Indonesian Journal of Chemical Science and Technology (IJCST)
State University of Medan, https://jurnal.unimed.ac.id/2012/index.php/aromatika

IJCST-UNIMED 2025, Vol. 08, No. 2 Page; 366 – 373
Received : June 24th, 2025 Accepted : Jul 25th, 2025 Web Published : Aug 29th, 2025

Growth Response of Mung Bean Plants *Vigna radiata* L. and Spinach *Amaranthus hybridus* L. Under Acidic and Alkaline Conditions

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ABSTRACT

This study investigates the growth response of mung bean Vigna radiata L. and spinach Amaranthus hybridus L. under controlled acidic neutral and alkaline environments across a wide pH gradient from pH 3 to pH 14. The work provides a comparative assessment of two species with distinct physiological characteristics to clarify how hydrogen ion concentration shapes vegetative development. The novelty of this study lies in its direct evaluation of extreme pH conditions using a uniform experimental design that allows both species to be examined under identical chemical exposure, enabling a clear contrast of tolerance thresholds. Plant height was recorded daily for 13 days to capture early stage vegetative dynamics. Both species exhibited their highest stability near pH 7 while severe deviations from neutrality reduced growth through nutrient imbalance and physiological stress. Mung bean showed moderate tolerance at pH 9.5 whereas spinach displayed enhanced performance within mild alkalinity. Strong acidity and strong alkalinity produced structural damage in both species. The findings highlight the critical role of soil pH in plant performance and provide foundational insight into species specific tolerance ranges that can support more informed management of crops grown in chemically variable environments.

Keywords: pH stress, mung bean, spinach, vegetative growth, acidity, alkalinity

1. INTRODUCTION

Acid base chemistry shapes many reactions and interactions that occur in natural and managed ecosystems. Acidity influences the charge balance of soils and solutions while also determining the availability of nutrients that plants require for sustained growth.[1] The concept has a long history in chemical science yet

e-ISSN : 2622-4968, p-ISSN : 2622-1349

its relevance remains central to modern environmental studies because pH variation governs the stability of biological structures and regulates the activity of many biochemical pathways.

Measurement of acidity relies on the detection of hydrogen ion concentration through colorimetric indicators or instrumental sensors. Simple indicators based on plant pigments show clear color transitions across a broad pH range while electrochemical devices allow precise quantification.[2] Although these techniques differ in complexity, they all highlight the importance of pH as a controlling variable in soil and water chemistry.

Soil pH plays a pivotal role in plant growth because it affects nutrient solubility, root permeability and microbial communities that support nutrient cycling.[3, 4] Conditions that deviate from an optimal pH range can disrupt mineral uptake, reduce photosynthetic efficiency and weaken plant resilience. Environmental pressures such as acid deposition and agricultural inputs further modify pH conditions, which makes the study of plant tolerance toward acidity and alkalinity increasingly important for sustainable crop production.

Mung bean *Vigna radiata* L. is a widely cultivated legume valued for its protein content and its adaptability to low input farming systems.[5] Its growth is influenced by soil chemistry and previous experimental evidence indicates that this species performs well in slightly acidic soils.[6, 7] When exposed to extreme acidity or alkalinity, physiological processes become impaired and the accumulation of biomass declines.

Spinach *Amaranthus hybridus* L. represents an important leafy vegetable with a high nutritional profile.[8] Despite its broad environmental tolerance, this species remains sensitive to marked changes in soil pH.[9] Variations in acidity alter nutrient uptake dynamics and influence the vegetative development of the plant. Understanding such responses is critical for improving cultivation practices, particularly in regions where soils undergo rapid chemical shifts.

Both species provide a suitable model for examining the influence of pH on early vegetative growth. Differences in tolerance and physiological adjustment can reveal how plants adapt to chemical changes in their environment. The present study investigates the growth response of mung bean and spinach under acidic and alkaline conditions. The findings aim to clarify the relationship between soil pH and plant performance by assessing changes in growth patterns when hydrogen ion concentration varies across a controlled gradient.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The study employed analytical grade acidic and alkaline solutions to generate controlled pH conditions. Acetic acid (CH_3COOH) present in vinegar with pH 3 and ascorbic acid ($C_6H_8O_6$) present in vitamin C with pH 5 were used as acidic treatments. Sodium bicarbonate ($NaHCO_3$) present in baking powder with pH 9.5 and sodium hypochlorite (NaOCl) present in bleach with pH 14 were used as alkaline treatments. Neutral conditions were represented by distilled water with pH seven.

