectively. These conditions were considered favourable for sweet potato production.

### 3.2 Analysis of Variance

Pooled data analysis from the two-year experiments (2022 and 2023) indicated that LOF treatment had a significant effect on chlorophyll a, carotenoid and proline contents. However, the treatments did not affect chlorophyll b, total chlorophyll, sweetness level, nitrogen uptake, phosphorus uptake, potassium uptake, leaf greenness, fresh plant weight, dry plant weight, number of tubers per plant or tuber weight per plot (Table 1).

**Table 1. Effects of moringa-leaf and seaweed based liquid organic fertilizer on physiological and agronomic indicators of sweet potato**

| No. | Observation variable | F-test | Coefficient of Variation (%) |
|---|---|---|---|
| **Physiological Indicators** | | | |
| 1 | Chlorophyll a content | 3.42 * | 24.44 |
| 2 | Chlorophyll content | 3.06 ns | 21.58 |
| 3 | Chlorophyll total | 2.76 ns | 17.52 |
| 4 | Carotenoid content | 7.52* | 7.58 |
| 5 | Prolin content | 5.88 * | 3.82 |
| 6 | Sweetness level | 0.41 ns | 3.17 |
| 7 | Nitrogen nutrient uptake | 2.73 ns | 9.17 |
| 8 | Phosphorus nutrient uptake | 0.50 ns | 5.72 |
| 9 | Potassium nutrient uptake | 2.11 ns | 5.28 |
| **Agronomic Indicators** | | | |
| 1 | Leaf greenness level | 1.76 ns | 2.93 |
| 2 | Fresh weight of plants | 1.16 ns | 5.88 |
| 3 | Dry weight of plants | 1.24 ns | 3.55 |
| 4 | Number of tubers per plant | 2.77 ns | 17.10 |
| 5 | Tuber weight per plant | 3.20 ns | 5.29 |
| 6 | Weight of tubers per plot | 2.17 ns | 2.80 |

*Notes: ns = not significantly different *= significantly different; F-table = 3.33*

### 3.3 Physiological responses

The results indicated that moringa leaf- and seaweed-based liquid organic fertiliser had significant effects on the chlorophyll a, carotenoid and proline contents of sweet potato plants grown in coastal land. The treatment effects on these variables are presented in Fig. 1.

The results showed that moringa leaf- and seaweed-based LOF affected chlorophyll a, carotenoid and proline contents (Fig. 1). These responses were thought to be related to the Mg content of moringa leaf- and seaweed-based LOF, because Mg is an important cofactor in chlorophyll a biosynthesis. Since Mg is the central atom in the chlorophyll a molecule, its availability directly affects the synthesis of this pigment. Reswari et al. (2019) reported that carotenoids were positively correlated with chlorophyll a and b, as well as plant production components. Kumar et al. (2024) reported that seaweed extracts contain bioactive compounds, such as betaine, mannitol, polysaccharides and phytohormones, that can increase plant tolerance to environmental stress. Anwar et al. (2007) reported that *Moringa oleifera* leaves contain bioactive compounds, including phenolics and carotenoids, that may contribute to antioxidant activity.

