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The combined effect of light spectra and antagonistic bacteria in inhibiting the growth of *Alternaria brassicicola*

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Abstract:

Plant growth-promoting rhizobacteria and their metabolites are considered alternatives to chemical pesticides for managing plant diseases. Additionally, light spectra directly affect plant growth and response to stress, as well as the growth and physiology of plant-associated bacteria and fungi. This study aimed to investigate the role of different light spectra on the growth of beneficial bacteria and pathogenic fungi and their antagonistic relationships. This research investigated the effect of full spectrum, red, blue, far-red, UVA, green light and dark conditions on the growth of the antagonistic bacterium *Bacillus pumilus* INR7 and the plant pathogenic fungus *Alternaria brassicicola* and the interaction between these two micro organisms under laboratory conditions. The results showed that the light spectra significantly affected the growth of the antagonistic bacterium. Green light had the greatest effect, while UVA had a small effect on the population growth of the bacterium. The light spectra also affected the growth and spore production of *A. brassicicola*. Blue light increased colony growth, while dark conditions reduced it in the pathogenic fungus. UVA, red, green and blue light showed no significant differences compared to the full spectrum in spore production, dark conditions reduced the spore population. Conversely, UVA increased growth, whereas dark conditions reduced growth of *A. brassicicola* in the inhibition halo test. Furthermore, green light had the greatest effect and dark conditions the least effect on mycelial growth of *A. brassicicola* in the presence of volatile compounds from the antagonistic bacterium. The results of these experiments showed that light spectra can influence the physiology of beneficial bacteria and pathogenic fungi, affecting bacterial populations, fungal growth, sporulation rates and their interactions.

Keywords: Biological Control, Volatile Organic Compounds, Population Growth, Inhibition Halo, *Bacillus pumilus* INR7

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Introduction

Pathogenic fungi significantly reduce crop yields, cause mycotoxin contamination and reduce product marketability (1, 2, 3, 4). Members of the genus *Alternaria* are necrotrophic plant pathogens that affect important economic crops (5). The use of chemical pesticides is a common strategy to control these diseases. In addition to chemical control, new methods such as biological control, heat treatment and natural products (including chitosan, essential oils, isothiocyanates, plant defence inducers and short wavelength light spectra) are essential. However, a combination of efficient methods that are compatible with the environment and human health is recommended in modern agriculture (6, 7). Considering the destructive effect of *Alternaria brassicicola* on cabbage family crops, it is necessary to find appropriate and practical methods to reduce disease severity in the field, greenhouse and storage (8, 9). The overuse of chemical pesticides in recent decades has led to several problems, including environmental contamination and the emergence of resistant races of the pathogen (9). Consequently, researchers are exploring alternative management strategies for the integrated management of fungal diseases (10).

Plant growth-promoting rhizobacteria can assist and protect the host against pathogens by producing volatile compounds, siderophores, antibiotics and other secondary metabolites. These metabolites can enhance plant resistance to pathogens both directly and by activating the host defence system (11). One method of biological control involves the use of volatile organic compounds (VOCs). These compounds can diffuse into the soil and aerial parts of plants and play an essential role in plant physiology and pathogen control (12).

Volatile compounds act as signalling molecules, facilitating communication between the plant and neighbouring microbes. In some cases they enhance the resistance of the host plant. These compounds can be rapidly dispersed in the air and, at low concentrations, can induce resistance in plants to a wide range of pests and plant pathogens (13, 14). Volatile compounds produced by *Bacillus* species have been evaluated as a novel method to control pathogens, particularly fungal diseases in plants (15, 16).

Several studies have investigated the effect of light spectra on the biology and physiology of various fungi, including *Alternaria* spp. However, the results have been variable and sometimes contradictory. This variation can be attributed to the specific light spectrum used and the duration of exposure (17, 18, 19, 20).

Light spectra can induce sporulation (18) and conidial germination (20) in *Alternaria* spp. Light intensity, particularly blue light, negatively modulated spore production in *A. alternata*. However, the effect of light on the inhibition of spore formation was reversible after one day of incubation in the dark. In *A. alternata*, light regulates mycotoxin production and sporulation in opposite ways. When spore formation is significantly reduced under blue light, the alternariol production increases two to three times (21). *Alternaria* spp. can sense and respond to light (18). Deletion of the white-collar 1 (WC-1) gene suppressed spore production in both dark and light conditions. Similarly, spore production in *Botrytis cinerea* is induced by near-UV light, whereas blue and green light had no effect on sporulation rate (22).

In *A. alternata*, conidia germination was reduced by 25 % after exposure to UVC light for 10 seconds. *A. alternata* was the only species able to grow under UVC light for 300-600 seconds. In contrast, *Penicillium janthinellum* spores were the most sensitive, with UVC light causing inactivation of all conidia after 30 seconds of exposure (20).

Light spectra also have a significant effect on the mycelial growth of pathogenic fungi. Blue and violet light inhibited the mycelial growth of *B. cinerea* by up to 22.3 and 15.16%, respectively. Moreover, red and violet light irradiation inhibited the growth of *B. cinerea* on tomato leaves by up to 32.08 and 36.74 %, respectively (23). Treatment of fava-beans with different light spectra prior to inoculation with *Alternaria tenuissima* showed that pathogen invasion was suppressed in plants pretreated with red light for 24 hours. Results indicated that the inhibition of disease in the leaves was due to the induction of resistance by the light treatment (19).

Light spectra also affect the virulence characteristics of pathogenic fungi, including toxin biosynthesis (18, 24, 25). Blue light suppressed the

mycotoxins alternariol and alternariol monomethyl ether by 69 and 77 %, respectively. Both toxins are polypeptides produced by *A. alternata*. Red light did not reduce toxin levels. When the fungi were grown under blue light, the total lipid content increased by 25 % compared to red light (24).

The aim of this study was to investigate the role of different light spectra in the growth of beneficial bacteria and pathogenic fungi and their antagonistic relationships. To our knowledge, the interaction of different light spectra and bacterial volatile compounds in the growth of the pathogenic fungus *A. brassicicola* needs to be investigated.

Materials and Methods

Preparation of antagonist bacterial isolate

Bacillus pumilus INR7 was obtained from the bacterial collection of the Department of Plant Pathology, Razi University. This strain was obtained from Prof. Kloepper, Auburn University, USA. It was originally isolated from the endo-rhizosphere of cucumber and is effective against several diseases. This strain has been formulated under the trade name The Yieldshield® (26).

