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Experimental Investigations of Yield Enhancement of Solanum Tuberosum Using LED Lighting and Controlled Environment

Mukid Valsangkar[1*], Harshwardhan Pandit[2]
[1]**(B. Tech. Scholar, Mechanical Engineering, Department of Technology, Shivaji University, Kolhapur. Maharashtra. India. 416004).*
[2]*(Assistant Professor, Mechanical Engineering, Department of Technology, Shivaji University, Kolhapur. Maharashtra. India. 416004).*
([*] Corresponding Author Email: mukid1805@gmail.com)

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ABSTRACT

This research investigates the optimization of starch accumulation in Solanum tuberosum through controlled manipulation of environmental factors, focusing on lighting, soil moisture, and air moisture. Using Signal-to-Noise Ratio (SNR), Means, and Standard Deviations as evaluation metrics, we assessed the impact of varying degrees of these elements on starch content—a vital indicator of plant health and productivity. Our findings demonstrate that specific combinations of artificial light (Light level 2), soil moisture (Level 3 at 70%), and air moisture (Level 2 at 60%) significantly enhance starch content in potato plants. Furthermore, we observed improvements in key plant growth parameters such as height, leaf number, and tuber yield under optimized conditions. These results have significant implications for agricultural practices, suggesting that precise management of environmental variables can optimize economic efficiency and product quality in potato production. This study underscores the importance of parameter optimization and experimental design in maximizing crop productivity in controlled environments, with potential applications in environmental science, horticulture, and agriculture. Future research could explore the mechanistic underpinnings of these effects and investigate additional variables influencing plant development and yield.

Keywords – starch accumulation, solanum tuberosum, controlled environment, horticulture, environmental factors, crop productivity, led lighting

I. INTRODUCTION

In horticulture and agriculture, optimizing the development and yield of plants has long been a primary goal. The possibility of controlled environments to maximize plant output has been explored by researchers and farmers alike with the advent of LED (Light Emitting Diode) lighting systems and other technological breakthroughs. Unlocking the full development potential of plants involves an understanding of the complex interactions between environmental elements including light, soil moisture, and air moisture. The present study aims to investigate the impact of LED lighting, soil moisture, and air moisture on plant starch accumulation, which is a crucial metric for assessing the physiological status and productivity of plants. Through the use of controlled trials and data analysis, this study hopes to offer insightful information about improving plants. LED lighting technology has been becoming increasingly prevalent in recent years primarily due to its energy efficiency, adaptability, and capacity to provide precise light wavelengths that are necessary for plant growth. This, along with improvements in our knowledge of plant physiology, has made it possible to manipulate growth parameters in controlled conditions with greater precision. Crucial elements of the plant's microenvironment, soil, and air moisture are crucial for transpiration, nutrient uptake, and general plant health. These elements working together with LED lighting have the potential to significantly affect photosynthesis, metabolism, and eventually the buildup of starch in plants. Through a methodical examination of the effects of these factors on starch content, this study seeks to optimize plant development tactics, promote sustainable farming methods, and advance indoor culture.

II. LITERATURE REVIEW

The literature on light effects on potato growth is extensive, encompassing studies investigating how varying light quality and intensity influence crucial aspects of plant development. Through controlled experiments and advanced lighting technologies like LEDs, researchers have explored potato responses to different light spectra and levels. Understanding these dynamics is essential for optimizing cultivation practices and improving crop yield. This review provides a concise summary of recent findings in this field.

A study by Khalil et al.[1] investigated the response of meristems and nodal cuttings from five potato varieties (Cara, Hermes, Lady Rosetta, Santana, and Spunta) to different LED light qualities (blue, red, red+blue, or white), along with varying light intensities (50, 75, and 100 µmol m-2 s-1) on nodal cuttings. The results revealed significant differences in meristem survival rates among the tested light qualities, with red LED light exhibiting the highest meristem survival rates for the Cara, Hermes, Lady Rosetta, and Spunta potato varieties. Additionally, during the multiplication phase, nodal cuttings exposed to red light quality demonstrated significantly higher plantlet lengths. White and red light resulted in vigorous plantlets, as indicated by higher dry weights (82.2 and 80.4 mg/plantlet, respectively).

