Primary production: why do houseplants go yellow when they do not get enough light?

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Why do houseplants turn yellow when they do not get enough light?

Some examples

Figure 1: Examples of affected plants with yellow leaves

Storyline

Most houseplants are typically light or dark green, but they can sometimes turn red, purple or yellow when stressed or unhealthy (Figure 1). These colours are caused by the pigments found inside the chloroplasts, which are localized in the cells of plant leaves. The green colour is produced by chlorophyll, which dyes the chloroplasts. The primary function of chlorophyll is to capture energy from the sun and to channel it to the machinery inside the chloroplast. Throughout the life of the plant, and depending on environmental light conditions, pigment colours may shift to yellow due to carotene accumulation.

1.- **Houseplants**

Let's start with a bit of history about houseplants. They have been popular since ancient times. Around 5,000 years ago, the ancient Egyptians are believed to have brought plants such as ferns and palm trees indoors for decoration and bringing a touch of nature into their homes. With the knowledge of so many years, one may assume that caringfor them should be simple. Interest in houseplants surged in the 19th century and the terrariums (small indoor greenhouse) became increasingly popular.

For years we have used plants indoors not only for decoration (as home decor), but also to improve air quality and mental well-being. Our favourite houseplants include succulents, spider plants, pothos and many more. There are small and large ones, with or without flowers, with soft or strong leaves, light or dark green colour, sometimes red or orange and even white. Plants need sunlight to grow and we can find them almost everywhere in the wild. However, houseplants have had to adapt to conditions such as of indirect sunlight, limited watering, and resistance to strict indoor situations. Many plants are visually appealing and add aesthetic value to homes. Here are some examples of houseplants (Figure 2), all of them need sunlight for healthy growth.

Figure 2: Some examples of houseplants

2.- **The importance of sunshine and photosynthesis**

The thermonuclear fusion reaction of hydrogen to helium represents the primary source of energy in the Sun. Plants harness this solar energy through photosynthesis, storing it in chemical molecules. The visible spectrum ranges from 400 to 700 nm, and is known as photosynthetically active radiation (PAR), but within this range plants absorb and use more efficiently the blue (400 to 520 nm) and red (600 to 700 nm) wavelengths.

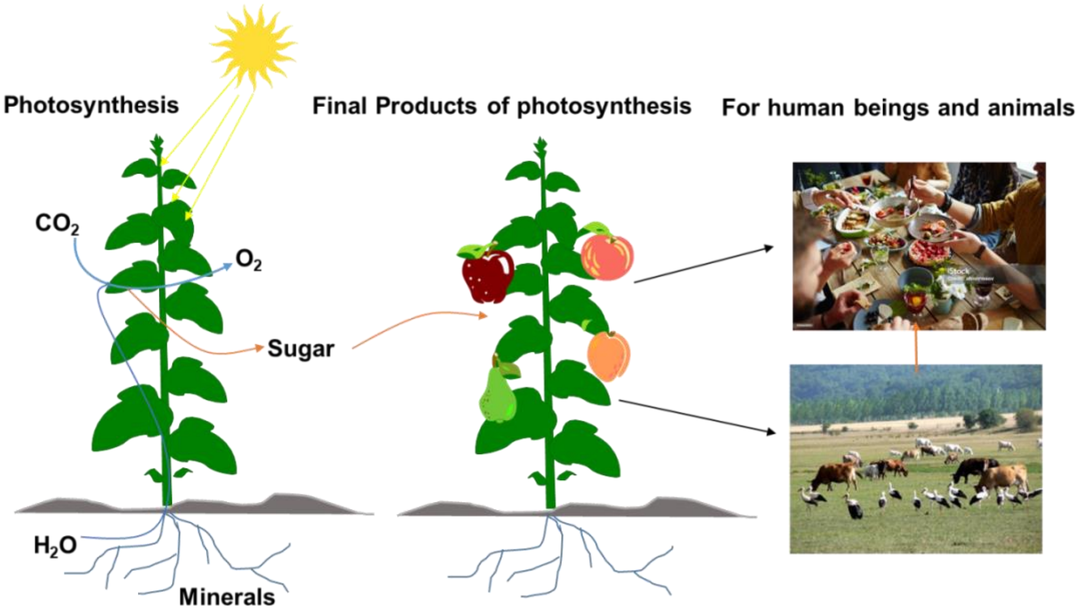

Figure 3: Main photosynthetic reactions in plants. Plants final products such as fruit, seeds, grains, cereals or tubers form the foundation of of human and animal nutrition.

