

## Post-Transplant Adaptation Failure of Mustard Greens (*Brassica juncea* L.) Under Nutrient Deficiency and Environmental Stress Conditions

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### ABSTRACT

This study evaluated the post-transplant adaptation failure of Mustard greens under nutrient deficiency and environmental stress conditions. The experiment was conducted from January to March 2026 using an experimental approach with four weeks of growth observation. Treatments consisted of liquid organic fertilizer application and a control without fertilizer. Observed parameters included plant height, stem length, leaf size, leaf number, physiological symptoms, and survival rate. The results showed that liquid organic fertilizer improved early vegetative growth; however, it was unable to maintain plant survival until the end of the observation period due to the combined effects of extreme temperature, unstable humidity, and pest attack. The findings confirm that plant adaptation failure is strongly influenced by the interaction between nutrient deficiency and environmental stress, indicating the need for adaptive cultivation management under climate change conditions.

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## INTRODUCTION

Mustard greens is one of the most important leafy vegetable commodities in tropical horticultural systems due to its high economic value, short production cycle, and relatively stable market demand throughout the year. This crop is widely cultivated at both household and commercial scales because of its adaptability to diverse agroecological conditions. Nevertheless, mustard productivity is strongly influenced by the early growth stage, particularly after transplanting, as this period represents a physiological transition that determines subsequent biomass accumulation. This phase is considered critical because plants are highly susceptible to root injury, changes in growing media, and environmental fluctuations that may reduce adaptation success.

Transplanting causes abrupt disturbances to the root system, particularly damage to fine roots responsible for water and nutrient uptake. Such disruption often results in transplant shock, characterized by temporary wilting, reduced vegetative growth, and decreased photosynthetic activity. According to Marschner (2012), impaired nutrient uptake during early growth can inhibit chlorophyll synthesis and structural protein formation, thereby disturbing plant metabolism. These conditions become more severe when the growing medium is unable to provide sufficient nutrients for root regeneration after transplantation. In leafy vegetables, nutrient limitations during the early stage frequently result in reduced leaf formation, stem elongation, and photosynthetic surface development.

Nutrient deficiency is recognized as one of the major limiting factors affecting post-transplant growth. Essential macronutrients such as nitrogen, phosphorus, and potassium play central roles in cell division, stem elongation, root development, and chlorophyll synthesis. Nitrogen deficiency causes pale leaves due to reduced chlorophyll content, phosphorus deficiency inhibits root development, and potassium deficiency impairs stomatal regulation, reducing water-use efficiency. These symptoms were observed in the control plants, which showed pale leaves, weak growth, and etiolation beginning in the second week of observation. This indicates that nutrient limitation accelerated the decline of plant physiological function.

In recent years, environmental pressure on horticultural systems has intensified as a consequence of climate variability. Extreme temperature, unstable rainfall patterns, and fluctuating humidity expose crops to increasingly complex abiotic stress. High temperature accelerates plant respiration and water loss through transpiration. Under these conditions, roots that have not fully recovered after transplanting are unable to compensate for water loss, resulting in turgor reduction and progressive wilting. In this study, such conditions became evident in the third week, when rising environmental temperatures coincided with visible wilting symptoms in both treatments.

According to Hasan M. M. (2022), elevated temperature increases respiration rates, causing a larger proportion of plant energy to be allocated to physiological maintenance rather than vegetative development. Similarly, Mishra S. (2023) explained that heat stress disrupts carbon metabolism and nutrient uptake, thereby reducing energy availability for new tissue

development. This is highly relevant to the present findings, where plants treated with liquid organic fertilizer still experienced mortality despite showing improved early growth. Thus, nutrient supply alone is insufficient under persistent environmental stress.

Under field conditions, plants rarely encounter a single stress factor in isolation. More commonly, multiple stress factors occur simultaneously, a phenomenon known as combined stress. The interaction between nutrient deficiency and environmental stress creates a more severe impact than individual stress factors because several metabolic pathways are disrupted simultaneously. Nutrient deficiency reduces the plant's capacity to synthesize protective compounds, while high temperature increases the production of reactive oxygen species (ROS), which damage cellular membranes. In the present study, this interaction was identified as the primary cause of growth decline and complete mortality during the four-week observation period.

