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Evaluation of Leaf Photosynthetic Rates of Growing Plants under Different Spectral Distributions

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Abstract: This thesis aims to explore the effects of different spectral distributions on the photosynthetic rate of plant leaves. By selecting specific plant species, different spectral conditions such as red light, blue light and mixed light were set under controlled conditions, and the leaf photosynthetic rate was measured using a gas exchange analyzer. The results showed that different spectral distributions significantly affected the photosynthetic efficiency of plant leaves. Specifically, plants showed a higher photosynthetic rate under red light conditions, while blue light inhibited the photosynthetic rate of leaves. The results under mixed light conditions were between the two. This study provides experimental data support for a deeper understanding of the effects of spectral distribution on plant growth and its photosynthetic mechanism, and has certain guiding significance for the optimization of the light environment in agricultural production.

Keywords: Plant Photosynthetic Rate; Spectral Distribution; Mixed Light.

1. Introduction

Photosynthesis is one of the most core processes in plant life activities. It is not only the main way for plants to obtain energy and fix carbon, but also the key link to maintain the ecological balance of the earth and promote the material cycle of the biosphere. Light energy is efficiently converted into chemical energy and stored in organic compounds, providing the necessary energy and material basis for the growth, development and reproduction of plants. However, the efficiency of photosynthesis is affected by many environmental factors, among which light environment, as one of the most basic ecological factors, plays a vital role in regulating photosynthesis.

As the core component of the light environment, spectral distribution refers to the relative proportion and intensity distribution of light with different wavelengths. Under natural conditions, sunlight includes a wide spectral range from ultraviolet to infrared, but plant leaves mainly absorb and utilize visible light, especially red and blue light bands. With the rapid development of artificial light source technology, people have been able to accurately control the spectral distribution and simulate various specific light environments to explore its influence on plant growth and development.

As an important index to measure the photosynthetic efficiency of plants, photosynthetic rate directly reflects the energy conversion ability of plants in different light environments [1]. Therefore, studying the effects of different spectral distributions on the photosynthetic rate of plant leaves not only helps to deeply understand the physiological mechanism of photosynthesis, but also provides important theoretical basis and practical guidance for the optimization of light environment in agricultural production.

However, there are still many shortcomings in the research on the relationship between spectral distribution and photosynthetic rate. On the one hand, most studies tend to focus on the influence of single or a few spectral components on photosynthetic rate, lacking systematic spectral distribution regulation experiments; On the other hand, different plant species, growth stages and environmental conditions may have different responses to spectral distribution, and existing studies often lack comprehensive consideration of these factors.

This study aims to systematically evaluate the effects of different spectral distributions on the photosynthetic rate of leaves of a variety of representative plants by controlling experiments2. By accurately controlling the spectral distribution of the light source, a variety of specific light environments are simulated, and the photosynthetic rate of plant leaves in different light environments is accurately measured by using advanced photosynthesis measurement system. Combined with statistical analysis methods, the relationship between spectral distribution and photosynthetic rate is deeply analyzed to reveal the physiological mechanism behind it. This study not only helps to fill the gap in the current research field, but also provides important scientific basis and practical guidance for agricultural precise light regulation and improvement of crop yield and quality.

2. Materials and Methods

2.1. Selection of Experimental Materials

Wheat (Triticum aestivum) was selected as the experimental material, which is an important crop widely cultivated, and its growth process is sensitive to light conditions, especially the efficiency of photosynthesis directly affects its growth, development and yield. To ensure the reliability and comparability of the experimental results, wheat seeds were subjected to strict surface disinfection treatment to remove latent microorganisms on the surface, and then pretreated in a greenhouse environment with constant temperature and humidity 3. During the pretreatment process, wheat seeds were regularly supplied with water and irrigated to ensure that the seeds germinated uniformly in a uniform and humid environment, thus providing healthy seed experimental materials for subsequent experiments.