Similarly, a study on potatoes by Rahman et al.[2] demonstrated that red and blue light together enhanced biomass accumulation and tuberization in potato plants, corroborating the findings of the present study regarding the beneficial effects of red and blue light on plant height, branch number, and biomass accumulation. Furthermore, previous studies in various crops have explored the relationship between light spectrum and tuber properties such as size distribution and fresh weight. Consistent with the current study's results regarding the greater quantity of medium-sized tubers, Rahman et al.[2] found that sweet potatoes produced medium-sized tubers when exposed to a combination of red and blue light.

Moreover, research by Rahman, et al.[3] investigated the growth of Golden King (V48) and Chungang (V41) potato cultivars under different artificial light combinations, including red+blue+far-red, red+blue+white, blue+far-red, blue+white, red+far-red, and red+white. The study maintained a constant temperature of 23/15 °C (day/night) and a relative humidity of 70%, with a photosynthetic photon flux density (PPFD) of 100 mol m−2s−1. The findings indicated that for both potato varieties, red+far-red light significantly improved plant development characteristics such as plant height, node number, leaf number, leaf length and width, as well as fresh and dried weight. Furthermore, for V48, the combination of red+blue+white light resulted in a higher total number of seed tubers per plant, while for V41, red+far-red light yielded the best results. Under red+blue+far-red light for V48 and red+blue+white light for V41, the fresh tuber weight was maximized.

Another study by Upadhyaya et al.[4] focused into how various LED lighting characteristics affect the growth and development of potato plants. When compared to a conventional white LED light (W100), it is discovered that a combination of red and blue LED lights (R30B70) improves a variety of plant growth characteristics, such as height, leaf number, and tuber yield. Furthermore, the R30B70 combination raises the activity of enzymes that scavenge free radicals as well as the concentration of advantageous substances including sugars, soluble proteins, and phyto-pigments. These results imply that enhancing the spectrum composition of LED lighting might greatly enhance the quality and growth of potato crops grown under regulated conditions, potentially resulting in improved yields and agricultural efficiency.

Oliveira et al.[5] evaluated that, the in vitro growth of many cultivars of Ocimum Basilicum using varied light sources. First, five basil cultivars were tested for how fluorescent and LED lights of various colors—yellow, blue, green, and red—affected them. Another experiment then examined the differences in performance between Growlux and Blue, two distinct LED lights. The results showed that basil plants grown in vitro did not do well in yellow lighting. Nonetheless, under fluorescent and LED lighting, the root diameters of three cultivars—Cinnamon, Grecco a Palla, and Limoncino—were comparable.

III. PROBLEM STATEMENT

Addressing the global demand for crops, encompassing food, fiber, and feed, is increasingly challenging due to population growth, dietary shifts, economic development, and urbanization trends.

Meeting these agricultural demands necessitates effective and sustainable farming practices[6,7]. Agroecological approaches, precision agriculture techniques, advancements in irrigation and water management, and technological innovations play pivotal roles in enhancing agricultural production. Furthermore, prioritizing sustainability and food security, initiatives supporting agricultural innovation, research and development (R&D), and rural infrastructure investment are imperative to meet the growing need for farming on a global scale.

IV. PROCESS PARAMETERS SELECTION

The following are the main parameters that were the focus of the experiments and they are categorized as follows.

A. Input Parameters-

1. Lighting Conditions

The lighting conditions for the experiment are varied over two levels,

a. Natural Lighting For this condition, samplings are kept under normal sunlight throughout the day till their full growth and harvesting. The duration of the daylight is approx. 12 hrs.

b. Artificial Lighting For this condition, samplings are kept away from natural sunlight but, under LED light for approx. 15 hrs. per day till their full growth and harvesting. The power of the LED panel is 20W with a beam angle of approx. 120° and kept at a height of approx. 50 cm above from pot for an even spread of light. It consists of two types of LED lights, 34 Red (650 nm) and 16 Blue (450 nm).

2. Soil Moisture

The soil moisture conditions for the experiment are varied over three levels, The water content of the soil is known as soil moisture. It can be described in weight or volume units. Remote sensing techniques or in situ probes (such as neutron or capacitance probes) can be used to assess soil moisture.[8] Soil moisture is maintained at 30%, 50%, and 70%.