The materials consisted of mung bean seeds (*Vigna radiata* L.), spinach seeds (*Amaranthus hybridus* L.) and garden soil that served as the growth medium. Polybags were used as planting containers. Universal indicator strips were employed to verify the pH values of each prepared solution. Plant height measurements were conducted using a calibrated ruler while visual observations were used to document leaf number and morphological changes throughout the growth period.

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2.2. Research Procedure

The experiment was designed to evaluate the growth response of mung bean and spinach under acidic and alkaline environments. Garden soil was homogenized and distributed into ten polybags of equal volume. Five polybags were assigned to mung bean and the remaining five were assigned to spinach.

Spinach seeds were germinated for ten days until the first true leaves emerged before transplantation into the polybags. Mung bean seeds underwent imbibition through overnight soaking to initiate germination and were planted directly afterward.

Each plant group received one of five treatments that represented different acidity levels. The first treatment applied acetic acid with pH three. The second treatment applied ascorbic acid with pH five. The third treatment applied sodium bicarbonate with pH nine point five. The fourth treatment applied sodium hypochlorite with pH fourteen. The fifth treatment served as the control and received only water with pH seven.

The volume of each solution applied to the soil remained constant for all treatments to ensure uniform exposure. Plant height, leaf development and visible morphological responses were recorded daily during the observation period. Differences in growth patterns were evaluated by comparing the responses of both species under each pH condition. The observations provided a basis for determining how variations in acidity and alkalinity influenced vegetative performance.

Stock solutions of citric, acetic, and ascorbic acids were prepared in deionized water. Working media were made by volumetric dilution of the corresponding stocks to prescribed test volumes of 10, 30, 50, or 100 mL, depending on the experiment. For mixture experiments, binary acid media (citric–acetic) were prepared by combining equal volumes of the respective single-acid working solutions to maintain the same total acid content as in single-acid runs. When food-grade vinegar or clarified citrus juice were used for comparison, they were first paper-filtered before use.

3. RESULTS AND DISCUSSION

3.1. Determination of acidic and alkaline solutions

Universal indicator strips confirmed that each solution produced a distinct pH level across a gradient of strong acidity to strong alkalinity. Distilled water showed pH 7, vinegar pH 3, vitamin C solution pH 5, sodium bicarbonate pH 9.5 and sodium hypochlorite pH 14. The range created a sequence of chemical environments that differed sharply in hydrogen ion concentration. This clear separation between treatments ensured that the plants were exposed to conditions capable of eliciting measurable physiological responses. Accurate establishment of pH levels was essential because shifts in acidity or alkalinity modify the solubility of essential ions, alter root surface charge and influence the movement of nutrients through the soil solution.[10] Such chemical changes affect membrane integrity, enzyme activity and overall metabolic efficiency which together determine the capacity of plants to maintain growth under contrasting environmental conditions.

3.2. Germination of mung bean seeds

Imbibition during overnight soaking initiated uniform water uptake and activated the early metabolic processes required for germination in mung bean seeds *V. radiata* L. The absorption of water caused the seed tissues to rehydrate and triggered enzymatic pathways that mobilize stored reserves within the cotyledons.[11, 12] These processes prepared the embryo for radicle growth and supported the transition from a dormant

e-ISSN : 2622-4968, p-ISSN : 2622-1349

physiological state to an active one. Seed viability and uniform germination were confirmed by the consistent emergence of primary roots prior to transplantation which indicated that the seeds responded predictably to hydration. Establishing uniform initial conditions was essential because it reduced the possibility that later differences in plant performance were influenced by variations in seed quality rather than by the pH treatments applied during the experiment. Figure 1 shows the stage of seed hydration and the appearance of the developing radicle which marks the beginning of successful germination.

Figure 1. Imbibition process in mung bean seeds

3.3. Plant growth

Table 1 presents the recorded height of mung bean and spinach across all pH treatments during the 13 day observation period. The dataset provides a clear overview of how each species responded to strong acidity, weak acidity, neutrality, weak alkalinity and strong alkalinity. The numerical values form the basis for evaluating the growth trends of both species and support the interpretation of their physiological responses under varying pH conditions.