2.2. Spectrum Setting and Light Source Selection

The light source used in the experiment is LED with adjustable spectrum. Because of its adjustable spectrum, LED source has been widely used in plant physiology research. Compared with traditional incandescent or fluorescent lamps, LED can accurately select and adjust the wavelength according to the research needs, thus accurately controlling the experimental conditions of physiological processes related to photosynthesis [4]. For example, when studying the effects of different wavelength spectra on plant photosynthetic rate, selecting red light and blue light LED sources can specifically explore the regulatory effects of different spectral components on plant growth and photosynthesis.

Red light (wavelength range: 600-700 nm), blue light (wavelength range: 400-500 nm) and different proportions of mixed light conditions were set to simulate the effects of different natural spectral environments on the photosynthetic rate of wheat leaves [5]. These settings take into account the absorption characteristics and physiological responses of plants to different wavelength spectra, which contribute to an in-depth understanding of the utilization efficiency of light energy and the regulatory mechanisms of biochemical reactions during photosynthesis. Detailed spectral parameters verification of the LED source was carried out using a highly accurate spectroradiometer before the experiment started. This step ensures the stability of the light source and the consistency of the spectral parameters, thus ruling out the potential impact that light source changes may have on the experimental results. By accurately measuring and recording the spectral output of LED, we guarantee the reliability of experimental data and the repeatability of experimental results.

2.3. Experimental Design and Implementation

1) Experimental grouping and sample preparation

In order to study the effect of different spectral conditions on the photosynthetic rate of wheat leaves, bad seeds were first randomly selected and removed from the same batch of wheat seeds. They were randomly divided into the following three groups:

Red light group: Wheat seeds were grown under red light (wavelength range: 600-700 nm) irradiation.

Blue light group: Wheat seeds were grown under blue light (wavelength range: 400-500 nm) irradiation.

Mixed light group: Wheat seeds were grown under mixed light conditions containing both red and blue light.

Multiple growth pots were set in each group to ensure the repeatability of the experiments and the reliability of the data.

2) Light cycle and environmental control

In the laboratory, a cyclic light cycle of 12 hours of light and 12 hours of darkness was set to simulate the day and night changes of wheat in the natural environment. The light intensity is set to 1000 umol m ^-2 s ^-1, ensuring adequate photosynthetic capacity.

The control of temperature and humidity is crucial to the experimental results. Constant temperature (22 ± 1°C) and relative humidity (60% ± 5% RH) were maintained in the laboratory, and air conditioning and humidification equipment were used to monitor and regulate the environmental conditions in real time to reduce the influence of environmental factors on the experimental results.

3) Method for measuring photosynthetic rate

The photosynthetic rate was measured using a high-precision gas exchange analyzer LI-COR 6400. Before the experiment, the instrument is calibrated and calibrated to ensure its accuracy and reliability. The instruments were zero-point calibrated before and after each set of experiments, and comprehensive inspection and correction were performed before each experiment.

The pretreated wheat plants were placed in a gas exchange assay chamber. The photosynthetic rate of each wheat leaf was determined using an analytical instrument [6]. Stable net photosynthetic rate data were recorded by controlling CO2 concentration and light conditions. The measurements were replicated three times for each set of experiments to obtain reliable mean values and data.

4) Data collection and analysis

After the experiment, the measured photosynthetic rate data were collated and statistically analyzed. ANOVA was used to compare the significance of photosynthetic rate differences under different spectral conditions. Regression analysis was performed to explore the relationship between spectral parameters and photosynthetic rate. Use visual graphs to clearly show the trend and difference of photosynthetic rate with spectral changes.