3. Air Moisture

The air moisture conditions for the experiment are varied over three levels. Air moisture is measured in terms of Relative Humidity. Relative Humidity is the ratio of the saturation vapor pressure of water at a given temperature to the partial pressure of water vapor in the air, commonly stated as a percentage.[9] Air moisture is maintained at 40%, 60%, and 80%.

B. Output Parameter

1. Weight

In order to provide a more nuanced knowledge of how lighting and environmental circumstances influence potato starch content, the study used potatoes of various weights in order to capture the full range of possible responses. Weight is measured in grams.

2. Starch Content

The objective of the study was to record the dynamic variations in starch content due to the influence of various lighting and environmental conditions by picking potatoes after they grew. This method gave researchers a comprehensive understanding of how the experimental settings affect starch accumulation at various phases of plant growth by providing important insights into the potatoes’ real-time responses to them. It is measured on the basis of Starch extraction (in grams), Yield (%), and Recovery (%).

$$\text{Yield (\%)} = \frac{Starch\ Extracted}{Weight\ of\ Sample} \times 100$$

$$\text{Recovery (\%)} = \frac{Starch\ Extracted\ (Actual)}{Starch\ Extracted\ (Standard)} \times 100$$

Starch Extracted (Standard) = 15.2 g[10]
Weight of sample = 100 g.

V. EXPERIMENTAL PROCEDURE

In this study, a comprehensive experimental design utilizing a full factorial approach was employed to investigate the influence of multiple input variables, including lighting conditions, soil moisture levels, and air moisture levels, on potato development and physiological characteristics. Both starch content and weight were selected as output variables to assess the effects of these input factors on potato growth. Through systematic variation of each input variable across its entire range of levels, the study aimed to elucidate the independent and combined impacts of lighting, soil moisture, and air moisture on starch accumulation and potato weight.

As shown in Fig. 1, Experimental setup was formed to maintain the closely monitored parameters. The experiment involved planting Potato 'Solanum Tuberosum' under controlled conditions, with meticulous attention to maintaining all parameters within predetermined ranges throughout the duration of the study. Specifically, the spectrum, intensity, and photoperiod of the lighting were carefully regulated using LED lighting systems, tailored to different growth stages and calibrated to simulate natural sunlight. Meanwhile, air moisture levels were meticulously controlled to ensure consistent humidity levels in the growth environment, while soil moisture levels were closely monitored and adjusted as necessary to sustain optimal hydration for potato growth.

By rigorously maintaining these parameters constant throughout the experiment, potential confounding variables were minimized, enabling the confident attribution of observed effects on potato growth, starch content, and weight to the manipulated conditions. This rigorous approach to parameter maintenance enhances the validity and reproducibility of the experimental results, providing robust insights into their impacts. Overall, the study offers valuable contributions to the optimization of cultivation techniques and the enhancement of crop production practices, with implications for sustainable agriculture and food security

Fig. 1. Experimental set-up using Artificial Light

VI. RESULTS

The experiment's findings as in Table 1, demonstrated the important relationships that affect potato development, starch content, and weight that exist between lighting conditions, soil moisture, and lighting air moisture levels. In particular, when compared to other combinations of environmental circumstances, potatoes grown under ideal illumination, moderate soil moisture, and controlled air moisture showed the maximum starch concentration and weight.

Table 1: Interaction and output

Run No.	**Factors**			**Response Variables**	
	Light cond.	**Soil Moisture (%)**	**Air Moisture (%)**	**Weight (gm.)**	**Starch (g,)**
1	Natural	30	40	32.5	10.3
2	Natural	30	60	32.8	10.6
3	Natural	30	80	33.2	11
4	Natural	50	40	34.3	11.3
5	Natural	50	60	36.7	11.5
6	Natural	50	80	35.6	11.4
7	Natural	70	40	35.1	11.7
8	Natural	70	60	35.3	12.1
9	Natural	70	80	34.8	11.5
10	Artificial	30	40	32.3	12.2
11	Artificial	30	60	32.6	12.1
12	Artificial	30	80	32.8	12.4
13	Artificial	50	40	33.1	12.9
14	Artificial	50	60	33.5	13.1
15	Artificial	50	80	33.2	13.6
16	Artificial	70	40	33.6	13.7
17	Artificial	70	60	33.5	14.1
18	Artificial	70	80	33.9	13.1

