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POPULAR SCIENCE ARTICLE

Synthetic Biology: Engineering Life for a Better Future

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Abstract:

Synthetic biology is about engineering life itself, designing and constructing biological systems with new and useful functions. The process has been facilitated by recent advancements in science, such as the development of the CRISPR-Cas9 technology. This form of biotechnology finds application in agriculture, healthcare and environmental conservation. Nevertheless, its adoption must be regulated to mitigate potential dangers to biodiversity.

Keywords: Synthetic, Biotechnology, CRISPR, Agriculture, Genomics

What is synthetic biology?

Synthetic Biology (SynBio) is a field that applies engineering principles to biology to design and build new biological parts, systems or even entire organisms. Instead of just modifying existing life, SynBio can create entirely new biological components that do not exist in nature. It treats living systems like DNA, RNA and proteins as programmable parts, similar to components in a machine.

A traditional engineer builds using available materials to construct buildings. However, a synthetic biologist does way more than that; he creates completely new materials and then apply them in creating biological machinery.

Synthetic biology refers to the practice of designing and creating artificial biological entities such as devices, molecules, systems or organisms by modifying their genetic material. The process entails using concepts borrowed from several disciplines such as computer science, engineering, chemistry, mathematics and biology. Researchers regard biological systems such as DNA, proteins and RNA as mechanical components. Consequently, they determine their roles and then combine them to generate new biological systems with unique functionalities.

The most significant distinction between SynBio and genetic engineering lies in the extent of genome modification in both cases. Genetic engineering involves transferring a single gene from one organism to another, while SynBio involves the transfer of multiple genes and even the creation of entirely new genes that do not occur in nature. This process can even involve the development of entirely new genomes, just like writing an entire new chapter in a novel rather than modifying a sentence.

Two major strategies exist that scientists adopt for SynBio.

Top-down approach: Start with an existing organism and modify it step-by-step until it meets their expectations.

Bottom-up approach: Build new biological systems from basic molecular components.

A Brief History of Synthetic Biology

Synthetic biology has its roots in the 1960s, when François Jacob and Jacques Monod discovered the *lac operon* in *Escherichia coli* in 1961, demonstrating that genes can function like switches, similar to electronic circuits. During the 1970s and 1980s, advances in gene cloning and recombinant DNA technology led to the rise of genetically engineered organisms. The 1990s saw the development of DNA microarrays and whole-genome sequencing, along with the widespread cultivation of genetically modified crops such as Bt cotton.

In the early 2000s, the term "synthetic biology" was introduced and in 2003, scientists at the Massachusetts Institute of Technology developed standardized biological parts called BioBricks and created the first synthetic gene circuits. A breakthrough came in 2012 with the development of CRISPR-Cas9, which enabled fast and precise gene editing and it was recognised with the Nobel Prize in Chemistry in 2020. Overall, synthetic biology has evolved into a rapidly advancing field focused on designing and constructing new biological systems.

Important Tools Used in Synthetic Biology

A variety of tools are used in synthetic biology, each serving a specific and distinct function. Their importance can be understood by viewing them as integrated components of a coordinated system, where each tool contributes to the efficient design, construction and functioning of complex biological processes.

The CRISPR-Cas9 system: Molecular scissors

The CRISPR-Cas9 system is probably the most popular technology in synthetic biology. It is a set of molecular scissors that, when aided by an RNA molecule guide, can precisely make a cut at a specific place in the genome of a living being. After the cut is made, it is possible either to remove a gene, replace it with a new one or simply fix it. Thus, the CRISPR-Cas9 system is highly efficient, cheap and reliable.

Cloning Using the Golden Gate Method - The assembly line

This method allows researchers to join multiple DNA fragments in a single step, making the process faster and more efficient. Instead of assembling pieces one by one, all components are combined at once. This is especially useful for building complex genetic systems that require several genes simultaneously. For example, introducing multiple genes to convert C3 rice into C4 rice would have taken years earlier, but with Golden Gate cloning, it can now be completed in just a few months.

RNA interference (RNAi) - Gene Silencer

One such defence mechanism of cells that researchers have made use of is RNAi. By using RNAi, one can silence a selected gene by injecting a particular double-stranded RNA into the cell. This is done without altering the genome of the organism. Some of the uses of RNAi in agriculture include protecting plants from insects, reducing toxin production in food plants and preventing fungal infections.

