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# EFFICACY OF HALOBACTERIAL- AND CYANOBACTERIAL-PIGMENTS AS PHOTOSENSITIZING MATERIALS

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## ABSTRACT

**In the present study, the photosensitizing activity of phycocyanin and bacteriorhodopsin pigments derived from *Halobacterium* and a cyanobacterium, isolated from solar saltpan sediments of Cape Comorin coast of Tamil Nadu (India), was assessed. Halobacterial strains were grown on halophillic agar and Zobell marine agar; and pigmented bacteria identified on the basis of morpho-biochemical characteristics. Cyanobacteria mats, gathered from the same environment, were grown on BG11 medium, and identified on the basis of morpho-biochemical characters as *Oscillatoria* sp., *Spirulina* sp. and *Microcystis* sp. Phycocyanin pigment was extracted from these cyanobacteria while bacteriorhodopsin pigment was extracted from *Halobacterium* sp. The pigments were extracted by a centrifugation process, and characterised by HPLC and UV spectroscopy. In addition, the photosensitization capacity of pigments was evaluated using $TiO_2$ thin film. The photosensitizing activity was assessed through band gap energy study using UV spectral analysis which was confirmed by FTIR and SEM analysis. Four probe tests were performed to measure the resistivity and conductivity of halobacterial and cyanobacterial pigment-coated $TiO_2$ thin films.**

**Keywords:** Bacteriorhodospin; conductivity; cyanobacteria, *Halobacterium* sp; pycocyanin, photosensitization; salt pan

## INTRODUCTION

The ocean ecosystem encompasses more than 70% of the earth's surface and harbours a wide range of habitats from tropical, shallow-water coral reefs to sub-zero and deep ocean depths (Rad *et al*., 2014). Extremophiles grow in extreme environments like high temperature, low oxygen condition, high nutrient availability, high light intensity, high NaCl concentration, high salinity, etc., thereby implying that these microbes are adapted to such environments (Goraj and Stpniewska. 2017).

Halobacteria are archaeal members of family Halobacteriaceae (Kuo, 2011). Halophiles consist of bacteria that produce attractive coloured pigments such as phycocyanin and bacteriorhodopsin. Gas vesicles, purple membranes, and red-orange carotenoids are the common characteristics (Anita and Pandey, 2013). Bacterial pigments reportedly absorb sunlight and accelerate evaporation by 30% (Ruiz *et al.*, 2004). This increases the growth of red halophiles as well as the rate of evaporation, thereby allows higher effective proportion of solar salts in seawater (Patak and Sardar, 2012).

Bacteriorhodopsin is a light-sensitive protein found in the purple membrane of *Halobacterium halobium,* which lives in saltwater environment. In this, halorhodopsin acts as a transporter of protons from the interior of cell to its exterior (Mohammadi, 2012). Light is used to create a proton gradient

in membrane-associated machinery. Halorhodopsin, along with other related systems, functions as a chloride pump and is involved in photo-sensing and photo-taxis (Fernández-Garca *et al*., 2012). It is currently evaluated as a good alternative material for building a molecular electron device and optical computer. For such an essential photo-physical substance, the effective biological production of bacteriorhodopsin has been examined (Roy *et al*., 2008).

Marine cyanobacteria, also known as blue-green algae, have been identified as potential candidates for the discovery of new antibiotics and their use as bacterial and fungal disease biocontrol agents (Petterson, 1996). More than half of the marine cyanobacteria have potential to be used for extracting the bioactive compounds that can destroy cancer cells. The prospective use of cyanobacteria in agriculture, aquaculture, nutraceuticals, and bioenergy are diverse and widely dispersed group of photosynthetic prokaryotes that use light as a source of energy, water as an electron donor, and $CO_2$ as a carbon source to execute plant-type oxygenic photosynthesis (Tomitani *et al*., 2006). They have a vital role in carbon, oxygen, and nitrogen cycles and contribute significantly to the primary production of diverse ecosystems, particularly freshwater and marine habitats. Phycobilliproteins present in cyanobacteria make up 40% of the total solubilized proteins. It has structured supramolecular aggregates called phycobilisomes, which are attached as closely spaced granules on the outer surface of thylakoid or photosynthetic membranes (Fatma, 2009). Phycobilliproteins are uniquely found in cyanobacteria and have numerous economic uses. They have been employed in biomedical research, food, pharmaceuticals, and cosmetics to substitute lethal synthetic colours, because of their unique spectroscopic properties and non-toxic nature. Solar panels involving nanotechnology convert sunlight into electricity more efficiently than normal designs, implying that solar power may become more affordable in future (Karna *et al*., 2011).