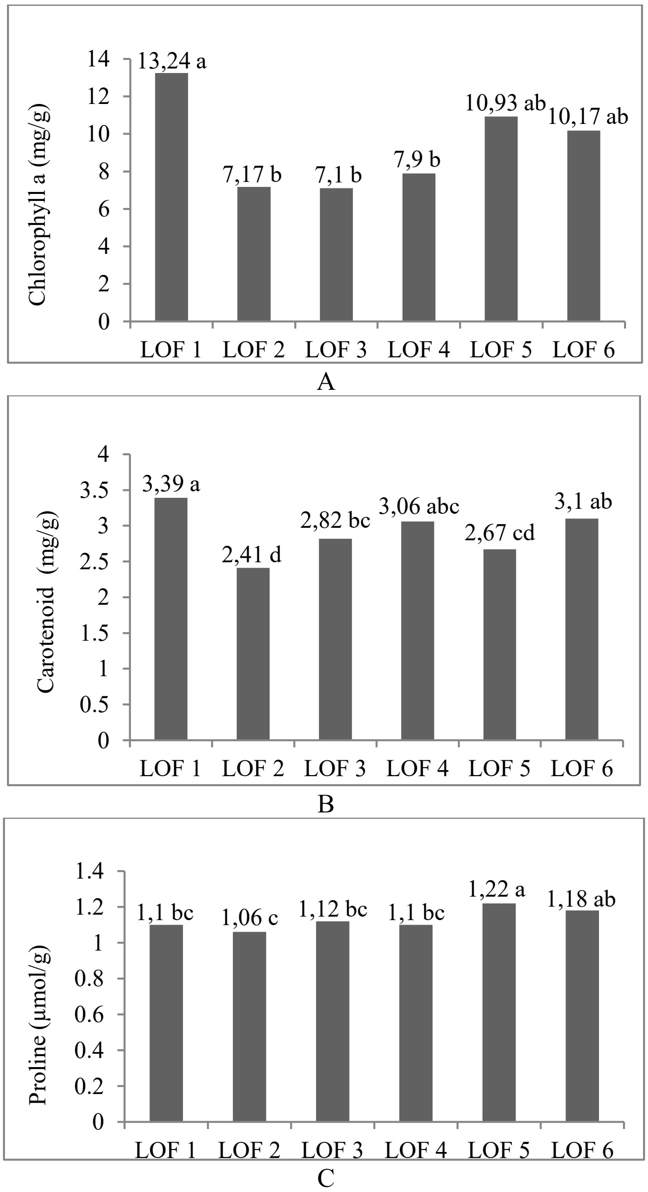


**Fig. 1. The effect of various types of liquid organic fertilizer (LOF) on the chlorophyll a (A), carotenoid (B), and proline (C) content of sweet potato plants**

*[Description: LOF1 (100% flowering moringa leaves), LOF2 (100% non-flowering moringa leaves), LOF3 (100% seaweed), LOF4 (50% seaweed + 50% flowering moringa leaves), LOF5 (50% seaweed + 50% non-flowering moringa leaves), LOF6 (50% seaweed + 25% flowering moringa leaves + 25% non-flowering moringa leaves). The average LOF followed by the same letter in each graph is not significantly different according to the 5% Least Significant Difference].*

The use of LOF increased chlorophyll a content, with the highest chlorophyll a content of 13.24 mg/g found in the LOF1 treatment (Figure 1A), which was not significantly different from the LOF5 and LOF6 treatments. The lowest chlorophyll a content was found in the LOF3 treatment. The LOF1 treatment was more effective in increasing chlorophyll a in sweet potato plants than the other LOF treatments. The increase in chlorophyll a under moringa leaf-based LOF treatment was thought to be closely related to the micro- and macronutrient content of the material. Nuapia et al. (2020) reported that *Moringa oleifera* leaves contain extractable macro- and micronutrient elements, including Mg. Chlorophyll content in sweet potato leaves can reflect photosynthetic activity and the ability of the plant to absorb and accumulate nutrients. Light intensity plays an important role in increasing chlorophyll a levels in plants because insufficient light reduces leaf chlorophyll content and may slow plant growth. High chlorophyll content in leaves may indicate increased availability of essential nutrients, such as carbohydrates, vitamins and minerals, in sweet potato tubers (Garfannsa et al., 2021). The chlorophyll a content in this study was higher than that reported by Suwignya et al. (2023), who found that the application of 30 g of mycorrhiza per planting hole produced a chlorophyll a content of 1.75 mg/g in sweet potato plants.

The application of LOF increased carotenoid content, with the highest carotenoid content of 3.39 µmol/g found in the LOF1 treatment (Figure 1B), which was not significantly different from the LOF4 and LOF6 treatments. The lowest carotenoid content was found in the LOF2 treatment. The LOF1 application was more effective in increasing carotenoid content in sweet potatoes than the other LOF treatments. This response may be attributed to the role of LOF in improving soil fertility, thereby allowing plants to absorb the nutrients required for carotenoid production. Carotenoids function as antioxidants that protect plants from environmental stress, and LOF can help plants adapt to suboptimal environmental conditions. According to Salisbury and Ross (1992), plant pigment and nutrient responses may be influenced by light conditions. According to Hashimoto et al. (2016), carotenoids absorb the blue-green spectrum of sunlight and transfer this energy to chlorophyll, thereby expanding the range of light absorption that supports photosynthesis. The carotenoid content in this study was lower than that reported by Irshad et al. (2025), who showed that the application of 1.5% dried moringa leaf extract increased carotenoid content in soybean plants by 8.3%.