Preparation of pathogenic fungal isolates

The fungal pathogen *A. brassicicola* was obtained

from the fungal culture collection of the Department of Plant Pathology, Urmia University, kindly provided by Dr. Abdullah Ahmadpour. The isolate was isolated and identified Dr. Yubert Ghosta.

Light spectrum equipment

Six light spectra were used, including full spectrum with a maximum wavelength of 650 nm, blue light with a maximum wavelength of 447 nm, red light with a maximum wavelength of 660 nm, green light with a maximum wavelength of 517 nm, far red light with a maximum wavelength of 741 nm, UVA with a wavelength of 365 nm and a dark environment. To uniform the light spectra, the PFD value of all lights except UVA was set to 50 $\mu\text{mol}/\text{m}^2/\text{s}$ using an optical spectrometer (UPRteck PG100N, Taiwan) (Fig.1). The characteristics of the UV spectrum were determined using another instrument (Lutron, UV-340A). The full spectrum light was considered representative of natural light and the dark condition represented the absence of light. The effect of the light spectra on the growth of antagonistic bacteria and pathogenic fungi was tested on a light shelf with six separate boxes to prevent collision of the spectra.



Fig. 1: Light shelf with six separate boxes. A: full spectrum light; B: far red; C: red light; D: UVA; E: blue light; F: green light

Determination of bacterial CFU by optical density

To determine bacterial CFU, a loop of the fresh bacterial culture on nutrient agar was transferred to a bottle containing 80 ml of nutrient broth medium and incubated overnight (12 h) at 25 °C on a shaker at 155 rpm. Then, the optical density of the sample was measured using a CamSpec M106 spectrophotometer. A bacterial dilution series in physiological serum was then prepared in 1 ml Eppendorf tubes. Then, 50 µl from 5 and 6 tubes were spread on three 8 cm Petri dishes. After 24 h, the number of colonies was counted. This process was repeated for different optical densities and a standard curve was fitted from the optical density and CFU/ml data (27).

Investigation of the population of the *B. pumilus* INR7 in the presence of different light spectrums

B. pumilus INR7 was transferred to a bottle containing 80 ml of nutrient broth and incubated as described above. The absorbance was then adjusted to an optical density of 0.45, equivalent to a population of 5.6×10^7 . A 500 µl bacterial suspension was transferred to 20 ml screw capped tubes. Then, the tubes were transferred to the light boxes at a temperature of 22-25 °C. The tubes were gently shaken every hour until the population reached equilibrium throughout the tube. The optical density of the bacterial suspensions was then measured every three hours for each tube using a spectrophotometer at 600 nm. This test was performed for 12 h with three replicates, and the results were reported based on the AUGC formula (28, 29, 30).

$$Ai = \frac{(G1 + G2) \times (T2 - T1)}{2}$$

$$Aii = \frac{(G2 + G3) \times (T3 - T2)}{2}$$

$$Aiii = \frac{(G3 + G4) \times (T4 - T3)}{2}$$

$$AUGC = Ai + Aii + Aiii + \dots + An$$

Ai...An = sample growth rate between two different evaluation times

G₁...G_n = srates in different sample growth evaluation time

T₁...T_n = different sample evaluation times

AUGC = total growth rate of the sample in different evaluations and times

Investigation of the effect of different light spectra on the growth of *A. brassicicola*

A. brassicicola was cultured in the center of an 8 cm Petri dish containing 20 ml of PDA medium and transferred to the light shelf at 22-25 °C. After one week, the Petri dishes were collected and the surface area of the fungal colony was measured using Digitizer software (v 6.3.0). The colony diameter was measured and the spore population was counted using a haemocytometer (31, 32) Slide. This experiment was conducted for one week and in three replicates (18, 23, 33).

Investigation of the integrated effect of light spectra and volatile compounds of *B. pumilus* INR7 on mycelial growth of *A. brassicicola*

A loop of the fresh culture of *B. pumilus* INR7 was transferred to part of an 8 cm I-plate containing 10 ml NA. Then, a plaque from a fresh culture of *A. brassicicola* was transferred to the other part of the I-plate containing the PDA. The Petri dishes were transferred to the light boxes under the temperature conditions mentioned in the previous experiments. After 12 days, the Petri dishes were collected and the colony size was measured. This experiment was carried out for one week and in three replicates (33).

Investigation of the combined effect of light spectra and *B. pumilus* INR7 on mycelial growth of *A. brassicicola* in the inhibition halo test

A loop of fresh culture of *B. pumilus* INR7 was streaked as a line on the 8 cm Petri dish containing 20 ml of the mixture of NA and PDA in a ratio of 1:1. Then, a plaque of fresh culture of *A. brassicicola* was then transferred to the center of the Petri dish. The dishes were transferred to light boxes at 22-25 °C. After ten days, the petri dishes were collected and the inhibition range between the antagonistic bacterium and a pathogenic fungus was investigated (34, 35, 36).

Data analysis

Analysis of variance and comparison of means were performed using the least significant difference (LSD, $P < 0.05$) method and generalized linear model (GLM) with SAS (SAS 9.4 TS Level 1M6). All experiments were conducted in a

completely randomized design (CRD) with at least three replications.

Results

The effect of light spectra on the population of *B. pumilus* INR7

The light spectra had a significant effect on the population growth of the antagonistic bacteria. The green light with an area under the growth curve (AUGC) of 2.53 had the most significant effect

compared to dark conditions and the full spectrum with indices of 1.91 and 1.66. Similarly, the far-red and red lights with AUGCs of 2 and 1.83, respectively, had no significant difference with dark conditions (Fig. 2). There was no statistically significant difference between full spectrum and red light. The blue spectrum and the UVA effect were significantly lower than the full spectrum, with AUGCs of 1.10 and 0.28, respectively.