Previous studies generally examined nutrient deficiency and temperature stress separately. Nutrient-related studies have mostly focused on biomass reduction, while temperature stress studies emphasized photosynthetic physiology. Limited research has integrated both factors during the post-transplant stage of mustard greens. This gap is significant because transplantation is one of the most vulnerable phases in crop production systems. This study contributes by directly evaluating the interaction between nutrient deficiency and environmental stress on plant growth response, physiological symptoms, and survival rate. This approach broadens understanding that cultivation success depends not only on nutrient input but also on plant capacity to withstand simultaneous environmental stressors.

In addition to abiotic stress, this study identified a biotic factor in the form of grasshopper infestation. The attack accelerated leaf tissue damage, chlorosis, necrosis, and tissue decay. Such damage reduced the photosynthetic area, thereby lowering the plant's capacity to generate energy. According to Novianto R. (2020), the combination of biotic and abiotic disturbances accelerates physiological decline because energy is diverted toward defense mechanisms. The uploaded research document showed that pest attacks appeared from the second week onward and intensified plant decline.

Application of liquid organic fertilizer in this study improved early growth, particularly plant height, stem length, and leaf length. This indicates that the fertilizer supplied nutrients capable of supporting cell division and elongation. These findings are consistent with those of Rahman M. (2023), who reported that liquid organic fertilizer improves nutrient uptake efficiency and microbial activity in soil. However, the present results revealed that enhanced initial growth did not guarantee plant survival until the end of observation, as all plants died in the fourth week.

The novelty of this study lies in its integrative evaluation of post-transplant adaptation failure in mustard greens by combining morphological, physiological, and survival parameters under actual stress conditions. Most previous studies assessed vegetative growth as the sole indicator of success, whereas this study demonstrates that positive initial growth does not necessarily

reflect successful medium-term adaptation. Plants receiving liquid organic fertilizer exhibited improved growth but still died due to accumulated combined stress. These findings enrich theoretical understanding of the relationship between early vegetative response and physiological resilience.

Based on this background, this study aimed to evaluate the effects of nutrient deficiency on vegetative growth of mustard greens after transplanting, analyze plant responses to environmental stress, and explain the adaptation failure mechanism caused by the interaction of these factors. The results are expected to provide a basis for developing more climate-adaptive horticultural systems, particularly during the highly vulnerable early growth stage.

## **LITERATURE REVIEW**

### ***Plant Adaptation Theory under Environmental Stress***

Plant adaptation refers to the physiological, morphological, and biochemical capacity of plants to maintain growth under changing environmental conditions. In horticultural crops such as Mustard greens, the post-transplant stage represents a critical phase because plants undergo abrupt changes in growing medium, humidity, temperature, and root distribution. Damage to fine roots during transplantation reduces the efficiency of water and nutrient uptake, resulting in metabolic disturbances. In the uploaded research context, this condition was identified as the primary cause of transplant shock, which subsequently reduced vegetative growth and plant survival.

According to Palmgren M. and Shabala S. (2024), successful plant adaptation under stress depends on the integration of hormonal signaling, cellular water balance, and metabolic capacity to tolerate accumulated stress. Once environmental pressure exceeds adaptive capacity, plants experience loss of turgor, stomatal closure, decreased photosynthetic efficiency, and eventually mortality. This framework is relevant to the present study, in which all plants died by the fourth week due to accumulated extreme temperature, fluctuating humidity, and biotic disturbance.

Wang Y. (2022) reported that transplant shock significantly reduces photosynthetic efficiency and root growth in leafy vegetables after transplantation. In contrast, Rosita (2021) found that supplemental nutrient application can accelerate vegetative recovery after transplanting. However, the present findings demonstrate that additional nutrient input only delayed physiological decline and did not fully prevent plant mortality.

H1: Nutrient deficiency significantly affects vegetative growth reduction and post-transplant adaptation failure in mustard greens.

### ***Nutrient Deficiency and Vegetative Growth Theory***

Plant nutrition theory explains that essential nutrients play fundamental roles in physiological processes such as photosynthesis, protein synthesis, root development, and cell division. Nitrogen is the major component of chlorophyll and amino acids; phosphorus supports ATP formation and root development; while potassium regulates osmotic balance and stomatal activity. Deficiency of any of these nutrients restricts new tissue formation and reduces plant capacity to respond to environmental stress.

