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VCE Biology ¾ Photosynthesis & Biochemical Pathways [2.1]

Workbook Solutions

Outline:

Biochemical Pathways	Pg 04-08		
Revision of Enzymes			
Coenzymes		Adaptations of Photosynthesis	Pg 27-36
_		C4 Photosynthesis	
<u>Photosynthesis</u>	Pg 09-20	CAM Photosynthesis	
Introducing Photosynthesis		Comparing Photosynthetic Pathway	s
Structure of Plants and Chloroplasts			
Light Dependent Stage		Factors Affecting Photosynthesis	Pg 37-42
Light Independent Stage			
		Applications of CRISPR-Cas9 in	
<u>Photorespiration</u>	Pg 21-26	<u>Photosynthesis</u>	Pg 43-44
Rubisco	-	_	
Photorespiration			
,			



Study Design Key Knowledge:

Study Design: Photosynthesis as an example of biochemical pathways



The general structure of biochemical pathways in photosynthesis from initial reactant to final product.

Inputs, outputs and locations of the light-dependent and light-independent stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required).

The role of rubisco in photosynthesis, including adaptations of C3, C4, and CAM plants to maximise the efficiency of photosynthesis.

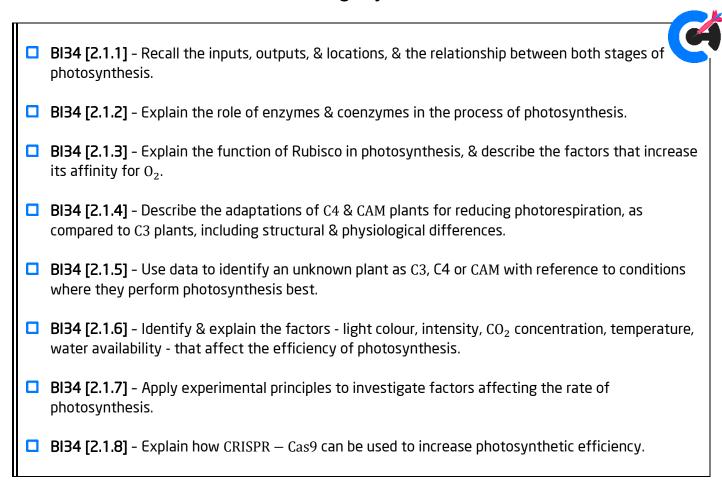
Potential uses and applications of CRISPR-Cas9 technologies to improve photosynthetic efficiencies and crop yields.

The factors that affect the rate of photosynthesis: light availability, water availability, temperature and carbon dioxide concentration.

https://www.vcaa.vic.edu.au/Documents/vce/biology/2022BiologySD.docx



Learning Objectives:





Section A: Biochemical Pathways

Sub-Section: Revision of Enzymes



What do we mean by biochemical pathway?



Do all reactions in a cell or organism happen at once?



Overview & Revision of Enzymes



- Biochemical pathways are incredibly important in the way our body functions both at a cellular level and overall.
 - Almost none of the processes or reactions in our body are "one-step processes".
- Ordinarily, you'd expect more steps to increase the time taken for a process to occur but the usage of enzymes allows us to control the rate of these pathways!

Active Recall: What are enzymes?



Head Tutor's Note: "Go through a quick 2 sentence defintion"

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Active Recall: What are the models of enzyme function?	?
Lock and key and induced fit - draw a diagram for it.	

<u>Active Recall:</u> What are the factors of enzyme function?



Go through temperature, pH and concentration, link this then to later on i.e these factors affect biochemical pathways because they affect the reaction as a whole.



Sub-Section: Coenzymes



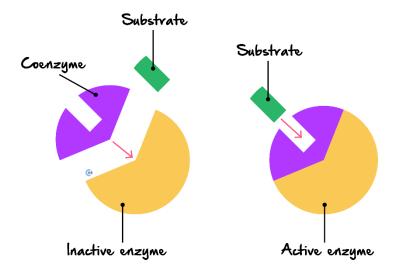
Do enzymes need any help in performing their function?



Coenzymes

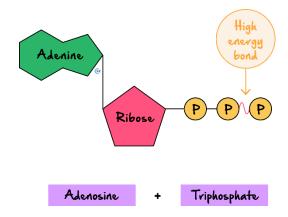


- These are molecules that are responsible for assisting in enzyme function in catalyzing the rate of reaction.
 - They can bind to the enzyme, changing the active site to allow for enzyme-substrate binding.



G They can provide protons and electrons for reactions i.e. act as electron and proton carriers.

• They can provide energy for cellular reactions.





Analogy









Key Takeaways



- ☑ Biochemical pathways involve multiple sequential reactions, each catalysed by specific enzymes.
- ☑ These pathways enable cellular efficiency by controlling reaction rates and ensuring metabolic balance.
- ✓ Importance of Enzymes:
 - Biological catalysts that reduce activation energy, allowing reactions to proceed faster.
 - They are specific to substrates, ensuring accurate reactions.
 - Models of enzyme activity: Lock-and-key and induced-fit models.

✓ Role of Coenzymes:

- Molecules like ATP, NADPH, and NADP⁺ assist enzymes by:
 - ✓ Providing energy (ATP).
 - ✓ Transferring electrons and protons (NADPH, NADP+).
 - ✓ Stabilising reactions and enabling enzymatic binding.



	Castors	Influencia	a Consuma	Cunction
\mathbf{Y}	Lacroiz	mnuencii	ıg ciizyiile	Function:

- **Temperature**: Optimal range boosts reaction rates, but extremes denature enzymes.
- **9 pH**: Deviations from optimal pH can reduce enzymatic activity.
- **G** Concentration: Reaction rates increase with substrate availability until saturation.

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Section B: Photosynthesis

Sub-Section: Introducing Photosynthesis



How do plants make their own food?



What are the steps of this process?



Overview

- Photosynthesis is the process by which plants convert light energy into chemical energy.
- "Make food from sunlight"
- There are many different ways that photosynthesis can occur in different species, and in VCE we look at some of the variations.
- The overall reaction is:

$$6CO_2 + 6H_2O \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

- CO₂ is said to be fixed to organic glucose.
- We can divide photosynthesis into 2 main stages:
 - The Light-Dependent Stage.
 - The Light-Independent Stage.