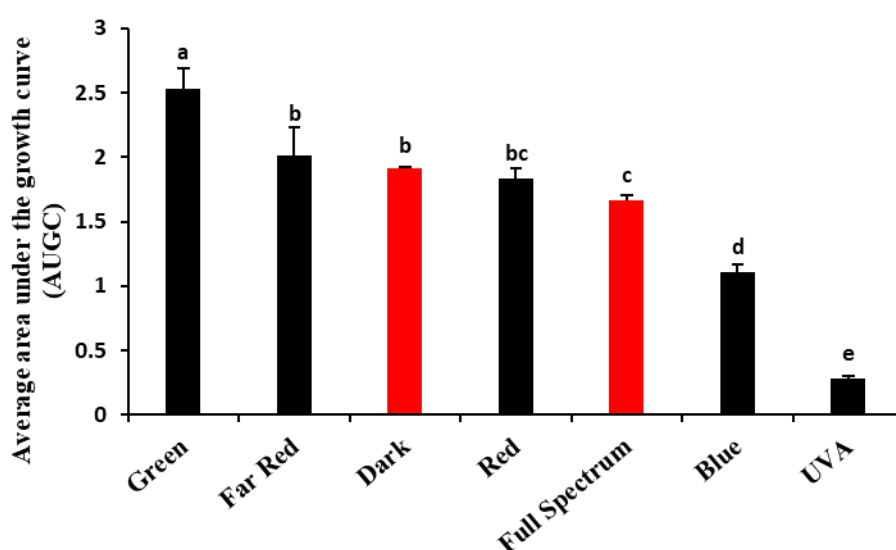


Fig. 2: The effect of different light spectra on the population growth of *B. pumilus* INR7 compared to full spectrum and dark treatments after 12 h. The experiment was conducted in a 22-25 °C light box. The numbers are the average of three replicates for each treatment and the error bars represent the standard deviation (SD). Comparisons of means were made using the least significant difference (LSD) at the 5 % probability level. Population growth was recorded at several time points to calculate the area under the growth curve (AUGC).

The effect of light spectra on mycelial growth of *A. brassicicola*

The blue light with an average mycelial growth of 51.3 mm, followed by the UVA and green together with an average of 47.6 mm, increased the growth of *A. brassicicola* significantly more than the full spectrum with an average of 1.44 mm (Fig. 3 and 4). The far red spectrum had less effect than the full spectrum with an average of 36.5 mm. Dark conditions, with an average of 33.1 mm, had the least effect on the growth of pathogenic fungi compared to other light spectra.

The effect of light spectra on the sporulation of *A. brassicicola*

As shown in Fig. 5, the UVA, red, green and blue light spectra showed no statistical difference from the full spectrum in the logarithm of the spore population. However, far red light with an average of 6.81 reduced the spore population compared to the full spectrum. Dark conditions, with an average of 6.53, had the least effect on the logarithm of the spore population in *A. brassicicola* compared to all light spectra.

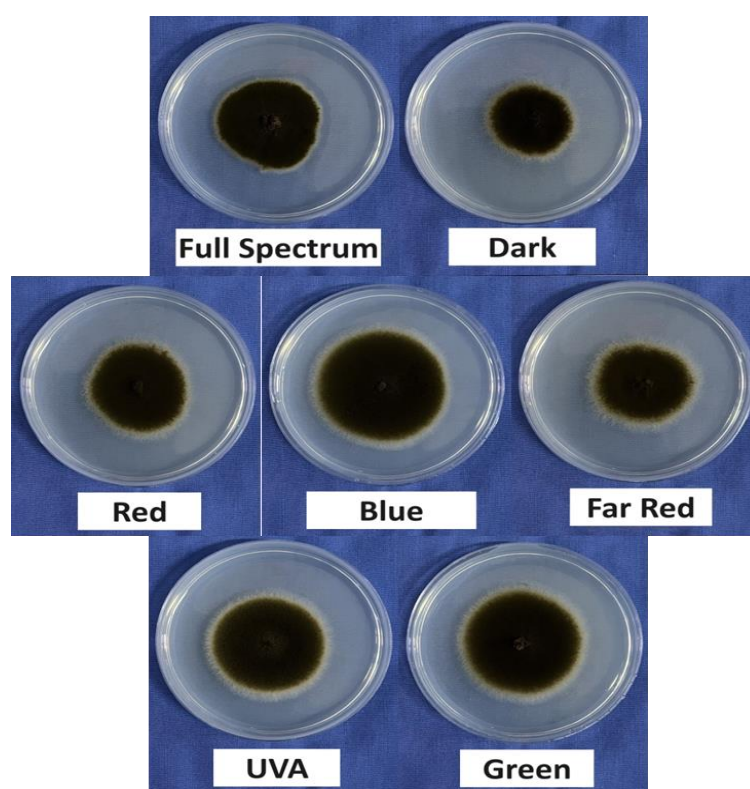


Fig.3: Effect of different light spectra on mycelial growth of *A. brassicicola* grown on potato dextrose agar at 22-25 °C compared to full spectrum and dark treatments after one week.

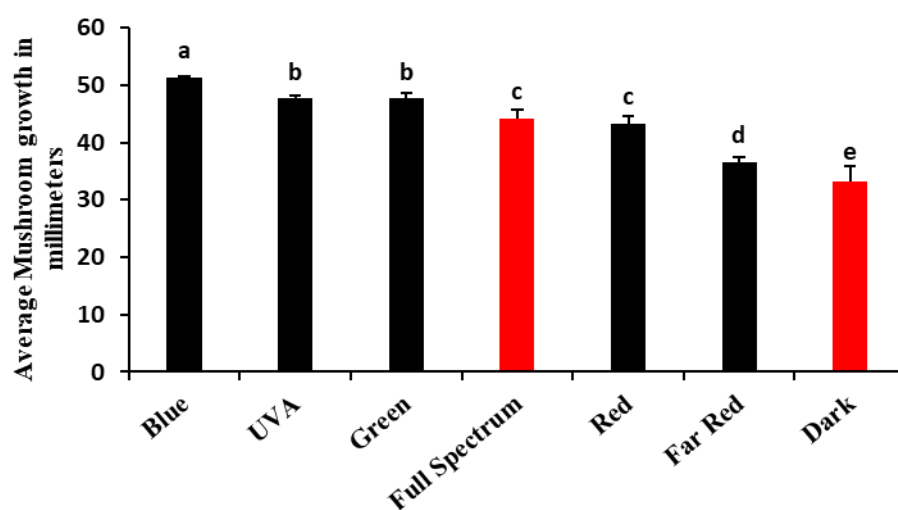


Fig. 4: The effect of different light spectra on mycelial growth of *A. brassicicola* compared to full spectrum and dark conditions after one week. The experiment was conducted in a 22-25 °C light box. The numbers are the average of three replicates for each treatment and the error bars represent the mean standard deviation (SD). Comparisons of means were made using the least significant difference (LSD) at the 5 % probability level.