Photosynthetic organisms cannot survive without light. In natural environments, sunlight is the primary driver of plant growth and productivity. But throughout the Earth's history, disruption in sunlight had profound effects on plant life and our planet. For instance, the Cretaceous-Paleogene mass extinction, 66 million years ago, had a significant impact on plant growth caused by dust and debris particles in the atmosphere, that blocked sunlight for nearly two years. This stopped photosynthesis worldwide, resulting in the extinction of around 50% of plant species, which in turn disrupted the food chain and led to widespread ecological collapse. Volcanoes, asteroids and other factors created bad conditions for plants in the past, which disrupted the food chain and led to mass extinctions. These events show how important photosynthesis is for the food chain and for life on the Earth.

The chloroplasts are considered the heart of plants, housing the machinery required for energy processing and to manufacture sugars and other backbones of the plants. Basically, inside the cholorplasts chlorophyll pigments together with proteins and other components convert solar energy into chemical energy. This energy facilitates the fixation of the atmospheric CO_2 and in combination with proton and electrons derived from water, H_2O, generates sugars and releases oxygen (Figure 3). Oxygen supports respiration living beings while sugars provide the structure of the plant and food for humans and animals when they produce fruit or seeds. By observing in detail the interior of the chloroplast, we can verify that the pigments are essential for the processes we have just described (Figure 4). Chlorophyll a and b are the most important for correct functioning of the photosynthetic machinery, but it cannot be ignored that it is the carotenoids which give the orange/yellow colour to the plant leaves. This colour is a symptom that informs us of the state of the plants due to lack of light, a nutrient or a disease. It is a defense mechanism that plants have developed.