Misconception



" Water reacts with CO2 to make glucose and oxygen!"

TRUTH: Photosynthesis is a biochemical pathway, there are a lot of steps and the water and CO_2 are involved at different stages!



Exploration: Where in a plant does photosynthesis occur?



Occurs in specialised cells generally (in C3 plants) and the actual process takes place in the chloroplast of the cell.

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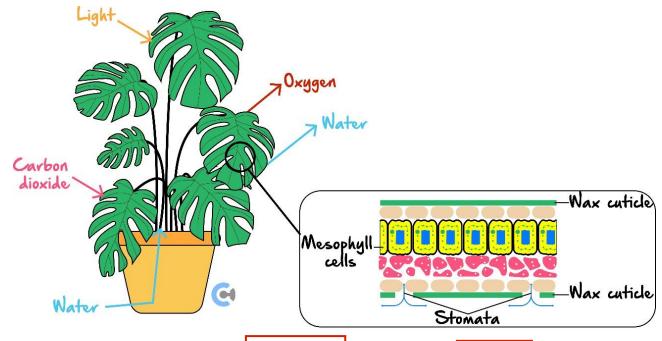


Sub-Section: Structure of Plants and Chloroplasts



Plant Structure and Photosynthesis

Photosynthesis, when thinking about plants, occurs in the ____ mesophyll ___ cells of a plant.

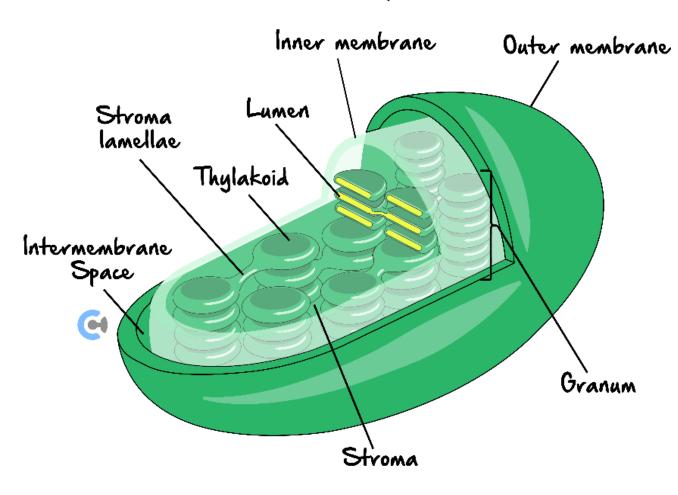


- Leaves are sealed off by the _____ wax cuticle ____, leaving the ____ stomata __ responsible for gas transfer from inside and outside the plant.
- Gearth Specifically, photosynthesis occurs in the chloroplasts of the actual mesophyll cells.



Chloroplasts

Chloroplast



This diagram shows the structure of a chloroplast in a plant cell - this is where photosynthesis occurs.

Exploration: Why is it green?

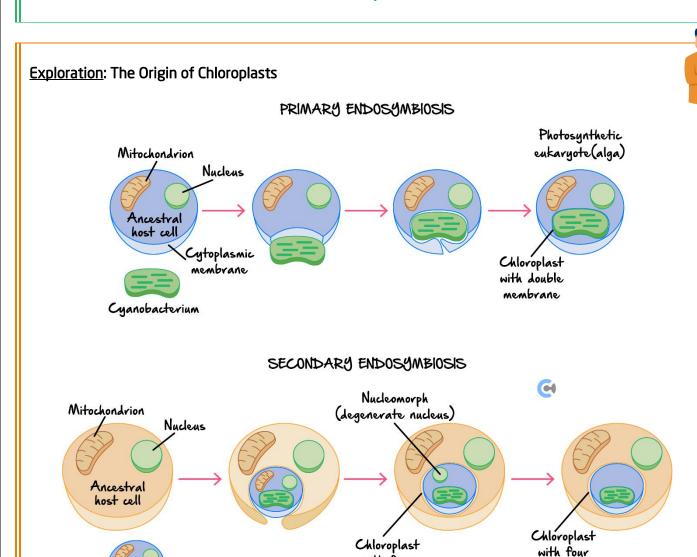




Why are plants green?



How did chloroplast evolve?



We can break photosynthesis into TWO key stages....

with four

membranes



membranes

Photosynthetic eukaryote(alga)



Sub-Section: Light Dependent Stage



Light-Dependent Stage



- The first set of reactions in photosynthesis as the name suggests it requires light!
 - Occurs inside the thylakoid membranes of the chloroplasts CHLOROPHYLL!
 - The purpose of this is to expressly convert the light energy of the sun, to chemical energy in the form of high-energy coenzymes.
- Involves 2 important coenzymes ATP and NADPH
 - ATP is the "energy currency" of the cell it provides energy to cellular reactions.
 - NADPH is an electron and proton carrier, it collects them and shuttles them at high energy from reaction to reaction around the cell.

<u>Inputs</u>	<u>Outputs</u>	<u>Location</u>
12H ₂ O	60 ₂	Thylakoid Membranes in Chloroplast
18ADP + Pi	18ATP	
12NADP+	12NADPH	





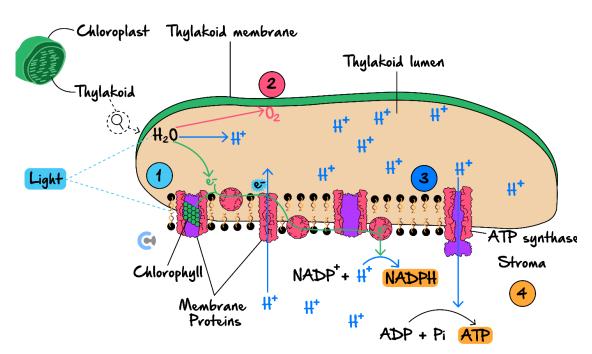
How does this work?



The Process of the Light-Dependent Reactions



- This is a complicated biochemical process but can be split into a few key steps.
 - G Light energy will hit the _ chlorophyll _ pigment, exciting _ electrons _ within it.
 - The _____energy ____ of these excited electrons is used by a protein to pump H⁺ ions into the lumen of the thylakoid membranes.
 - To replace the electrons used in that process, water is split to H^+ , electrons and O_2 . O_2 escapes as a waste product, while the H^+ add to the increasing concentration inside the lumen.
 - H⁺ ions will flow down their ___ concentration ___ from inside the lumen into the stroma, via an enzyme called ___ ATP synthase ___.
 - ATP synthase uses its kinetic energy to make ATP.
 - NADP+ collects the H+ and the electrons to make NADPH.