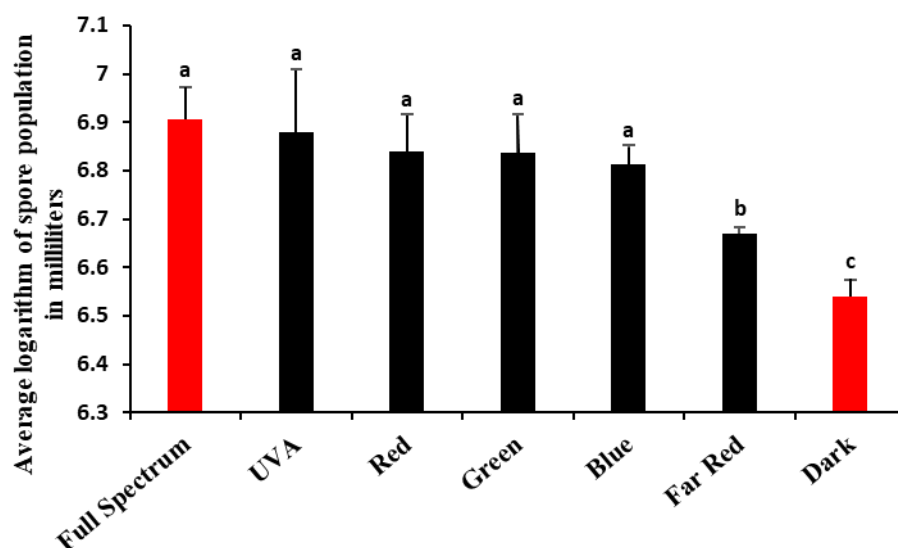


Fig. 5: The effect of different light spectra on the spore population of *A. brassicicola* compared to full spectrum and dark conditions after one week. The experiment was conducted in a 22-25 °C light box. The numbers are the average of three replicates for each treatment and the error bars represent the mean standard deviation (SD). Comparisons of means were made using the least significant difference (LSD) at the 5 % probability level.

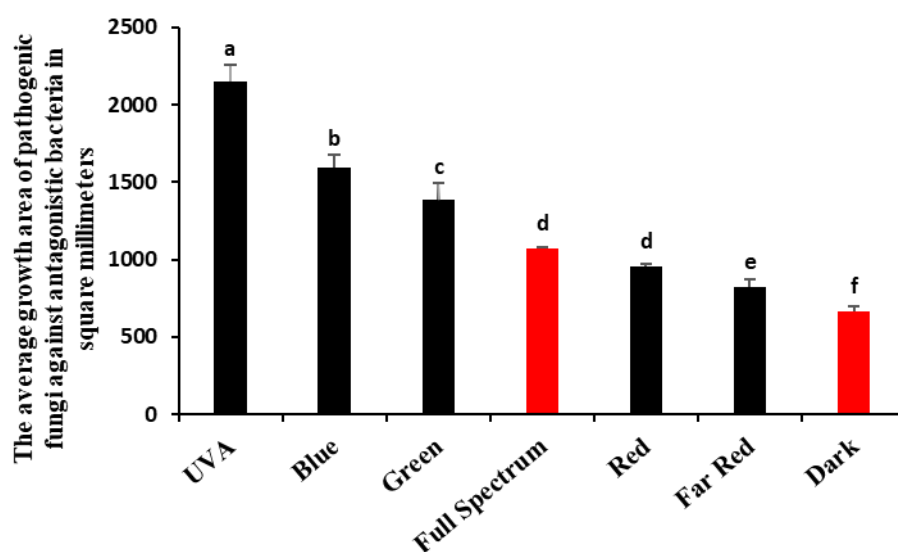


Fig. 6: Antagonistic effect of *B. pumilus* INR7 bacteria against *A. brassicicola* in the presence of different light spectra during ten days. The experiment was conducted in a light box at 22-25 °C. The numbers are the average of three replicates for each treatment and the error bars represent the mean standard deviation (SD). Comparisons of means were made using the least significant difference (LSD) at the 5 % probability level.

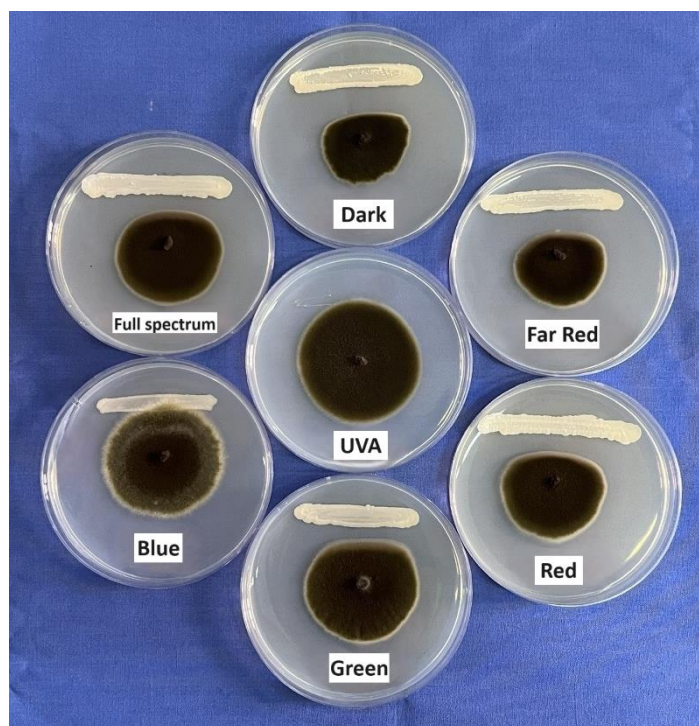


Fig. 7: Antagonistic effect of *B. pumilus* INR7 against *A. brassicicola* in the presence of different light spectra after 10 days compared to full spectrum and dark treatments. The culture medium used was a combination of potato dextrose agar and nutrient agar in a 1:1 ratio.

The combined effect of different light spectra and *B. pumilus* INR7 on mycelial growth of *A. brassicicola*

The mutual effect of UVA, blue and green light spectra and antagonistic bacteria with colony growth areas of 2146.7, 1598.9 and 1386.8 mm² respectively increased the growth of the fungus compared to the full spectrum with an average of 1068.4 mm² (Fig. 6). However, the far-red light spectrum with an average of 822.5 mm² had a significantly lower effect than the full spectrum. Dark conditions with an average of 666.4 mm² had the least effect on increasing fungal colony area in the presence of antagonistic bacteria. Notably, the antagonistic bacterial colony was weakly formed in the presence of the UVA light spectrum. However, fungal growth was highest in the presence of UVA light (Fig. 7).