According to Marschner (2012), nutrient deficiency during vegetative growth results in chlorosis, smaller leaves, weak stems, and biomass reduction. These symptoms correspond closely to the findings of the current study, especially in the control treatment where pale leaves, weak growth, and etiolation appeared from the second week onward.

Rahman M. (2023) stated that liquid organic fertilizer enhances vegetative growth by stimulating soil microbial activity and improving nutrient availability. Conversely, Sugumar (2024) explained that under high-temperature conditions, nutrient supplementation alone may not sustain physiological stability. This is consistent with the present findings, where liquid organic fertilizer improved early growth but failed to maintain plant survival until the end of the observation period.

H2: Liquid organic fertilizer improves early vegetative growth but cannot prevent adaptation failure under severe environmental stress.

### ***Combined Stress Theory***

Combined stress theory explains that plants in field conditions are typically exposed to multiple stress factors simultaneously. The interaction between nutrient deficiency and environmental stress is synergistic, producing greater damage than each stress acting independently. Nutrient deficiency reduces the plant's ability to synthesize stress proteins and antioxidant enzymes, while high temperature increases the production of reactive oxygen species (ROS), which damage cellular membranes and tissues.

In the present study, the interaction among nutrient deficiency, extreme temperature, unstable humidity, and pest attack resulted in progressive growth decline leading to complete mortality. According to Hasan M. M. (2022), heat stress increases transpiration and decreases photosynthetic efficiency. Meanwhile, Novianto R. (2020) demonstrated that pest infestation in weakened plants accelerates tissue damage and reduces survival rate.

This theory emphasizes that adaptation success is influenced not only by nutrient availability but also by the plant's ability to maintain physiological homeostasis under simultaneous environmental pressures. Therefore, adaptation failure should be evaluated using an integrative framework that combines growth performance, physiological symptoms, and survival indicators.

H3: The interaction between nutrient deficiency and environmental stress significantly contributes to post-transplant adaptation failure in mustard greens.

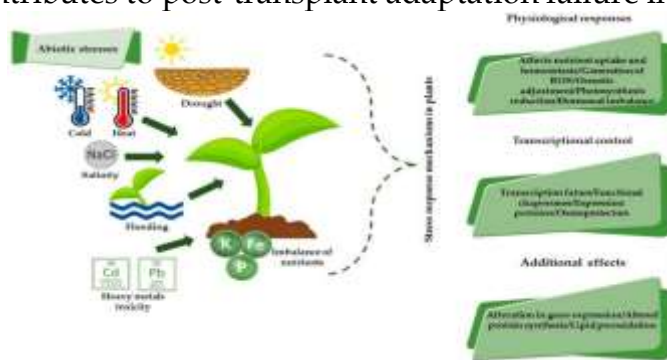


Figure 1. Conceptual Framework

### **Conceptual Framework**

The conceptual framework of this study is based on the causal relationship between treatment variables and plant responses. Independent variables consist of nutrient deficiency and environmental stress. Nutrient deficiency is represented by the absence of fertilizer, while environmental stress includes high temperature, humidity fluctuation, and pest disturbance. These variables affect plant physiological processes, particularly water uptake, metabolism, and photosynthesis.

Subsequent physiological disruption influences vegetative growth parameters, including plant height, stem length, leaf length, leaf width, and leaf number. In addition, visual indicators such as chlorosis, necrosis, wilting, and tissue decay were observed as physiological stress symptoms. The final outcome was evaluated through plant survival rate at the end of the observation period.

The framework demonstrates that plant adaptation failure is the result of complex interactions among nutrient limitation, environmental stress, and biotic disturbance occurring simultaneously during the post-transplant phase. Thus, cultivation practices focusing solely on nutrient input are insufficient to ensure successful plant adaptation under unstable environmental conditions.

### **METHODOLOGY**

This study employed a quantitative experimental approach with a controlled observational design to evaluate post-transplant adaptation failure of Mustard Greens under nutrient deficiency and environmental stress conditions. The experimental approach was selected to directly assess vegetative growth responses and physiological resilience of plants during the early post-transplant period, which is considered the most critical stage for root re-establishment and metabolic stabilization. The observation period lasted four weeks after transplanting, corresponding to the vulnerable adaptation phase during which transplanted seedlings experience rapid physiological adjustment.