All three factors exhibited statistically significant effects on the outcomes that were assessed, according to multiple significant interactions between the components were also discovered by using statistical analysis software. Furthermore, it was shown that differences in illumination spectrums had an impact on starch accumulation, with potatoes exposed to particular wavelengths exhibiting increased growth and starch output.

Response Table

In order to evaluate the effects of illumination, soil moisture, and air moisture on potato development parameters specifically, starch content and weight a variety of crucial procedures were involved in the statistical analysis of the data.

Signal To Noise Ratio

Signal to noise ratio is used to evaluate the quality of a signal with respect to background noise. Greater SNR values are preferred in this situation because they indicate a stronger signal than noise. Table 2 clearly shows Artificial Lighting has clearly superior output than conventional lighting conditions.

Table 2: S/N Ratio of Interactions

Levels	Light Condition	Soil Moisture	Air Moisture
1	23.60	23.65	24.04
2	24.67	24.25	24.20
3	-	24.50	24.16
Δ	1.07	0.85	0.16
Rank	1	2	3

***Criterion: Larger is Better**

Means

One of the most important indicators of average performance across various levels of experimental parameters is the mean, which is a measure of central tendency. In this analysis, we primarily evaluate the means of three important variables. Greater mean values are often suggestive of superior performance, which is consistent with the standard criteria employed in this analysis. Table 3 shows that a controlled environment of soil moisture has a significantly better output.

Table 3: Means of Interactions

Levels	Light Condition	Soil Moisture	Air Moisture
1	22.87	22.07	22.75
2	23.09	23.35	23.16
3	-	23.53	23.04
Δ	0.22	1.47	0.41
Rank	3	1	2

***Criterion: Larger is Better**

Standard Deviation

An important tool for understanding how data points are distributed around the mean is the standard deviation, which is a measure of distribution. In some situations, it is preferable to reduce variability in order to guarantee accuracy and consistency in results. Using the "Smaller is Better" criterion, this study examines the standard deviation of three important factors: air moisture, soil moisture, and light condition as mentioned in Table 3. It shows that if variation has to be minimized, Artificial lighting conditions should be followed.

Table 4: Standard deviation of interactions

Levels	Light Condition	Soil Moisture	Air Moisture
1	16.41	15.04	15.18
2	14.24	15.63	15.43
3	-	15.32	15.38
Δ	2.17	0.59	0.25
Rank	1	2	3

***Criterion: Smaller is Better**

Graphical Representation

The statistical analysis graphs are represented in Fig. 3 shows the interaction of different parameters with output starch and weight.

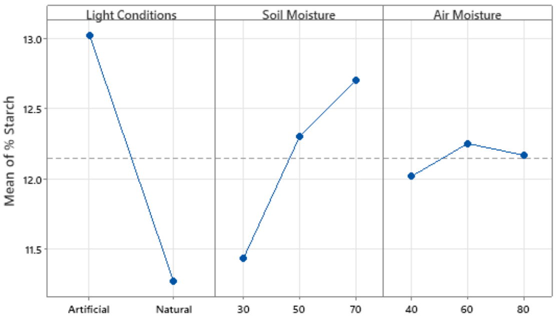

Fig. 2: Main Effects Plots for Starch

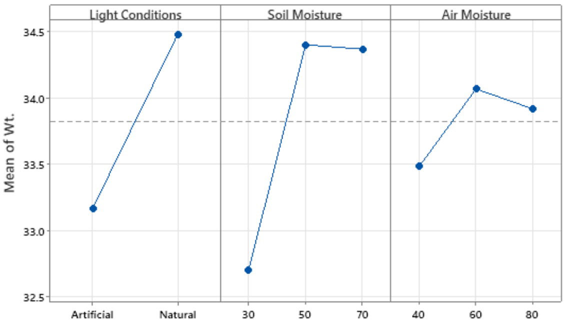

Fig. 3: Main Effects Plots for Weight

VII. INTERPRETATION

It's critical to understand the consequences of Signal-to-Noise Ratio (SNR), Means, and Standard Deviations taken together when assessing the effectiveness of various degrees of experimental factors.