- 1 Light energy energises chlorophyll which pumps H⁺and splits water
- 2 Oxygen released
- 3 Ht and e generate NADPH and ATP
- 4 NADPH and ATP are inputs for the light-independent stage



NOTE: The specific details of these reactions and each step will NOT be assessed by VCAA.



ALSO NOTE: These details ARE useful in solidifying your own understanding and recognising the inputs, outputs and locations as required by VCAA.

w

TIP: Focus more on the inputs, outputs and locations of the process as required by VCAA, but also don't be afraid to think outside the box and think about how these steps may impact the process of photosynthesis.

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Sub-Section: Light Independent Stage



Light Independent Stage



- This is the second stage of photosynthesis, directly following the light-dependent reactions.
 - Occurs inside the ____ stroma __ of the chloroplasts.
 - The purpose of this is to fix carbon to become an organic compound which can then be used as a chemical energy source.
- Uses the direct products of the light-dependent stage.

<u>Inputs</u>	<u>Outputs</u>	<u>Location</u>
6CO ₂	Glucose (C ₆ H ₁₂ O ₆)	Stroma in Chloroplast
18ATP	18ADP +Pi	
12NADPH	12NADP+	

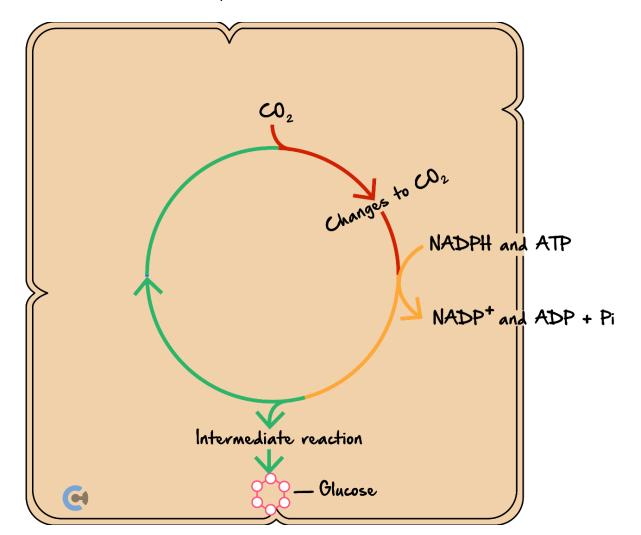




The Process of the Light-Independent Stage



- \blacktriangleright Essentially, a cycle of reactions that involves turning CO_2 into glucose.
 - © CO₂ first enters the ____ "Calvin Cycle" ___ and reacts with the enzyme ____ Rubisco to fix it into an organic carbon compound.
 - Through a bunch of reactions, the H⁺ ions, electrons and energy from them combine with the carbon compound, ultimately getting to a glucose precursor, which is the product of the Calvin cycle.
 - This is then converted to glucose via an intermediary reaction.
 - In the Calvin cycle, the oxygen remaining after the breakdown of CO₂ combines with leftover H⁺ and electrons to form the output water.



TIP: Keep focusing on the inputs, outputs and location!





NOTE: Some people may use the term light-independent stage interchangeably with the "Calvin cycle" – the Calvin cycle does NOT have glucose as a final product whereas the light-independent stage DOES.



<u>Exploration</u>: What happens to the coenzymes in photosynthesis once they have been uploaded in the LID stage?



Key Takeaways



- ✓ Overview:
 - Photosynthesis converts light energy into glucose, a chemical energy source for plants.
 - Balanced equation:

$$6CO_2 + 6H_2O \xrightarrow{light} C_6H_{12}O_6 + 6O_2$$

- Divided into two stages:
 - 1. Light-dependent stage: Captures light to produce energy-rich molecules (ATP, NADPH).
 - 2. Light-independent stage: Uses ATP and NADPH to synthesise glucose from CO₂.



✓ Light-Dependent Stage:

- Inputs: Light, H_2O , ADP + Pi, NADP⁺.
- Outputs: Oxygen, ATP, NADPH.
- **G** Location: Thylakoid membranes in chloroplasts.
- Process:
 - 1. Light excites electrons in chlorophyll, passing them to the electron transport chain.
 - 2. Water undergoes photolysis, producing oxygen, electrons, and protons.
 - **3.** ATP synthase generates ATP as protons flow down their gradient.
 - **4.** NADP⁺ captures high-energy electrons to form NADPH.

✓ Light-Independent Stage:

- **᠖ Inputs**: CO₂, ATP, NADPH.
- Outputs: Glucose, ADP + Pi, NADP+.
- Location: Stroma of the chloroplast.
- Process:
 - 1. The Calvin cycle begins with CO_2 fixation by Rubisco.
 - **2.** Energy from ATP and NADPH converts CO₂ into 3-carbon molecules.
 - **3.** The final steps produce glucose and regenerate RuBP to continue the cycle.
- Note: This stage depends on ATP and NADPH from the light-dependent stage.

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Section C: Photorespiration

Sub-Section: Rubisco



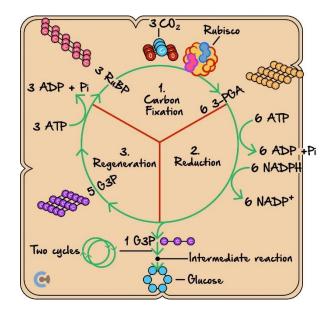
What is Rubisco?



What does it do?

Role of Rubisco in Photosynthesis

- Rubisco is a very important enzyme that is involved with the very first step of the Calvin cycle.
 - This reaction is the ____ carbon fixation ____ step (turning CO₂ into an organic molecule _).
 - G Initiates the _____ Calvin cycle
- Calvin Cycle Overview:
 - \bullet Carbon Fixation CO_2 and RuBP are converted into 3-PGA, by Rubisco.
 - Reduction NADPH gives electrons to an intermediate, to form G3P.
 - Regeneration G3P molecules are also converted to regenerate the RuBP required for step 1.