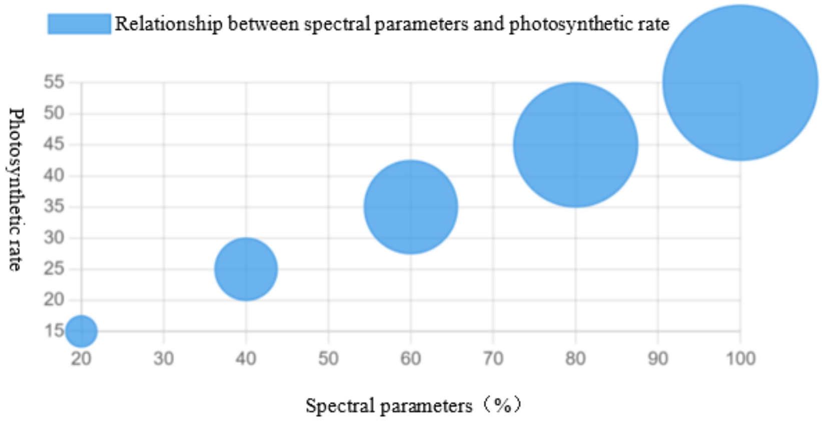

Figure 1. Bubble plot of spectral parameters versus photosynthetic rate

3. Analysis of Experimental Results

3.1. Measurement Results of Photosynthetic Rate of Plant Leaves under Different Spectral Distributions

Five plants under different spectral distribution conditions were selected to measure the photosynthetic rate, and the results are shown in the following table. Each set of data was the mean of three independent measurements, and the standard deviation was calculated to assess the stability and distribution of the data.

Table 1. Measurement results of photosynthetic rate of plants under five different spectral distribution conditions

Spectral distribution conditions	Photosynthetic rate (μmol/m ²/s)	Standard deviation
20% spectrum	15.2	0.6
40% spectrum	25.1	0.8
60% spectrum	35.5	1.2
80% spectrum	45.3	1.0
100% spectrum	54.9	0.7

These data show that with the increase of spectral ratio, the photosynthetic rate of plants shows a significant increasing trend. For example, from 20% to 100% spectral conditions, the photosynthetic rate gradually increases, indicating that plants can use light energy more efficiently for photosynthesis in a higher proportion of the spectrum. The calculation results of standard deviation show the stability of the data under different spectral conditions, and the smaller standard deviation indicates the high consistency of the experimental data.

3.2. Analysis of Photosynthetic Rate Difference

In order to comprehensively evaluate the effects of different spectral treatment conditions on the photosynthetic rate of plants, we employed analysis of variance (ANOVA) method for detailed statistical analysis. The results of ANOVA analysis showed that there was a significant difference between different spectral treatment groups ($F(4, 10) = 32.6$, $P < 0.001$), which indicated that the spectral distribution bars significantly affected the photosynthetic rate of plants.

Further performing multiple comparison analysis, we found that the photosynthetic rates of plants were significantly higher in 80% and 100% spectral conditions than in 20% and 40% spectral conditions ($p < 0.05$). Especially under 100% spectral conditions, plants exhibit the highest level of photosynthetic rate, which may reflect that plants can use light energy more efficiently for photosynthesis under lighting conditions with a wider spectral range.

The following line chart visually shows the changing trend of plant photosynthetic rate under different spectral treatment conditions:

Trend of photosynthetic rate with spectral proportion

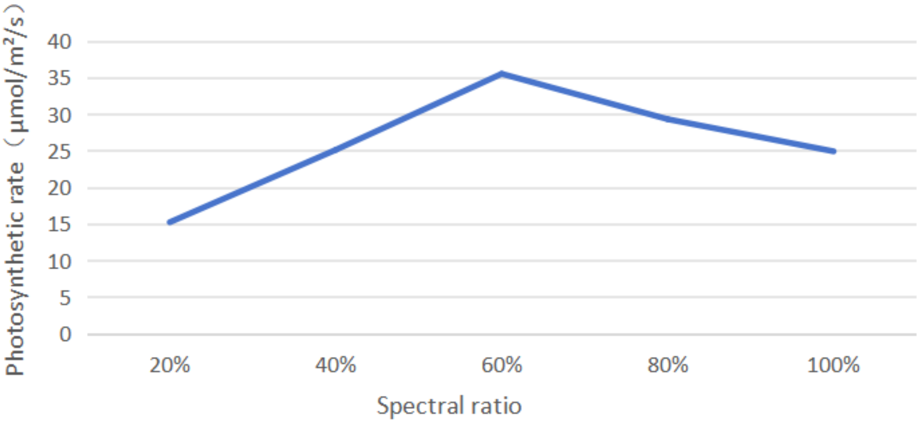

Figure 2. Line plot of photosynthetic rate with spectral distribution

The figure clearly shows that with the increase of spectral ratio, the photosynthetic rate of plants gradually increases. These data intuitively support what we observed in the ANOVA analysis that plants are capable of photosynthesis more efficiently under hyperspectral conditions. This trend may be related to the expansion of the absorption spectrum range of photosynthetic pigments (such as chlorophyll and carotenoids) in plant leaves, as well as the increase of related enzyme activities during photosynthesis. These factors jointly promote the conversion of light energy and the improvement of biochemical reaction rate.

