Time to translate

A Roadmap For Photosynthesis To Drive Crop Improvement

Society needs more resilient crops

Climate change is driving abiotic stresses that negatively impacts crop health and yields. This reduces primary production, threatening food, feed and energy security, and the bioeconomy. New climate resilient crops are urgently needed.

Photosynthesis - an underexploited trait

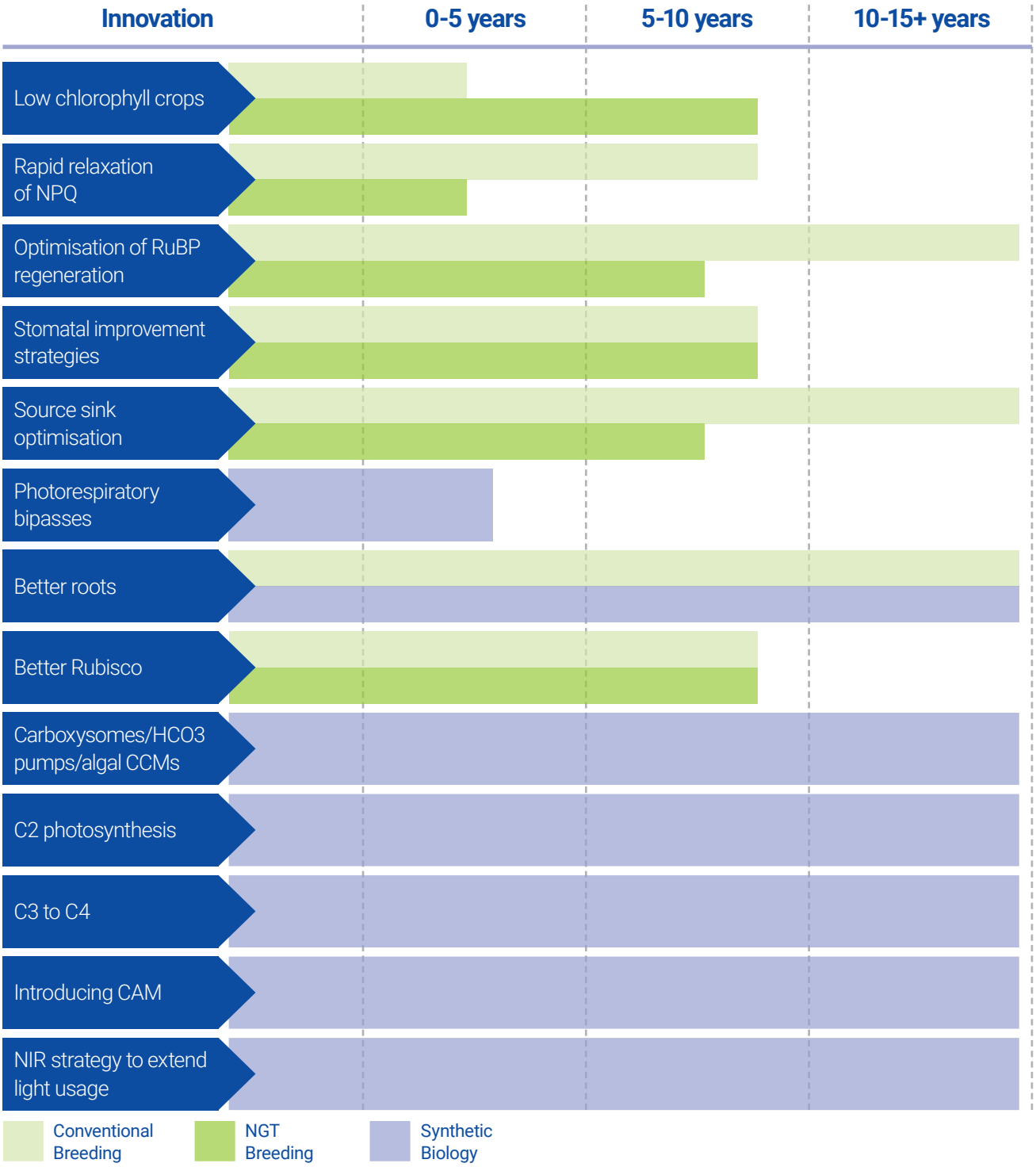
Photosynthesis is a complex process but has many underexploited traits with great potential to improve crop yield and resilience to climate change. Recent scientific advances have demonstrated significant improvements in crop productivity through improving photosynthesis efficiency. Multiple innovations have been developed by the research community to varying Crop Technology Readiness Levels (TRL).

