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RESEARCH PAPER

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Understanding growth patterns of mung beans (*Vigna radiata*) through polynomial interpolation: Implications for cultivation practices

Alfred P. Pantaleon*, ZJ G. Villanueva, Marisol C. Salvador, Venus D. Siong

College of Graduate Studies, Don Mariano Marcos Memorial State University, Mid La Union, Philippines

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Key words: Polynomial interpolation, Mung bean modeling, Mung bean growth approximation

Abstract

This study aims to explore the germination and growth patterns of mung bean seeds (*Vigna radiata*) through a polynomial interpolation fitting approach in a controlled environment. Mung beans are also popular in Asian diets, are used in many dishes, and have lots of nutritional value. The study is meant to describe the germination and growth pattern of mung beans over six successive days, performing height measurements and polynomial regression analysis for growth model development. Polynomial interpolation involves investing mung bean seeds in water and then measuring the average height of the beans each day. The data were analyzed using Newton's divided difference polynomial interpolation. The findings revealed an initial phase of steep growth, followed by a steadier increase, signifying the plant's maturity. The study has given a useful insight into various aspects of the growth dynamics of mung bean and has made a set of suggestions for the improvement of growth conditions concerning the crop and a research direction that can be followed in the future to further improve the yield of the crop.

* **Corresponding Author:** Alfred P. Pantaleon ✉ falfredpantaleon22@gmail.com

Introduction

A common food in Asian cuisine, mung beans are high in fiber, protein, and phytochemicals that are bioactive. They grow quickly and do well in warmer regions. For the coexistence of plant species and the development of communities, soil is an essential natural resource. It is important for the extraction of nutrients and water, which creates an environment that is conducive to plant growth. An essential stage in the life cycle of terrestrial angiosperms, seed germination has an impact on plant growth and seedling establishment. The following environmental elements have an impact on seed germination: light, oxygen, temperature, water, and chemical environment.

Dormancy patterns that fluctuate seasonally can interfere with seed germination and seedling survival. In order to produce crops efficiently, it is necessary to comprehend the factors that contribute to variation in seedling emergence. Unfavourable seed-bed conditions can impact a seedling's pre- and post-germination stages (Musa *et al.*, 2022). Moreover, Philippines, an Asian country, is a nation that depends on agriculture. This country's geographic location in the Tropics is largely responsible for this fact. The majority of the crops that Filipinos utilize to prepare the meals that they serve at their dining tables, aside from rice, are produced by them. In the country, homes have a variety of fruits, vegetables, and root crops growing in their backyards. One of the vegetables commonly planted in the fields or backyards is the mung bean or “monggo” bean.

Mung bean sprouts, referred to as toge in the Philippines, are tiny green beans that are a member of the legume family and are frequently used as a vegetable in cooking. Rich in vitamins, minerals, and nutrients, they are thought to be beneficial for a variety of illnesses. Growth in the population and the rising number of people consuming mung bean sprouts as a main course, side dish, or substitute for other foods are driving demand for these sprouts. Since mung bean sprouts may be grown both indoors and outdoors, growing them is an excellent incentive. The straightforward process of germination typically takes four to five days. For optimal germination, the pH of the soil, seedling positioning, and soil preparation are all critical. Common home items like containers, cloth/towels, and tap water can be used for indoor sprouting. It can grow for as long as the customer desires, but the typical germination time is between two and five days (Salvador *et al.*, 2021).

In Asia, mung beans, scientifically known as Vigna radiata, are a mainstay in global cuisines (Pratap *et al.*, 2021). Factors such as temperature, light, and moisture generally influence the growth and development of mung beans (Amitrano *et al.*, 2020). Farmers can significantly improve the yields of their crops if they will be able to understand how mung beans grow and as a result optimize their cultivation techniques. Hence, there is a promising potential for such agricultural practices in this study.

Past research primarily focused on statistical analysis of the growth and development of mung beans, as studied by Idrisov *et al.* (2021) and Jadhav *et al.* (2023). Specifically, the study of Jadhav *et al.* (2023) delves into the multivariate analysis of the growth of mung beans. On the other hand, Idrisov *et al.* (2021) studied the statistical analysis of mung beans’ growth, development, and grain yield. However, there are limitations in this analysis, specifically in the complex connections between environmental factors and the development of plants.