The use of LOF increased proline content, with the highest proline level of 1.22 µmol/g found in the LOF5 treatment (Figure 1C), which was not significantly different from the LOF6 treatment. The lowest proline level was found in the LOF2 treatment. The application of LOF5 was more effective in increasing proline content in sweet potato plants than the other LOF treatments. The presence of non-flowering moringa leaves in LOF5 and LOF6 appeared to increase proline production in sweet potato. The increase in proline levels after applying LOF made from non-flowering moringa leaves may be related to the abundance of natural phytohormones in young moringa leaves, particularly cytokinins such as zeatin, together with auxins and gibberellins, which function as biostimulants that promote cellular metabolism and enhance stress-response mechanisms (Fuglie, 1999; Mashamaite et al., 2022). These hormonal effects may trigger the biosynthesis of amino acids, including glutamate, which is the main precursor for proline synthesis in higher plants (Szabados & Savouré, 2010). In addition, moringa leaves provide free amino acids, phenolic compounds, vitamins and antioxidants (Moyo et al., 2011), which can support physiological stress priming, a process in which plants accumulate osmoprotectants and increase antioxidant capacity even under mild or non-stress conditions (Conrath, 2011). This finding is important for efforts to produce sweet potato in coastal land. Proline accumulation under these conditions facilitates osmotic adjustment, stabilises proteins and membranes, and reduces reactive oxygen species (ROS) damage (Hayat et al., 2012). In addition, macro- and micronutrients provided by moringa-based LOF, such as nitrogen, potassium, calcium, magnesium, iron and zinc, may enhance enzymatic activity and metabolic efficiency, further promoting proline biosynthesis (Mashamaite et al., 2022). Therefore, the observed increase in proline levels in sweet potato probably indicates the combined influence of phytohormone stimulation, precursor amino acid availability, and enhanced antioxidant and osmotic regulation initiated by the bioactive constituents of non-flowering moringa leaves.

In addition, this increase was also thought to be related to the ability of seaweed LOF to increase plant tolerance to osmotic stress, such as salinity. Proline helps maintain water balance in plant cells and protects cell structures from damage. Thus, moringa leaf LOF may help plants become more resistant to unfavourable environmental conditions by increasing proline content. According to Haryuni et al. (2025b), biochemical compounds in brown seaweed may increase the tolerance of vegetable plants to environmental stresses such as drought and salinity. One physiological response to salinity is the accumulation of proline, an osmoprotectant compound that plays a role in maintaining cell turgor and osmotic balance (Ilyas et al., 2024). Proline also protects plants from damage caused by reactive oxygen species (ROS), which can harm cell membranes, proteins and DNA (La et al., 2019).

According to Meriem (2020), proline is a secondary metabolite that accumulates in plants affected by salinity. The higher the proline content, the greater the potential resistance of the plant to drought stress. Thus, proline can be used as an indicator of plant resistance to drought stress because it serves as an osmoregulatory compound that helps maintain plants under stress (Larasani, 2022). Another role of proline is as a ROS scavenger. Proline metabolism drives cellular signalling processes by increasing ROS formation in mitochondria through the electron transport chain. The ability of proline to influence different cellular outcomes may be regulated by the level of ROS produced in mitochondria. The higher the proline increase in plants, the more tolerant the plants may be to drought stress (Nurmalasari, 2018). Proline content increases sharply when plants are exposed to salinity stress (Hessini et al., 2019). According to Rahmah et al. (2025), higher salinity inhibits plant growth but increases proline levels.