Photosensitizing activity plays a vital role in visible light absorption, which is measured by the sensitization of semiconductors via surface-absorbed dye molecules. The linear four-probe method is one of the most common and widely used methods for measuring semiconductor resistivity. $TiO_2$ is a high-band gap semiconductor with outstanding optical transmittance and transparency to visible light. The band gap is the smallest energy difference between the valence band's top and the conduction band's bottom. $TiO_2$ films can also be used in dye-sensitized photovoltaic cells, anti-reflective coatings, gas sensors, electrochromic displays, and planar wave guides, among other electronic device applications (Pandey *et al*., 2007).

The recent discoveries of new taxa useful for several biotechnological applications and processes, including biopolymers, biosurfactants, exopolysaccharides, compatible solutes, and bioactive compounds (carotenoids, anti-tumour, and antimicrobial substances, etc.), have increased interest in living microbes i.e. halophilic microbes, in hypersaline environments (Chattopadhyay *et al.*, 2008). This study was aimed to analyse the bacteriorhodopsin and phycocyanin pigments, isolated from saltpan-dwelling halophilic bacterium *Halobacterium* sp. and cyanobacteria, respectively, and evaluate its potential for use as a photosensitizing agent.

## MATERIALS AND METHODS

### *Sample collection*

Saltpan sediment and cyanobacterial mat samples were collected in sterile polythene bags from Manakudi Saltpan of Cape Comorin Coast in Tamil Nadu (India). The samples were transported to the laboratory in ice chest.

### *Cultivation of Halobacterium* sp.

Soil samples were serially diluted and inoculated into halophilic agar medium (g $L^{-1}$): casein acid hydrolysate 10.0, yeast extract 10.0, protease peptone 5.0, disodium citrate 3.0, potassium chloride 2.0, magnesium sulphate 25.0, sodium chloride 250.0, agar 20.0, final pH 7.2, and Zobell marine agar

(g $L^{-1}$): peptone 5.0, yeast extract 1.0, ferric citrate 0.1, sodium chloride 19.45, magnesium chloride 8.8, sodium sulphate 3.24, calcium chloride 1.8, potassium chloride 0.55, sodium bicarbonate 0.16, potassium bromide 0.08, strontium chloride 0.034, boric acid 0.022, sodium silicate 0.004, sodium fluorate 0.0024 and ammonium nitrate 0.001; incubated at 37°C for 3-8 days at pH 7.6 (Manikandan *et al*., 2009). After incubation, pigmented colonies were identified by their morphological and biochemical characteristics (Holt *et al*., 1994).

***Enrichment of marine cyanobacteria***

Cyanobacterial mats were cultivated in mass culture. A loopful of algal mat was suspended in 5 mL sterilised distilled water, homogenised with different shaking methods, and 0.5 to 1.0 mL was added to the cultivation medium, like BG-11 medium (g $L^{-1}$): $NaNO_3$, 1.5; $K_2HPO_4.3H_2O$, 30 µg $MgSO_4.7H_2O$, 0.075; $CaCl_2.2H_2O$, 0.03; citric acid, 0.006; ammonium citrate, 0.006; $Na_2EDTA$, 0.0001; $Na_2CO3$, 0.02; $H_3BO_3$ 2.86; $MnCl_2.4H_2O$, 1.81; $ZnSO_4.7H_2O$, 0.222; $Na_2MoO_4$ $2H_2O$, 0. 390; $CuSO_4$ $5H_2O$, 0.079; and CO $(NO_3)_2$ $6H_2O$, 0.049 after inoculation the culture medium were incubated at pH 7.5 for 4-7days. After incubation, the cyanobacterium was identified by using a compound light microscope (Behle, *et al*., 2020).

***Extraction and purification of bateriorhodopsin from halobacterial strain***

The highest pigment-producing strain was selected on the basis of high growth, pigment, and degree of cell pigmentation. The pigmented halobacterial strain was grown in 50 mL Zobell marine broth containing 25% NaCl in a 250 mL Erlenmeyer flask and incubated on a rotary shaker at 120 rpm for 20 days at 25°C. The cells were harvested by centrifugation at 10000 rpm for 15 min, once the cell culture reached early stationary phase. The cells were washed twice with 4M NaCl solution and centrifuged, and the pigment was extracted by acetone, methanol, and hexane solvents (Zhang *et al*., 2018)**.**

