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Artificial Photosynthesis - A De-Novo Tool in Animal Nutrition

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Abstract

Food demand is growing globally, but food production is ultimately constrained by the energy conversion efficiency of photosynthesis. The animal feed industry is the primary driver of high demand for large volumes of nutritional protein, which is also suitable for use in meat substitute products. Recent research on the synthetic manufacture of the nutritional protein L-Alanine using a type of artificial photosynthesis is being developed. Artificial photosynthesis system is proposed as an efficient alternative route to capture carbon dioxide to produce nutritional protein for growing global demand. The carbon dioxide which is removed from the atmosphere, is first turned into methanol using green electricity and hydrogen. This methanol is later converted into L-alanine in a multi-stage process using synthetic enzymes. Some studies reported that, this method was extremely effective and generated very high yields. L-alanine is one the most important components of protein which is essential to animal nutrition. Compared to growing plants, this method requires far less space to create the same amount of L-alanine, when the energy used comes from solar or wind energy sources. The more efficient use of space means a kind of artificial photosynthesis can be used to produce the same amount of feedstuffs on significantly fewer acres. This paves the way for a smaller ecological footprint in animal nutrition, especially, the high-throughput systems like intensive aquaculture.

Keywords: Climate change, L-Alanine, Photosynthesis, Solar fuels

Introduction

Global food demand is on the rise, yet the efficiency of photosynthesis, which converts energy into food, sets an ultimate limit on food production. Artificial photosynthesis aims to address the constraints of biological photosynthesis. It is a chemical process that imitates natural photosynthesis by transforming sunlight, water and carbon dioxide into carbohydrates

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and oxygen. This process encompasses the creation of solar fuels and the reduction of carbon dioxide to various compounds like methane, methanol, formaldehyde, formate, carbon monoxide, or oxalate, as well as the conversion of protons into hydrogen molecules.

Prerequisite for Artificial Photosynthesis

Photosynthesis is influenced by a multitude of external and internal factors, including the quantity, dimensions, maturity and positioning of leaves, as well as the characteristics of mesophyll cells and chloroplasts within leaves. Additionally, factors such as sunlight availability, carbon dioxide levels and water supply play vital roles.

The efficiency of photosynthesis in plants typically remains below 10%. While light is a crucial component of photosynthesis, excessive light exposure can harm and disrupt this process. As industrialization continues to expand and society grows, there is a diminishing supply of plants and forests. Consequently, there is an increasing need for alternative approaches to address these challenges.

Mechanism of Artificial Photosynthesis

Light harvesting system

- Materials that absorb light with a suitable wavelength of light that has sufficient energy to promote an electron from a low energy molecular orbital (ground state) to a higher energy orbital (excited state).
- Materials absorbs light in the visible region of the electromagnetic spectrum i.e. 400-700 nm.
- The conversion of solar energy directly to electrical energy is termed photovoltaics whilst the conversion of solar energy to chemical energy is called photosynthesis.
- The semiconductors for solar cells but those have low efficiency.
- According to recent developments we have thin film solar cells, multiple junction solar cells, organic/polymer solar cells, Quantum Dot Solar Cells (QDSCs), and Dye Sensitised Solar Cells (DSSCs).

Water oxidation

- Water oxidation is one the successful development for water splitting cell with sunlight. It involves the removal of 4H and 4e together with the generation of an O-O bond. Splitting of water requires an energy input of about 2.5 volts.

$$H_2O \rightarrow 4H + O_2 + 4e$$

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- Manganese: a single atom manganese triggers the natural process that uses sunlight to split water, the using of manganese is a biomimetic approach in artificial photosynthesis.
- Cobalt oxide: recently developed clusters of Nano-sized cobalt oxide (COO) have been found to be stable and highly efficient triggers in an artificial photosynthesis.
- The other molecular rationally design WOCs performance based on ligand modifications, choice of transition metal, oxidation state and geometry, through space interactions, electronic coupling, and active site hindering are also seen in recent developments.