The combined effect of different light spectra and volatile compounds from *B. pumilus* INR7 on the mycelial growth of *A. brassicicola*

The highest growth of *A. brassicicola*, with an average increase of 42.3 mm, was observed under the combined effect of green light and bacterial volatile compounds, surpassing the full spectrum, which had an average increase of 39.3 mm. Blue light, with an average growth of 40.6 mm, showed a statistically significant difference from the full spectrum in promoting the growth of the pathogenic fungus. The UVA, red and far red spectra with a mean of 39, 38.6 and 38.3 mm, respectively, did not show a statistically significant difference compared to the full spectrum. Dark conditions gave the lowest mycelial growth of pathogenic fungi, with an average of 35.3 mm having the lowest effect on mycelial growth of pathogenic fungi compared to light spectra. The colony of *B. pumilus* INR7 was weakly formed in UVA light, consistent with the results of the inhibitory halo test (Fig 8 and 9).

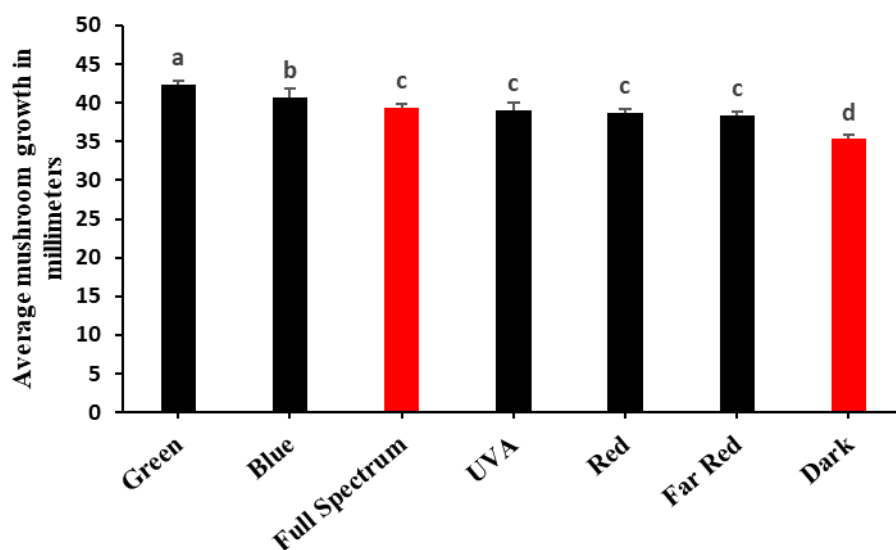


Fig. 8: Effect of different optical spectra and volatile compounds of *B. pumilus* INR7 in inhibiting the growth of *A. brassicicola* after 12 days. The experiment was conducted in a light box at 22-25 °C. The numbers are the average of three replicates for each treatment and the error bars represent the mean standard deviation (SD). Comparisons of means were made using the least significant difference (LSD) at the 5 % probability level.

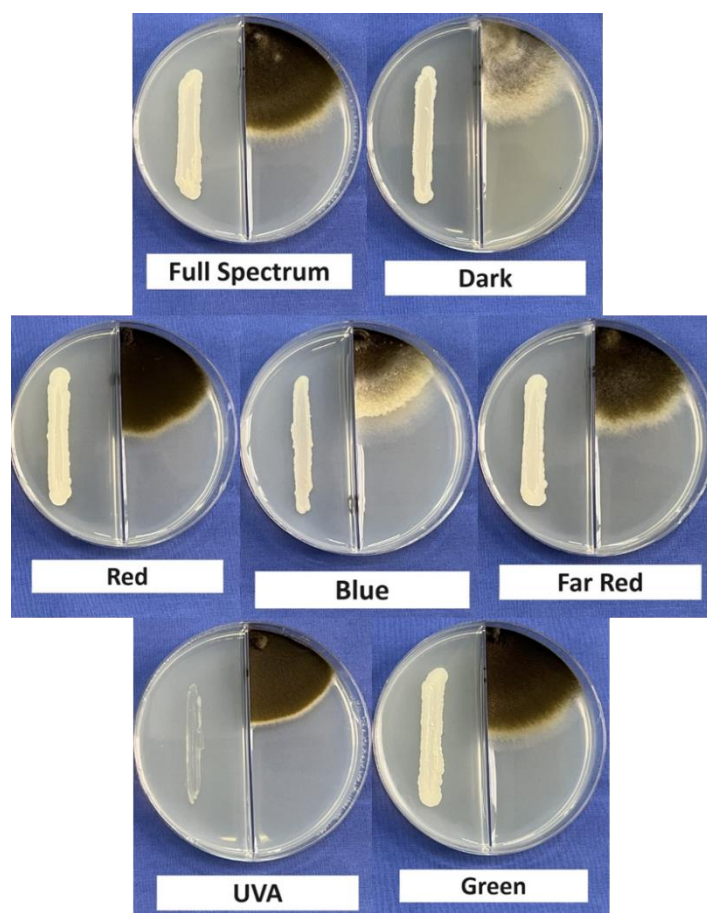


Fig. 9: Effect of different light spectra and volatile compounds of *B. pumilus* INR7 on the mycelial growth of *A. brassicicola* compared to full spectrum and dark conditions after 12 days. The culture medium used to develop the antagonistic bacteria in this test was a mixture of nutrient agar and potato dextrose agar in a 1:1 ratio. Potato dextrose agar was also used as a fungal culture medium.

Discussion

Light receptors are known to modulate many light-dependent processes in *A. alternata*. Interestingly, blue light prevents sporulation in *A. alternata*, whereas red light reverses this negative effect. It has been reported that *A. alternata* has a complete set of blue and red photoreceptors (18, 21). However, in the current study, the effects of blue and red light spectra were statistically similar. Light spectra also influence spore production (18) and germination (20) in *Alternaria* spp. Light intensity, particularly blue light, negatively modulates spore formation in *A. alternata* (18). In the present study, there was no significant difference in the spore population between the light spectra; only the dark treatment reduced the spore population. Furthermore, alternating periods of light and dark conditions maximizes mycelial growth compared to continuous exposure to light or dark exposure (37).

Research on *Neurospora crassa* shows that blue light has the greatest effect on the growth and physiology of the fungus, whereas red light plays a dominant role in *Aspergillus nidulans*. The physiological difference between these fungi can explain this variation (21). In the current study, blue light also significantly promoted the growth of pathogenic fungi, whereas red light had less effect.

In a separate investigation of the effect of red, green, blue and full spectrum light on mycelial growth and spore germination of *Colletotrichum acutatum*, it was found that red and green light increased mycelial growth, whereas blue light, full spectrum, and dark conditions decreased growth (38). Some of these findings differ from those of the present study, where blue light had a more significant effect on the growth of pathogenic fungi than red and green light. Additionally, green light increased the growth of pathogenic fungi more than dark conditions in this study.