Table 1. Growth data of mung bean and spinach under acidic neutral and alkaline treatments

Types of plants	Type of solution	Plant height on day- (cm)												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Mung bean	Water pH 7 (A1)	17	17.5	18	18.5	19	19	19	19.3	19.3	19.3	19.5	19.5	19.8
	Vinegar pH 3 (A2)	19	19	19	19	19	19	19	19	19	19	19	19	19
	Vitamin C pH 5 (A3)	16	16.3	16.5	16.8	17	17	17	17	17	17	17	17	17
	Sodium bicarbonate pH 9 (A4)	17	17.3	17.5	17.8	18	18.2	18.2	18.5	18.7	18.7	19	19.4	19.7
	Sodium hypochlorite pH 14 (A5)	17	17,5	18	18.5	19	19	19	19	19	19	19	19	19

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Spinach	Water pH 7 (B1)	7	7	7.5	7.8	8	8.3	8.5	8.7	9	9.3	9.5	9.8	10
	Vinegar pH 3 (B2)	7	7	7.5	7.7	8	8	8	8	8	8	8	8	8
	Vitamin C pH 5 (B3)	8	8	8	8	8	8	8	8	8	8	8	8	8
	Sodium bicarbonate pH 9 (B4)	9	9	9	9	9	9	9	9	9	9	9	9	9
	Sodium hypochlorite pH 14 (B5)	6	6.3	6.5	6.8	7	7	7	7	7	7	7	7	7

3.4. Growth response and interpretation for mung bean

Mung bean showed the greatest stability under neutral conditions. Height increased progressively across the 13 day period and leaves remained turgid and green. The neutral environment supports optimal nutrient availability and enzymatic function which explains sustained elongation.[13] Strong acidity arrested elongation and suppressed leaf development. Persistent acidity reduces root membrane permeability and increases solubility of potentially toxic ions which impairs uptake of essential macronutrients including nitrogen magnesium and potassium.[14] The plateau observed under pH 5 suggests partial tolerance at weak acidity but prolonged exposure prevented recovery.

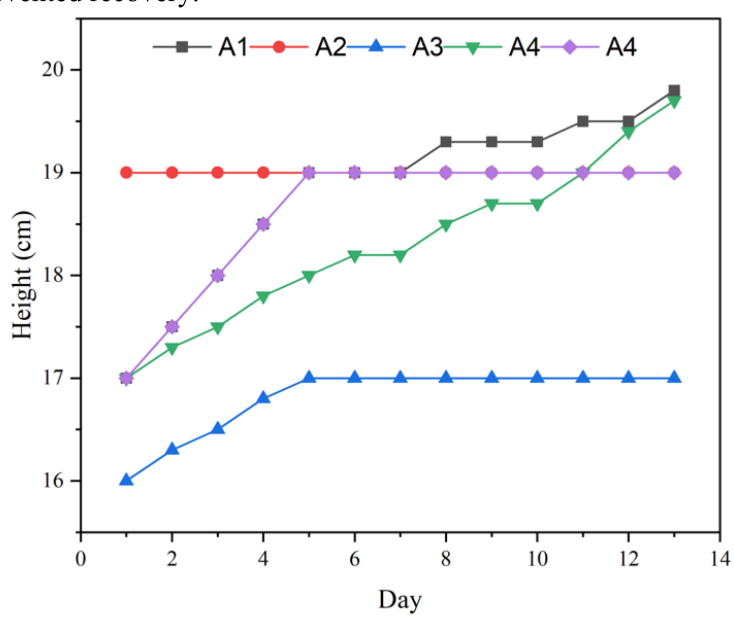

Figure 2. Growth pattern of mung bean under different pH conditions

Weak alkalinity allowed continued growth albeit at a slower rate than neutral conditions.[15, 16] Reduced solubility of micronutrients such as iron and manganese at higher pH likely limited metabolic rates and slowed expansion. Strong alkalinity induced visible tissue damage including leaf necrosis and partial defoliation. Stem elongation continued at a reduced pace which implies that carbon allocation favored stem maintenance over leaf expansion under stress. The observed symptoms imply combined effects of nutrient imbalance osmotic stress and membrane destabilization. Figure 2 presents the overall pattern of mung bean growth throughout the experimental period.

3.5. Growth response and interpretation for spinach

Spinach performed well in neutral conditions with steady height increments and regular leaf development. The species showed greater tolerance to weak alkalinity than to weak acidity. The pH 9.5 treatment produced the tallest spinach plants which indicates that moderate alkalinity did not limit the uptake of key nutrients required for vegetative growth and may have favored availability of certain anions. Strong acidity strongly limited growth and leaf development. Acidic stress likely reduced chlorophyll synthesis and impeded root function. Strong alkalinity produced leaf yellowing fragility and detachment which signals impaired nutrient translocation and membrane function.[17] Figure 2 presents the overall pattern of spinach growth throughout the experimental period.