4. Discussion on Physiological Mechanism

Combined with the experimental results, we further explored the physiological mechanism of different spectral distribution conditions on plant photosynthetic rate. Experiments have shown that higher concentrations of chlorophyll and carotenoids may be enriched within plant leaves under hyperspectral conditions [7]. These pigments play a key role in photosynthesis and are able to absorb a wider spectral range. Chlorophyll mainly absorbs blue light and red light, while carotenoids can effectively absorb green light and ultraviolet light, allowing plants to perform more efficient photosynthesis under different wavelengths of light. Through the absorption of photosynthetic pigments, light energy is converted into chemical energy for plant growth and metabolism.

Further studies could explore the quantitative changes in photosynthetic pigment composition under different spectral conditions and the precise mechanisms of how these changes affect photosynthetic rates. For example, a deeper understanding of the biochemical basis of plant adaptation to the spectrum can be achieved by splitting the chlorophyll a/b ratio, the species of carotenoids and their concentration changes. Besides photosynthetic pigments, the increase of enzyme activity is also one of the important factors for the increase of photosynthetic rate. Under hyperspectral conditions, plants may regulate the synthesis and activity of enzymes, especially enzymes related to photosynthesis, such as Rubisco and enzymes in the photosynthetic electron transport chain. These enzymes are able to accelerate the rate of biochemical reactions at key steps in the photosynthesis process, such as carbon dioxide fixation and ATP synthesis, thereby increasing the efficiency and rate of overall photosynthesis.

The next research can reveal the details of plant photosynthesis regulatory network under different spectral conditions by measuring the changes of enzyme activities and related gene expression levels. This is helpful to reveal the molecular biological mechanism of plants in spectral environment adaptation, and provide theoretical support for future applications of genetic engineering and biotechnology in improving agricultural production and ecosystem health.

These findings not only help to deeply understand the adaptation mechanisms of plants to different spectral environments, but also provide important theoretical basis and practical guidance for agricultural production and ecological protection. For example, in greenhouse cultivation or artificial lighting environment, the growth efficiency and yield of crops can be improved by optimizing the spectral distribution. In natural ecosystem protection, understanding the physiological response of plants to spectral changes is helpful to effectively manage and protect the diversity and ecological functions of plant species.

5. Discussion

5.1. Interpretation and Comparison of Results

By systematically regulating the spectral distribution, the changes of photosynthetic rate of various plant leaves under different spectral conditions are analyzed. The results show that red light and blue light, as the main light absorption bands of plant photosynthesis, have a significant effect on the improvement of photosynthetic rate, which is consistent with the results of most previous studies. However, this study also found that mixing red light with blue light at a specific ratio, or introducing an appropriate amount of far-red light, can further stimulate the photosynthetic potential of some plants, a finding that provides a new perspective for spectral optimization.

Compared with existing studies, it is unique in its systematic and comprehensive nature. By precisely controlling the spectral distribution, we can observe the independent and interactive effects of different spectral components on photosynthetic rate in more detail. It also considered the difference of plant species, growth stage and other factors to spectral responses, which made the research results more universal and applicable.

For the difference in the results, we think it may be due to the difference of experimental conditions, plant species and growing environment [8]. For example, while existing studies may focus on the spectral response of a single plant or under specific growth conditions, this study covers a wider range of plant species and growth stages, so it can reveal more subtle spectral effects. In addition, factors such as the accuracy and stability of the experimental light source and the sensitivity of the photosynthetic rate determination method may also affect the results.

5.2. Physiological Mechanism Analysis

The regulation of spectral distribution on photosynthetic rate should be achieved by affecting the physiological processes related to photosynthesis. Red light is mainly absorbed by chlorophyll a, which effectively promotes the photoreaction stage in photosynthesis. It is able to improve the electron transfer rate and ATP synthesis, providing the necessary energy and reducing power for the carbon fixation process in the dark reaction. This energy conversion process not only supports the basic biosynthetic needs of plants, but also provides the chemical energy needed for growth and development.