The effect of light on colony growth and sporulation was investigated for three isolates of *Monilinia laxa* and showed that the highest mycelial growth occurred in the presence of red light, followed by green light, daylight and dark conditions (39). This finding contrasts with the results of the present study, where blue light had the highest effect on the mycelial growth of the

pathogenic fungus compared to green, full spectrum, and dark conditions.

In *Alternaria cichorii*, conidiophores are induced by UV radiation with a wavelength of less than 340 nm, especially at higher temperatures. Conversely, sporulation is inhibited by exposure to black light blue (blb, 310-420 nm) and blue light (530-360 nm), especially at lower temperatures. The inhibition of sporulation by blb is associated with blue spectra and increases with rising temperature. Prolonged exposure to blb (≥ 3 days) results in a temperature-dependent increase in the spore population (40). These findings were similar to those of the present study, without taking into account the mentioned temperature conditions and the fungal species studied, because blue light positively affects sporulation in *A. alternata*.

The near UV light spectrum induced sporulation of *B. cinerea*. Infrared, red and yellow light have little effect on fungal sporulation, while blue and green light have no effect (22). This finding is somewhat similar to our results, as UV light had a positive effect on the sporulation of our fungus. In contrast, red, blue and green light, similar to UV light, also had a positive effect on sporulation in our study.

The results of our experiments indicate that light spectra can significantly affect the physiology of beneficial bacteria and pathogenic fungi. Specifically, light spectra affect bacterial population, the growth of pathogenic fungi, the rate of sporulation and their interactions. Future research should focus on determining the minimum exposure time required to achieve optimal effect of light on disease management. Our findings can be applied to storage and greenhouse conditions.

Light spectra affect bacterial physiology and responses. Blue light inhibits the twitching movement of *Acinetobacter baylyi* ADP1 bacteria at a maximum temperature of 20 °C (41). An engineered *Pseudomonas aeruginosa* strain (called pctm) with light-dependent intracellular cAMP levels, by inducing a light-activated adenylate cyclase (bPAC) gene into the bacteria, caused a 15-fold increase in expression of the responsive promoter after exposure to blue light. cAMP and an 8-fold increase in twitching activity (42).

Light stimulated the growth of *Bacillus amyloliquefaciens* JBC36 compared to dark-grown treatments. Red light regardless of intensity, increased swarming and caused significant biofilm formation at 240 $\mu\text{mol}/\text{m}^2/\text{s}$ (43).

Exposure to low intensities of the UVA spectrum increases biofilm formation in *P. aeruginosa*. This is the result of the present study: UVA light increases biofilm formation after green light, as do other light spectrums. In addition, placing bacterial cells near the UVA spectrum can increase two known characteristics of bacterial cell adhesion, including cell surface hydrophobicity and swimming motility. This contradicts the results of this study, as the antagonistic bacteria did not swim in the vicinity of the UVA spectrum. The results of other findings show that the UVA spectrum can, to some extent, influence the formation of bacterial biofilm by affecting the early stages of growth development (44).

Blue light regulates motility and biofilm formation in many species of the genus *Acinetobacter*, including *Acinetobacter calcoaceticus*. In several *Acinetobacter* species, blue light is a critical factor in determining the balance between motility and quiescence at 24 °C. In contrast, in *Acinetobacter baumannii*, blue light prevented both motility and biofilm formation, a finding that is consistent with the results of this research, in which blue light influenced biofilm formation by antagonistic bacteria and showed no

significant difference compared to the other spectra used, except for green light. Light-dependent regulation of motility was observed not only at 24 °C but also at 37 °C in species other than *A. baumannii* (45).

In the pathogen *Pseudomonas syringae* pv Tomato DC3000 (Pto), both full and blue light spectra suppressed motility while enhancing bacterial adhesion to plant leaves. These effects were reversed by mutation of the blue light receptor (46).

The antimicrobial effect of the UVA LED spectrum (365 nm, 0.28 mW/cm², in tap or continuous mode) on biofilm formation of *Candida albicans* and *Escherichia coli* has been reported. This was determined by assessing colony forming units and observing morphological changes of bacterial cells within the biofilm using a scanning electron microscope. The results showed that after five minutes of exposure to the UVA light spectrum, more than 90% of the living microorganisms in the biofilms were destroyed. Tap irradiation at 1 to 1000 Hz showed greater antimicrobial efficacy than continuous irradiation. Tap irradiation at 100 Hz for 60 min almost eliminated the microorganisms in the biofilm (>99.9%), whereas 20 min irradiation caused significant damage to both microbial species. These results are in agreement with the results of the present study(47).

References

- (1) Aam G, Mv Q, Ol P. Mycofumigation for the Biological Control of Post- Harvest Diseases in Fruits and Vegetables: A Review. *Austin Journal of Biotechnology & Bioengineering*. 2015;2(4):1-8.
<https://austinpublishinggroup.com/biotechnology-bioengineering/fulltext/ajbtbe-v2-id1051.php>
- (2) Gotor-Vila A, Teixidó N, Di Francesco A, Usall J, Ugolini L, Torres R, et al. Antifungal effect of volatile organic compounds produced by *Bacillus amyloliquefaciens* CPA-8 against fruit pathogen decays of cherry. *Food Microbiology*. 2017;64:219-25.
<https://doi.org/10.1016/j.fm.2017.01.006>
- (3) Mari M, Bautista-Banos S, Sivakumar D. Decay control in the postharvest system: Role of microbial and plant volatile organic compounds. *Postharvest Biology and Technology*. 2016;122:70-81.
<https://doi.org/10.1016/j.postharvbio.2016.04.014>
- (4) Tozlu E, Kotan MŞ, Tekiner N, Dikbaş N, Kotan R. Biological control of postharvest spoilage in fresh mandarins (*Citrus reticulata* Blanco) fruits using bacteria during storage. *Erwerbs-obstbau*. 2019;61(2):157-64.
<https://doi.org/10.1007/s10341-018-0412-8>
- (5) Walton JD. Host-selective toxins: agents of compatibility. *Plant Cell*. 1996;8(10):1723-33.
<https://doi.org/10.1105/tpc.8.10.1723>
- (6) Romanazzi G, Lichter A, Gabler FM, Smilanick JL. Recent advances on the use of natural and safe alternatives to conventional methods to control postharvest gray mold of table grapes. *Postharvest Biology and*