The bacterial pigments were analyzed by scanning the absorbance in the wavelength region of 200-800 nm using UV-VIS scanning spectrophotometer. The total pigment content in solvent extracts was estimated by measuring the absorbance at 490 nm (Shiu *et al*., 2015). The highest pigment-producing strain was selected on the basis of high growth, pigment, and degree of cell pigmentation. A separating funnels containing extracted pigment bacteriorhodopsin with acetone solution and 0.5 times of petroleum ether, as well as 2 mL of saturated NaCl solution. The petroleum ether phase was collected after the removal of acetone layer, which was re-extracted with acetone, and the bacterial pigments were analyzed by scanning the absorbance in the wavelength region of 200-800 nm using UV-VIS scanning spectrophotometer. The total pigment content in solvent extracts was estimated by measuring the absorbance at 490-525 nm (Winder *et al*., 2008; Shiu *et al*., 2015). Bacteriorhodopsin composition was calculated using the following formula: 1% extinction coefficient = 2100

$$\text{Bacteriorhodopsin extraction} = \frac{\text{mL of petroleum ether x A471}}{\text{21 x bacterial dry weight}} \text{ x 100}$$

***Extraction and purification of phycocyanin from a cyanobacterial strain***

The phycocyanin was extracted from cyanobacteria through a combination of two procedures: addition of 0.1 M phosphate buffer (pH 7.0), followed by five successive freezing and thawing cycles of biomass in order to disrupt the cell walls and consequently isolate the phycocyanin. The evaluation of extract was based on the concentration of phycocyanin (Patil *et al*., 2006; Kumar *et al*., 2014; Hazra and Kesh, 2017).

$$\text{FC} = \frac{(\text{A620} - 0.474\ (\text{A652})}{5.4} \text{ x 100}$$

Where: FC = concentration of phycocyanin (in mg x $mL^{-1}$); $Abs_{620}$ = Absorbance at 620 nm and $Abs_{652}$ = Absorbance at 652 nm (Eriksen, 2008).

***Characterization of bacteriorhodopsin and phycocyanin pigments***

The phycocyanin and bacteriorhodopsin pigments, separated by thin layer chromatography, were redissolved in acetone and subjected to FTIR spectroscopy (Perkin Elmer, Inc., USA) for transmission

profiles of pigments, which were recorded at 45-4000 $cm^1$ (Terpugov and Degtyareva, 2001; Rehman *et al*., 2020). The HPLC analysis of pigments was done on HPLC (Schimadzu LC-10AT VP) (Lazarova *et al*., 2009; Kumar *et al*., 2014).

***Photosensitization study***

For photosensitization study, transparent microscopic glass slides (2.5 x 2.5 cm) were used as substrates. The glass substrates, washed with detergent and rinsed with tap- and deionized-water, were soaked in hot chromic acid at 90°C for 15 min, washed again with deionized water and kept in an ultrasonic water bath for 15 min. $TiO_2$ solution was prepared using titanium tetraisopropoxide (TTIP), ethanol (as solvent), and acetyl acetone. TTIP (1 mL) was mixed with 10 mL ethanol and stirred for 10 min using a magnetic stirrer to obtain milky white solution. To this mixture, 1 mL acetyl acetone was added and stirred for 30 min to obtain an orange-coloured solution. Again, 10 mL ethanol was added to the solution and stirred for 3 h. The prepared solution was kept in open air for 48 h to age, and the gel was formed. To prepare $TiO_2$ film, the gel was dropped onto the glass substrate and rotated @ 3000 rpm for 10 sec by using a spin coater. The substrate was dried at 150°C for 10 min in a muffle furnace. The process of spinning and drying was repeated to obtain three-coated films. The coated films were annealed at 550°C for 1 h. $TiO_2$ coated thin films were soaked in bacteriorhodopsin and phycocyanin-containing beakers for 72 h and subjected to UV and FTIR spectrum analysis. Since the measurement of band gap of materials is important in semiconductor, nanomaterial, and solar industries, the band gap was determined from its UV absorption spectrum (Glass *et al*., 2018).

***SEM analysis***

Surface morphological characterization of $TiO_2$ was prepared by using TTIP as a source of $TiO_2$ and then mixed with isopropanol in a molar ratio of 1:20. The solution was then stirred for 5 min. A few drops of acetic acid were added to it as catalysts during stirring process. The solutions were continuously mixed for 1 h by using a magnetic stirrer to obtain a clear homogeneous solution. The final solution was deposited on silica wafer at a spin rate of 1000 rpm for 30 sec. The samples were dried in an oven for 10 min at 60°C. The samples were annealed at different temperatures (400, 500, and 600°C) for 1 h. The preparation of $TiO_2$ thin film with 10 drops of bacteriorhodopsin followed the same steps as above. A pigment sample (about 10 drops) was dropped into the solution of $TiO_2$ and a clear solution of $TiO_2$ was formed. It was continuously stir for 30 min at room temperature (Palomares *et al*., 2003; Halin *et al*., 2020).

***Four probe method***

Four probe method was used to measure the resistivity of semiconductors. $TiO_2$-coated thin film and bacteriorhodopsin- and phycocyanin-coated thin films have electrical conductivity and these films were used to check the resistivity of samples as per Hannachi *et al*. (2018), and Yu *et al*. (2019).

