Improving Crop Yield

Pursuing more efficient **photosynthesis**

Hidde Jansen

Photosynthesis is one of the key factors influencing crop yield. In practice, however, we find that the efficiency of photosynthesis in modern varieties is far from optimal. Based on field studies, researchers from the Jan IngenHousz Institute (JII) are exploring the role that genetic variation and environmental conditions play on the efficiency of photosynthesis. As part of their research, they are developing advanced sensors and data science tools. Collaboration with other universities and breeders is crucial in this, says JII research fellow Tom Theeuwen. "We really want to see what's happening with photosynthesis in crops while they are in the field."

Climate change and population growth are putting increasing pressure on food security. To be able to feed the world whilst limiting the negative impact of food production on the environment, it is vitally important that crops are cultivated as effectively as possible. Photosynthesis – the process by which plants use sunlight to convert water and CO_2 into oxygen and sugars – plays an important role in this. The more efficient the photosynthesis, the higher the crop yield.

But the relationship between photosynthesis and yield is extremely complex, and that makes improving photosynthesis a huge challenge, says research fellow Tom Theeuwen. "The efficiency of photosynthesis in a crop is determined by various processes in the plant, which in turn are influenced by various genes – for which also variation exist. These processes are also dependent on external conditions like light and temperature, and the influence of these conditions also varies for each crop, genotype and growth phase."

Jan IngenHousz Institute

Understanding and improving photosynthesis is the key focus of the Jan IngenHousz Institute (JII). JII is an independent institute that was founded in 2022 by the philanthropic Photosynthesis 2.0 Research Fund and Wageningen University & Research (WUR), and is led by well-known photosynthesis researcher David Kramer. Scientists from many different disciplines are working on understanding, controlling and improving photosynthesis.

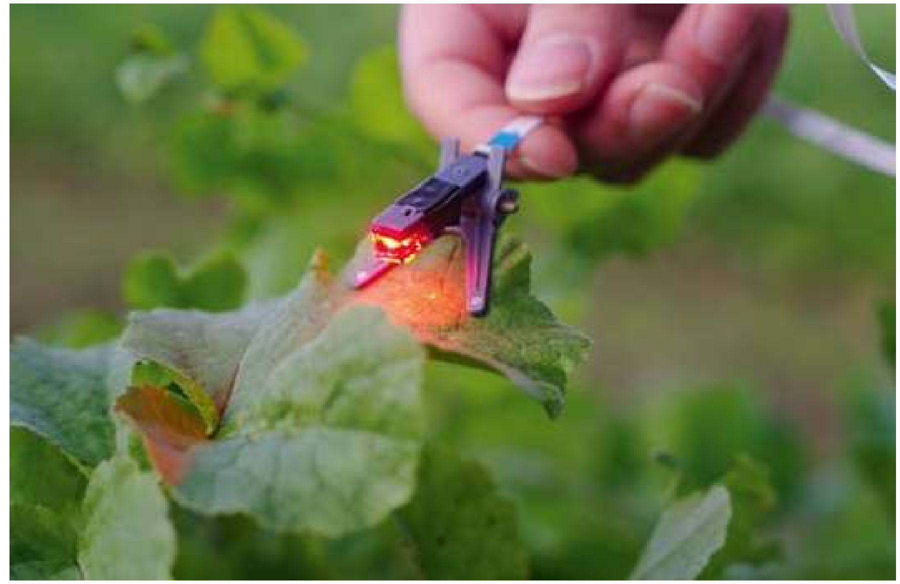
Theeuwen: "Much of the existing research into photosynthesis consists of individual projects, which requires finding new funding for each project. Through our institute, we can invest more broadly and long-term and put high-risk research on the map, ultimately creating more impact. That does not mean the end of photosynthesis research at WUR. We really are complementary, so the idea is that JII and WUR will collaborate on many projects and share knowledge. We will do this by aligning with existing research, as well as setting up new projects ourselves."

Research into making photosynthesis more efficient is not new, says Theeuwen. "But what distinguishes JII is our focus on genetic variation in crops and the use of large-scale field research. Currently, a lot of research is lab-based. That produces valuable knowledge, but these are controlled conditions, while many processes are influenced by conditions in the environment. And that environment is incredibly dynamic, which is impossible to simulate. Sunlight can change in a second, the temperature is constantly fluctuating, and a gust of wind blowing through a crop affects the humidity. These are all elements that influence photosynthesis. In view of the complexity of genetic variation and the influence of the environment, we really need to go into the field to gain insight into the real-life limiting factors for the efficiency of photosynthesis in relation to the crop yield."

Tom Theeuwen in the growth chamber of Netherlands Plant Eco-phenotyping Centre (NPEC), another collaborator of JII

Improve photosynthesis

To develop these insights, the researchers at JII use advanced sensors and data science tools. Theeuwen: "Good equipment to measure photosynthesis is available, but expensive. Moreover, the manual operation requires a lot of human involvement. That is a considerable limitation for any study, because a team of researchers can only measure a hundred plants per day. And it produces just one measurement per plant. What we want is to measure photosynthesis for thousands of plants continuously.



Prototype of a new sensor to make continuous photosynthesis measurements, developed by JII together with Michigan State University

Genetic variation

In addition to plant cell nuclei, DNA is also found in organelles. These are small, specialised compartments with specific functions, like chloroplasts and mitochondria. Both chloroplasts and mitochondria contain 100–150 genes that code for proteins essential to their function. For plants to function properly, optimal coordination between chromosomal, chloroplastic and mitochondrial genes is essential. Until now, however, little was known about the significance of organellar genetic variation and how it influences plant performance.