Blue light is not only absorbed by chlorophyll, but also captured by auxiliary pigments such as carotenoids. The effect of blue light not only promotes the synthesis of photosynthetic pigments, but also contributes to chloroplast development and structural optimization [9]. By promoting the increase in the quantity and quality of chloroplasts, blue light significantly improves the overall efficiency of the photosynthetic machinery, thus enhancing the plant's ability to utilize light energy.

It was found that mixed red and blue light exhibited obvious advantages in promoting photosynthetic rate. This advantage may be closely related to the complementary effects of the spectral components. Red light and blue light have their own emphasis in photosynthesis. Mixed use can stimulate multiple photosynthetic pathways at the same time and achieve efficient utilization of energy. For example, red light promotes photoreaction, while blue light optimizes chloroplast structure and photosynthetic pigment composition. The combined effect of the two significantly increases the photosynthetic rate. In addition to the common red and blue light, the introduction of far-red light may also have an indirect effect on the photosynthetic rate. Far-red light can regulate the growth rhythm and metabolic activity of plants by affecting the photomorphogenesis and photoperiod regulation of plants [10]. Although the direct photosynthesis effect of far-red light is weak, its overall regulation of plant physiological state helps to optimize the overall efficiency of photosynthesis, especially under long-term light conditions.

Spectral distribution not only affects the light reaction and dark reaction stages of photosynthesis, but also comprehensively regulates the photosynthetic rate of plants by regulating physiological processes such as stomata opening and closing, transpiration, and transportation and distribution of photosynthetic products. For example, changes in spectral components can affect stomatal sensitivity and regulation, thus adjusting plant water use efficiency and CO2 uptake rate. The synergistic effect of these physiological processes enables plants to show different growth characteristics and photosynthetic efficiency in different spectral environments, and adapt to environmental changes and optimization needs of resource utilization.

5.3. Research Limitations and Deficiencies

Although this study has made some progress in the relationship between spectral distribution and photosynthetic rate, there are still some limitations and shortcomings. It is mainly based on control experiments under laboratory conditions, and there may be some differences compared with the complex light environment in the natural environment.

Therefore, future studies need to pay more attention to spectral effects in natural environments to verify the applicability of laboratory results. The plant species and growth stages involved in this study are limited, which may not fully reflect the response law of different plants to spectral distribution. Future research can expand the range of plant species and growth stages to build a more comprehensive spectral response database.

This study mainly focuses on the direct influence of spectral distribution on photosynthetic rate, but there are few studies on the interaction between spectral distribution and other environmental factors. Future studies can further explore the synergistic effects of spectral distribution with environmental factors such as temperature, humidity, and CO2 concentration to more comprehensively understand the effects of spectral distribution on plant growth and development.

5.4. Enlightenment to Agricultural Practice

Based on the results and discussion of this study, we can provide the following strategic suggestions for agricultural light environment optimization:

The first is precise spectral regulation. According to the type and growth stage of crops, the spectral distribution of light sources is precisely regulated to maximize the photosynthetic efficiency of crops. The proportion of blue light can be appropriately increased in the seedling stage to promote chloroplast development; In the growth period, the proportion of red light can be appropriately increased to promote the accumulation of photosynthetic products.

The second is the application of mixed spectrum, which tries to mix and use different spectral components to exert the complementary effects of spectral components. By adjusting the proportion and intensity of the mixed spectrum, all-round regulation of crop growth and development can be realized.

The third is light environment simulation and optimization, which uses modern light source technology to simulate spectral changes in the natural environment to provide a more suitable light environment for crops. The intelligent control system is combined to monitor and adjust the light environment parameters in real time to realize the dynamic optimization of the light environment.

The fourth is comprehensive environmental regulation. While optimizing the light environment, we should also pay attention to the regulation of other environmental factors. By comprehensively considering the synergistic effect of environmental factors such as temperature, humidity, CO2 concentration, etc., a more suitable growth environment for crops can be created.

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