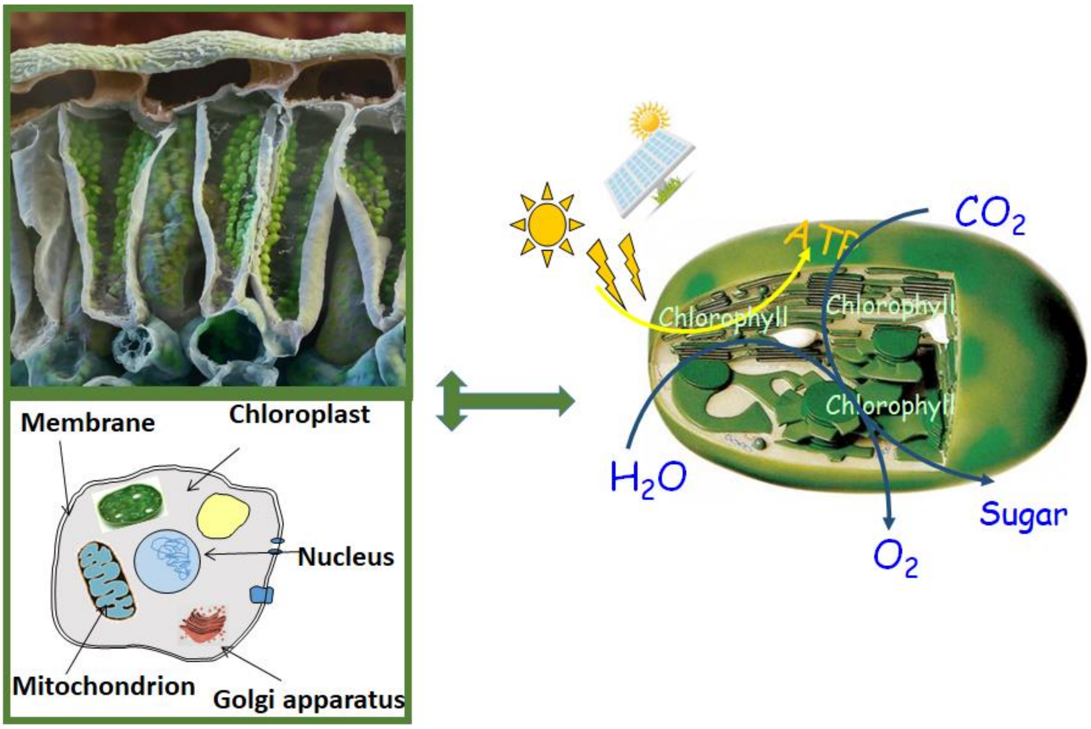

Figure 4: A microscopy view inside plant cells and chloroplasts.

3.- **Photosynthetic Pigments**

Pigments are molecules that absorb light and give plants their colours (Figure 5). Flowers and fruits contain various organic pigments that absorb light. Leaves, stems, and roots also contain pigments, including anthocyanins, flavonoids, flavins, and quinones. However, none of these should be considered as photosynthetic pigments. Photosynthetic pigments are able to absorb energy from sunlight and make it available to the photosynthetic apparatus. In land plants, there are two kinds of photosynthetic pigments: chlorophyll and carotenoids.

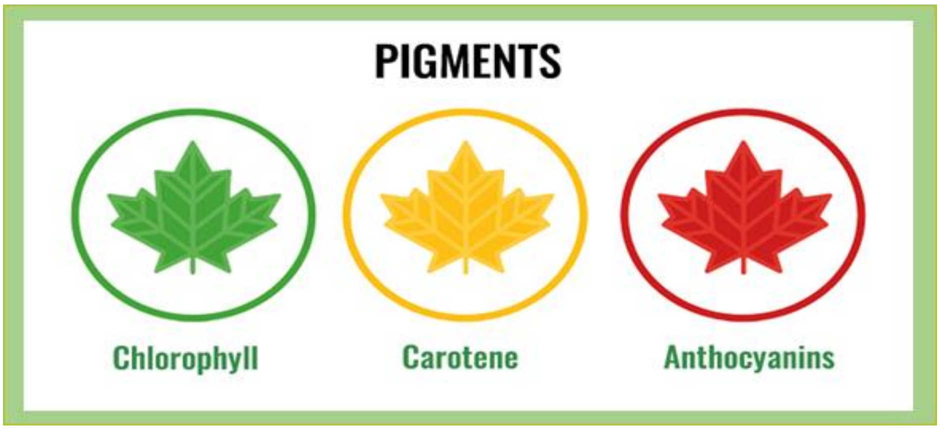

Figure 5: Main pigments in plants

a) What is chlorophyll?

Chlorophyll (from Greek chloros = green and phyllon = leaf) is the green pigment in the chloroplasts of plant cells. It absorbs sunlight, which is vital for the process of photosynthesis, allowing plants to convert light energy into chemical energy. During photosynthesis, chlorophyll absorbs energy from blue- and red-light while reflecting green light, making plants appear green (Figure 6) (Virtanen, 2022).

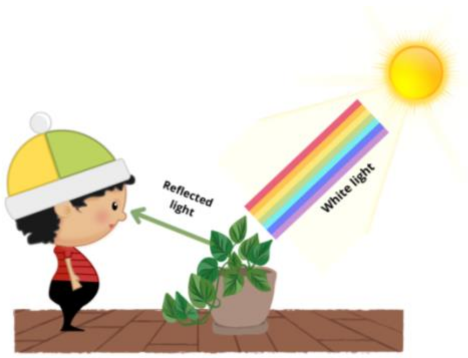

Figure 6: Plants appear green because chlorophyll absorbs mostly blue and red light, but green light is mainly reflected.

Chlorophyll consists of porphyrin ring structures linked to a hydrocarbon tail. There are several types of chlorophyll, including chlorophyll a and b, each playing a specific role in absorbing light (Figure 7).