The experiment consisted of two treatment groups: a control without fertilization and an application of Fullgrow Liquid Organic Fertilizer. These treatments were designed to compare the capacity of mustard plants to sustain early growth under different nutrient availability levels. The use of liquid organic fertilizer was based on its rapid nutrient availability and stimulation of soil microbial activity, which has been reported to improve nitrogen and phosphorus uptake during early vegetative growth. In this study, the treatment was further evaluated to determine whether improved initial growth could maintain plant survival under simultaneous environmental stress.

The experiment was conducted from January to March 2026 in a semi-open greenhouse system. The plant population consisted of all mustard seedlings aged approximately 14 days after sowing, characterized by 3–4 fully expanded leaves and a transplant-ready morphology. Samples were selected purposively based on uniformity, healthy appearance, and absence of physical damage. Each seedling was transplanted into a polybag containing topsoil mixed with organic substrate, then assigned to one of the two treatments. All experimental units were observed weekly for four consecutive weeks. Independent variables consisted of nutrient treatment and environmental stress exposure, while dependent

variables included plant height, stem length, leaf length, leaf width, number of leaves, physiological symptoms, and survival rate.

The experimental procedure involved media preparation, seedling selection, transplantation, fertilizer application, maintenance, periodic observation, visual documentation, and data analysis. The growth medium consisted of topsoil amended with organic matter to maintain water-holding capacity and structural porosity. Transplanting was conducted manually in the morning to minimize immediate water stress. Liquid organic fertilizer was applied directly around the root zone according to the treatment protocol. Weekly observations were conducted using direct measurements and visual assessments. Morphological parameters were measured using a ruler and caliper, whereas physiological symptoms were recorded through visual indicators including chlorosis, necrosis, wilting, and leaf tissue damage caused by pest attack.

Growth measurements were performed longitudinally. Plant height was measured from the stem base to the highest growing point. Stem length was measured from the soil surface to the last leaf junction. Leaf dimensions were determined from the longest leaf. Leaf number was counted manually. Physiological symptoms were documented through leaf color changes, turgor reduction, and tissue degradation. According to Petra Marschner, morphological indicators and leaf visual symptoms are reliable markers for detecting nutrient imbalance and environmental stress during the vegetative stage.

The plant growth model was expressed as:

$$Y_{ij} = \mu + P_i + \varepsilon_{ij}$$

**Where:**

$Y_{ij}$  = observed value of the j-th sample under the i-th treatment;

$\mu$  = general mean;

$P_i$  = treatment effect;

$\varepsilon_{ij}$  = experimental error.

This model was used to quantify treatment effects on all growth parameters.

To evaluate stress intensity, the stress response index was calculated as:

$$S = \frac{Nd + Kl + Mt}{To} \times 100\%$$

**Where:**

$S$  = stress index;

$Nd$  = number of damaged leaves;

$Kl$  = wilting score;

$Mt$  = plant mortality;

$To$  = total observed plants.

This equation integrated morphological damage and survival parameters into a composite indicator of adaptation stress. Data were analyzed descriptively and inferentially. Descriptive statistics were used to summarize weekly growth averages, morphological changes, and physiological symptoms. Inferential analysis was conducted using analysis of variance (ANOVA) at the 5% significance level to identify treatment effects on vegetative growth. Significant differences were further analyzed using Duncan's Multiple Range Test (DMRT).

According to Kwanchai A. Gomez and Arturo A. Gomez, ANOVA remains an appropriate statistical method for evaluating treatment differences in agronomic experiments involving continuous variables.

Visual observation and field documentation supported interpretation of quantitative data. This combined approach enabled direct linkage between numerical growth responses and actual physiological conditions of the plants. The findings showed that fertilizer treatment improved early growth performance but failed to sustain plant survival until the final observation. Extreme temperature fluctuations, unstable humidity, and pest infestation contributed to progressive plant decline. Therefore, the methodological framework confirmed that post-transplant adaptation failure was not solely caused by nutrient limitation but by complex interactions between abiotic and biotic stress factors during the critical acclimatization period.