Group comparisons among treatments indicated significant differences between treatment groups, particularly for chlorophyll a and carotenoid variables (Table 2). The LOF1 group consistently showed the highest values for the three physiological parameters observed. For chlorophyll a, LOF1 produced a value of 13.24 mg/g, which was 84.7% higher than LOF2 (7.17 mg/g). Compared with LOF3 (7.10 mg/g), the average of LOF1 and LOF2 (10.21 mg/g) was about 43.8% higher. LOF1 was also higher than LOF4 (7.90 mg/g) by 28.7%. However, LOF5 showed a significant increase (10.93 mg/g), which was 53.3% higher than LOF2 (7.13 mg/g). Overall, the LOF4, LOF5 and LOF6 group (average 10.17 mg/g) was slightly higher than the LOF1, LOF2 and LOF3 group (9.17 mg/g), with a difference of 10.9%.

**Table 2. Effect of liquid organic fertilizer from moringa leaves and seaweed on chlorophyll a, carotenoids, and proline in sweet potato plants**

| Comparison | Chlorophyll *a* (mg/g) | Carotenoid (µmol/g) | Proline (µmol/g) |
|---|---|---|---|
| LOF1 vs LOF2 | 13.24 a vs 7.17 b | 3.39 a vs 2.41 b | 1.10 a vs 1.06 a |
| LOF1,2 vs LOF3 | 10.21 a vs 7.10 a | 2.90 a vs 2.82 a | 1.08 a vs 1.12 a |
| LOF,3 vs LOF4 | 10.17 a vs 7.90 a | 3.11 a vs 3.06 a | 1.11 a vs 1.10 a |
| LOF,3 vs LOF5 | 7.13 b vs 10.93 a | 2.61 a vs 2.67 a | 1.09 b vs 1.22 a |
| LOF1,2,3 vs LOF4,5,6 | 9.17 a vs 10.17 a | 2.87 a vs 3.10 a | 1.09 b vs 1.18 a |

*Notes: Numbers followed by the same letter in the same row indicate no significant difference at the 5% level of significance of orthogonal contrasts. LOF1 (100% flowering moringa leaves), LOF2 (100% non-flowering moringa leaves), LOF3 (100% seaweed), LOF4 (50% seaweed + 50% flowering moringa leaves), LOF5 (50% seaweed + 50% moringa leaves not yet flowering), LOF6 (50% seaweed + 25% moringa leaves flowering + 25% moringa leaves not yet flowering).*

With respect to carotenoid content, LOF1 recorded the highest value of 3.39 µmol/g, which was 40.7% higher than LOF2 (2.41 µmol/g). The difference between LOF1,2 (2.90 µmol/g) and LOF3 (2.82 µmol/g) was relatively small (2.8%). LOF1,3 (3.11 µmol/g) was slightly higher than LOF4 (3.06 µmol/g), with a difference of 1.6%. LOF5 (2.67 µmol/g) was slightly higher than LOF2,3 (2.61 µmol/g), with a difference of about 2.3%. The LOF4,5,6 group (3.10 µmol/g) was higher than LOF1,2,3 (2.87 µmol/g), with a difference of 8.0%.

In terms of proline content, values were relatively stable among treatments, but LOF5 showed the highest accumulation (1.22 µmol/g), which was 11.9% higher than LOF2,3 (1.09 µmol/g). LOF1 (1.10 µmol/g) was slightly higher than LOF2 (1.06 µmol/g), with a difference of about 3.8%. LOF3 (1.12 µmol/g) was higher than LOF1,2 (1.08 µmol/g), with a difference of 3.7%. The LOF4,5,6 group (1.18 µmol/g) was higher than LOF1,2,3 (1.09 µmol/g), with a difference of 8.3%. In addition, the LOF1 group consistently produced the highest values for chlorophyll a and carotenoids and showed competitive proline accumulation. The differences among treatments were statistically significant, particularly between LOF1 and LOF2, which showed significant differences in all parameters. Meanwhile, the LOF4,5,6 group showed an increasing trend in carotenoids and proline, although this trend was not as strong as the dominance of LOF1 in chlorophyll a.