- Chlorophyll a: The most essential pigment for photosynthesis in all plants, algae, and cyanobacteria. It absorbs light in the blue-violet and red parts of the spectrum.
- Chlorophyll b: An accessory pigment in green algae and plants that absorbs orange-red light and differing structurally from chlorophyll a.
- Chlorophyll c: Found in marine algae such as brown algae and diatoms, it is similar to chlorophyll a but has a slightly different structure.
- Chlorophyll d: Present in red algae and cyanobacteria, adapted for deep-water photosynthesis.
- Chlorophyll f: Found in some cyanobacteria, it absorbs light in the infrared range.

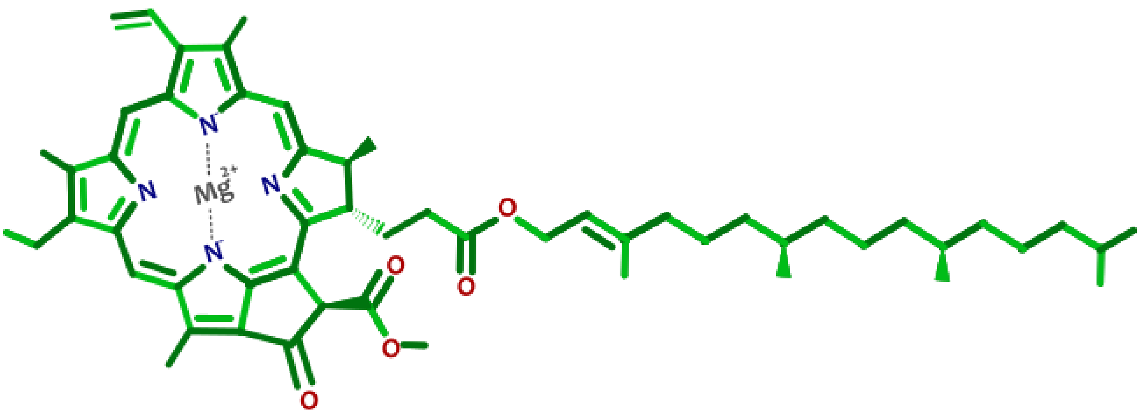

Figure 7: Chemical structure of chlorophyll includes a hydrophobic (‘water-fearing’) tail that inserts into the chloroplast thylakoid membrane and a porphyrin ring head (a circular cluster of atoms surrounding a magnesium ion) that absorbs light.

b) What are carotenoids?

Carotenoids are natural organic pigments found in plants, algae, certain fungi, and bacteria. They display a variety of colours, including yellow, orange, red and purple. Carotenoids act as accessory pigments and are capable of absorbing light in the violet and blue-green regions of the electromagnetic spectrum. They expand the range of light wavelengths that plants can utilize for photosynthesis and enhance overall light capture efficiency.

The chemical structure of carotenoids allows us to classify them into two main groups: carotenes and xanthophylls (Figure 8). Carotenes are non-oxygenated carotenoids such as beta-carotenes responsible for the orange colour of carrots. Xanthophylls are oxygenated derivatives of carotenes that function as antioxidants and protect photosynthetic cells. The most common carotene is the Lycopene, the red pigment found in red fruit and tomatoes.

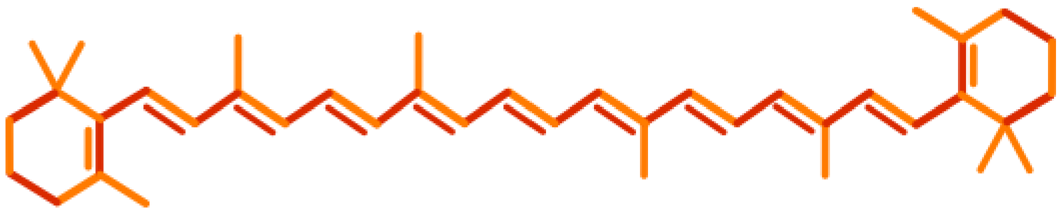

Figure 8: Chemical structure of Beta-carotene. This carotenoid is responsible for the orange colour of carrots and the orange-red hues found in many plant-based foods. The name “beta-carotene” comes from the Latin name for carrot.