## RESULTS AND DISCUSSION

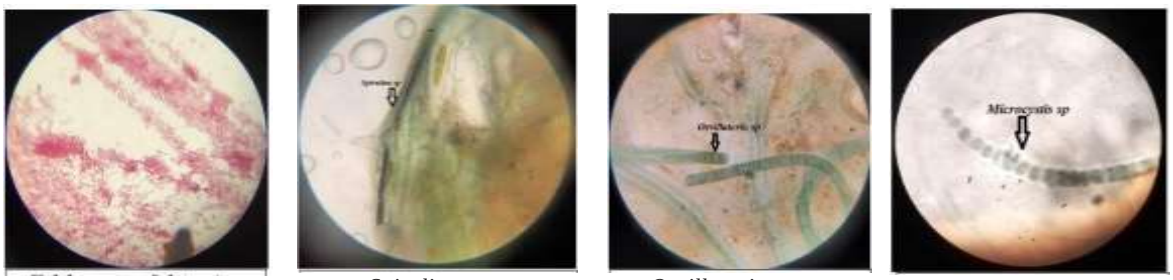
***Isolation and identification of Halobacterium and cyanobacteria***

Marine halobacteria were isolated from Saltpan sediment samples and their identity confirmed on the basis of their capability to produce red orange-coloured colonies in *Halobacterium* selective medium (Fig. 1) and biochemical characterization. The *Halobacterium* sp. isolates were Gram negative, rod-shaped, motile, catalase and oxidase positive, methyl red and Voges Proskayer positive, indole and citrate negative, and gelatinase positive. On the basis of culturo-morpho-biochemical characterization, the maximum bacteriorhodopsin producing isolate was tentatively identified as *Halobacterium salinarium* (Hasan and Mohammadian, 2011). From the algal mats collected, three cyanobacteria *viz*., *Oscillatoria* sp., *Spirulina* sp., and *Microcystis* sp., were isolated by pure culture techniques and identified on the basis of microscopic observation (Fig. 2) (Bakiyaraj *et al*., 2014).

**Table 1: Estimation of phycocyanin pigments of the isolated marine cyanobacteria**

| Marine cyanobacteria | Phycocyanin $OD_{620}$ value | Allophycocyanin $OD_{620}$ value | Phycoerythrin $OD_{620}$ value |
|---|---|---|---|
| *Oscillatoria* sp. | 0.564 ± 0.04 | 0.342 ± 0.03 | 0.268 ± 0.02 |
| *Spirulina* sp. | 0.421 ± 0.03 | 0.164 ± 0.02 | 0.165 ± 0.03 |
| *Microcystis* sp. | 0.186 ± 0.02 | 0.394 ± 0.02 | 0.284 ± 0.02 |

**Fig. 1: *Halobacterium* sp. grown on halophilic medium (left) and Zobell marine medium (right)**



*Halobcaterium salainarium* *Spirulina* sp. *Oscillatoria* sp. *Microcystis* sp.

**Fig. 2: Marine cyanobacterial isolates**

***Estimation of phycocyanin from cyanobacteria***

The extracted phycobiliproteins were estimated and the level of phycocyanin and allophycocyanin in the cyanobacteria measured. The results revealed the presence of three types of phycobiliproteins (phycocyanin, allophycocyanin, and phycoerythrin) in varying proportions in cyanobacteria (Khazi *et al*., 2018). *Oscillatoria* sp. had higher amount of phycobiliprotein than *Spirulina* sp., while *Microcystis* sp. possessed lessee amount of phycopiliprotein (Table 2). *Oscillatoria* phycobiliprotein was evaluated for future photosensitivity studies.

**Table 2: Resistivity and conductivity of the sample under dark condition**

| Samples | Resistivity ($\Omega$) | Conductivity ($\Omega^{-1}$ cm$^{-1}$) |
|---|---|---|
| $TiO_2$ | $1.950\times10^{6}$ | $0.512\times10^{6-}$ |
| Bacteriorhodopsin/$TiO_2$ | $0.244\times10^{6}$ | $4.098\times10^{-6}$ |
| Phycocyanin / $TiO_2$ | $0.360\times10^{6}$ | $2.770\times10^{-6}$ |

***UV spectral analysis of bacteriorhodopsin and phycocyanin***

UV spectral analysis revealed maximum absorption at 525 nm (Fig. 3), thereby indicating the presence of bacteriorhodopsin in *Halobacterium* sp. The *Halobacterium* strain had a third rhodopsin-like pigment that showed phototactic responses. The spectroscopic analysis revealed the presence of this third retinal-containing pigment in *Halobacterium* membrane fractions (Cao *et al*., 2015). The extracted phyocyanin pigment from 3 cyanobacterial isolates was subjected to UV spectral analysis by using a UV-Vis spectrophotometer (Shimadzu, UV 1650 PC), which confirmed the presence of phycocyanin by showing absorbance at 620 nm (Fig. 3).