- **Signal-to-Noise Ratio (SNR):**
  Higher SNR values are regarded to be better in this analysis since they show a stronger signal in comparison to background noise. The SNR-based ranking offers information about the quality of the results at various factor levels. As an illustration, Level 2 of Light Condition has the best signal-to-noise ratio (SNR) ranking, demonstrating higher performance.

- **Means:**
  In this case, larger mean values are seen as better indicators. The central tendency or average performance across various levels of the components is revealed by the ranking based on mean values. As an illustration, Level 3 of Soil Moisture had the highest mean ranking, demonstrating exceptional performance in reaching higher mean values of the result.

- **Standard Deviation**
  Indicated by smaller standard deviation values, which are seen as more desirable. Standard deviation-based ranking offers information about data variability or dispersion at various factor levels. Level 2 of the Light Condition, for example, performed better in obtaining the least variability in the result, ranking highest in standard deviations.

- **Percentage of Starch**
  Higher starch percentages are often recommended since they show superior starch accumulation performance. The percentage-based ranking of the components offers information about how effective each level of the factors is at encouraging the production of starch. For instance, Level 2 of Light Condition performed better in promoting starch accumulation, indicated by its highest starch percentage ranking.

- **Weight**
  In general terms, higher weights are preferred because they indicate more plant growth and yield. The weight-based rating provides insight on how well-suited each level of the growth-promoting elements is for plants. For example, the greatest weight ranking for Soil Moisture Level 3 indicates that it performs better in promoting plant development and weight gain.

VIII. DISCUSSION

The experiment used Signal-to-Noise Ratio (SNR), Means, and Standard Deviations as criteria to evaluate the performance of various degrees of Air Moisture, Soil Moisture, and Light Condition. The rankings that were determined by these criteria offered insightful information about how effectively each degree of the elements affected the result variables. According to the response table and graphs of the experiments, it is significant that the Light level 2 i.e. Artificial Light, Soil moisture level 3 i.e.70%, and Air moisture level 2 i.e. 60% have a superior effect on the plant yield in terms of starch content. The results of this study have significant ramifications for parameter optimization and experimental design in a number of disciplines, including environmental science, horticulture, and agriculture. Future studies could look more closely at the underlying mechanisms causing the impacts that are seen and analyse other variables that might have an impact on the desired results.

IX. CONCLUSION

In conclusion, this study systematically examined the effects of varying light conditions, soil moisture levels, and air moisture levels on key outcome variables such as weight, starch percentage, means, standard deviations, and signal-to-noise ratio (SNR). The analysis yielded important insights into the relative efficacy of different combinations of these factors in influencing experimental outcomes. Specifically, Level 2 of the Light Condition exhibited superior performance in terms of SNR and Standard Deviations, indicating a more robust signal-to-noise ratio and reduced outcome variability. Additionally, Level 3 of Soil Moisture ranked highest in Means, suggesting its superior effectiveness in achieving higher mean values of the dependent variables. These findings underscore the critical importance of optimizing soil moisture and light conditions to enhance experimental results.

Furthermore, the analysis revealed that certain combinations of experimental variables led to increased starch accumulation and plant growth, highlighting the significance of this knowledge for optimizing agricultural practices and enhancing crop output. Overall, this research advances our understanding of how air moisture, soil moisture, and light conditions impact experimental outcomes, providing valuable insights for decision-making in agricultural management, parameter optimization, and experimental design.

Future studies could explore additional factors that may influence experimental results and delve into the underlying physiological mechanisms driving the observed effects. Longitudinal studies assessing the long-term effects of different environmental variables on plant productivity and growth would also be valuable. Ultimately, the conclusions drawn from this study hold significant implications for environmental science, agricultural research, and practical applications in farming. They pave the way for future developments in sustainable and productive farming methods, contributing to the advancement of agricultural practices and global food security initiatives.

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