Gene Drives - The transfer of characteristics within a population

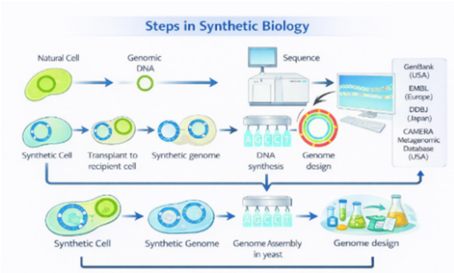
The term "gene drive" refers to the genetic mechanism that makes it possible for specific characteristics to disseminate very fast within a population, contrary to the normal process where characteristics are transferred equally to only half of the offspring. With the gene drive technology, traits are transmitted to almost all offspring. Gene drives can be applied in the sterilization of insects to minimize their population without using chemical pesticides.

Regulated Promoters - The On/Off Switch

A promoter is a control switch that activates a gene when needed and deactivates a gene when not necessary. Regulated promoters can be activated by certain conditions, such as temperature changes or the appearance of pests. These are used in response to external conditions. For instance, in the case of a heat wave, a heat-activated promoter will activate a heat-stable form of a photosynthesis enzyme for the crops.

How Synthetic Biology Works: The Steps

In synthetic biology, there is a cyclical process which can be referred to as Design, Build, Test and Learn. Each step serves a specific function and the scientists go through the entire cycle several times. The figure has been developed based on the framework described in Kuiken *et al.,* 2014.



Synthetic Biology in Agriculture - What has been accomplished?

Agriculture is one of the most difficult sectors today. The population of the earth is increasing at an alarming rate and according to estimates, it will be somewhere near ten billion by 2050. Apart from the above, the effects of global warming are such that there will be droughts, higher temperatures and erratic seasons. This is where synthetic biology can be useful.

Pest control in insects

The early successes include Bt cotton, which has a gene from the bacteria, *Bacillus thuringiensis* and produces proteins that kill some insects but not others. This has greatly minimized the use of pesticides. In addition, synthetic biology can enhance insect resistance by adding several genes for resistance and using RNAi-based biopesticides targeting certain insects.

Enhancing photosynthesis

Efficient photosynthesis will greatly increase the yields. SynBio provides means for altering enzymes that take part in photosynthesis. Thus, activation of the cytochrome b6f will lead to better light harvesting, while inhibition of photorespiration will contribute to increased biomass and seed production.

Control of fungal diseases

However, fungal diseases such as wilt due to Verticillium and Fusarium cannot be addressed using conventional breeding techniques. The application of synthetic biology makes gene stacking possible, thus offering resistance to a number of diseases at once. Furthermore, with CRISPR-Cas9, genetic material can be edited without adding any alien DNA.

Nutrient efficiency improvements

Fertilizers are produced using energy and can harm the environment. Synthetic biology seeks to engineer crops to fix atmospheric nitrogen, like how leguminous plants do. This could be achieved by incorporating nitrogen-fixation capabilities (such as nitrogenase enzymes) or by making plants more attractive to nitrogen-fixing bacteria.

Impacts on Biodiversity - Opportunities and Threats

Technology is neither positive nor negative; the effect will depend on how it is utilized. For example, the use of a controlled gene drive that eliminates harmful insects from one specific locality will be positive. However, the lack of control in its usage can negatively affect ecosystems.

Conclusion

In summary, synthetic biology is one of the most significant technological advancements in recent times. From initial research on genetic regulation, it has developed into an innovative technology used in designing biological systems. It can solve complex issues using advanced technologies, including CRISPR-Cas9, Golden Gate cloning, RNAi, gene drives and regulated promoters. Synthetic biology can revolutionize agricultural practices by decreasing the use of insecticides and increasing photosynthetic efficiency, providing high yield and resource-efficiency. The development of such crops is vital in ensuring future food security amid global warming. Nevertheless, it is important to use synthetic biology responsibly since misuse could harm biodiversity. As a result, proper regulations, scientific accuracy and public enlightenment should guide its use.

Conflict of interest:

The authors declare that they have no conflict of interest

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