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Active Recall: What is carbon fixation?	?
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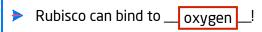


Sub-Section: Photorespiration



What else can Rubisco bind to?







photorespiration Leads to something called _ which does __ NOT _ produce glucose.

Rubisco 02 Calvin cycle photorespiration

photosynthesis can be completed

glucose is produced / plant can survive and grow × energy is wasted in reactions × no photosynthesis – no glucose is produced × plant survival and growth can suffer

Discussion: Why can Rubisco bind to oxygen?



Explain that those molecules might have similar shapes.

NOTE: The specifics of Rubisco's function are not necessary to remember fully but can be useful in understanding its shortcomings.





Exploration: Why is it a flaw for Rubisco to be able to bind to O_2 as well?



If there is no binding of CO_2 to Rubisco then there is no photosynthesis (specifically the Calvin cycle).

What factors affect photorespiration?



Exploration: In what condition would a plant most likely undergo photorespiration?



- Factors Impacting Photorespiration!
- Relative Concentrations
 - \bullet Higher concentration of O_2 leads to a higher affinity of Rubisco to O_2 .

- Temperature
 - \bullet Higher temperatures increase the affinity of Rubisco to 0_2 .

- Knowing this then photorespiration will be increased in hotter environments and drier environments
 - Explain the plant closing the stomata AND the temperature causing higher affinity as two different points.





Context



- Plants, over time, to adapt to certain environmental conditions have seen changes result in their processes of photosynthesis to overcome the Rubisco problem.
- Generally, this is seen through the changes in the Light Independent Stage there are two types we talk about in VCE, C4 plants and CAM plants.

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Key Takeaways



- ✓ Role in Photosynthesis:
 - G Catalyses CO₂ fixation in the Calvin cycle, initiating the synthesis of organic molecules.
 - Gan also bind oxygen, resulting in photorespiration.
- ✓ Photorespiration:
 - An inefficient process where oxygen binds to Rubisco, wasting energy and reducing glucose production.
 - Triggered by:
 - High temperatures, which increase Rubisco's affinity for oxygen.
 - Arr Low CO_2 levels, often due to stomatal closure in hot, dry conditions.
 - Hence normal (C3 plants) perform worse in hotter and drier environments.



What can plants do to overcome this problem?



Section D: Adaptations of Photosynthesis

Sub-Section: C4 Photosynthesis



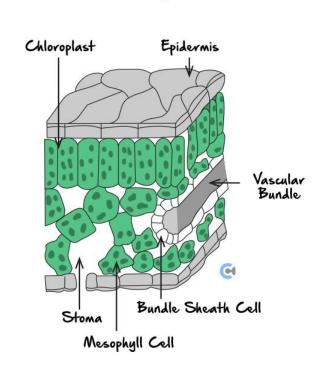
Context

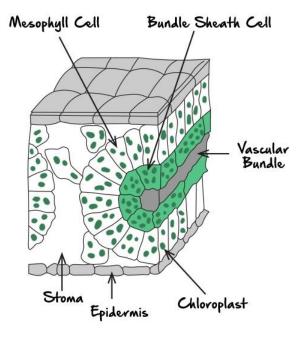


- C4 photosynthesis is essentially a process of photosynthesis that has been adapted slightly to suit hotter and humid conditions better.
 - The key difference can be described as the actual fixation of CO₂ by Rubisco occurring in a separate cell to the initial light-dependent interactions.
- C4 photosynthesis is used by plants such as corn, sugarcane, switchgrass and some weeds.

a. C₃ leaf







TIP: You don't need to remember the full biochemical pathway as I will explain it, but understand that it will help you describe the differences between C3, C4 and CAM photosynthesis.

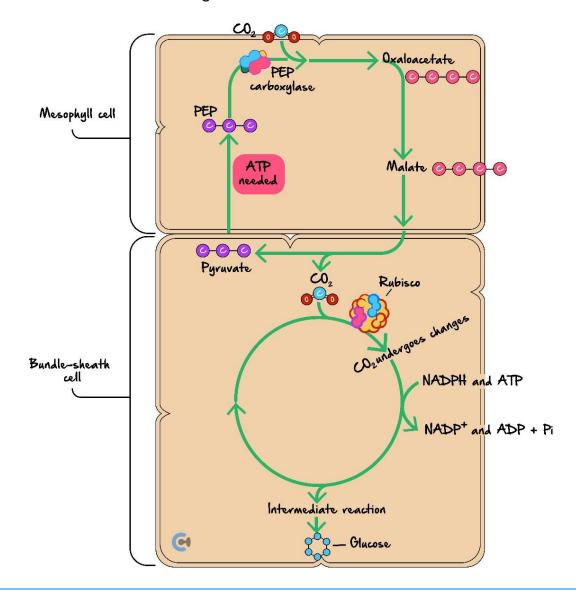
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The Process



- Light-Dependent Stage remains the same and occurs in a chloroplast of a mesophyll cell.
- However, the light-independent stage is split across 2 cells.
 - ${}^{\bullet}$ CO $_2$ enters the mesophyll cell, and instead of first interacting with Rubisco, it reacts with PEP and is fixed by the enzyme PEP carboxylase, creating oxaloacetate. PEP Carboxylase does NOT interact with O $_2$!
 - Oxaloacetate is converted into malate which can be transported to bundle and sheath cells.
 - Malate is released to CO₂ in the bundle and sheath cell which then reacts with Rubisco to trigger the Calvin cycle, resulting in the production of glucose.
 - The pyruvate that is formed from the breakdown of malate, is taken back to the mesophyll cell with the use of some ATP to regenerate PEP.





Exploration: Will the stomata be open or closed here?



It will keep the stomata open for gas exchange - water stress isn't a big deal. Even if the stomata is closed still works well due to the physical separation. Overcomes the increase in affinity in higher temperatures even if the stomata are open to prevent concentrations from building up.

Discussion: Why is this important that the PEP carboxylase has no affinity for O₂?



Head Tutor's Note: ""

so that it doesn't enter another

pathway which might not produce

oxaloncetale even in high Or

(oncentrations)

<u>Discussion:</u> How does this process overcome the problem of photorespiration in hot and dry conditions?



Head Tutor's Note: ""

By syrating the light independent stage into 2 cells, which separates indisco from where or will be, hence avoiding Rubis co briding to De and causing photoregarater.