In a November 2024 paper from his PhD, supervised by Mark Aarts of Plant Genetics, Tom Theeuwen is changing that. In PNAS, the researchers demonstrate that genetic variation in chloroplast and mitochondrial DNA plays a key role in the variation in photosynthesis among Arabidopsis thaliana plants.

For their research, the authors developed a new method for generating so-called *cybrids* on a large scale. In a cybrid, the original chloroplasts and mitochondria are replaced by those from another plant. "By combining the chromosomes of one of four different Arabidopsis plants with the chloroplasts and mitochondria of one of 60 other Arabidopsis plants, we were able to create 240 unique cybrids," says Aarts.

This is the first time such a large set of cybrids has been produced, and it indicates that this approach could also be applied to agricultural crops, bringing a similar method within reach for plant breeding companies.

"In the past, it was very complicated and time consuming to study the contribution of chloroplastic and mitochondrial variation to energy production and photosynthesis in plants—but now it is feasible." According to Mark Aarts, this discovery expands the possibilities for plant scientists and breeders to explore and enhance energy production and photosynthesis.

So, one of the first things we did, in collaboration with Michigan State University, was develop a new sensor with the idea that we can then follow the photosynthesis of a plant from germination to harvesting."

This means that you don't need to go into the field every day, and you can monitor the photosynthesis of thousands of genotypes simultaneously and continuously, says Theeuwen. "The ability to continuously measure photosynthesis in detail outside really signifies a major step forward. We will then be able to link crop yield to the data about how photosynthesis responds to field conditions. We can measure crop development and yield by flying drones over the field a couple of times a week. By linking this data, we will hopefully discover which genotypes contain interesting photosynthesis properties and – even more importantly – under which conditions these properties are limiting for crop yield. You can then use these insights for plant breeding. Our ultimate goal is to provide breeders with the tools to improve photosynthesis."

Accurate and continuous measurements also produce a new challenge: a huge flow of data. Theeuwen: "A sensor measures twenty photosynthesis parameters and ten environmental factors on each plant. We receive those data, for example, ten times a second. Multiply that by a couple of thousand plants and several months. That's a lot of data! So we need to develop tools and methods to process all this data

A JII researcher in the field, working with the MultispeQ, a sensor developed by JII's scientific director David Kramer

Jan IngenHousz

The Jan IngenHousz Institute takes its name from the 18th-century Dutch physician and chemist Jan IngenHousz. Born in Breda, he studied medicine at the University of Leuven and moved to England soon after graduating.

With his idea of using inoculation against smallpox not individually but in groups, he became an important force behind the immunisation campaign. He treated George III's court, but also the village of Hertfordshire. As a mark of gratitude, he became the King's personal physician. He later travelled to Vienna to inoculate the family of the Austrian Empress Maria Theresa and subsequently served as court physician. After his rise to fame, IngenHousz had plenty of time to do research. Among other things, IngenHousz discovered that the green parts of plants use light energy for growth, thereby laying the foundation for photosynthesis research.

Collaboration, diligence and integrity were important values for IngenHousz. Today, he is remembered as an open and critical global citizen, a social man with an international outlook. These are the values on which the Jan IngenHousz Institute aims to build further.

and link it to genetics and yield. To do this, we work together with data scientists from WUR. Due to the huge amount of data, we are also looking at solutions using artificial intelligence (AI). However, we need to use AI carefully. AI is incredibly useful for processing and making data-based predictions. But if you leave too much to AI, you will still not properly understand the extent to which photosynthesis is limiting for crop yield. Because you can't really see what's going on. And that's exactly what we do want to know."

Working together where it counts

Around the campus in Wageningen, preparations for the first field trials are underway. But JII is hoping to also do experiments using living labs in other regions. Theeuwen: "Also in places where food security-related challenges are a daily issue, like in Africa. Despite being based in Wageningen, we won't limit ourselves to WUR. The research fellows at JII are the linking pin in the various collaborative projects. You should see JII as a sort of club house where all the knowledge and innovation relating to photosynthesis comes together and cross-pollinates."

In its photosynthesis research, JII not only joins forces with knowledge institutes, but also with breeders. According to Theeuwen, that collaboration is very important for several reasons. "On the one hand because we need input, such as information about the current plant breeding practices and the genetic material, but also because we want our knowledge to be taken up in practise as much as possible. Breeders are ultimately the ones that market those new varieties. Therefore we see our role as gathering knowledge and developing sensors and methods for data analysis and interpretation, which can then be used in breeding programmes in which photosynthesis can serve as a marker. To ensure optimal alignment, we need to work together from the beginning. This means setting up field trials with businesses, for example, and we really encourage agriculturalists to get in touch with us."

The fact that JII embarks on collaborations with agriculturalists does not mean that the knowledge acquired will not be widely available, Theeuwen emphasises. "On the contrary, we follow the open science philosophy. Obviously, there is an element of confidentiality in proprietary information, but for us it's ultimately about the insights it delivers. We are currently building an open science platform on which photosynthesis measurements from our research can be viewed and used by others. In addition, we will use insights that we obtain in research projects to develop new sensors that we can then make available to other universities, institutes and businesses for further research or practical applications. We will be a global knowledge and innovation hub for photosynthesis research."