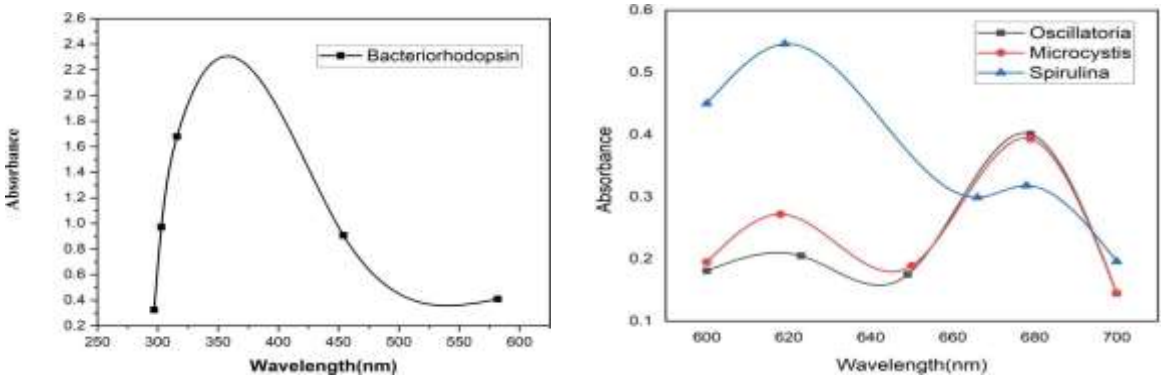



**Fig. 3: UV spectral analysis of a bacteriorhodopsin (left side) and phycocyanin (right side)**

***HPLC analysis of bacteriorhodopsin and phycocyanin***

During HPLC analysis the peak of bacteriorhodopsin appeared at various retention times. The peak obtained at a retention time of 2.507 indicated the presence of bacteriorhodopsin pigment (Fig. 4) and was in line with Khanafari *et al.* (2010). In present study, the retention time of bacteriorhodopsin was obtained at 3.653, which revealed the presence of bacteriorhodopsin as monoesters.

Phycocyanin of marine cyanobacteria were subjected to HPLC analysis. It revealed the retention times at 2.453, 2.455 (49.46%), 2.367 (10.97%), and 2.020 (11.80%) (Fig. 4). The fraction of phycocyanin chromophore was found in HPLC chromatogram at 2.3 and 2.4 min (Suresh *et al*., 2009).