<u>Discussion:</u> Why don't all plants use C4 if it overcomes photorespiration issues so efficiently?



Not all plants live in hot and humid conditions hence do not need to waste extra energy doing C4 photosynthesis





Key Takeaways



- Achieves this by fixing CO_2 to a different carbon compound and transferring that to a bundle and sheath cell.
- ☑ This means that Rubisco can operate in an environment that has high temperatures and is humid, improving photosynthetic efficiency.

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Sub-Section: CAM Photosynthesis



Overview

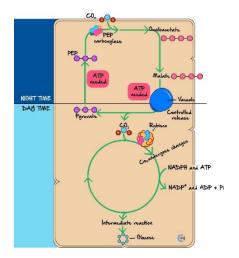
- Primarily suited to hot and dry conditions where they become more forgiving at night.
 - G Light-dependent stage and initial carbon fixation are separated by time.
- Found in plants such as cacti, pineapples etc.



Will the stomata remain open or closed?

The Process

- Light-Dependent Stage will occur during the day as normal.
- As the stomata are closed during the day, the only time CO₂ enters during the night, when there aren't enough products of the light-dependent stage.
 - \bigcirc To overcome this, CAM plants fix O_2 to malate and store it in vacuoles. This process is similar to O_2 plants, where O_2 is converted into oxaloacetate and then malate.
 - During the day, there is a controlled release of the malate into CO₂, which allows the concentrations to be maintained to minimise the impact of photorespiration.
 - There is ATP required to convert pyruvate into PEP and to release and store it in the vacuoles.





<u>Discussion:</u> How does this process overcome the problem of photorespiration in hot and dry conditions?



Discussion: Why doesn't every plant do CAM photosynthesis?



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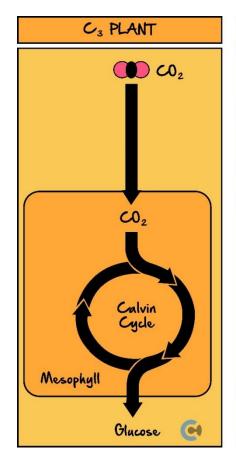


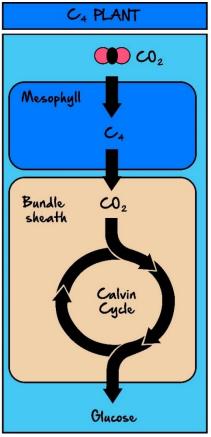
Sub-Section: Comparing Photosynthetic Pathways

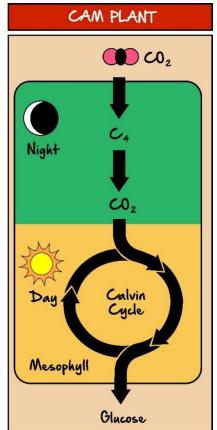
<u>Type</u>	<u>C3</u>	<u>C4</u>	CAM	
Separation of CO ₂ fixation and Rubisco	No	Between Cells	Between Night and Day	
Stomata Open	Day	Day	Night	
Advantages	No extra energy consumed	Minimises photorespiration	Minimizes photorespiration and also reduces water loss	
Disadvantages	Photorespiration Susceptibility	Extra Energy Consumed	Extra Energy Consumed	
Adapted to	Moderate, wet or cool habitats	Hot sunny habitats	Hot and extremely dry habitats	
Examples	80% of plants including trees	Corn, Sugarcane	Cacti, Pineapples	

Plant Characteristic	<u>C3 Plant</u>	<u>C4 Plant</u>	CAM Plant
ldeal temperature for photosynthesis	15-25°C	30-40°C	> 40°C
Pathway to fix CO ₂	Only Calvin cycle	C4 pathway and Calvin cycle	C4 pathway and Calvin cycle
Stomata during the day	Yes	Yes	No
Photorespiration occurring	High	Low	Only observed in the middle of the day.
Water loss during the day	High	Moderate	Low
Plant growth rate	Moderate	Fast	Very slow









Key Takeaways



- ✓ C4 Photosynthesis:
 - Adapted for: Hot, humid environments where high temperatures and high oxygen concentrations would otherwise promote photorespiration.
 - Key Features:
 - ✓ Spatial Separation of Processes:
 - Mesophyll Cells:
 - Arr CO₂ enters the leaf and is initially fixed into a 4-carbon compound (usually oxaloacetate) by **PEP carboxylase**, an enzyme with no affinity for oxygen.
 - Oxaloacetate is then converted into malate, a stable intermediate, which is transported to bundle sheath cells.



Bundle Sheath Cells:

- Malate releases CO₂, creating a high local concentration around Rubisco, ensuring that Rubisco binds CO₂ rather than oxygen.
- ✓ The Calvin Cycle operates in these cells to produce glucose.

Key Enzymes:

- Arr PEP carboxylase for the initial fixation of CO_2 .
- ☑ Rubisco operates only in CO₂-enriched bundle sheath cells, minimising photorespiration.

Energy Costs:

Additional ATP is required to transport malate and regenerate PEP (phosphoenolpyruvate), but this is compensated by the reduction in photorespiration.

✓ Advantages:

- Reduces water loss since stomata can remain partially closed without affecting CO₂ intake.
- Operates efficiently in environments with high light intensity and high temperatures.
- **Examples**: Corn, sugarcane, millet, sorghum.

CAM Photosynthesis:

Adapted for: Arid conditions where water conservation is critical, such as deserts and dry environments.

Key Features:

▼ Temporal Separation of Processes:

Night:

- Stomata open during cooler, more humid nighttime conditions to minimise water loss.
- \mathbf{V} CO₂ is fixed into oxaloacetate by **PEP carboxylase** and stored as malate in vacuoles.
- \checkmark This allows the plant to stockpile CO_2 without excessive water loss.



Day:

- Stomata remains closed to conserve water.
- Malate is transported from vacuoles to the chloroplast, where it releases CO₂ for the Calvin Cycle.
- ✓ The high internal CO₂ concentration reduces the risk of photorespiration even in high temperatures.

✓ Energy Costs:

- CAM is energy-intensive due to the storage and controlled release of malate.
- ATP is required to regenerate PEP for repeated CO₂ fixation.