Chlorophyll a, carotenoids and proline are key compounds that support photosynthesis, adaptation to environmental stress and crop yield accumulation. Chlorophyll functions as the main pigment for capturing light energy during photosynthesis, whereas carotenoids protect against oxidative damage and assist in light energy transfer (Zulfiqar et al., 2021). Proline functions as an osmotic protectant and an indicator of plant response to abiotic stress. Furthermore, Table 3 suggests that significant differences between treatment groups showed that group one consistently produced the highest values for chlorophyll a, carotenoids and proline. The results show that the LOF1 treatment consistently produced the highest values for chlorophyll a, carotenoids and proline compared with the other treatment groups. Physiologically, the increase in chlorophyll a content reflected higher photosynthetic efficiency, which contributed directly to plant biomass production capacity (Nazari et al., 2024). Higher chlorophyll content also indicated that the LOF1 treatment was able to maintain chloroplast structural integrity and slow pigment degradation during the active growth phase.

The results also indicated that group one may have received a LOF formulation with bioactive compounds and nutrients that were more suited to the metabolic needs of sweet potatoes. This advantage indicated that the treatment formulation in this group was more effective in stimulating photosynthetic activity and adaptive responses in sweet potatoes. The bioactive compounds and growth hormones in LOF1 used in group one were thought to play a role in increasing photosynthetic pigment synthesis and proline accumulation as indicators of physiological tolerance. The increases in carotenoid levels in the LOF1 and LOF4,5,6 groups indicated activation of the plant photoprotective mechanism. Carotenoids play a role in reducing free radicals and protecting the photosystem from oxidative damage (Arslansoy & Fidan, 2024), especially when plants experience mild stress, such as temperature fluctuations or light intensity changes. The higher carotenoid content in these groups indicated that the treatment was able to trigger a preventive adaptive response to environmental stress. Higher proline accumulation in the LOF5 and LOF4,5,6 groups showed that the treatment triggered a biochemical response to mild stress. Proline functions as an osmoprotectant, membrane stabiliser and redox buffer, and plays a role in maintaining cellular osmotic balance under suboptimal conditions (Shivani et al., 2025). Although the proline value in LOF1 was not as high as that in LOF5, the consistently high values across the three parameters indicated that LOF1 provided balanced physiological stimulation between photosynthetic efficiency and stress resistance.

Overall, the significant differences between treatment groups indicated that the LOF1 formulation had potential as a physiological stimulant for improving plant performance through increased photosynthetic capacity and activation of protective mechanisms against mild stress. These findings were consistent with the theory that the combination of growth hormones and bioactive compounds in liquid organic fertilisers can modulate the expression of genes related to pigment synthesis and secondary metabolites.

Stomatal density in the LOF6 treatment tended to be higher than that in the other LOF treatments. The treatment appeared to affect stomatal density in sweet potato plants. This may have been due to the influence of active compounds in the treatment on epidermal cell differentiation during leaf formation, as well as the plant adaptive response to microenvironmental changes caused by the treatment. According to Sulistyowati et al. (2019), stomatal density is influenced by factors such as sunlight and temperature. Light intensity can reduce the transpiration rate, so plants may adapt by reducing stomatal density. The stomatal density in this study was higher than that reported by Oktavian et al. (2024), who showed that the application of a 25% LOF concentration of moringa leaves + 75% AB-Mix produced the best result for the number of stomata in mustard plants, namely 28.22 mm2.

**Table 3. Effects of moringa-leaf and seaweed based liquid organic fertilizer on physiological indicators of sweet potato**

| Treatments | Chlorophyl *b* (mg/g) | Chlorophyl total (mg/g) | Sweetness level (Brix) | N uptake ( %) | P uptake (%) | K uptake (%) |
|---|---|---|---|---|---|---|
| LOF1 | 6.35 a | 18.64 a | 10.67 a | 1.40 a | 1.56 a | 1.94 a |
| LOF2 | 4.93 a | 11.21 a | 10.67 a | 1.12 a | 1.52 a | 1.94 a |
| LOF3 | 7.12 a | 13.47 a | 10.67 a | 1.27 a | 1.59 a | 1.97 a |
| LOF4 | 7.74 a | 14.74 a | 10.83 a | 1.14 a | 1.48 a | 1.88 a |
| LOF5 | 4.19 a | 14.16 a | 10.50 a | 1.34 a | 1.55 a | 1.73 a |
| LOF6 | 6.33 a | 15.54 a | 10.50 a | 1.32 a | 1.53 a | 1.89 a |