## RESEARCH RESULTS

The results demonstrated that the application of Fullgrow Liquid Organic Fertilizer positively influenced the initial growth response of Mustard Greens during the post-transplant stage; however, this beneficial effect did not persist until the end of the observation period. All plants, both fertilized and unfertilized, died by the fourth week. This finding indicates that improved early growth alone was insufficient to sustain plant adaptation when environmental stress and biotic disturbances occurred simultaneously. The observations were consistent with the primary data documented in the experimental records.

### *Early Vegetative Growth*

Observations during the first and second weeks revealed clear differences between the liquid organic fertilizer treatment and the control. Fertilized plants showed greater stem elongation, larger leaf dimensions, and better maintenance of green tissue color. In contrast, the control plants exhibited slower development accompanied by early physiological symptoms such as chlorosis and reduced turgor.

Table 1. Mean Growth Parameters During Weeks I-II

| Parameter         | Control | Organic Fertilizer |
|-------------------|---------|--------------------|
| Plant height (cm) | 3.5     | 3.0                |
| Stem length (cm)  | 2.0     | 4.5                |
| Leaf length (cm)  | 5.0     | 6.5                |
| Leaf width (cm)   | 3.0     | 4.0                |
| Number of leaves  | 4       | 4                  |

The data indicated that treated plants exhibited relatively superior vegetative growth, particularly in stem length and leaf expansion. Although the control plants initially had slightly greater height, subsequent observations showed growth decline. This suggests that plants without nutrient supplementation were unable to maintain stable physiological development.

According to Petra Marschner, nutrient availability during early vegetative growth is essential for sustaining chlorophyll synthesis and tissue expansion. Similarly, Rahman (2023) reported that liquid organic fertilizer enhances nutrient uptake efficiency and microbial activity, thereby supporting early biomass development. The present findings align with this, as fertilizer application promoted leaf enlargement and stem growth, yet did not ensure survival under prolonged stress.

### *Growth Category Evaluation*

To interpret growth performance, the three-box method was applied.

Table 2. Growth Performance Classification

| Score         | Category |
|---------------|----------|
| 50.00–100.00  | Low      |
| 100.01–150.00 | Medium   |
| >150.00       | High     |

Based on the calculated scores, the fertilizer treatment reached the medium category in the second week, whereas the control remained in the low category. This difference indicates a positive initial response due to improved nutrient availability.

### *Physiological Changes*

By the second week, control plants exhibited chlorosis, reduced stem thickness, and narrow pale leaves. Fertilized plants maintained relatively green foliage but began showing tissue damage caused by green grasshopper infestation. These symptoms suggest that physiological decline had already begun due to the combined effects of environmental stress and pest pressure.

Petra Marschner explained that chlorosis is a common early symptom of nitrogen deficiency, leading to reduced chlorophyll synthesis and impaired photosynthesis. In addition, Hasan M. M. (2022) reported that high temperature accelerates water loss, reduces turgor pressure, and increases plant susceptibility to biotic disturbances.

### *Plant Survival*

Beginning in the third week, all plants exhibited progressive turgor loss. Leaves curled, wilted, and partially developed necrotic tissue. By the fourth week, all experimental units had died. This indicates that environmental stress exerted a stronger influence than nutrient treatment.

Plant survival rate was calculated using:

$$SR = \frac{N_h}{N_t} \times 100\% \quad SR = N_t N_h \times 100\%$$

Where:

$SR$  = survival rate;

$N_h$  = number of surviving plants;

$N_t$  = total observed plants.

Final survival value:

**SR=0%SR=0\%SR=0%**

This result confirms that no plants survived until the end of the experiment.

### ***Statistical Analysis***

Analysis of variance indicated that organic fertilizer significantly affected early vegetative growth but had no significant effect on final survival.

Table 3. Summary of ANOVA Results

| Variable     | F-value | Significance    |
|--------------|---------|-----------------|
| Plant height | 5.74    | Significant     |
| Stem length  | 6.18    | Significant     |
| Leaf length  | 4.92    | Significant     |
| Survival     | 0.00    | Not significant |

The F-values indicate that fertilizer significantly influenced early morphological parameters. However, no difference was detected in survival because all plants experienced total mortality. This confirms that positive early growth response does not necessarily correlate with medium-term adaptation success.