✓ Advantages:

- Extremely water-efficient, making CAM plants well-suited to survive in desert ecosystems.
- Adaptable to prolonged periods of water scarcity.
- **Examples**: Cacti, pineapples, agave, jade plants.

<u>Characteristic</u>	<u>C3 Plants</u>	<u>C4 Plants</u>	<u>CAM Plants</u>
Temperature Optimum	15-25°C	30-40°C	> 40°C
Pathway	Calvin Cycle	C4 + Calvin Cycle	C4 + Calvin Cycle
Stomata Open	During the day	During the day	At night
Photorespiration	High	Low	Minimal
Water Loss	High	Moderate	Very low
Growth Rate	Moderate	Fast	Very slow

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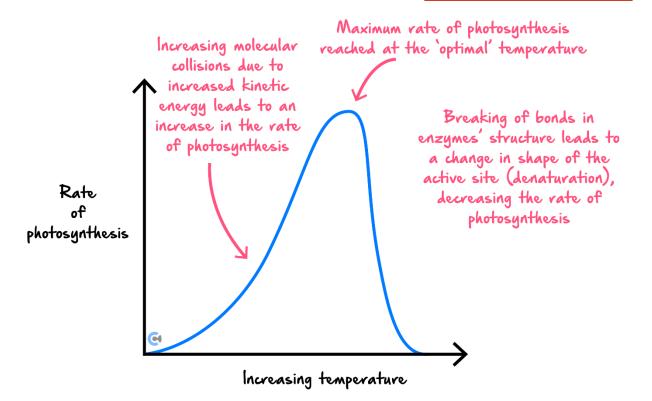


Section E: Factors Affecting Photosynthesis (7 Marks)

Exploration: Factors

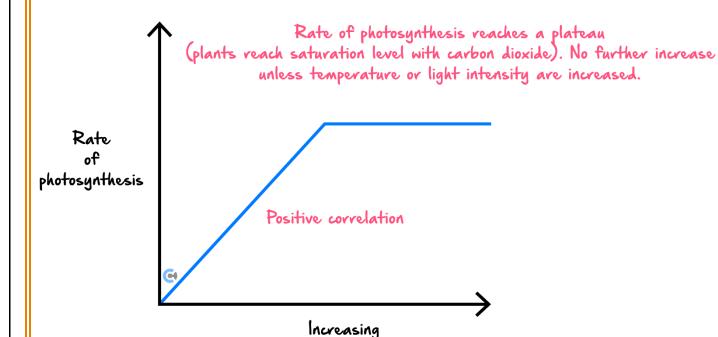
- There are a number of factors that impact the rate of photosynthesis in plants.
- These factors do not act in isolation, it is important to realise that it is all of them working in combination to determine the rate of photosynthesis.
- Light:
 - Generally speaking, the more light, the _____ faster ____ the rate of photosynthesis will occur.
 - G Happens to a certain extent until limited by other factors.
- Temperature:

• Increasing the temperature will increase the rate until enzymes begin to denature



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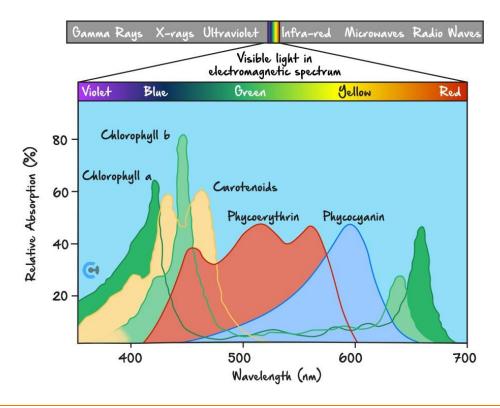
- Water:
 - More water available will generally __increase _ the rate of photosynthesis. However, plants maintain water the best out of all other factors!
- CO₂ availability:
 - More CO₂ available will generally _ increase _ the rate of photosynthesis, until
 other factors become limiting ____.



carbon dioxide concentration

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- Colour:
 - Different wavelengths of light are absorbed to different extents!



Exploration: How else might temperature and water influence the rate of photosynthesis?



Talking about higher temperatures leading to photorespiration, whilst lower water stores trap gas inside the cells.

Exploration: How will these factors affect C3, CAM and C4 plants differently?





Question 1 (7 marks)

A student found an unusual plant species growing in the local park. Without knowing what type of plants they were, the student undertook experiments to identify the photosynthetic output of the plants as measured by the rate of starch formed per day. Plants of the same size were exposed to different environmental conditions, and the rate of starch formed per day was measured. The results are shown in the table below.

Temperature (°C)	Light Source	CO ₂ (%)	Relative Humidity (%)	Rate of starch formed (mg/day)
20	White	5	70	1.7
20	White	1	70	1.3
20	White	5	30	1.9
20	Green	5	30	0.6
20	Blue	5	30	1.6
40	White	5	70	3.2
40	White	1	70	2.6
40	White	5	30	3.4
40	Green	5	30	0.8
** 40	Blue	5	30	2.9

^{**}VCAA inspired from 2023!

a. To which plant group (C3, C4 or CAM) would this unusual plant species most likely belong? Justify. (3 marks)

The plant species most likely belongs to the C4 group. This is justified by the following:

- 1. High starch production at $40^{\circ}C$: C4 plants are adapted to high temperatures and show higher efficiency in starch production under such conditions (3.4 mg/day at $40^{\circ}C$).
- 2. Efficient CO_2 utilization: The plant shows better starch formation at 5% CO_2 , a characteristic of C4 plants that concentrate CO_2 to reduce photorespiration.
- 3. Temperature adaptation: C4 plants are more efficient at higher temperatures, which is evident in the plant's response to $40^{\circ}C$ conditions.



	ny does exposing the plants to green or blue light as opposed to white light affect the formation of starch					
Ju	stify your answer. (4 marks)					
_	Exposing the plants to green or blue light instead of white light affects starch formation					
	because:					
	1. Green light absorption: Plants reflect most of the green light, meaning it is not effectively					
	absorbed for photosynthesis, leading to lower starch formation.					
	2. Blue light absorption: Blue light is absorbed more efficiently by chlorophyll, promoting					
	photosynthesis and higher starch production compared to green light.					
	3. White light absorption: White light contains all wavelengths, including blue and red, which					
	are efficiently absorbed by chlorophyll, supporting optimal photosynthesis and leading to					
	higher starch formation.					
	4. Starch production data: The plants produced more starch under white $(3.4 mg/day)$ and					
	blue light $(1.6 mg/day)$ compared to green light $(0.6 mg/day)$, showing the importance of					
	light absorption in starch formation.					

