MICROALGAE INTRODUCTION

Introduction

When thinking about the exciting scientific initiatives at NASA, algae don't typically come to mind. However, insight into nature can come from unexpected places. Algae, which most people view as a nuisance that often shows up in swimming pools and bird baths, is actually a group consisting of many thousands of species that exhibit an incredibly diverse array of interesting properties. Many people don't realize that a variety of products—from thickeners in ice cream and fertilizers that help crops grow, to nutritional supplements and ingredients in cosmetics—all come from one or more of these amazing algal species! NASA scientists realized a long time ago that the long history of algae-based discoveries on earth could be continued on space-based missions.

The word "algae" refers to an incredibly extensive and diverse group of aquatic organisms. There are two types: macroalgae and microalgae. The large multicellular macroalgae are found in freshwater environments such as ponds and streams, as well as in marine environments. These organisms are easily visible to the naked eye and tend to be measurable in inches, although giant kelp in the ocean can grow to well over a hundred feet in length. In contrast, microalgae are tiny single-celled organisms that grow in aqueous (*i.e.*, watery) environments and are measurable in micrometers (a micrometer is one one-millionth of a meter). Microalgae are commonly found in bogs, marshes, and swamps, although species may exist in a variety of habitats.

In 2018, NASA astronauts aboard the International Space Station (ISS) performed experiments[1] on *Chlamydomonas reinhardtii* (aka "Chlamy"), an algae species that has provided scientists with insights into the secrets of life for many decades. This particular mission involved experiments that attempted to identify the genetic attributes necessary for optimizing Chlamy's growth in a microgravity environment. In addition, a number of experiments were designed to determine whether stresses linked to the microgravity environment onboard the ISS would trigger Chlamy to produce valuable compounds that could be utilized either by astronauts in space or by people on Earth.

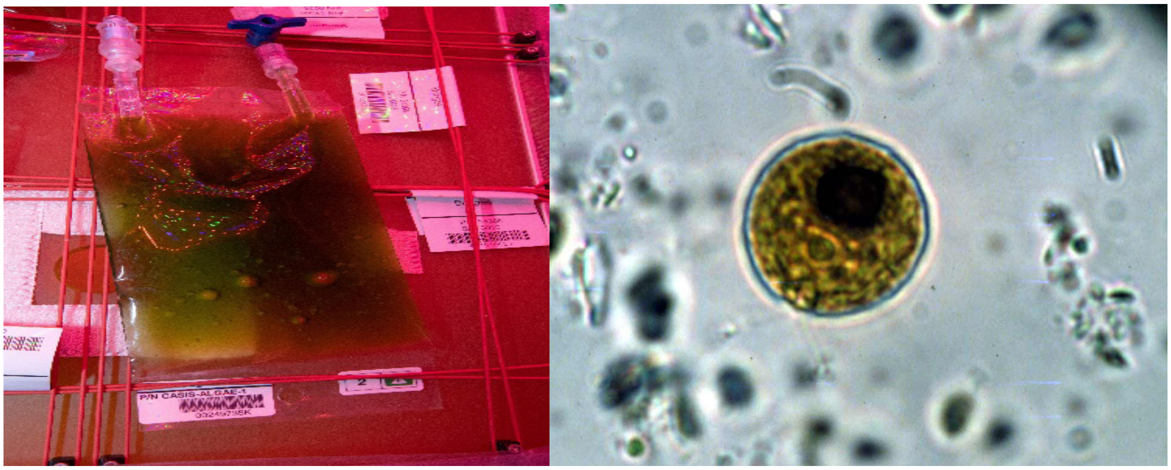

Figure 1. (left) Bag containing *Chlamydomonas reinhardtii* aboard the International Space Station[2]; (right) Micrograph of *Chlamydomonas reinhardtii*[3]

While NASA continues its important work with Chlamy, we now find ourselves at the beginning of a new algae project – a project that *you* can be a part of! The new alga (no, that is not a typo – did you know that *alga* is the singular form of the word *algae?)* at the center of this new mission is called *Haematococcus pluvialis*. Those algae species sure can be tongue twisters, can't they? Why don't we borrow a page from the Chlamy scientists and call *Haematococcus pluvialis* "Pluvi?" Whew…that is easier for *all* of us!

You may be asking the question, "Of all of the algal strains that NASA could have chosen to study aboard the ISS, why did they choose Pluvi?" In order to answer that question, let's start with some seemingly unrelated questions:

1) Have you ever wondered why salmon, shrimp and flamingos are pink?

2) Have you ever thought about the types of things that NASA does to help keep its ISS astronauts healthy despite them living in the hazardous environment of space?

Let's address these questions one at a time:

1) Salmon, shrimp and flamingos are pink because they eat Pluvi and other strains of algae that make a compound known as **astaxanthin**. Astaxanthin is one of the most potent antioxidants known to science[4], and has a deep red color. Organisms that consume large quantities of it tend to be either red or pink in color.

