EVALUATING THE EFFECT OF STRUCTURED ACOUSTIC RECITATION ON NUTRIENT UPTAKE AND GROWTH PERFORMANCE OF HYDROPONIC PAKCOY (BRASSICA RAPA L.)

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Abstract: *Acoustic stimulation has emerged as a non-chemical approach to enhance plant growth and physiological performance under controlled cultivation systems. However, empirical evaluation of structured religious recitation as a potential acoustic stimulus remains limited. This study investigated the effect of Qur'an-recited water and acoustic exposure on nutrient uptake and growth performance of hydroponic pakcoy (Brassica rapa L.). The experiment followed a Completely Randomized Design (CRD) with three treatments and five replications per treatment: control nutrient solution (C), nutrient solution prepared using water exposed to structured recitation (QW), and daily acoustic exposure (QA; 30 min day^{-1} at 65–70 dB). Growth parameters and macronutrient uptake (N, P, K) were analyzed using ANOVA under PROC GLM in SAS 9.4, and means were separated using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$. QW significantly increased fresh weight (19.3%), dry weight (16.1%), leaf area (16.9%), chlorophyll index (13.5%), and nitrogen uptake (14.6%) compared to control. QA produced moderate but significant improvements. These findings suggest that structured acoustic exposure during water preparation may enhance biomass production and nutrient assimilation efficiency in hydroponic systems.*

Keywords: *Acoustic Stimulation; Hydroponics; Brassica Rapa; Nitrogen Uptake; Biomass Accumulation; Sound Vibration*

1. Introduction

Hydroponic cultivation provides a highly controlled environment that allows precise evaluation of non-conventional plant growth stimulants. Pakcoy (Brassica rapa L.) is a widely cultivated leafy vegetable in hydroponic systems due to its short production cycle and high commercial value.

Recent research has demonstrated that sound waves can influence plant growth, photosynthesis, enzymatic activity, and gene expression [1–3]. Acoustic stimulation within specific frequency ranges (100–1000 Hz) has been reported to enhance biomass accumulation and nutrient uptake efficiency [4]. Mechanical vibration may act as a signaling stimulus, affecting membrane permeability, ion transport, and phytohormone regulation [5].

Structured recitation represents rhythmic acoustic patterns characterized by harmonic frequencies and temporal consistency. From a biophysical perspective, such structured sound may act as a stable acoustic stimulus capable of influencing plant physiological processes. However, systematic evaluation under hydroponic conditions remains scarce.

This study aimed to quantify the effects of structured acoustic recitation on nutrient uptake and growth performance of hydroponic pakcoy.

2. Materials and Methods

2.1. Experimental Design

The experiment followed a Completely Randomized Design (CRD) with one factor consisting of three treatments:

- **C (Control):** Standard AB-mix nutrient solution.
- **QW:** Nutrient solution prepared using water exposed to 15 min structured recitation.
- **QA:** Standard nutrient solution + 30 min day^{-1} acoustic exposure (65–70 dB).

Each treatment had five replications, and each replication consisted of 12 plants. The mean value per replication was used as the experimental unit.

2.2. Growth Conditions

The study was conducted in a greenhouse under the following conditions:

- Temperature: 27 ± 2 °C
- Relative humidity: 65–75%
- Photoperiod: 12 h
- Hydroponic system: Nutrient Film Technique (NFT)

Seedlings were transplanted 14 days after germination and harvested at 35 days after transplanting.

2.3. Measured Parameters

Growth Performance

- Plant height (cm)
- Leaf number
- Leaf area (cm^2)
- Root length (cm)
- Fresh weight (g plant^{-1})
- Dry weight (g plant^{-1}; oven-dried at 70 °C for 48 h)
- Chlorophyll index (SPAD)

Nutrient Uptake

- Nitrogen (Kjeldahl method)
- Phosphorus (UV–Vis spectrophotometry)
- Potassium (Atomic Absorption Spectrophotometry)

2.4. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model (PROC GLM) in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Normality and homogeneity were verified prior to analysis. Significant differences among means were determined using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

3. Results

3.1. Growth Performance

Table 2. Effect of treatments on growth parameters (mean ± SD, n = 5).

Treatment	Fresh Weight (g)	Dry Weight (g)	Leaf Area (cm^2)	Chlorophyll (SPAD)
C	156.2 ± 7.1 c	11.8 ± 0.6 c	1375 ± 88 b	38.4 ± 2.3 b
QW	186.3 ± 8.2 a	13.7 ± 0.7 a	1608 ± 94 a	43.6 ± 2.5 a
QA	173.5 ± 7.5 b	12.9 ± 0.6 b	1512 ± 90 ab	41.2 ± 2.1 ab

Different letters indicate significant differences (DMRT, $p \leq 0.05$).