According to Kwanchai A. Gomez and Arturo A. Gomez, significant vegetative growth differences may not represent actual physiological resilience when environmental factors become dominant limiting variables.

### ***Interpretation of Findings***

The findings demonstrate that successful plant adaptation is determined not solely by nutrient availability but by the interaction among temperature stress, humidity fluctuation, and biotic pressure. The application of liquid organic fertilizer improved early growth by supplying essential nutrients; however, it failed to maintain plant homeostasis under prolonged environmental stress.

This observation supports the combined stress theory, which states that multiple simultaneous stressors produce synergistic negative effects on plant physiology. According to Michael Palmgren and Sergey Shabala, nutrient deficiency combined with extreme temperature reduces antioxidant capacity and accelerates cellular damage. The present study reinforces that the post-transplant stage is a highly critical period in mustard cultivation, and initial vegetative performance should not be considered the sole indicator of successful adaptation.

## **DISCUSSION**

The present study demonstrated that the application of Fullgrow Liquid Organic Fertilizer improved the initial growth response of Mustard Greens after transplantation; however, this treatment was insufficient to maintain plant survival until the end of the observation period. These findings indicate that favorable early growth does not necessarily reflect successful medium-term physiological adaptation. During the post-transplant stage, plants are highly

vulnerable because root systems have not fully recovered from mechanical disturbance, resulting in limited capacity for water and nutrient uptake. Under such conditions, additional nutrient supply only provides temporary support, while prolonged environmental stress remains the dominant limiting factor. This is consistent with the experimental observations, where all plants died by the fourth week despite improved early growth in the fertilizer-treated group.

The enhanced growth observed in the fertilized treatment suggests that nutrients were initially available in sufficient quantities to support cell division and elongation. Nitrogen supplied through the organic fertilizer contributed to chlorophyll formation, while organic compounds likely stimulated soil microbial activity that enhanced nutrient mobilization. This finding is in agreement with the work of Rahman (2023), who reported that liquid organic fertilizers improve vegetative performance in leafy vegetables by increasing biological fertility of the growing medium. However, the current results reveal that such improvements were temporary. Once temperature increased and humidity fluctuated, plant physiological performance declined in both treatments. This indicates that nutrient availability alone cannot ensure successful adaptation without a stable growing environment.

Physiological symptoms observed during the experiment—including chlorosis, necrosis, leaf narrowing, and progressive wilting—indicate complex metabolic disruption. Chlorosis in the control treatment reflects nitrogen deficiency that reduced chlorophyll synthesis, while necrotic tissue and damaged leaves in the fertilized treatment indicate cellular injury caused by external stress factors. According to Petra Marschner, such visual symptoms are common indicators of nutrient imbalance and impaired photosynthetic activity. In this study, these symptoms were intensified by elevated temperature, which accelerated transpiration and caused plants to lose water faster than the damaged root system could absorb it.

Environmental conditions had a stronger influence than nutrient treatment throughout the experiment. High temperature fluctuations and unstable humidity created prolonged abiotic stress. Hasan M. M. (2022) explained that elevated temperature increases plant respiration, causing metabolic energy to be diverted toward maintaining cellular stability rather than supporting growth. This explains why fertilized plants also died by the end of the experiment. Although nutrient supply was adequate in the early phase, physiological energy was redirected to stress adaptation processes. Consequently, initial growth should not be considered the sole indicator of cultivation success.

A significant finding of this study was the interaction between abiotic and biotic stress factors. The infestation of green grasshoppers accelerated leaf damage at a time when plants were already experiencing heat stress and water deficiency. Tissue damage reduced the photosynthetic surface area, further limiting carbohydrate production and energy availability. Novianto (2020) reported that pest attacks on environmentally stressed plants accelerate physiological deterioration because energy reserves are already depleted. The

current findings confirm this mechanism, showing that pest attack did not act independently but intensified the impact of ongoing stress.

These observations strongly support the combined stress theory, which states that two or more simultaneous stressors produce synergistic effects on plant damage. Nutrient deficiency reduces the plant's capacity to synthesize protective proteins and antioxidant enzymes, while high temperature increases production of reactive oxygen species (ROS), which damage cellular membranes and tissues. When combined with pest infestation, tissue degradation occurs more rapidly. According to Michael Palmgren and Sergey Shabala, combined stress disrupts plant homeostasis far more severely than individual stress factors. This study extends that concept to post-transplant mustard cultivation under tropical conditions.