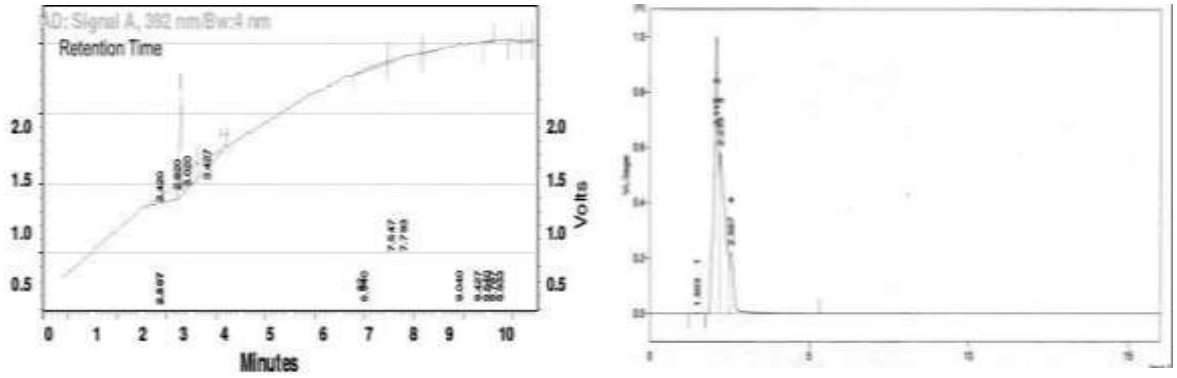



**Fig. 4: HPLC analysis of pigments; Bacteriorhodopsin (left side) and phycocyanin (right side)**

***Photosensitization study***

At room temperature, the UV-visible absorption spectrum of $TiO_2$ thin film was smaller than that of bacteriorhodopsin-coated $TiO_2$ thin film and phycocyanin-coated $TiO_2$ thin film in UV-visible region. The optical absorption peaks were observed at 40% in UV region and 42% in visible region in $TiO_2$ thin film (Guo *et al.*, 2015). Bacteriorhodopsin-coated $TiO_2$ thin films have 72% absorption in UV region and 60% in visible region (Fig. 5). The phycocyanin-coated $TiO_2$ thin film revealed that different absorption peaks greater than 100% were observed in the UV region, and a maximum of 80% absorption was observed in visible region. The band gap studies showed $TiO_2$ is a large-band gap semiconductor, which gained a lot of importance as a catalyst in the breakdown of organic substances under UV illumination. The term "band gap" refers to the energy difference between the top of the valence band and the bottom of conduction band, and the electrons are able to jump from one band to another. For an electron to jump from a valence band to a conduction band it requires a specific minimum amount of energy for the transition, which is the band gap energy. The top of valence band and the bottom of conduction band occur at the same value of momentum. The direct band gap calculations are given by the plot of $(\alpha h\nu)^n$ vs. photon energy ($h\nu$) for inter-band transitions.

$$(\alpha h\nu)^n = A\,(h\nu - Eg)$$

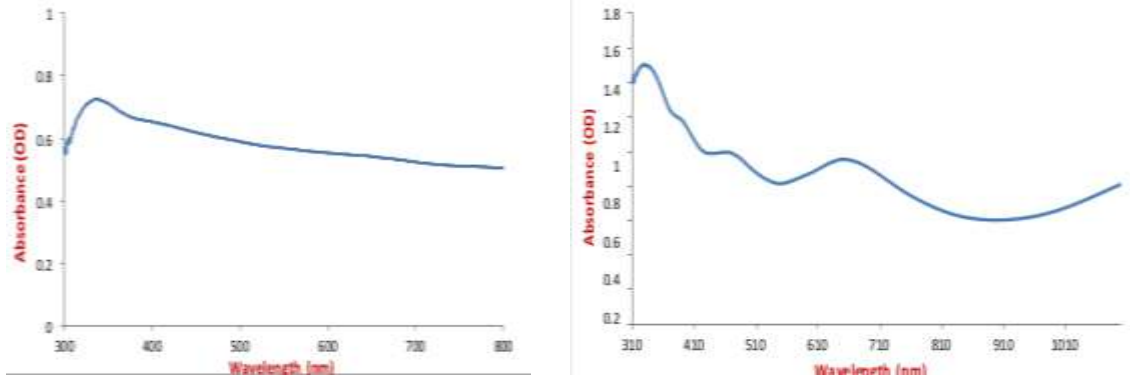



**Fig. 5: UV spectra analysis of a) bacteriorhodopsin and b) phycocyanin coated with $TiO_2$ thin film**

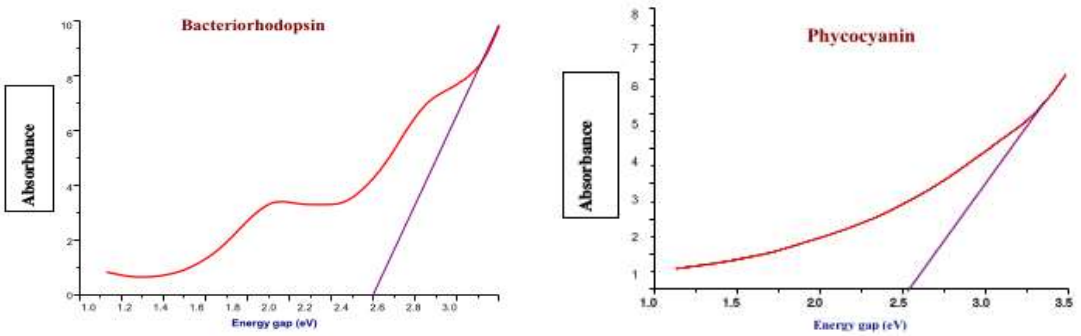



**Fig. 6. Band gap value of bacteriorhodopsin (left side)and phycocyanin coated with $TiO_2$ thin film (right side)**

The calculated direct band gap values were 3.6, 2.4, and 2.5 eV. The $TiO_2$ thin film band gap value was 3.6 eV (Xiang *et al.*, 2009; Karna *et al.*, 2011). $TiO_2$ along with the bacteriorhodopsin and phycocyanin-coated $TiO_2$ thin film band gap values of 2.5 and 2.4 eV, are lower than that of $TiO_2$ thin film (3.6 eV). The low band gap value is only used for high action of photosensitizing activity (Fig. 6).