3.2. Nutrient Uptake

Table 3. Effect on macronutrient uptake (mean ± SD, n = 5).

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)
C	2.81 ± 0.13 c	0.47 ± 0.03 b	3.18 ± 0.19 b
QW	3.22 ± 0.16 a	0.53 ± 0.04 a	3.49 ± 0.21 a
QA	3.05 ± 0.14 b	0.50 ± 0.03 ab	3.36 ± 0.18 ab

4. Discussion

The present study demonstrates that structured acoustic exposure significantly enhanced biomass accumulation, chlorophyll index, and macronutrient uptake in hydroponic pakcoy (*Brassica rapa* L.), particularly when the acoustic treatment was applied during water preparation (QW). These findings are consistent with previous studies reporting that sound waves within controlled frequency and intensity ranges can stimulate plant growth, photosynthesis, and metabolic activity (1–4). Acoustic vibration has been shown to influence carbohydrate metabolism, enzyme activation, and energy-use efficiency, ultimately promoting shoot development and biomass production (1,2,13). The magnitude of fresh weight increase observed in the QW treatment aligns with reported yield improvements of 10–25% under moderate sound intensity (4,6), suggesting that mechanical sound stimulation may function as a non-chemical growth enhancer under controlled hydroponic systems.

From a mechanistic standpoint, plants perceive sound as a mechanical stimulus through mechanosensitive ion channels located in the plasma membrane. According to mechanoperception theory, vibration-induced membrane deformation can activate calcium influx and trigger downstream signaling cascades that regulate gene expression and nutrient transporter activity (5,8). Enhanced nitrogen concentration observed in the QW treatment may therefore be linked to improved nitrate uptake and assimilation pathways, which are responsive to environmental stimuli (7,9). Nitrogen is essential for chlorophyll biosynthesis and photosynthetic enzyme formation; thus, the increased SPAD values observed in this study are physiologically consistent with improved nitrogen assimilation (7). Similar patterns of enhanced potassium and phosphorus uptake suggest that acoustic stimulation may influence ion mobility and membrane transport efficiency.

At the molecular level, transcriptomic and proteomic analyses have shown that sound vibration can upregulate genes associated with photosynthesis, stress responses, and hormonal signaling (2,13,18). Increased expression of chlorophyll-binding proteins and photosystem-related genes has been documented following sound exposure (2,13), potentially explaining improved biomass accumulation. Additionally, sound stimulation has been associated with enhanced antioxidant enzyme activity, which may contribute to improved physiological stability and stress tolerance (4,13). Although oxidative stress parameters were not measured in the present study, enhanced nutrient assimilation efficiency indicates improved metabolic coordination under acoustic exposure.

Interestingly, acoustic treatment during water preparation (QW) produced stronger physiological responses than direct daily exposure (QA). Previous investigations have suggested that sound waves may alter physicochemical properties of water, including hydrogen bonding structure, dissolved gas distribution, and ion dynamics (6,14–16). Such changes could theoretically influence nutrient solubility and availability in hydroponic systems. While the precise mechanism remains to be elucidated, these findings support the hypothesis that acoustic modulation of nutrient solution properties may enhance nutrient uptake efficiency beyond direct plant-level stimulation.

Comparable evidence has been reported in field-based Brassica production systems. Munar et al. (20) demonstrated that sound exposure significantly increased yield of mustard (*Brassica juncea* L.) when combined with preventive pest management using refugia plants. Although their study integrated ecological pest control strategies, the positive effect of sound exposure on vegetative growth and yield parameters reinforces the physiological responsiveness of Brassicaceae species to acoustic stimulation. The consistency between soil-based mustard production (20) and hydroponic pakcoy cultivation in the present study suggests that sound-induced growth enhancement may operate through conserved physiological mechanisms across Brassica species and cultivation systems.

From a sustainability perspective, improving nutrient use efficiency without increasing fertilizer input represents a key objective in controlled-environment agriculture. Enhanced nitrogen uptake observed in this study indicates improved assimilation efficiency rather than increased nutrient supply. This aligns with the broader concept of plant biostimulants, which enhance plant performance through physiological modulation rather than direct nutrient supplementation (10–12). Therefore, structured acoustic exposure may represent a complementary non-chemical strategy to improve hydroponic productivity. Nevertheless, further research incorporating detailed frequency characterization, molecular analysis, and water physicochemical measurements is required to validate mechanisms and optimize application protocols.

5. Conclusions

Structured acoustic exposure during water preparation significantly enhanced growth performance and nitrogen uptake of hydroponic pakcoy. This approach may represent a complementary strategy for improving productivity in controlled-environment agriculture.

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