In the photosynthetic organs of plants, carotenoids are involved in photosynthesis, harvesting light energy and transferring it to the chlorophyll. When leaves receive a large amount of energy, this excess energy can damage the photosynthetic apparatus. Carotenoids absorb excess energy from chlorophyll and release it as heat.

In the non-photosynthetic organs of plants such as fruit, pericarps, seeds, roots, and flowers, carotenoids act as photo-protectors, antioxidants, colour attractants and precursors of plant hormones (Maoka 2020).

c) What are anthocyanins?

Anthocyanins are water-soluble vacuolar pigments found in all the tissues of higher plants, including leaves, stems, roots, and especially in flowers and fruit, such as strawberries (Figure 9). They are responsible for the shiny orange, pink, red, violet, and blue colours of the flowers and fruit of many plants. Anthocyanins are polyphenols that act as natural sunscreens, absorbing UV light to protect plant cells. They belong to the flavonoid group, a class of secondary plant metabolites.

Figure 9: Ripe strawberry fruit contains anthocyanin. The change of pigments is observed throughout the different stages of strawberry ripening, from green (chlorophyll) to red (anthocyanin).

Anthocyanins are non-photosynthetic pigments that have many diverse functions within plants. The bright red and purple colours produced by anthocyanins serve to attract pollinators in flowers, whilst in fruit the colourful skin attracts animals to eat the fruit, thereby dispersing the seeds. They also act as a sunscreen, protecting the plant cell from high light stress by absorbing blue-green and ultraviolet light.

Anthocyanin pigments have been widely used as natural food colourants. However, the colour and stability of these pigments are influenced by pH, light, temperature and structure (Figure 10). At an acidic pH condition, anthocyanins are red pigments, whilst they shift to blue in a basic environment. However, at basic pH, anthocyanins are unstable and tend to degrade to dark brown oxidized compounds (Malotti 2020).

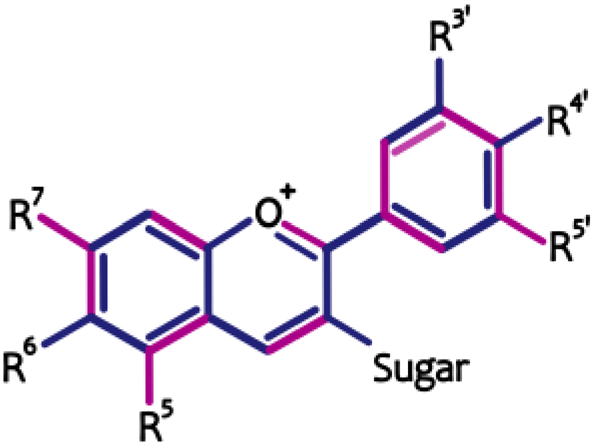

Figure 10: Chemical structure of the anthocyanin (anthocyanidins with a sugar group). In certain positions on these cyclic structures, hydrogen atoms are replaced by different functional groups (R = OH, $-OCH_3$).

4) Light is essential to avoid plants going yellow

The term "plant stress" is used to describe a state of imbalance in plants caused by external conditions that fall outside the optimal range for their development, such as an insufficient exposure to light. This imbalance results in disruption to cellular homeostasis, thereby preventing plants from reaching their maximum yield potential. Two principal categories of stress can be identified: abiotic stress, which is caused by non-biological factors such as temperature extremes, water deficit or excess, salinity, nutrient deficiencies , chemical products, light deficit or excess and nutritional deficiencies or excesses; and biotic stress, which is caused by biological factors such as diseases, pests, and viruses. In response to stress, plants may exhibit a range of adaptations, but too much stress can harm them.