- Technology. 2012;63(1):141-7.
<https://doi.org/10.1016/j.postharvbio.2011.06.013>
- (7) Troncoso-Rojas R, Tiznado-Hernández ME. Chapter 5 - *Alternaria alternata* (Black Rot, Black Spot). In: Bautista-Baños S, editor. Postharvest Decay. San Diego: Academic Press; 2014. p. 147-87. <https://doi.org/10.1016/B978-0-12-411552-1.00005-3>
- (8) Macioszek VK, Gapińska M, Zmienko A, Sobczak M, Skoczowski A, Oliwa J, et al. Complexity of *Brassica oleracea*-*Alternaria brassicicola* susceptible interaction reveals downregulation of photosynthesis at ultrastructural, transcriptional, and physiological levels. *Cells*. 2020;9(10):2329. <https://doi.org/10.3390/cells9102329>
- (9) Martinko K, Ivanković S, Lazarević B, Đermić E, Đermić D. Control of Early Blight Fungus (*Alternaria alternata*) in Tomato by Boric and Phenylboronic Acid. *Antibiotics* (Basel). 2022;11(3):1-12. <https://doi.org/10.3390/antibiotics11030320>
- (10) Pal KK, Gardener BM. Biological control of plant pathogens. *The Plant Health Instructor*. 2006;2(5):1117-42. <https://doi.org/10.1094/PHI-A-2006-1117-02>
- (11) Wang W, Zhai Y, Cao L, Tan H, Zhang R. Endophytic bacterial and fungal microbiota in sprouts, roots and stems of rice (*Oryza sativa* L.). *Microbiological Research*. 2016;188-189:1-8. <https://doi.org/10.1016/j.micres.2016.04.009>
- (12) Sharifi R, Ryu CM. Revisiting bacterial volatile-mediated plant growth promotion: lessons from the past and objectives for the future. *Ann Bot*. 2018;122(3):349-58. <https://doi.org/10.1093/aob/mcy108>
- (13) Zhou J-Y, Li X, Zheng J-Y, Dai C-C. Volatiles released by endophytic *Pseudomonas fluorescens* promoting the growth and volatile oil accumulation in *Atractylodes lancea*. *Plant Physiology and Biochemistry*. 2016;101:132-40. <https://doi.org/10.1016/j.plaphy.2016.01.026>
- (14) Ryu C-M, Farag MA, Hu C-H, Reddy MS, Wei H-X, Paré PW, et al. Bacterial volatiles promote growth in *Arabidopsis*. *Biological Sciences*. 2003;100(8):4927-32. <https://doi.org/10.1073/pnas.0730845100>
- (15) Tilocca B, Cao A, Migheli Q. Scent of a killer: Microbial volatilome and its role in the biological control of plant pathogens. *Frontiers in Microbiology*. 2020;11:41. <https://doi.org/10.3389/fmicb.2020.00041>
- (16) Parafati L, Vitale A, Restuccia C, Cirvilleri G. Performance evaluation of volatile organic compounds by antagonistic yeasts immobilized on hydrogel spheres against gray, green and blue postharvest decays. *Food microbiology*. 2017;63:191-8. <https://doi.org/10.1016/j.fm.2016.11.021>
- (17) Correia C, Magnani F, Pastore C, Cellini A, Donati I, Pennisi G, et al. Red and Blue Light Differently Influence *Actinidia chinensis* Performance and Its Interaction with *Pseudomonas syringae* pv. *Actinidiae*. *Int J Mol Sci*. 2022;23(21):1-21. <https://doi.org/10.3390/ijms232113145>
- (18) Pruß S, Fetzner R, Seither K, Herr A, Pfeiffer E, Metzler M, et al. Role of the *Alternaria alternata* blue-light receptor LreA (white-collar 1) in spore formation and secondary metabolism. *Applied and environmental microbiology*. 2014;80(8):2582-91. <https://doi.org/10.1128/AEM.00327-14>
- (19) Rahman MZ, Honda Y, Arase S. Red-Light-Induced Resistance in Broad Bean (*Vicia faba* L.) to Leaf Spot Disease Caused by *Alternaria tenuissima*. *Journal of Phytopathology*. 2003; 151(2):86-91. <https://doi.org/10.1046/j.1439-0434.2003.00685.x>
- (20) Valero A, Begum M, Leong SL, Hocking AD, Ramos AJ, Sanchis V, et al. Effect of germicidal UVC light on fungi isolated from grapes and raisins. *Lett Appl Microbiol*. 2007;45(3):238-43. <https://doi.org/10.1111/j.1472-765X.2007.02175.x>
- (21) Igbalajobi O, Yu Z, Fischer R. Red- and Blue-Light Sensing in the Plant Pathogen *Alternaria alternata* Depends on Phytochrome and the White-Collar Protein LreA. *mBio*. 2019;10(2):1-17. <https://doi.org/10.1128/mbio.00371-19>
- (22) Tan KK, Epton HAS. Effect of light on the growth and sporulation of *Botrytis cinerea*. *Transactions of the British Mycological Society*. 1973;61(1):145-57.

[https://doi.org/10.1016/S0007-1536\(73\)80096-8](https://doi.org/10.1016/S0007-1536(73)80096-8)

(23) Xu H, Fu Y-n, Li T-l, Wang R. Effects of different LED light wavelengths on the resistance of tomato against *Botrytis cinerea* and the corresponding physiological mechanisms. *Journal of Integrative Agriculture*. 2017; 16(1):106-14. [https://doi.org/10.1016/S2095-3119\(16\)61435-1](https://doi.org/10.1016/S2095-3119(16)61435-1)

(24) Häggblom P, Niehaus WG. Light effects on polyketide metabolism in *Alternaria alternata*. *Experimental Mycology*. 1986; 10(3):252-5. [https://doi.org/10.1016/0147-5975\(86\)90009-5](https://doi.org/10.1016/0147-5975(86)90009-5)

(25) Häggblom P, Unestam T. Blue light inhibits mycotoxin production and increases total lipids and pigmentation in *Alternaria alternata*. *Applied and Environmental Microbiology*. 1979; 38(6): 1074-7. <https://doi.org/10.1128/aem.38.6.1074-1077.1979>

(26) Jeong H, Choi S-K, Kloepper JW, Ryu C-M. Genome Sequence of the Plant Endophyte *Bacillus pumilus* INR7, Triggering Induced Systemic Resistance in Field Crops. 014;2(5):10. <https://doi.org/10.1128/genomea.01093-14>

(27) Boukouvalas DT, Prates RA, Lima Leal CR, de Araújo SA. Automatic segmentation method for CFU counting in single plate-serial dilution. *Chemometrics and Intelligent Laboratory Systems*. 2019; 195:103889. <https://doi.org/10.1016/j.chemolab.2019.103889>