Polynomial interpolation is a mathematical method that can create a more precise representation of how different variables are related in complex data sets (Gasca and Sauer, 2000). There were varied studies on polynomial interpolation, such as predicting the stock prices of food corporations (Chan, 2015), studying the various types and behaviors of polynomial interpolations on the unit circle (Bahadur, 2022) and expounding the different types of polynomial interpolation in several variables (Gupta and Sharma, 2022). Also, literature on polynomial interpolation focused on (This mathematical method is not yet expounded in crops such as mung beans.

Furthermore, Gupta and Sharma (2022) have expounded on the use of mathematical modeling in the growth of plants and specifically how polynomial interpolation is helpful for the prediction of plant growth. Still, no research has been done in this manner for mung beans.

A gap exists at present in the current literature specifically on how mung beans grow using polynomial interpolation. This study fills the above-mentioned gap by using polynomial interpolation to study how mung beans grow in a controlled environment. Specifically, the researchers have (i) measured mung bean growth over a specified number of days and (ii) used polynomial interpolation in creating a model showing mung bean growth. Hence, the study aims to help us comprehend the growth pattern of mung beans and gives us ideas for growing this crop to improve its yield. The scope of the study includes the growth of mung beans in a controlled setting over six days. The data collected will be analyzed using the polynomial interpolation method.

Materials and methods

Research design

This study used a quantitative research design. Quantitative research aims to analyze and collect numerical data with an emphasis on objective measurements and statistical, mathematical, or numerical analysis of data collected through polls, questionnaires, and surveys, or by manipulating pre-existing data using computational techniques. The study also employed an experimental setup for data gathering. According to Barbagallo *et al.* (2017), the experimental setup refers to the exact arrangement and conditions used to test a hypothesis or research question (Fig. 1).

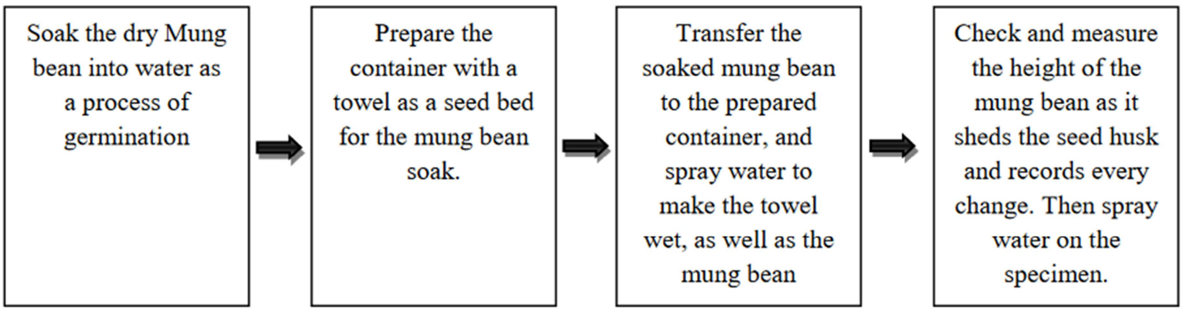


Fig. 1. Mung bean procedural setup of the study

Tools and supplies

The research study used 10 mung bean seeds as the specimen, a small towel, water, and a beaker.