***FTIR analysis of bacteriorhodopsin and phycocyanin-coated $TiO_2$ thin film***

The FTIR spectral analysis of bacteriorhodopsin-coated $TiO_2$ thin film (Fig.7) revealed that the FTIR data had peak values at 1571.99, 1548.84, 1571.99, and 1516.05. Each peak represented the functional group of bacteriorhodopsin, which has the molecular formula $C_{40}H_{52}O_4$. We analyzed the FTIR spectra of precursor and precursor solution prepared by alkoxide process. The C-O stretching in diethanolamine appeared at 1088 $cm^1$. The shift in band position is attributed to the C-O stretching to shift to a lower wavelength, i.e., from 1088 to 1049 $cm^1$, showing the weakening of C-O bond due to its chelation with $TiO_2$ octahedron (Dioumaev and Lanyi, 2007).

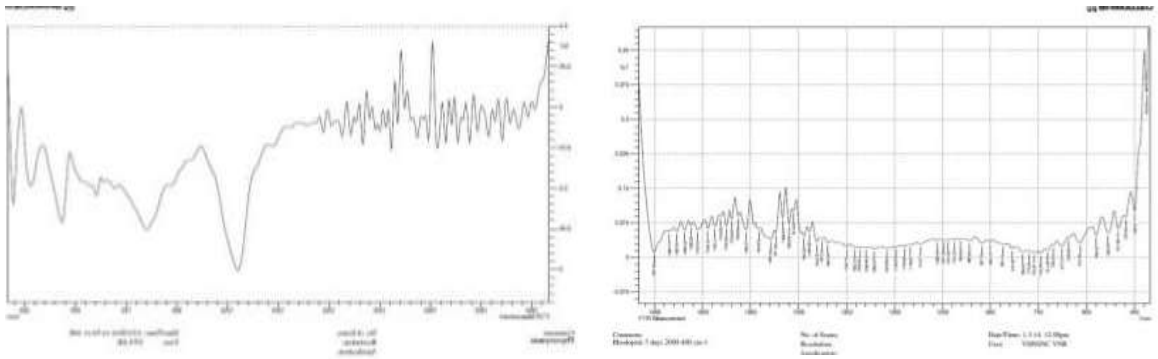


**Fig. 7: FTIR analysis of extracted pigments; Bacteriorhodopsin (left side) and Phycocyanin-coated with $TiO_2$ thin film (right side)**

The phycocyanin-coated $TiO_2$ thin film was analyzed by FTIR and compared with the previous finding as a result of FTIR analysis. The results revealed the type of phycocyanin pigment present in marine cyanobacteria sample was *Oscillatoria* sp. (Fig. 7b). The band positions 2575, 2325, 3525, and 3575 $cm^{-1}$ matched those attributes to the presence of proteins of phycocyanin (Prabakaran *et al.*, 2020; Duygu *et al.*, 2012). FTIR analysis of *Chlorella vulgaris* and *Scenedesmus obliqus* determined the spectral features and showed 11 distinct bands assigned to a range of vibrationally active chemical groups, including residual water (-OH), lipid (-CH2), cellulose (-C=O), and protein (amide).

***SEM analysis of $TiO_2$ coated with bacteriorhodopsin pigment***

The surface morphologies of samples were characterized by scanning electron microscopy to investigate the coating process of surface morphologies obtained by spin coating method at 3000 rpm with different samples (Mayabadi *et al.*, 2014). Fig. 8 shows the morphologies of $TiO_2$-coated thin

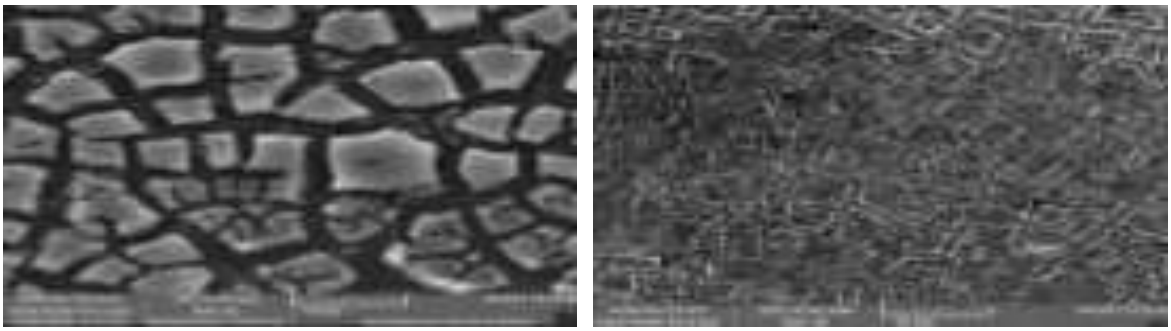


**Fig. 8: SEM analysis of pigments derived from *Halobacterium* sp.: Pure$TiO_2$ thin film (left side) and bacteriorhodopsin for $TiO_2$ coated thin film (right side)**

films. The samples had hexagonal crystal-like morphology. Bacteriorhodopsin-coated $TiO_2$ thin film showed interconnected, dense patch-like structure of nanoparticles (Fig. 8).