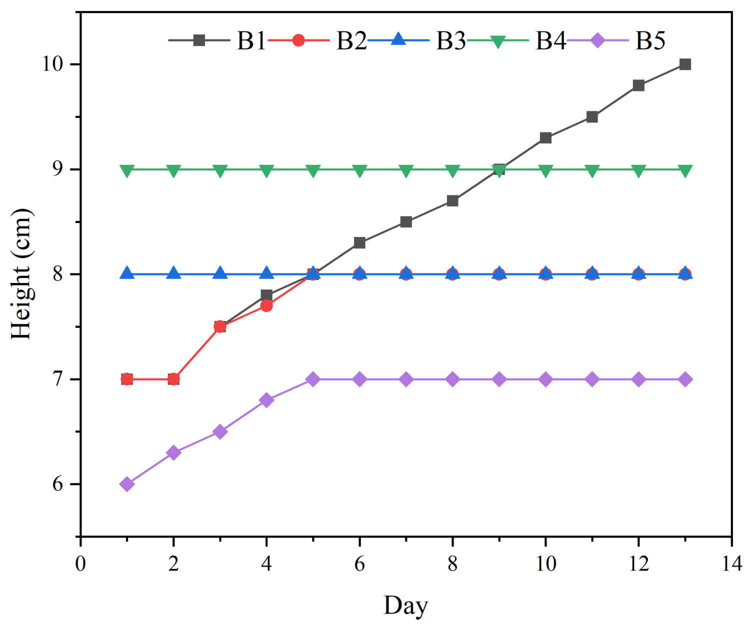

Figure 3. Growth pattern of spinach under different pH conditions

3.6. Comparative analysis and mechanistic considerations

The two species exhibit distinct tolerance windows. Mung bean favors near neutral conditions and tolerates weak alkalinity better than strong acidity. Spinach tolerates mild alkalinity and demonstrates rapid decline under strong acidity. These species specific patterns reflect differences in root morphology cation exchange capacity and internal nutrient demand.

e-ISSN : 2622-4968, p-ISSN : 2622-1349

Mechanistically pH affects solubility of macronutrients and micronutrients.[2] At low pH increased solubility of aluminum and manganese can reach phytotoxic levels which inhibits root growth. At high pH iron and manganese become insoluble which limits chlorophyll synthesis and causes interveinal chlorosis. pH also influences microbial communities that mediate nitrogen transformations and phosphorus availability which further alters plant nutrition.[13] The observed leaf necrosis root impairment and altered elongation rates are consistent with disruptions in nutrient uptake oxidative stress and impaired photosynthetic capacity.

The findings indicate that maintaining soil pH near neutral optimizes growth for both species in short term cultivation. For mung bean practitioners maintaining pH close to 6 will favor stable vegetative growth and likely improve subsequent reproductive performance. For spinach cultivation slight alkalinity within the range tested may be acceptable and could support rapid leaf accumulation. Soil testing and targeted amendment should be recommended when pH departs from these ranges. Organic matter additions and balanced fertilization strategies can buffer pH fluctuations and improve nutrient retention.

This study provides controlled comparisons across a broad pH gradient but several limitations require attention. Replication details and statistical analysis were limited in the present dataset and should be expanded in future experiments to permit rigorous hypothesis testing. The use of household reagents to create pH treatments introduces confounding components other than hydrogen ion concentration such as acetate bicarbonate and hypochlorite ions which may exert biochemical effects independent of pH. Future work should employ buffered solutions or defined salts to isolate pH effects. Longer term experiments that include reproductive stages and measurements of biomass chlorophyll concentration nutrient content and root architecture will provide more complete understanding of agronomic outcomes.

4. CONCLUSION

The study confirmed that soil pH strongly regulates the vegetative performance of mung bean *V. radiata* L. and spinach *A. hybridus* L. across acidic neutral and alkaline conditions. Both species demonstrated their highest growth stability near neutrality while extreme acidity and alkalinity disrupted nutrient balance and reduced physiological efficiency. The findings emphasize the importance of maintaining soil pH within the tolerance range of each species to support consistent growth and to minimize chemical stress. The outcomes also highlight the need for careful pH management in cultivation systems to ensure reliable plant development under variable environmental conditions.

ACKNOWLEDGEMENT

The authors express sincere appreciation to the lecturers of the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan for their guidance, thoughtful input and consistent support during the completion of this research and the preparation of the manuscript on the effect of citric, acetic and ascorbic acids on paracetamol solubility.

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e-ISSN : 2622-4968, p-ISSN : 2622-1349