Research instruments and data gathering procedures

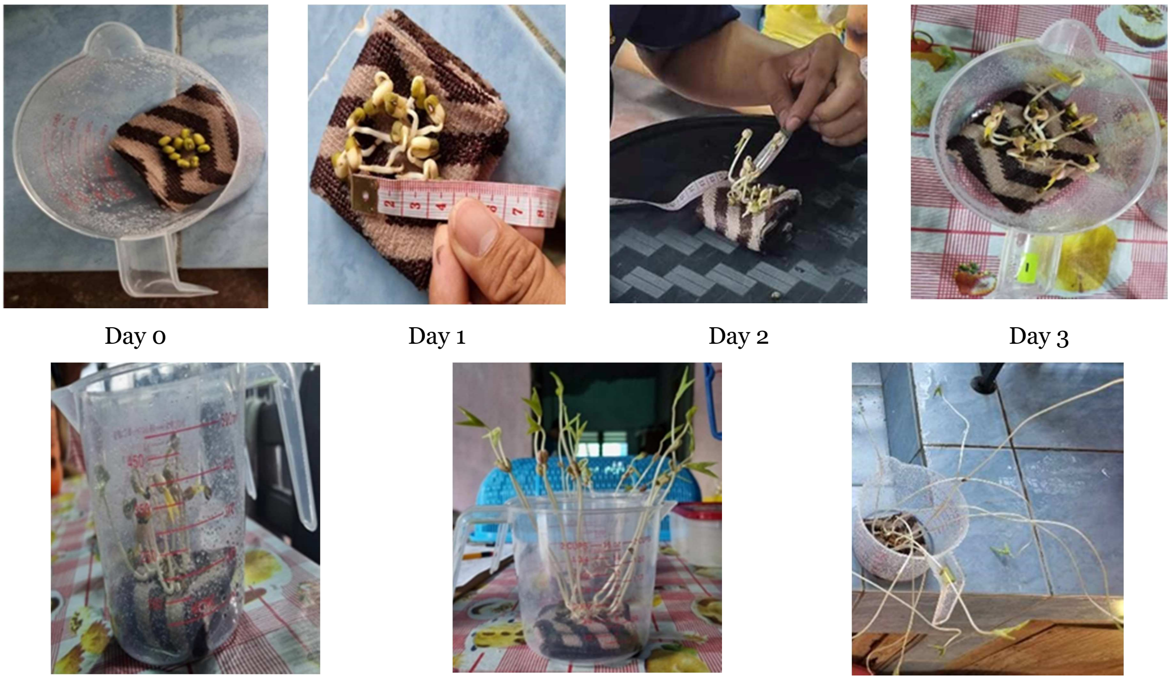
The researchers used a simple recording sheet to record the observations at any stage of the experiment. The measurement was done every morning. The recorded heights were used as a guide in computing the possible height of the mung bean in the identified days (Fig. 2). Research instruments and data collection were carefully planned to reduce the possibility of systematic errors in collecting, analysing, and interpreting data on the growth of mung beans. To achieve this, the study adopted this quantitative research design with an emphasis on experimental study and polynomial interpolation to analyse the growth patterns of mung beans when grown in a controlled physical environment.

Data analysis (Numerical analysis)

The data collected during the recording were tallied using a tape measure as a measuring instrument. Furthermore, the gathered data went through the process of Polynomial interpolation computation and interpretation. Polynomial interpolation is a mathematical technique offered for the construction of a polynomial that goes through certain given values. It is to get a desired polynomial equation that shall bear the required characteristic for equating it to data points. This method is rare and quite useful in cases where one wants to approximate certain values lying in between the data values.

In the actual analysis of the growth of mung beans, polynomial interpolation was used to fit the best polynomial model of the growth profile of the beans over specified days. From the researcher's observed data, the polynomial function was used to map and estimate the growth pattern of the mung beans. Thus, to carry out polynomial interpolation, the given problem is solved using Newton's Divided Difference formula. This formula is undertaken by establishing the differences between the data points to estimate the polynomial coefficients necessary for the correct polynomial that fits the given data. In this way, the researchers were able to guess the height of the mung beans during the days that researchers did not take the measurements.

Polynomial interpolation was one of the numerical methods that helped in the growth data analysis of the mung beans and provided information on the growth pattern of the crop that can be used to fine-tune the proper environment for growing Mung Beans to boost yield.



Day 0 Day 1 Day 2 Day 3

Day 4 Day 5 Day 6

Fig. 2. Mung bean setup measurements at different day periods

The study's analysis technique, notably the use of polynomial interpolation to better understand mung bean growth patterns, appears to be solid and well-structured. The research strategy used a quantitative technique with an experimental setting, which is appropriate for assessing numerical data and carrying out controlled tests. The use of polynomial interpolation as a numerical method to assess mung bean growth data is a viable and novel strategy that can provide useful insights into plant growth patterns.