(28) Hall BG, Acar H, Nandipati A, Barlow M. Growth rates made easy. *Molecular biology and evolution*. 2014;31(1):232-8. <https://doi.org/10.1093/molbev/mst187>

(29) Mira P, Yeh P, Hall BG. Estimating microbial population data from optical density. *PLoS One*. 2022;17(10):e0276040. <https://doi.org/10.1371/journal.pone.0276040>

(30) Yousefvand M, Harighi B, Azizi A. Volatile compounds produced by endophytic bacteria adversely affect the virulence traits of *Ralstonia solanacearum*. *Biological Control*. 2023;178:105145. <https://doi.org/10.1016/j.biocontrol.2022.105145>

(31) Siricharoen P, Humphries U. Automated Spore Counting using Morphology and Shape. *Proceedings of the 2019 11th International*

Conference on Bioinformatics and Biomedical Technology; Stockholm, Sweden: Association for Computing Machinery; 2019. p. 22–6. <https://doi.org/10.1145/3340074.3340085>

(32) Avin F. Easy way to count spores and prepare spore suspension by Hemocytometer 2019. https://www.researchgate.net/publication/337772212_Easy_way_to_count_spores_and_prepare_spore_suspension_by_Hemocytometer

(33) He C-N, Ye W-Q, Zhu Y-Y, Zhou W-W. Antifungal Activity of Volatile Organic Compounds Produced by *Bacillus methylotrophicus* and *Bacillus thuringiensis* against Five Common Spoilage Fungi on Loquats. *Molecules*. 2020;25(15):1-14. <https://doi.org/10.3390/molecules25153360>

(34) Archana T, Rajendran L, Manoranjitham SK, Santhana Krishnan VP, Paramasivan M, Karthikeyan G. Culture-dependent analysis of seed bacterial endophyte, *Pseudomonas* spp. EGN 1 against the stem rot disease (*Sclerotium rolfsii* Sacc.) in groundnut. *Egyptian Journal of Biological Pest Control*. 2020;30(1):119. <https://doi.org/10.1186/s41938-020-00317-x>

(35) Pandey DK, Tripathi NN, Tripathi RD, Dixit SN. Fungitoxic and phytotoxic properties of the essential oil of *Hyptis suaveolens* / Fungitoxische und phytotoxische Eigenschaften des ätherischen Öls von *Hyptis suaveolens*. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz / Journal of Plant Diseases and Protection*. 1982;89(6):344-9. <http://www.jstor.org/stable/43214961>

(36) Soliman SA, Khaleil MM, Metwally RA. Evaluation of the Antifungal Activity of *Bacillus amyloliquefaciens* and *B. velezensis* and Characterization of the Bioactive Secondary Metabolites Produced against Plant Pathogenic Fungi. *Biology*. 2022;11(10):1-21. <https://doi.org/10.3390/biology11101390>

(37) Hubballi M, Nakkeeran S, Raguchander T, Anand T, Samiyappan R. Effect of environmental conditions on growth of *Alternaria alternata* causing leaf blight of noni. *World Journal of Agricultural Sciences*. 2010;6:171-7. [https://www.idosi.org/wjas/wjas6\(2\)/10.pdf](https://www.idosi.org/wjas/wjas6(2)/10.pdf)

(38) Yu SM, Ramkumar G, Lee YH. Light quality influences the virulence and

physiological responses of *Colletotrichum acutatum* causing anthracnose in pepper plants. *Journal of Applied Microbiology*. 2013; 115(2):509-16.

<https://doi.org/10.1111/jam.12252>

(39) Rodríguez-Pires S, Espeso EA, Rasiukevičiūtė N, Melgarejo P, De Cal A. Light-Photoreceptors and Proteins Related to *Monilinia laxa* Photoresponses. *Fungi*. 2021;7(1):32.

<https://doi.org/10.3390/jof7010032>

(40) Vakalounakis DJ, Christias C. Light quality, temperature and sporogenesis in *Alternaria cichorii*. *Transactions of the British Mycological Society*. 1986;86(2):247-54.

[https://doi.org/10.1016/S0007-1536\(86\)80152-8](https://doi.org/10.1016/S0007-1536(86)80152-8)

(41) Bitrian M, González RH, Paris G, Hellingwerf KJ, Nudel CB. Blue-light-dependent inhibition of twitching motility in *Acinetobacter baylyi* ADP1: additive involvement of three BLUF-domain-containing proteins. *Microbiology*. 2013;159 (Pt_9): 1828-41.

<https://doi.org/10.1099/mic.0.069153-0>

(42) Xia A, Qian M, Wang C, Huang Y, Liu Z, Ni L, et al. Optogenetic Modification of *Pseudomonas aeruginosa* Enables Controllable Twitching Motility and Host Infection. *ACS Synthetic Biology*. 2021;10(3):531-41.

<https://doi.org/10.1021/acssynbio.0c00559>

(43) Yu S-M, Lee YH. Effect of light quality on

Bacillus amyloliquefaciens JBC36 and its biocontrol efficacy. *Biological Control*. 2013;64(3):203-10.

<https://doi.org/10.1016/j.biocontrol.2012.11.004>

(44) Pezzoni M, Pizarro RA, Costa CS. Exposure to low doses of UVA increases biofilm formation in *Pseudomonas aeruginosa*. *Biofouling*. 2018;34(6):673-84.

<https://doi.org/10.1080/08927014.2018.1480758>

(45) Golic A, Vaneechoutte M, Nemec A, Viale AM, Actis LA, Mussi MA. Staring at the Cold Sun: Blue Light Regulation Is Distributed within the Genus *Acinetobacter*. *PLOS ONE*. 2013;8(1):e55059.

<https://doi.org/10.1371/journal.pone.0055059>

(46) Río-Álvarez I, Rodríguez-Herva JJ, Martínez PM, González-Melendi P, García-Casado G, Rodríguez-Palenzuela P, et al. Light regulates motility, attachment and virulence in the plant pathogen *Pseudomonas syringae* pv *tomato* DC3000. *Environmental Microbiology*. 2014;16(7):2072-85.

<https://doi.org/10.1111/1462-2920.12240>

(47) Zhao Z, Rho H, Shapiro N, Ling L, Perreault F, Rittmann B, et al. Biofilm inhibition on surfaces by ultraviolet light side-emitted from optical fibres. *Nature Water*. 2023;1(7):649-57.

<https://doi.org/10.1038/s44221-023-00111-7>