The loss of chlorophyll results in the development of chlorosis, a condition characterised by the yellowing leaves due to chlorophyll degradation. Chlorosis is a condition that affects plants when they are deprived of light (a stress situation), resulting in a lack of photosynthesis and reduced chlorophyll production. For example, a houseplant will lose its green colouration and may exhibit yellowish hues when placed in a room where it does not receive an adequate level of light. Lacking light results in insufficient photosynthesis in plants, which weakens them. The reduction in light levels impedes the synthesis of chlorophyll, resulting in the characteristic yellowing of leaves. Plants with inadequate light exhibit stunted growth, impairing the capacity of the plant to produce essential nutrients. When the leaves of houseplants become yellow it is because they are ill and suffering from stress. The chlorophyll turns from green to yellow. If no solution is given, the houseplants can die in a few days. Different reasons are responsible for this drastic change.

Here is a good example of the relationship between the chlorophyll and light. Pea seeds were grown for a few days in the dark (Figure 11). The leaves were white (E=etiolated) and the stem became very tall searching for the light in comparison to pea seeds grown under sunlight (V:

green) shorter and green leaves. When etiolated plants are exposed to sunlight, the leaves become increasingly green thanks to the synthesis of the chlorophyll.

Figure 11: Pea seeds grown for a few days in the dark and then subjected to different light periods the increase of the chlorophyll pigment can be observed. The light dependence of chlorophyll is clear.

5) Preventing houseplants from turning yellow

A good recommendation is to find out about the light needs of each type of houseplant. Knowing the name of the plant and searching for specific information can provide interesting ideas for caring for them. The advice of the florist or nursery where you bought the houseplant would also be helpful (Figure 12).

Adjust placement of the plants; move plants to a well-lit area, such as a window. However, be careful and avoid excessive direct sun light since in for certain houseplants it might provoke the leaves to become pale. Additionally some houseplants can grow in shady areas of the house.

Figure 12: Phototropism, another interesting aspect of the attraction of plants to light!

6) Other causes of yellowing leaves?

Apart from light deficiency, nutrient imbalance can cause chlorosis. Plant nutrients are the ingredients that plants need to grow and develop. There are two main types of plant nutrients: macronutrients and micronutrients. Macronutrients are needed in larger quantities and include nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. Micronutrients are needed in smaller amounts and include iron, manganese, zinc, copper, boron, molybdenum and chlorine. Deficiencies in particular nutrients can result in a variety of symptoms in plants. For this reason, it is therefore vital that plants are grown in soil that contains all the necessary elements for optimal plant growth. For instance, a deficiency of nitrogen, iron or magnesium has been known can lead to yellowing leaves. It is important to note that magnesium makes the leaves green because it is found in chlorophyll, which is what gives leaves their colour. In addition, it is essential to consider other factors, including soil pH, which can affect nutrient uptake. Irrigation problems can also cause chlorosis. These include over watering, poor soil drainage, extreme temperatures, or root damage.

There are a few ways to deal with nutrient deficiencies in plant leaves. One is to spray the leaves with nutrients, which they can soak up quickly. You can also use fertilisers that have the nutrients they are missing in the right amounts. It is also important to adjust the soil pH (a measure of soil acidity), as this makes it easier for the nutrients to be used by the plants. A pH range of between 6.5 and 7.0 is widely considered to be the optimal level for the majority of plant life. Adding organic matter, compost, or other soil conditioners can help to keep the nutrients in the soil. You can also use deficiency correctors as chelating agents, which are substances that can join with metal ions in a watery solution to allow them to move through the plant. Chelating agents are used for iron chlorosis, calcium, magnesium, zinc, copper, and other micronutrients. Balanced fertilisation, tailored to the needs of the plant and soil conditions, is another effective method. Proper irrigation management, making sure the soil is moist enough, is crucial for optimal nutrient uptake. It is important to accurately identify deficiencies and apply the right treatments whilst maintaining a nutritional balance in plants.

Relevance to sustainable development goals and grand challenges

Advice: Maintaining healthy houseplants relates to several SDGs including:

Goal 1: provide adequate light and a good situation towards the sun.

Goal 2: ensure proper watering.

Goal 3: supply essential nutrients.

Pupil Participation

1. **Class discussion**: Explore the role of pigments, light needs and their importance.

a) What is the real function of the pigments?

b) Light is essential for the health of houseplants but what else?
c) Do you think that all houseplants need the same sunlight?
d) Are some pigments important for human health?