In terms of data collection, the study measured the height of mung beans over a six-day period, which is an acceptable timescale to observe growth patterns. The data acquired, as shown in Tables 1 and 2, clearly depicts the growth progression of the mung beans. The use of Newton's Divided Difference method to polynomial interpolation computation is a standard mathematical technique for reliably calculating polynomial coefficients.

In terms of randomness and noise in data, the report makes no explicit mention of randomization procedures or noise reduction strategies. However, careful planning of study tools and data collection procedures was intended to reduce systematic errors in data gathering and analysis. Polynomial interpolation can help smooth out noise in data, resulting in a more accurate portrayal of growth trends.

While the data obtained over six days may not fully represent long-term growth tendencies, it does provide useful insights into the early phases of mung bean development. To improve the reliability of the research and results, future studies might gather data over a longer length of time to examine the entire life cycle of mung beans and account for potential changes in growth rates.

Results

The researchers observed and recorded the average height of mung beans over six days. The researchers were able to use polynomial interpolation analysis to predict the growth of mung beans as exemplified below. From the information collected and data analyzed, various features concerning growth patterns and rate of growth of mung beans under controlled conditions were obtained. This section deals with the development trends that are noticed, as well as mathematical tools to analyse it, and the relevancy and significance of the general conclusions for the promotion of the proper cultivation of mung beans.

Table 1. Average height of mung bean

Day	x	1	2	4	5	6
Height(cm)	f(x)	1.95	5.20	22.23	26.73	27.93

Table 1 shows the average growing height of mung beans over different days of growth. The data presented in the table refers to the growth progression of the mung bean plant, its growth being measured according to the height in centimeters. From all the results presented in a table, the growth rate of each day measured differs but the height increases over the days measured. With that, we can use Newton's divided difference method using unequal intervals in finding the approximate height on day 3 which was not measured, and the height presumed to be achieved by the mung bean setup within the 7 days.

Table 2 shows the divided difference table for the average height of mung beans over specific days. The table displays the differences in height measurements between consecutive days, providing insights into the growth pattern of the mung beans. The values in the table are crucial for calculating interpolated heights and understanding the rate of growth over time. Table 2 shows the computation using Newton's Divided Difference Formula, and with this formula, we can approximately calculate the height of the mung beans at days 3 and 7, denoted as f(3) and f(7), respectively.

Table 2. Divided difference table

x	*f(x)*	*Δf(x)*	*Δ²f(x)*	*Δ³f(x)*	*Δ⁴f(x)*
1	1.95				
		3.25			
2	5.20		1.76		
		8.52		-0.77	
4	22.23		-1.34		0.14
		4.50		-0.08	
5	26.73		-1.65		
		1.20			
6	27.93				

Newton Divided Difference:

$f(x) = f(x_0) + (x - x_0)\Delta f(x_0) + (x - x_0)(x - x_1)\Delta^2 f(x_0) + (x - x_0)(x - x_1)(x - x_2)\Delta^3 f(x_0) + \ldots$

Based on the divided difference table, the polynomial that will be used for interpolation is

$f(x)=1.95+(3.25)(x-1)+(1.76)(x-1)(x-2)-(0.77)(x-1)(x-2)(x-4)+(0.14)(x-1)(x-2)(x-4)(x-5)$

To solve for f(3) and f(7), use the polynomial function and value given by the divided difference table.

For f(3):

$f(3)=1.95+(3.25)(x-1)+(1.76)(x-1)(x-2)$

$f(3)=1.95+(3.25)(3-1)+(1.76)(3-1)(3-2)$

$f(3)=11.97$

This value represents the interpolated height of the mung bean on Day 3. The mung bean showed significant growth by more than doubling its height from the previous day, indicating a phase of rapid growth during this period.

For f(7):

f(7)=1.95+(3.25)(x-1)+(1.76)(x-1)(x-2)-(0.77)(x-1)(x-2)(x-4)+(0.14)(x-1)(x-2)(x-4)(x-5)

f(7)=1.95+(3.25)(7-1)+(1.76)(7-1)(7-2)-(0.77)(7-1)(7-2)(7-4)+(0.14)(7-1)(7-2)(x-4)(7-5)

f(7)=30.15

This value corresponds to the interpolated height of the mung bean on Day 7. The growth rate continues, albeit at a slower pace compared to earlier days, suggesting that the plant may be nearing its maximum height or that growth conditions are stabilizing.