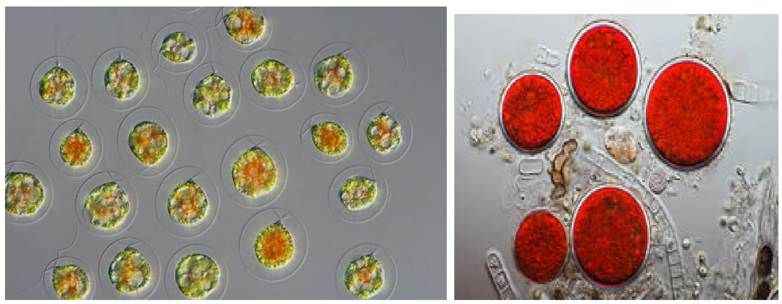

Figure 2. (left) *Haematococcus pluvialis* in early-stage astaxanthin production[5]; (right) *Haematococcus pluvialis* in late-stage astaxanthin production[6]

2) Astronauts aboard the International Space Station spend many consecutive months in space, and they face challenges that those of us on earth don't have to face. For example, the microgravity environment that they live in places stress on their muscles and bones because they don't have to work as hard as they do on earth where they constantly experience a gravitational field. As a result, these tissues often atrophy[7] unless the astronauts pay close attention to their nutrition and exercise regimens. In addition, they are constantly exposed to much higher levels of radiation than most of us because they don't have the protection of Earth's atmosphere while they are in space. Astaxanthin, a very potent antioxidant, can promote astronaut health aboard the ISS and generate tremendous long-term benefits for them.

Figure 3. Astronaut Steve Lindsey exercises while aboard the International Space Station[8]

The next question you may be asking is, “Why does Pluvi make astaxanthin in the first place?” It turns out that a number of species naturally contain astaxanthin. When conditions are favorable, Pluvi is a green alga and when they are stressful, the rapid increase in astaxanthin production turns the algae bright red. For Pluvi, astaxanthin production increases significantly when the microorganism is under stress. There are many types of stressors that can trigger the shift from green to red, but in most cases intense light is one of the stressors (typically in combination with a second stressor like nutrient deprivation or high salt concentration). During its “stressed out” phase, Pluvi changes from either a **non-motile** (*i.e.*, not capable of movement) cell or a **motile biflagellated** (*i.e.*, capable of movement because of the presence of two swimming appendages called **flagella**) cell to a **cyst** (*i.e.*, a tough, protective capsule capable of surviving harsh environments) filled with astaxanthin and therefore red in color. While, as you can imagine, the biological details of Pluvi’s life cycle are quite complex[11], astaxanthin essentially serves as a potent “sunscreen” for Pluvi that protects it from intense light and other stressors.

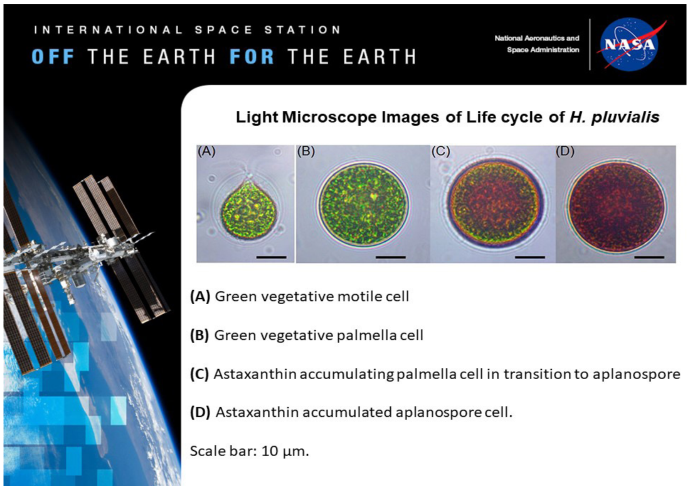

Figure 4. Light Microscope Images of *Haematococcus pluvialis* life cycle morphological stages[12]

So, you may be wondering why we care so much about astaxanthin, from a human perspective. While the jury is still out on the specific health benefits as an antioxidant, evidence suggests that it can serve as an enormous boost for many aspects of health. The primary benefit of any antioxidant is to neutralize **free radicals** (highly reactive molecules with unpaired electrons that are generated via normal biological processes). Free radicals cause *oxidative* damage to tissues and DNA and anti*oxidants* help prevent this damage. Astaxanthin is a potent antioxidant, being 6,000 times more effective than vitamin C, 550 times more effective than vitamin E and 40 times more effective than beta-carotene[13]. A number of studies indicate that this potent antioxidant activity can result in a number of health benefits including:

1) Brain health by preserving cognitive function[14].
2) Male fertility by helping improve sperm quality[15].
3) Reduction in eye fatigue[16].
4) Reduction in artherosclerosis[17].
5) Enhanced memory[18].
6) Demonstrated multiple beneficial effects when it comes to upping exercise performance and preventing injury[19].
7) Enhanced immune response[20].

8) Inhibition of proliferation (rapid increase) and spread of cancer cells[21].

9) Improved skin appearance and health[22].

10) Decreased chronic inflammation[23].

11) Improved joint health and reduced pain associated with rheumatoid arthritis[24]

12) Exhibited a number of anti-aging effects[25].

Figure 5. (left) Nutraceuticals are food supplements that enhance human health and well-being[9]; (right) Astaxanthin is a popular nutraceutical because of its powerful antioxidant properties[10].

Studies exemplified by the list above suggested that astaxanthin may hold a number of benefits for human health. For that reason, NASA has decided to investigate the potential that astaxanthin may hold for astronaut health on long duration space exploration.