Example (for teacher): Plant anthocyanins have been widely studied for their medicinal properties. These natural chemicals have been found to help with diabetes, cancer, inflammation, heart disease, obesity and infections. Therefore, anthocyanins extracted from edible plants are potential pharmaceutical ingredients.

2. **Pupil Awareness**:

. Do all houseplants need the same care?

. Do all houseplants need the same sunlight intensity?

. Prepare a small dossier with recommendations for the care of houseplants.

3. **Hands-on Experiments**:

(1) Plant leaf chromatography to identify pigments

Go outside with the pupils and collect leaves of different colours from the trees. Autumn is the one of the best periods in which you can find the greatest variety in the colour of the leaves of the trees, from dark green to yellow, going through dark red or orange.

Cut a piece of leaf of equal size, no more than 1 x 2cm. A round punch could be very useful. Place each piece of leaf in an Eppendorf tube or mortar. Add 1 millilitre of 96% ethanol and extract the pigments. If available transfer the extraction to an Eppendorf tube from the mortar and centrifuge for 3 minutes. You will see the different tonality, as shown in the image below (Figure 13).

Use a pipette or Pasteur pipette to take a little of this solution and drop it to the bottom of a 1cm x 10cm strip of laboratory paper. And then put this strip of paper into a beaker/glass containing 1 cm of 96% ethanol. Let the alcohol migrate from the bottom to top (Figure 13). After approximately 30 minutes you will see several bands of different colours according to the pigment extracted from the leaves.

Compare the bands corresponding to the different pigments and discuss what the function of each one is according to the sunlight the houseplant needs.

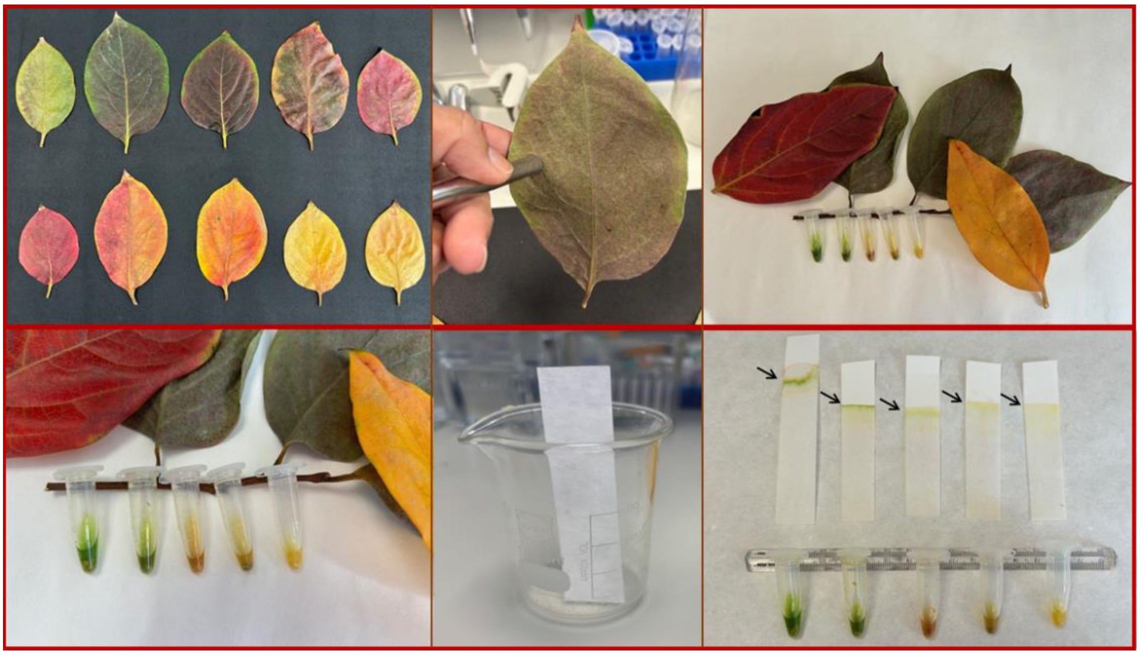

Figure 13: Plant leaf chromatography to identify pigments

(2) Phototropism

In a shoe box with a hole in the side, place a bean seed wrapped in moistened cotton. Allow several days for the seed to germinate, and open the box to observe in which direction the plant has grown.