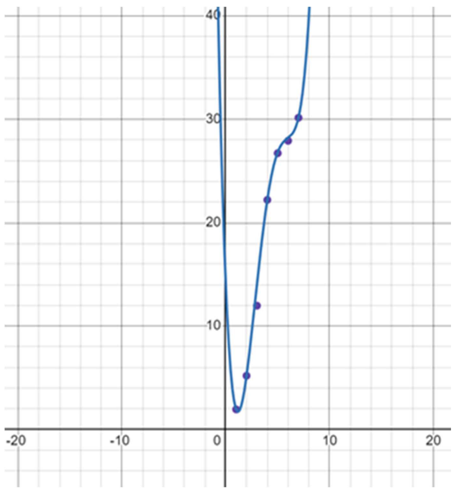
The significant growth observed in the mung bean from Day 3 to Day 7 aligns with the typical growth pattern of plants, showcasing an initial rapid increase followed by a slowing growth rate as the plant matures. This finding can be crucial in understanding the growth stages of mung beans and optimizing cultivation conditions for better yields.

Table 3. Height of mung bean with interpolation

Day	x	1	2	3	4	5	6	7
Height (cm)	f(x)	1.95	5.20	11.97	22.23	26.73	27.93	30.15

Table 3 shows the interpolated heights of the mung beans as observed during the seven days. The table shows the progression of mung bean growth in terms of height, with each day representing a specific measurement point. The interpolated heights provide a more detailed understanding of how the mung beans grew during the observation period. By implication, the data in Table 3 could potentially provide information on the growth progression of mung beans, in the form of phases of accelerated or slower growth, conditions that limit growth, and the gradual trend of elongation of the beans over time. The knowledge of such growth patterns may help adjust cultivation parameters, providing suitable conditions for plant growth, and consequently — enhancing the yield.

Graphical representation of the mung bean setup at different day periods through polynomial interpolation and regression are shown in Fig. 3 and 4.



X-Axis: Days of Observation

Y-Axis: Height of Mung Beans (centimeters)

Fig. 3. The graphical representation of the mung bean setup at different day periods through polynomial interpolation

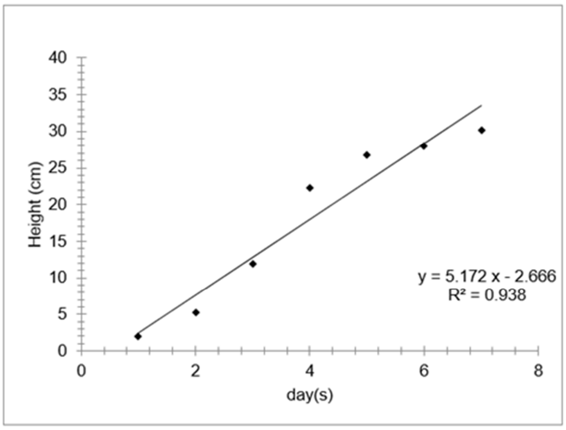


Fig. 4. The graphical representation of the mung bean setup at different day periods through regression

Discussion

From result, an increase from its initial measurement of size, proving that the mung bean plant showed much growth for six days. Data also showed that the plant still has a potential for further increasing its growth rates, thus suggesting that this process should be tightly controlled and optimized to achieve the maximum result. Moreover, the general growth measurements from day 1 to day 6, were taken at different intervals which may suggest variations in growth rates or reactions to the environmental conditions at any growth stage of the mung bean plant. Furthermore, the height of the mung bean plant recorded on the last day of the study is less compared to the previous day, which implies that the rate of growth of the mung bean plant is decreasing, therefore the rate of growth of the mung bean plant has reached its optimum level or growth has slowed because the plant may be reaching its maturity.

The findings validate the study by Sharma *et al.* (2018) on the growth analysis of mung beans grown in controlled environmental conditions, where the data revealed that enhanced optimum physical appearance and yield were achievable if slight variations in growth conditions were well managed. Further, Patel and Singh (2014) also investigated the effect of environmental factors on mung bean plant growth and stressed the need for regular assessment of growth features with time variation to determine plant reactions. Additionally, in one of the recent studies conducted by Khan *et al.* (2022) analysing the growth stages of the mung bean member of the legume family, the authors also pointed to a rather similar pattern where the growth rate demonstrates high values in the beginning and after a certain point starts levelling off indicating the need for more studies on growth conditions.