Proton reduction

- The reduction of protons into molecular hydrogen is a two-electron process, and from a thermodynamic point of view, sometime this process is thermodynamic suitable but kinetically slow due to absence of suitable catalysts.

$$H_2O + 2e \rightarrow H_2 + 20H$$

Rhodium and platinum, cobalt, nickel, molybdenum is used because of their high reactivity towards protons as colloids and their ability to easily form metal hydrides in both aqueous and organic medium.

Carbon dioxide reduction

Significance of Artificial Photosynthesis

Production of Acetate from CO_2 Electrolysis

A two-stage electrochemical procedure transforms carbon dioxide into acetate, which functions as both a carbon and energy source for various organisms such as algae, yeast and mushroom-producing fungi. Integrating this carbon fixation system with photovoltaics presents a more energy-efficient method for food production. Figure 1 indicated A combined electrochemical-biological system for the production of food from CO2.

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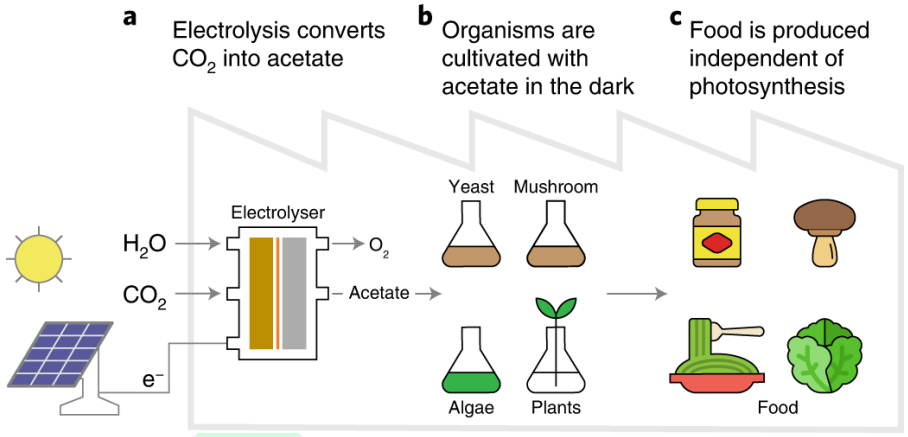

Figure 1: A combined electrochemical-biological system for the production of food from CO_2 (Hann *et al.*, 2022)

Nutritional Animal Feed Protein through Artificial Photosynthesis

Addressing the challenging balance between the ever-expanding global population and environmental preservation could find support in the synthetic manufacturing of a critical nutritional amino acid, L-Alanine.

Pathways for Conversion of CO_2 into Sustainable L-Alanine

Carbon dioxide extracted from the atmosphere undergoes an initial conversion into methanol through the use of sustainable energy sources like green electricity and hydrogen. Following this step, a biotechnological method employs synthetic enzymes in a multi-stage process to transform the methanol intermediate into L-alanine.

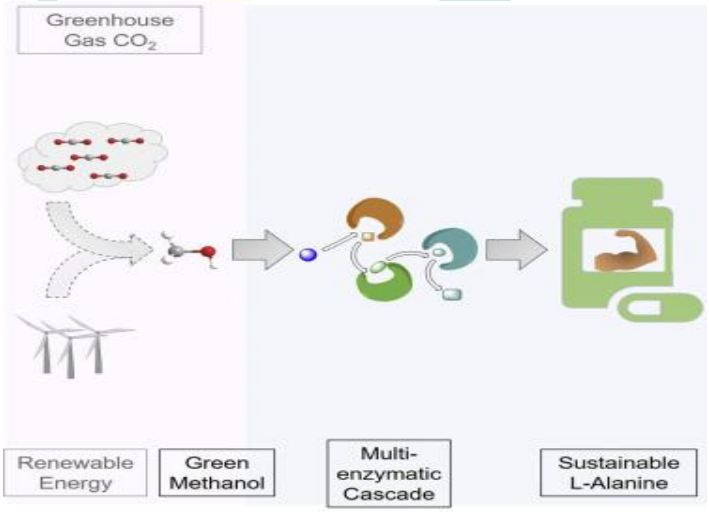

Figure 2: Cell-free enzymatic L-alanine synthesis from green methanol (Willers *et al.*, 2023)