The plants produce more starch under white and blue light because these lights are better

absorbed by the plant, driving more efficient photosynthesis than green light.

TIP: Make sure you know which environment works for each plant type.



- Try and compare "like" measurements, i.e. where only one variable is changing.
- Look for overall trends in the data as well as individual measurements referenced in your answers.



- Factors Affecting Photosynthesis:
 - Light Intensity:
 - ✓ Increased light boosts the rate of photosynthesis until other factors become limiting.
 - Saturation occurs when enzymes and substrates are fully utilised.
 - Temperature:
 - ✓ Optimal temperature allows enzymes to function efficiently.
 - Beyond the optimal range, enzymes denature, and photorespiration increases.



_				
(H)	Water	Avai	labil	litv:

- ☑ Essential for photolysis in the light-dependent stage.
- ightharpoonup Limited water leads to stomatal closure, reducing CO_2 intake.
- **©** CO₂ Concentration:
 - ☑ Higher CO₂ levels increase the rate of photosynthesis until Rubisco is saturated.
- G Light Wavelength:
 - ☑ Blue and red light are most effective; green light is reflected, giving plants their colour.

Space for Personal Notes		



Section F: Applications of CRISPR-Cas9 in Photosynthesis

Overview



- CRISPR-Cas9 is a gene editing technology which allows us to make precise edits.
- If we can determine greater control over this technology, we can use it to alter the DNA of crops to make them more suited to our needs - increasing their efficiency and crop yields.

Exploration: Why would it be important to try and increase crop yields and efficiency?



- Rising global population need more food
- Land usage in growing the food might be take up too much if more food is required
- Makes it more profitable economic incentive

Potential uses of CRISPR-Cas9



- CRISPR-Cas9 can alter and intervene at a variety of stages in the plant's cycle which could improve the efficiency of photosynthetic processes.
 - Improve the Calvin Cycle. How?

Enzymatic improvements - Rubisco. Altering C3 plants and their pathways. Alternative routes to photorespiration to reduce it.

Plant Tolerance?

Improved drought tolerance. Frost tolerance. Heat stress.

Diseases?

CRISPR-Cas9 can be used to improve plant resistance to diseases by editing genes that control immune responses, making plants more resistant to pathogens. Additionally, it can be used to enhance the plant's ability to recover from infections, ultimately improving crop yields and plant health.



Product Enhancement?

Make the actual crop better, and last longer to prevent wastage.

Chemical Efficiency?

CRISPR-Cas9 can improve the chemical efficiency of plants by modifying genes involved in photosynthesis, nutrient uptake, and metabolic pathways. This can lead to enhanced growth, better resource utilization, and improved crop yields, optimizing the plant's ability to convert sunlight and nutrients into energy more efficiently.

<u>Exploration</u>: What would be the steps in applying this gene editing tool to determine and improve crop yields?



- Understanding the process of photosynthesis in that specific plant and making sure that inefficiencies are highlighted.
- Computer modelling to determine inefficiencies.
- Determining the genes responsible and the necessary edits.
- Designing CRISPR-Cas9 to undertake these edits.

- Applications of CRISPR in Photosynthesis:
 - Potential Improvements:
 - **☑ Rubisco Efficiency**: Modify Rubisco to reduce oxygen binding, minimising photorespiration.
 - **C4 and CAM Pathways**: Introduce these adaptations into C3 crops for broader resilience.
 - ☑ Environmental Tolerance: Engineer plants to tolerate drought, heat, or frost.
 - ✓ Yield Enhancement: Optimise photosynthesis for greater crop production.
 - Steps in CRISPR Application:
 - 1. Identify inefficiencies in photosynthesis using computational models.
 - 2. Target genes responsible for inefficiencies.
 - **3.** Design CRISPR systems to edit these genes precisely.
 - **4.** Test and refine plants for improved photosynthetic performance.





Contour Check

<u>Learning Objective</u>: [2.1.1] - Recall the inputs, outputs, & locations, & the relationship between both stages of photosynthesis

Study Design

Inputs, outputs and locations of the light-dependent and light-independent stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required).

- ☐ Light-Dependent Stage:
 - o Inputs: Light, water, ADP + Pi, NADP+
 - Oxygen, ATP, NADPH
 - O Location: _ Thylakoid membranes in chloroplasts _
 - O Process:
 - 1. Light excites electrons in chlorophyll, passing them to the electron transport chain.
 - 2. Water undergoes photolysis, producing oxygen, electrons, and protons.
 - **3.** ATP synthase generates ATP as protons flow down their gradient.
 - **4.** NADP⁺ captures high-energy electrons to form NADPH.



	Light-	Indepe	ndent	Stage:
_				

- O Inputs: ___ CO₂, ATP, NADPH ____.
- Outputs: __Glucose, ADP + Pi, NADP+ _.
- O Location: __ Stroma of the chloroplast __
- O Process:
 - 1. The Calvin Cycle begins with CO₂ fixation by Rubisco.
 - 2. Energy from ATP and NADPH converts CO₂ into 3-carbon molecules.
 - 3. Final steps produce glucose and regenerate RuBP to continue the cycle.
- Note: This stage depends on ATP and NADPH from the light-dependent stage.



<u>Learning Objective</u>: [2.1.2] – Explain the role of enzymes & coenzymes in the process of photosynthesis

Study Design

The general structure of biochemical pathways in photosynthesis from initial reactant to final product.

Key Takeaways

	Role	of Coen	zymes:
--	------	---------	--------

- Molecules like ATP, NADPH, and NADP⁺ assist enzymes by:
 - Providing energy (ATP).
 - Transferring electrons and protons (____NADPH, NADP+____)
 - Stabilising reactions and enabling enzymatic binding.

■ Importance of Enzymes:

- O Biological catalysts that reduce activation energy, allowing reactions to proceed faster.
- They are specific to substrates, ensuring accurate reactions.
- Models of enzyme activity: Lock-and-key _ and _ induced-fit _ models.