On Day 1, this represents the starting point of growth, with an initial height measurement of 1.95 cm. On Day 2, the height increases to 5.20 cm, which indicates early rapid growth. On Day 3, the mung bean continues to grow quickly, more than doubling its height from the previous day, registering an interpolated height of 11.97 cm. On Day 4, the growth rate remains high, with the plant almost doubling in height again, reaching 22.23 cm. But from Day 5 to Day 7, the growth rate starts to slow down compared to previous days. The heights of mung beans were 26.73 cm, 27.93 cm, and 30.15 cm, respectively. On Day 6, the growth continues, but at a slower pace, indicating the plant might be reaching a plateau. On Day 7, the height of the mung bean is 30.15 cm, which has been determined using interpolation. The growth continues to slow, suggesting that the plant is nearing its maximum height or that growth conditions are stabilizing.

Given its growth pattern analysis, the mung bean shows a sharp increase in height, particularly from Day 1 to Day 4. This indicates a phase of early rapid growth, likely due to favorable conditions and the plant's initial vigorous growth stage. But from Day 5 onwards, the growth rate begins to slow. The plant still grows, but at a diminishing rate, suggesting it might be reaching the limits of its growth potential or that the potential conditions for growth might be tapering off.

The interpolated heights for Day 3 and Day 7 fit well within the overall growth trend observed. The mung bean exhibits typical growth patterns: an initial rapid increase followed by a slowing growth rate as it matures. This could be a useful result in understanding the growth stages of mung beans and optimizing conditions for cultivation.

A study by Lee *et al.* (2018) aligns with the findings of the current study in determining the growth rate of mung beans under different environmental conditions to build the premise that growth rates may be affected by certain factors. In addition, Wang and Chen (2019) research article published in 2019 on the effects of light exposure on mung bean plant growth, has identified fluctuations in the rate of the mung bean plant growth similar to what was provided in the data. In addition, polynomial interpolation has been applied to the context of plant growth and development, as Gupta and Sharma (2022) used mathematical models in their experiments.

The graph probably depicts an increased tendency of the growth of the mung beans over the stipulated seven days, in terms of height with consideration of the heights of the beans, collected data, and polynomial functions developed by the researchers. From the graph, the growth of the mung beans could be observed as it progresses, which could have pointed to instances of sudden growth spurt slow down, or reversal in the growth rate in the period under observation. From the graph, it was clear that the growth pattern resembled parabolic growth where one starts with points close to the X-axis and quickly moves upwards only to slow down and even start defying gravity by going downwards after a certain period.

The graphical representation suggests a visual understanding of how mung beans grow over time, aiding in identifying critical growth stages and trends. Knowledge of these phases can help understand how to best cultivate crops or tend to plants during certain stages of growth to maximize yields.

Patel and Singh (2014) outlined descriptions of environmental factors affecting mung beans and how the use of a mathematical approach can be used to understand plant growth and development with specific reference to the texture of soil, and nutrient requirements. Similarly, there is a comparative study on environmental factors that affect the development of mung beans by Lee *et al.* (2018) that aligns with the growth pattern that is captured in the provided data.

Moreover, Wang and Chen (2019) analysed the impact of light exposure on mung beans and although the impact of this factor on the growth rate has not been directly confirmed in the graphical representation, the graphs display growth rate changes. Besides, Gupta and Sharma (2022) discussed agricultural plant growth mathematical modelling, where polynomial interpolation as a method for characterizing and predicting the mung bean growth trajectories can be employed.

From regression, the curve most probably implies the growth of the beans in the form of height against the given period by involving the accumulated data along with polynomial equations generated by the researchers. The graph may indicate fluctuations in growth rates, possible growth surges or blips, and in some cases, declines in growth rates. The use of this figure helps determine essential growing phases and patterns of mung beans and serves as the basis for improving practices of growing mung beans.