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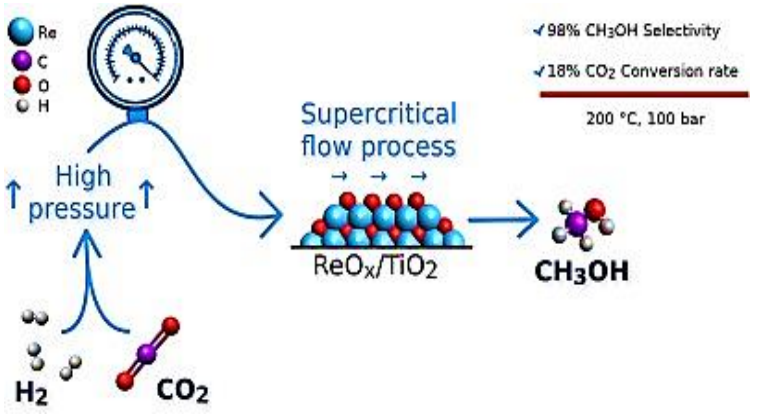

Figure 3: Process involved in conversion of CO_2 into methanol (Gothe *et al.*, 2020)

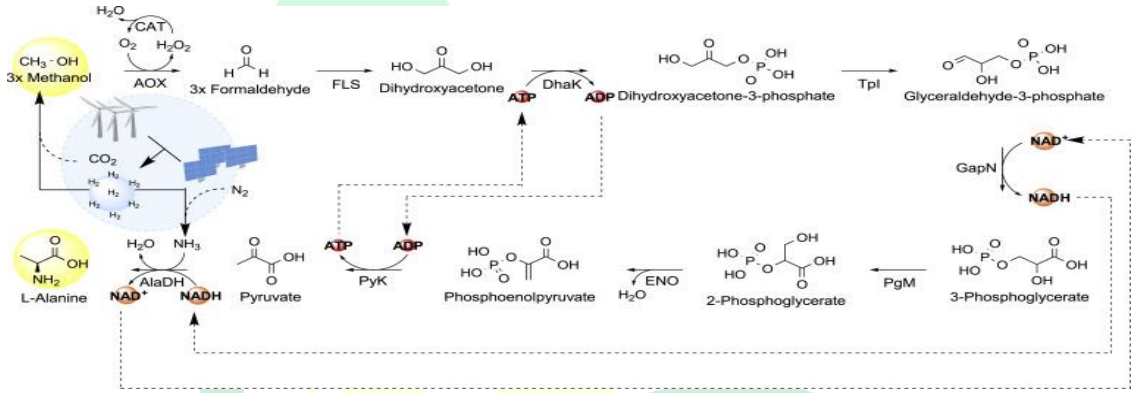

Figure 4: Cell-free enzymatic L-alanine synthesis from green methanol (Willers *et al.*, 2023)

Requirement of L-Alanine in Fish

Alanine plays a significant role in the conversion of sugar into energy.

- Processing vitamins B like pantothenic acid and pyridoxal phosphate.
- Facilitating the metabolism of tryptophan.
- Protecting cells from oxidative damage.
- Helping maintain normal cholesterol levels.
- Gustatory stimulant amino acids.

The animal feed industry is the primary driver of high demand for large volumes of nutritional protein which is also suitable for use in meat substitute products.

Advantages of Artificial Photosynthesis for Sustainable Feed

- This method requires far less space to create the same amount of L-Alanine, when the energy used comes from solar or wind power sources.
- This paves the way for a smaller ecological footprint.

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- Extremely effective and generate very high yield.
- Bioeconomy and hydrogen economy in combination.
- Help to make feed production more energy- efficient.

Conclusion

We are already confronting the potential for disastrous climate change due to the release of carbon dioxide into the atmosphere from fossil fuel combustion. Therefore, artificial photosynthesis offers a promising avenue for generating energy while simultaneously mitigating carbon dioxide emissions.

"*If you can't make your own sunlight, store bought is fine*."

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