*Notes: Numbers followed by the same letter in the same column are not significantly different at the 5% level. LOF1 (100% flowering moringa leaves), LOF2 (100% non-flowering moringa leaves), LOF3 (100% seaweed), LOF4 (50% seaweed + 50% flowering moringa leaves), LOF5 (50% seaweed + 50% moringa leaves not yet flowering), LOF6 (50% seaweed + 25% moringa leaves flowering + 25% moringa leaves not yet flowering).*

The results showed that all LOF treatments (moringa leaf- and seaweed-based liquid organic fertiliser) had no effect on chlorophyll b values, which ranged from 4.19 to 7.12 mg/g; total chlorophyll values, which ranged from 11.21 to 18.64 mg/g; sugar content, which ranged from 10.50 to 10.83 °Brix; nitrogen uptake, which ranged from 1.12 to 1.40%; phosphorus uptake, which ranged from 1.48 to 1.59%; or potassium uptake, which ranged from 1.73 to 1.97% (Table 3).

Chlorophyll b and total chlorophyll were important indicators for assessing the photosynthetic capacity of sweet potatoes. Chlorophyll b functions as an accessory pigment that broadens the light absorption spectrum, whereas total chlorophyll reflects the overall accumulation of photosynthetic pigments that support biomass production efficiency. Increases in these two variables have the potential to strengthen vegetative growth and support optimal tuber formation. The results of the study showed that all LOF treatments did not affect chlorophyll b and total chlorophyll in sweet potato leaves (Table 3). Chlorophyll b in the LOF4 treatment was 7.74 mg/g, which tended to be higher than that in the other LOF treatments (Table 3). Meanwhile, total chlorophyll in the LOF1 treatment (18.64 mg/g) tended to be higher than that in the other LOF treatments (Table 3). When chlorophyll a synthesis increased significantly, plants may have allocated metabolic resources towards chlorophyll a, causing chlorophyll b to decrease relatively. Chlorophyll b plays a role in absorbing light at certain wavelengths. Chlorophyll b content tended to be lower than chlorophyll a and total chlorophyll because chlorophyll a plays a more efficient role in plant chlorophyll formation and light capture. The chlorophyll b content in this study was lower than that reported by Suwignya et al. (2023), who showed that the application of 10 g of mycorrhiza per planting hole resulted in a chlorophyll b content of 27.18 mg/g in sweet potato plants. Meanwhile, the total chlorophyll content in this study was higher than that reported by Reyni and Binawati (2023), where the application of 150 ml of a combination of banana stem LOF and moringa leaves resulted in a total chlorophyll content of 3.05 mg/g in mustard greens.