(3) Plant growth assay

Take two identical plants and place one in the light and one in the dark, watering only when necessary. Over time, because of the ability of chlorophyll to capture light for photosynthesis, observe how the plant in the sunlight grows better. Meanwhile, the plant in the dark will begin to turn yellow and may grow less.

(4) Sunlight needs

Put some vermiculite in two empty plastic cups. Gently insert several pea seeds soaked overnight, and water. Place one of the cups beside the window (Figure 14) so that the sun shines on it or in a growth chamber if available and the other in a dark place (box or similar). Water as needed. After between 5-7 days observe the differences.

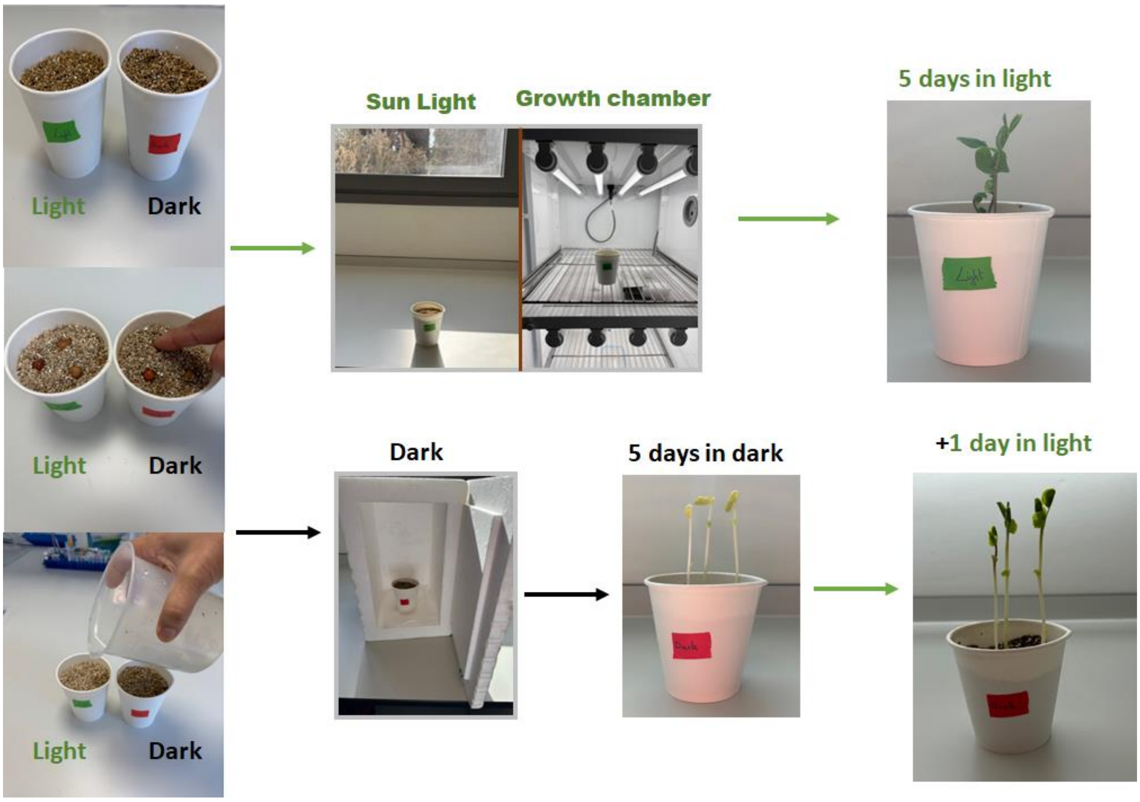

Figure 14: Pea growth under light and dark conditions.

The Evidence Base, Further Reading and Teaching Aids

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