

Lecture 6a: Pigments and Photosynthesis

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1 Lecture Transcript: Pigments and Photosynthesis

1.1 Introduction

Good morning everyone, welcome back to BDC 223. Today we're going to follow on from our lectures on light, and we're going to be talking about pigments and photosynthesis. Much of today's discussion, and also the next couple of lectures about pigments as well as chromatic adaptation, is based on two papers I need you to read. The papers are both on eComva; you can find them there. Please read them while working through these lectures—it's quite important that you understand their content. Everything I'm going to talk about today will be explained in a lot greater detail in those two papers.

1.2 Overview of Pigments in Photosynthetic Organisms

So, in order to exploit the light available in the environment, plants and algae—indeed, all photo-oxygenic organisms—rely on a range of pigments that extract energy from light and convert it into chemical potential energy in the process of photosynthesis.

The predominant pigment in all photo-oxygenic production on Earth, and in all plants, algae, and cyanobacteria, is a molecule called chlorophyll-a. The chlorophyll-a pigment takes light energy and converts it into chemical energy. It is the only pigment that plays such a central role in photosynthesis. There are many other pigments called accessory pigments; they do not directly drive photosynthesis but support light harvesting.

1.3 Absorption Properties of Chlorophyll-a and Accessory Pigments

Chlorophyll-a absorbs light mainly in the blue and red regions. In the previous lecture you saw that visible light falls between roughly 390 nm to around 760 nm. That's the range of photosynthetically active radiation. However, within that range, not all light is equally effective at driving photosynthesis. This is because chlorophyll-a can maximally absorb light at 440 nm (blue light) and 675 nm (red light).

Regardless of where these primary producers are—on land, in water, or elsewhere—they are sensitive to blue and red light. If they do not have sufficient light at precisely those wavelengths, their rate of photosynthesis will be impaired.

Here are some graphs (Slide reference) that show the absorption for chlorophyll-a and chlorophyll-b. Chlorophyll-a, shown as the red line, has two main peaks: one around 425 nm (blue) and one in the red region around 660 to 675 nm. Chlorophyll-b has similar peaks but they are shifted: the blue peak sits nearer to 460 nm, closer to green, and the red peak falls slightly toward the orange region.

Chlorophyll-b does not drive photosynthesis directly, but it can harvest light and pass that energy to chlorophyll-a, thus broadening the range of light absorbed and utilised for photosynthesis. You'll notice that, in the middle of these spectra, there is a gap—a region where light is available yet not absorbed by chlorophyll-a or b. This is often referred to as the “green gap” and is the reason why plants appear green: green light is not absorbed by the major photosynthetic pigments in most leaves, so it is reflected back into the environment and to our eyes.

1.4 The Green Gap and Accessory Pigments

Plants have evolved various pigments to fill that green gap. Among the most notable of these are carotenoids, which include beta-carotene, and the phycobilins, such as phycoerythrin and phycocyanin. Carotenoids are also the pigments responsible for the orange colour in carrots, as indicated by the orange line on many absorption spectra.

The carotenoids and phycobilins absorb light in the green gap and pass that energy on to chlorophyll-a, enabling photosynthesis that would otherwise not occur at those wavelengths. These are called accessory pigments because they complement the absorption range of chlorophyll-a and make photosynthesis more effective in sub-optimal light conditions.

At first glance, the diversity of accessory pigments appears as vast as the diversity of light climates in the ocean, on land, and in freshwater. However, later experiments—especially those by Engelman, Haxo, and Blinks (to be discussed in your papers)—demonstrate that the diversity of accessory pigments does not necessarily correspond to the diversity of environmental light conditions.

1.5 Classification and Function of Pigments

There are three main pigment classes:

1. **Chlorophylls** – The major photosynthetic pigments. Chlorophyll-a is primary, with chlorophylls-b and -c acting as accessory pigments that transfer absorbed energy to chlorophyll-a.

2. **Carotenoids** – Includes beta-carotene and xantho-phylls, which also serve as accessory pigments.
3. **Phycobilins** – Reddish or purplish pigments, including phycocyanin and phycoerythrin, mainly found in certain algae and cyanobacteria.

Across all photoautotrophs, there are more than forty pigments involved. They bind differently to the proteins making up the photosynthetic machinery, expanding the plant's ability to absorb different wavelengths, especially in the green gap, and maintain high photosynthetic efficiency in a range of environments.

Especially in algae, the types of pigments present can indicate taxonomic relationships and phylogenetic heritage. By extracting pigments from a seawater sample, for example, one can deduce the classes of algae present. Similar underpinnings occur in terrestrial plants, with certain pigments associated with specific plant types.