Nutrient uptake, including N, P and K uptake, is an important indicator for supporting sweet potato growth and productivity. According to Wang et al. (2024), N plays a role in vegetative tissue formation and chlorophyll synthesis, P supports root development and tuber formation, and K plays a role in regulating water balance, transporting photosynthetic products and improving tuber quality. These three elements synergistically affect sweet potato biomass accumulation and yield. The results showed that all LOF treatments did not affect NPK nutrient uptake (Table 3). N uptake in the LOF1 treatment (1.40%) tended to be higher than that in the other LOF treatments (Table 3). P uptake in the LOF3 treatment (1.59%) tended to be higher than that in the other LOF treatments (Table 3), and K uptake in the LOF3 treatment (1.97%) tended to be higher than that in the other LOF treatments (Table 3). The results showed that all LOF treatments did not significantly affect NPK uptake. Previous research by Haryuni et al. (2025a) identified nutrient levels of 1.74% N, 1.06% P and 1.11% K in seaweed LOF; 1.60% N, 1.11% P and 1.18% K in moringa leaf LOF from non-flowering branches; and 1.58% N, 1.17% P and 1.28% K in moringa leaf LOF from flowering branches. The N content in soil is one of the factors that influences nitrogen uptake by plants and the N content in tissues. Nitrogen uptake in this study was lower than that reported by Kamil and Arifandi (2019), who showed that the application of 3.3 kg of rice husk charcoal resulted in nitrogen uptake of 1.98%. Hakim et al. (2018) found that phosphorus plays a significant role in metabolism and promotes tuber development in sweet potatoes. Phosphorus uptake in this study was lower than that reported by Afandi et al. (2017), who showed that applying 15 tons/ha of chicken manure resulted in phosphorus uptake of 8.44 kg in sweet potatoes. According to Agung et al. (2020), adequate K availability stimulates nutrient uptake by roots and promotes protein and carbohydrate synthesis, resulting in root enlargement into tubers. Potassium uptake in this study was lower than that reported by Afandi et al. (2017), who showed that the application of 15 tons/ha of cow manure resulted in potassium uptake of 40.87 kg.
The sweetness level of tubers reflects sucrose accumulation as a result of photosynthesis and serves as an indicator of yield quality, although it was not directly related to vegetative growth. All LOF treatments did not affect the sweetness level of sweet potatoes. The sweetness level of the LOF4 treatment was 10.83 °Brix, which tended to be higher than that of the other LOF treatments (Table 3). Although moringa leaf and seaweed LOF had the potential to enhance vegetative growth, the results of this study indicated that these treatments did not have a significant effect on the sweetness level of sweet potatoes. This was thought to be because the nutrient composition of LOF did not directly contribute to sugar synthesis and accumulation in tubers and was probably influenced by environmental factors.

### 3.4 Agronomic Responses

All LOF treatments had no effect on leaf greenness, which ranged from 38.73 to 41.04%; fresh plant weight, which ranged from 1.33 to 1.47 kg; dry plant weight, which ranged from 1.15 to 1.22 g; number of tubers per plant, which ranged from 2.50 to 4.00; tuber weight per plant, which ranged from 1.27 to 1.48 kg; or tuber weight per plot, which ranged from 3.37 to 3.58 kg (Table 4).

The results showed that the moringa leaf LOF and seaweed LOF treatments did not have a significant effect on leaf greenness, fresh weight or dry weight of the plants. This lack of effect was thought to be due to the bioactive characteristics of LOF, which were more associated with vegetative stimulation and were not sufficient to increase physiological parameters related to tuber productivity. The greener the leaves, the higher the chlorophyll content. In addition, plants with high chlorophyll content are capable of higher levels of photosynthesis. Furthermore, leaf colour can be used to visually determine the presence or absence of nitrogen deficiency or excess symptoms. The leaf greenness level in this study was higher than that reported by Oktavian et al. (2024), who showed that the application of a 25% moringa leaf + 75% AB-Mix LOF concentration produced the best leaf greenness level in mustard plants, namely 38.50%.

**Table 4. Effects of moringa-leaf and seaweed based liquid organic fertilizer on agronomic indicators of sweet potato**

| Treatments | Leaf greenness level | Fresh weight of plants (kg) | Dry weight of plants (g) | Number of tubers per plant | Tuber weight per plant (kg) | Weight of tubers per plot (kg) |
|---|---|---|---|---|---|---|
| LOF1 | 39.79 a | 1.47 a | 1.22 a | 2.50 a | 1.27 a | 3.37 a |
| LOF2 | 38.98 a | 1.45 a | 1.18 a | 3.00 a | 1.30 a | 3.41 a |
| LOF3 | 41.04 a | 1.33 a | 1.15 a | 3.67 a | 1.39 a | 3.54 a |
| LOF4 | 38.73 a | 1.38 a | 1.15 a | 3.67 a | 1.35 a | 3.47 a |
| LOF5 | 38.89 a | 1.37 a | 1.15 a | 3.17 a | 1.33 a | 3.41 a |
| LOF6 | 38.95 a | 1.40 a | 1.17 a | 4.00 a | 1.48 a | 3.58 a |