<u>Learning Objective</u>: [2.1.3] - Explain the function of Rubisco in photosynthesis, & describe the factors that increase its affinity for \mathbf{O}_2

Study Design

The role of rubisco in photosynthesis, including adaptations of C3, C4, and CAM plants to maximise the efficiency of photosynthesis.

- Role in Photosynthesis:
 - Rubisco fixes CO₂ into organic molecules in the Calvin Cycle, initiating the synthesis of organic molecules.
 - Can also bind oxygen, resulting in photorespiration
- Photorespiration:
 - An inefficient process where oxygen binds to Rubisco, wasting energy and reducing glucose production.
 - O Triggered by:
 - High temperatures, which increase Rubisco's affinity for oxygen _.
 - Low CO₂ levels, often due to stomatal closure in hot, dry conditions



<u>Learning Objective</u>: [2.1.4] - Describe the adaptations of C4 & CAM plants for reducing photorespiration, as compared to C3 plants, including structural & physiological differences

Study Design

The role of rubisco in photosynthesis, including adaptations of C3, C4, and CAM plants to maximise the efficiency of photosynthesis.

Key Takeaways				
C_4	Phot	osyn	thesis:	
0	-		for : Hot, humid environments where high temperatures and high oxygen ations would otherwise promote photorespiration.	
0	Key	Feat	ures:	
		Spatia	al Separation of Processes:	
	C) M	esophyll Cells:	
			${\rm CO_2}$ enters the leaf and is initially fixed into a 4-carbon compound (usually oxaloacetate) by _ PEP carboxylase , an enzyme with no affinity for oxygen.	
			Oxaloacetate is then converted into malate, a stable intermediate, which is transported to bundle sheath cells.	
	() Bı	undle Sheath Cells:	
			Malate releases CO_2 , creating a high local concentration around Rubisco, ensuring that Rubisco binds with CO_2 rather than oxygen.	
			The Calvin Cycle operates in these cells to produce glucose.	
	C) Ke	ey Enzymes:	
			PEP carboxylase for the initial fixation of CO_2 .	
			Rubisco operates only in CO_2 -enriched bundle sheath cells, minimising photorespiration.	



☐ Energy Costs:						
	 Additional ATP is required to transport malate and regenerate PEP (phosphoenolpyruvate), but this is compensated by the reduction in photorespiration. 					
O Examples: Corn, sugarca	ne, millet, sorghum.					
☐ CAM Photosynthesis :						
Adapted for: Arid cond	itions where water conservation is critical, such as deserts and dry environments.					
Key Features:						
Temporal Separation	of Processes:					
O Night:						
Stomata ope loss.	ns during cooler, more humid nighttime conditions to minimise water					
☐ CO₂ is fixed i vacuoles.	nto oxaloacetate by _ PEP carboxylase _ and stored as malate in					
O Day:						
Stomata rem	ains closed to conserve water.					
Malate is transfor the Calvir	nsported from $\underline{\hspace{0.1cm}}$ vacuoles $\underline{\hspace{0.1cm}}$ to the chloroplast, where it releases CO_2 n Cycle.					
The high in high temporal	nternal CO_2 concentration _ reduces the risk of photorespiration even eratures.					
Energy Costs:						
 CAM is energy-intensive due to the storage and controlled release of malate. 						
 ATP is required to regenerate PEP for repeated CO₂ fixation. 						
Cacti, pinea	apples, agave, jade plan					



<u>Learning Objective</u>: [2.1.5] - Use data to identify an unknown plant as C3, C4, or CAM with reference to conditions where they perform photosynthesis best

Key Takeaways

- Key Indicators in Data:
 - C3 Plants: Moderate temperatures (15–25°C), high photorespiration under high oxygen conditions, and significant water loss during the day.
 - C4 Plants: High temperatures (30–40°C), low photorespiration due to CO₂ concentration mechanisms, and moderate water efficiency.
 - CAM **Plants**: Extreme heat (> 40°C), minimal photorespiration, stomata open at night to conserve water, very slow growth.

<u>Learning Objective</u>: [2.1.6] – Identify & explain the factors - light colour, intensity, CO₂ concentration, temperature, water availability - that affect the efficiency of photosynthesis

Study Design

The role of rubisco in photosynthesis, including adaptations of C3, C4, and CAM plants to maximise the efficiency of photosynthesis.

- Light Intensity:
 - o Increased light boosts the rate of photosynthesis until other factors become limiting
 - Saturation occurs when enzymes and substrates are fully utilised.
- Temperature:
 - Optimal temperature allows enzymes to function efficiently
 - O Beyond the optimal range, enzymes denature, and photorespiration increases.



□ Water Availability:			
Essential for photolysis in the light-dependent stage			
○ _ Limited water leads to stomatal closure, reducing CO₂ intake			
□ CO ₂ Concentration:			
Higher levels increase the rate of photosynthesis until Rubisco is saturated.			
□ Light Wavelength:			
Blue and red light are most effective; green light is reflected, giving plants their colour.			

<u>Learning Objective</u>: [2.1.7] - Apply experimental principles to investigate factors affecting the rate of photosynthesis

Key Takeaways

This objective can be achieved by applying the information in [2.1.6] to design experiments that test the impact of individual or combined factors such as light intensity, CO₂ concentration, or temperature on photosynthesis. By controlling variables and measuring outputs (e.g., oxygen release, and starch production), the specific role of each factor can be analysed.



<u>Learning Objective</u>: [2.1.8] – Explain how CRISPR-Cas9 can be used to increase photosynthetic efficiency

Study Design

Potential uses and applications of CRISPR-Cas9 technologies to improve photosynthetic efficiencies and crop yields.

- Potential Improvements:
 - O Rubisco Efficiency: Modify Rubisco to reduce oxygen binding, minimising photorespiration
 - O C4 and CAM Pathways: Introduce these adaptations into C3 crops for broader resilience
 - Environmental Tolerance: ____ Engineer plants to tolerate drought, heat, or frost
 - Yield Enhancement: Optimise photosynthesis for greater crop production
- Steps in CRISPR Application:
 - 1. Identify inefficiencies in photosynthesis using computational models
 - 2. __Target genes responsible for inefficiencies
 - 3. Design CRISPR systems to edit these genes precisely
 - 4. Test and refine plants for improved photosynthetic performance



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