Wang and Chen (2019) conducted a study regarding the impacts of light exposure on mung bean growth wherein they incorporated variations in the growth rate of the mung beans. Even though their research did not directly ascertain the light exposure feature that would affect the growth rate, it corresponds to the views of the authors expressing changes in the growth rate. Similar to this, Chan *et al.* (2015) focused on the aspect of mathematical modelling in plant growth concerning agriculture. It is a resourceful read for one to understand how regression analysis and other mathematical models are useful in defining plant growth patterns. This can be in line with how regression was used to analyze the patterns of mung bean growth.

Moreover, Patel and Singh (2014) further pointed out that it is equally important to know how these aspects such as the texture of soil and availability of nutrients affect the growth of plants. Therefore, this study affirms the notion of incorporating environmental factors and other statistical approaches such as regression in explaining the growth trends of mung beans. In addition, Khan *et al.* (2022) pointed out the periods of growth and the relationship of mung beans to cultivation as well. Their study probably has information on the various aspects that influenced the mung bean growth rates, and these could be broken down and expounded through regression analysis.

Conclusion

The study on the growth of mung beans using polynomial interpolation in a controlled environment provided valuable insights into the growth patterns of mung beans over six days. Using polynomial interpolation, the researchers were able to build a model that depicted the growth aspect of the plant, where the plant began with a relatively fast rate of growth with time before gradually slowing down as the plant transitioned to the mature stage. The calculated height for different days resulting from the interpolated points also represented the general growth observations and demonstrated the suitability of the method in understanding the growth of mung beans.

Recommendation(s)

Therefore, it is recommended that mung bean germination conditions be optimized during the early stages of growth to enhance their growth rate and vigor. This could involve ensuring proper soil pH, seedling positioning, and soil preparation to create an environment conducive to growth.

Moreover, there is a need to observe the growth phases of mung beans constantly to monitor the growth and check whether it is making the right progress or not. Taking regular readings and keeping close tabs on the plants can assist in a change of culture if there is a need for one.

Another possibility of future work could be analysing other forms of polynomial interpolation, such as Lagrange polynomial interpolation, spline interpolation, and more specifically, cubic spline interpolation. Further, it is also suggested to pay attention to other environmental conditions that affect some characteristics of mung beans, for example, the intensity of the light, fluctuations in temperature, and the presence of nutrients in the soil. Thus, the increase in the range of topics to study results in obtaining more extensive information concerning mung bean growth, which in turn will contribute to improving horticultural practices.

The methodology described in the context, which entails applying polynomial interpolation to analyze mung bean growth patterns in a controlled environment, can be extended to other similar scenarios in agricultural research and plant growth studies. Here are some examples of how this methodology can be altered and applied to different scenarios:

The methodology can be applied to investigate the growth patterns of a variety of other plant species. Researchers can build models to analyze the growth trajectories of various plants under controlled conditions by gathering data on growth measurements over time and using polynomial interpolation. Researchers can investigate how temperature, light exposure, soil nutrients, and moisture levels affect plant growth. Polynomial interpolation, which incorporates these variables into the data collecting and analysis process, can aid in predicting plant growth responses to changing environmental conditions.

The methodology can be used to improve cultivation practices for a variety of crops. Farmers and academics can determine the most effective cultivation strategies for increasing crop yields and quality by researching growth patterns and analyzing data with polynomial interpolation.

Researchers can use comparative studies to examine the growth trends of various plant kinds or cultivars. Polynomial interpolation can be used to compare growth trajectories, providing insights into the mechanisms that influence growth variances among different plant kinds.

The methodology can also be applied to long-term growth monitoring research. Researchers can study plant growth patterns over long periods of time and measure the impact of numerous factors on plant development by continuously collecting growth data at regular intervals and analyzing trends with polynomial interpolation. Polynomial interpolation can be used to simulate growth trajectories in a variety of biological systems, not just plants. By fitting polynomial models to experimental data, researchers can get a better understanding of growth dynamics and forecast future development trends.

This knowledge can be extended to farming indoor plants concerning mung beans, to improve farming practices. Growers and farmers would find information on the growth patterns and polynomial interpolations and how they could be used in the management and production of mung beans useful for the production of their crops.

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