***Characteristics of the linear four probe method***

The halobacterial cyanobacterial pigment was coated on a $TiO_2$ thin film and subjected to the linear four-probe method under dark conditions (Fig. 9a) and UV illumination (Fig. 9b). The resistivity of $TiO_2$ thin film, bacteriorhodopsin, and phycocyanin-coated $TiO_2$ thin film drastically falls from $10^6$ Ω to $10^3$ Ω after illumination with UV light (Table 3 and 4) The conductivity of bacteriorhodopsin is high under UV illumination (Suciu *et al*., 2011). The resistivity of the electrical study of bacteriorhodopsin and phycocyanin-coated $TiO_2$ thin films shows that they can be potential candidates for solar cell applications.

**Table 3: Resistivity and conductivity of bacteriorhodopsin and phycocyanin pigments under UV illumination**

| Samples | Resistivity (Ω) | Conductivity ($\Omega^{-1}$ $cm^{-1}$) |
|---|---|---|
| $TiO_2$ | $2.27\times10^3$ | $0.440\times10^{-3}$ |
| Bacteriorhodopsin/$TiO_2$ | $0.76\times10^3$ | $1.316\times10^{-3}$ |
| Phycocyanin/$TiO_2$ | $0.91\times10^3$ | $1.098\times10^{-3}$ |

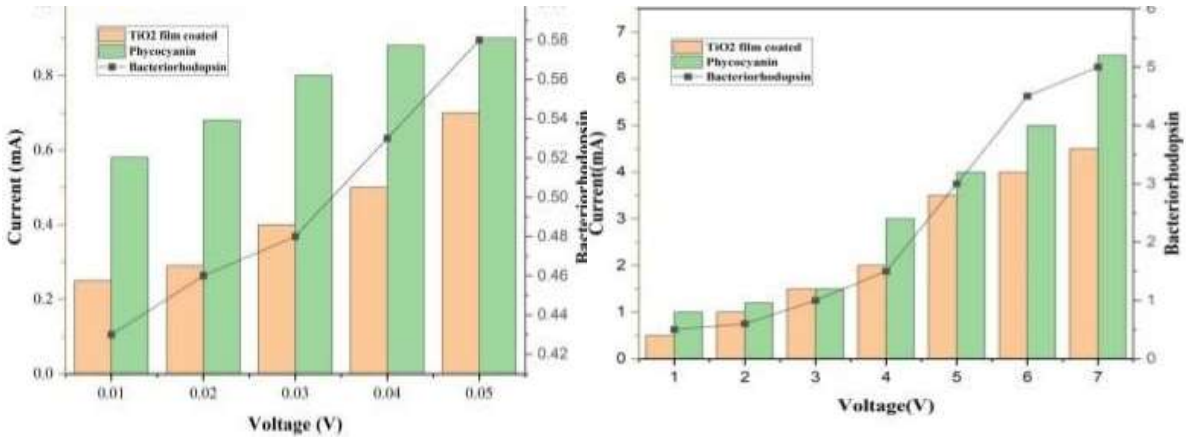



**Fig. 9: Four probe methods of resistivity and conductivity analysis of bacteriorhodopsin and phycocyanin pigments under dark condition (left side) and under UV illumination condition (right side)**

**Conclusion:** Nature has devised elaborate photosynthetic machinery for harvesting solar energy. The photosynthetic machinery comprises of a number of photoactive proteins that harvest solar energy and synchronize their functions to make the photosynthesis an efficient process. Bacteriorhodopsin in *Halobacterium* sp. is a protein embedded in the purple membrane of bacterium, uses light energy to pump protons from the cytoplasmic side to the extracellular side of cells, in the same way light is

transformed into electrochemical energy. Phycocyanin pigments, the phycobilliproteins of marine cyanobacteria, serve as major accessory pigments during photosynthesis, help to optimize light capture and energy transfer. Both these sensory pigments were evaluated for their photosensitivity along with $TiO_2$ semiconductor. The study revealed that the resistivity of photosynthetic pigment-coated $TiO_2$ thin film was drastically reduced. Based on the photosensitivity studies, both bacteriorhodopsin and phycocyanin can be potential candidates for solar cell fabrication. Further structural properties of photosynthetic pigments are needed to make these sensory pigments realize their potential as efficient photosensitizing substances.

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**Declarations of competing interests:** The author declares that they have no conflict of interest.

**Credit authorship contribution statement:** Data analysis, sample processing, and the original draught all contributed to the interpretation of the results. B. Ambika and G. Ramanathan revised the manuscript, conceptualised it, read the final manuscript suggestion, and validated the confirmation.

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