1.6 What is Photosynthesis?

Photosynthesis is the conversion of light energy—radiant energy—into chemical potential energy. It drives carbon fixation: uptake of CO_2 from the environment, splitting water, and releasing oxygen as a byproduct. The reactions occur in the photosystems I and II.

As a function of light intensity, photosynthesis responds with an increased rate—to a point. This relationship is described by the photosynthesis-irradiance (PI) curve.

1.7 The Photosynthesis-Irradiance (PI) Curve

The PI curve (Slide reference):

- **Y-Axis:** Rate of photosynthesis, measured by carbon incorporation (e.g., $\text{mg C m}^{-2} \text{ s}^{-1}$, $\text{mg C m}^{-2} \text{ hr}^{-1}$, or $\text{mg C m}^{-2} \text{ day}^{-1}$).
- **X-Axis:** Irradiance (light intensity).

Initially, the PI curve is linear: as irradiance increases, photosynthesis increases at a rate defined by the slope α (alpha). Alpha reflects the plant's sensitivity to changes in irradiance. A steep alpha (steep slope) means more sensitivity to small changes in light; a shallow slope indicates less sensitivity and a need for greater changes in light intensity to affect photosynthesis rate.

At a certain point, the rate reaches saturation, denoted as I_k . This occurs where the extrapolated horizontal maximum rate (P_{max}) intersects with the linear part of the curve. Beyond this, increasing light does not increase photosynthetic rate since all the photosynthetic machinery is working at full capacity—much like pressing a car accelerator to the floor when the engine cannot go faster.

Should irradiance keep increasing, photosynthesis can decline—a phenomenon called photoinhibition. Here, excessive light can cause actual damage, or trigger protective mechanisms within the photosynthetic apparatus to prevent damage, analogous to running a car engine past its operating limits.

Respiration occurs at all times, consuming oxygen, while photosynthesis (in the presence of light) produces it. At low light, the rate of oxygen production by photosynthesis is less than the rate of

consumption by respiration, resulting in net negative oxygen production. The light compensation point is the irradiance where net oxygen production is zero.

Net photosynthesis: Above the compensation point—positive net oxygen evolution.

Gross photosynthesis: Total oxygen produced, regardless of respiration.

Understanding these parameters—the light compensation point, α , P_{max} , I_k , etc.—is crucial. We'll revisit this concept in practical sessions where you will fit models to real data.

1.8 Effects of Environmental Stress

P_{max} represents the maximum photosynthetic capacity, which is influenced by many stresses, including thermal stress, nutrient stress, and light stress. Any of these can reduce a plant's capacity to sustain P_{max} , and a reduction in this parameter is often the first sign of environmental stress. Measuring these rates gives insights into how and when plants become stressed.

Here are some indicative values (Slide reference):

- Intertidal environments: light saturation might occur at $400\text{--}600\mu\text{mol m}^{-2}\text{ s}^{-1}$
- Sublittoral species (deeper): saturated at $150\text{--}250\mu\text{mol m}^{-2}\text{ s}^{-1}$
- As depth increases, saturation occurs at progressively lower irradiances.
- Some deep-water plants can become photoinhibited at what would seem to us like relatively dim light.

These values— I_C , I_K , P_{max} , α —vary among species, being determined both by environmental adaptation and genetic heritage, and thus serve as good indicators of a plant's typical habitat and stress response.

1.9 Absorption Spectrum vs Action Spectrum

Before moving on, it's critical to distinguish the absorption spectrum from the action spectrum.

- **Absorption spectrum:** Measures the amount of light absorbed by all pigments at every wavelength—essentially, how much light is not reflected or transmitted.
- **Action spectrum:** For each wavelength, measures the biological effect—oxygen evolution rate—that results from absorption.

Typically, the action and absorption spectra match well, but not perfectly. For instance, between about 450 and 500 nm, there is a mismatch. This occurs because, beyond the optimal absorption peak of chlorophyll-a, carotenoids start absorbing light. While they can capture light within this region, they are less efficient at passing the energy to chlorophyll-a, resulting in a lower action than absorption value.

This demonstrates that the ability of accessory pigments to pass energy to chlorophyll-a is not perfectly efficient; some energy is lost in the process. Nonetheless, the presence of carotenoids extends the range in which photosynthesis can be driven by chlorophyll-a.

In summary, accessory pigments are essential in harvesting a broader range of light and making photosynthesis effective under varied light environments, even if energy transfer from accessory to primary pigments is not perfectly efficient.

Bibliography