*Notes: Numbers followed by the same letter in the same column are not significantly different at the 5% level. LOF1 (100% flowering moringa leaves), LOF2 (100% non-flowering moringa leaves), LOF3 (100% seaweed), LOF4 (50% seaweed + 50% flowering moringa leaves), LOF5 (50% seaweed + 50% moringa leaves not yet flowering), LOF6 (50% seaweed + 25% moringa leaves flowering + 25% moringa leaves not yet flowering)*

The fresh weight of tubers was influenced by water uptake by the plants and by the roots, which contribute significantly to tuber formation. The number and size of tubers would affect their weight. The fresh plant weight in this study was lower than that reported by Kurniawan et al. (2024), who found that applying 50 ml/litre of moringa leaf LOF produced the best fresh weight of mustard greens, namely 71.89 g. Plant dry weight, which is related to high NPK nutrient uptake, was associated with increased dry weight because nutrient uptake accelerates plant tissue synthesis, root growth and photosynthetic efficiency, and helps distribute carbohydrates throughout the plant. Previous research by Atanjinji and Lewu (2024) showed that the application of 50 ml of moringa leaf extract produced the best result for soybean dry weight.

All LOF treatments did not affect the number of tubers per plant, tuber weight per plant or tuber weight per plot. It appeared that LOF bioactivity was more dominant in stimulating vegetative growth, whereas the application time was not synchronised with the tuber enlargement phase. The number of tubers per plant in this study was higher than that reported by Santrum et al. (2024), where the application of 80 mL/L moringa leaf LOF resulted in 3.75 eggplant fruits per plant. According to Kurniawan (2021), tuber weight is influenced by nutrient conditions in the soil. Under good and balanced nutrient conditions, plant tubers become heavier. The tuber weight per plant in this study was higher than that reported by Armaniar et al. (2024). The application of moringa leaf LOF at a concentration of 150 mL/L water showed the highest yield per plant, namely 333.58 g. The tuber weight per plot in this study was lower than that reported by Noer (2022), where the application of moringa leaf LOF at a concentration of 700 mL/L water resulted in a fruit weight per plot of 3.70 kg.

The novelty of this research was the increase in proline content in sweet potato grown in coastal land in response to the application of LOF composed of moringa leaves and seaweed. The increased proline level in sweet potato after applying LOF made from non-flowering moringa leaves provides promising evidence for the use of these leaves as a major constituent of organic fertiliser to support better adaptation of sweet potato production in coastal land.

## 4. Conclusions

The application of moringa leaf- and seaweed-based liquid organic fertilisers influenced selected physiological responses of sweet potato grown in coastal soil. Pooled results from two growing seasons showed significant treatment effects on chlorophyll a, carotenoid and proline contents. The liquid organic fertiliser prepared from 100% flowering moringa leaves produced the highest chlorophyll a and carotenoid values, indicating a stronger response in photosynthetic pigment accumulation. The formulation containing 50% seaweed and 50% non-flowering moringa leaves produced the highest proline content, suggesting a possible role in physiological adjustment under coastal soil conditions. However, the tested formulations did not significantly affect chlorophyll b, total chlorophyll, tuber sweetness, nitrogen uptake, phosphorus uptake, potassium uptake, leaf greenness, fresh plant weight, dry plant weight, number of tubers per plant, tuber weight per plant or tuber weight per plot. Therefore, the main effect of the treatments in this study was observed in selected physiological indicators rather than in agronomic yield. The findings suggest that moringa leaf and seaweed liquid organic fertilisers may contribute to physiological responses in sweet potato, but further research is needed before making strong recommendations for yield improvement or fertiliser substitution in coastal soil.

## 5. Limitation

This study did not include an untreated control or a standard mineral fertiliser treatment, limiting comparison with conventional or no-fertiliser conditions. All plots received vermicompost, which may have reduced the detectable effect of LOF. The chemical composition of each LOF formulation was not fully reported. Year effects and treatment × year interactions were not presented, although data from two growing seasons were pooled. Some physiological mechanisms were inferred rather than directly measured, and stomatal density was mentioned but not fully reported.

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### Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

## Competing Interests

Authors have declared that no competing interests exist.

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