From a scientific perspective, this research contributes to a broader understanding that early vegetative growth does not necessarily indicate physiological resilience. Previous studies frequently used plant height or leaf number as primary indicators of cultivation success. In contrast, the present findings demonstrate that even when plants exhibit improved early growth, total mortality may still occur. This expands the interpretation of cultivation performance, emphasizing that survival rate and physiological symptoms must be incorporated alongside morphological parameters.

Practically, these findings suggest that crop management during the post-transplant stage should adopt an integrated approach. The use of Fullgrow Liquid Organic Fertilizer should be accompanied by microclimate management, particularly humidity regulation, protection against extreme temperature, and early pest control. Without such integrated management, nutrient supplementation provides only short-term benefits. Therefore, adaptive cultivation technologies are increasingly essential in tropical horticultural systems facing unpredictable climate variability.

## **CONCLUSION**

This study demonstrated that application of Fullgrow liquid organic fertilizer improved the early vegetative growth of mustard greens following transplanting, particularly in stem elongation and leaf expansion. However, the positive initial response did not translate into sustained plant survival throughout the observation period. All experimental units reached complete mortality by the fourth week, indicating that early vegetative enhancement alone was insufficient to ensure successful acclimatization under continuous environmental stress.

The failure of plant adaptation was associated with the combined influence of nutrient limitation, elevated temperature, unstable humidity, and pest infestation. These factors acted simultaneously and intensified physiological disruption, reducing the capacity of the plants to maintain water balance, photosynthetic efficiency, and tissue integrity. The findings confirm that post-transplant establishment represents a critical phase in leafy vegetable cultivation, during which external stressors may override the short-term benefits of nutrient supplementation.

The study further highlights that early growth parameters cannot be considered the sole indicator of successful cultivation. Morphological

improvement observed during the first two weeks did not correlate with medium-term survival. Therefore, assessment of transplant adaptation should incorporate a more integrated framework that combines morphological indicators, physiological symptoms, and survival performance. Such an approach provides a more accurate understanding of plant resilience under tropical field conditions, particularly under increasingly variable climatic conditions.

## RECOMMENDATIONS

Based on the findings, several practical recommendations can be proposed:

1. The application of liquid organic fertilizer should be integrated with microclimate management, particularly humidity regulation and protection against excessive solar heat, to minimize environmental stress during the acclimatization period.
2. Preventive pest management should be implemented during the first weeks after transplanting, as plants under physiological stress become more susceptible to herbivore attack and secondary tissue damage.
3. Future cultivation strategies should combine nutrient management with environmental buffering technologies, such as partial shading, mulching, or controlled irrigation, to improve transplant survival in tropical horticultural systems.

## ADVANCED RESEARCH

This study has several methodological limitations that should be acknowledged. First, the observation period was limited to four weeks after transplanting, which only captured the early adaptation phase and did not extend to recovery, full vegetative development, or harvest stage. Second, the experimental design included only two treatment groups, namely untreated control and liquid organic fertilizer application, which restricted evaluation of dose-response relationships. Third, the assessment focused primarily on morphological observations and visible stress symptoms, while physiological variables such as chlorophyll concentration, antioxidant activity, and transpiration rate were not instrumentally measured. These limitations may affect the depth of interpretation regarding the mechanisms underlying adaptation failure.

Future studies should adopt a multivariate and factorial design to better evaluate interactions among nutrient availability, environmental stress, and plant resilience. Testing multiple fertilizer concentrations, integrating biofertilizers, and applying partial shading systems would provide broader insights into stress mitigation. Measurement of physiological indicators such as chlorophyll index, relative water content, stomatal conductance, and antioxidant enzyme activity is also recommended to explain the biochemical basis of stress responses.

Longer observation periods extending to harvest are needed to determine whether early stress affects final biomass production and marketable yield. In addition, climate-adaptive cultivation technologies such as organic mulching, semi-protected structures, and microbial biostimulants should be evaluated as

integrated strategies for improving transplant success in tropical vegetable production systems.

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