Industry has a strong interest in photosynthesis-driven crop improvement, but collaborative projects and an enabling environment are needed to bridge the translation gap for 'smart' crop development.

Conventional modern breeding and New Genomic Techniques (NGTs) provide pathways to exploit these innovations. The time to translate is now.

European Strategic Research Agenda and Road Map to 2030

Timeline for strategies to reach crop TRL7



Crop TRL	Definition	
TRL1	Basic principles for improving target crop(s) identified	**Preliminary evaluation**
TRL 2	Crop improvement concept formulated	
TRL 3	Experimental proof of concept (laboratory level)	**Experimental testing**
TRL 4	Improvement validated in a crop model (laboratory level)	
TRL 5	Improvement validated in a field/glass house environment	**Pre-commercial assessments**
TRL 6	Pre-breeding with improved traits in a relevant environment	
TRL 7	**Improved prebreeding crop line demonstration in a grower/farm environment**	**Commercial Deployment**
TRL 8	Breeding in elite crop line achieved and qualified	
TRL 9	Elite crop line incorporating trait(s) proven in commercial growing environments	

Evidence for dramatic crop improvements

Advances in genomics, phenotyping, and modelling now enable scientists to demonstrate the yield benefits of improving photosynthesis in genetically modified plants.

Barley	Chlorophyl tuning: A pale green barley line showed a 40-50% reduction in transpiration rate under drought stress and 40% increased photosynthetic efficiency under high light conditions (BestCrop).[1]
Potato	Expression of a glycolate dehydrogenase polyprotein (DEFp) led to 12-45% increases in potato tuber yield (PhotoBoost).[2]
	Introduction of algal carbon concentration mechanism components into potato chloroplast led to 17-42% enhanced tuber yield (PhotoBoost).[3]
	Integration of a novel oxygen scavenging pathway showed 25-31% enhanced yield and increased photosynthesis related metabolites (PhotoBoost).[3]
Soybean	Accelerating plant recovery from photoprotection delivered a 33% improvement in seed yield.[4]
Rice	The overexpression of a transcription factor that regulates photosynthetic capacity led to a 41-68% yield increase.[5]
	Overexpressing Rubisco in rice enhanced yields by 17-28%.[6]

[1]Persello et al., 2024, Plant Cell Rep, 43, 246; [2]Nölke & Schillberg, 2020, In: Climate Change, Photosynthesis and Advanced Biofuels. [3] Unpublished PhotoBoost project; [4]De Souza et al. (2022), Science, 377, 851–854. [5]Wei et al. (2022), Science, 377, eabi8455; [6]Yoon et al. (2020), Nat Food, 1, 134–139.

Recommendations

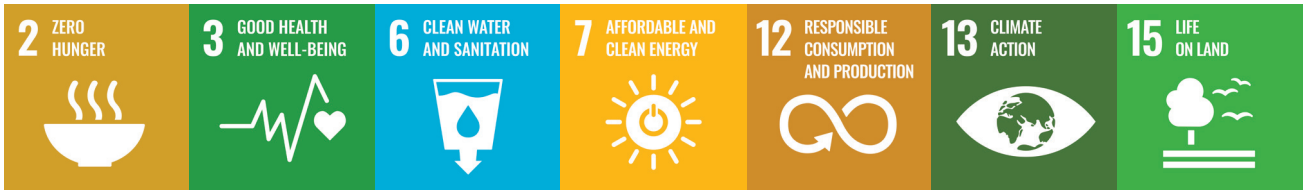
- ✔ Crop development can be a 10–15 year investment, this demands a systematic approach. Research on relevant germplasm, improved genetic resources, tools, computational models and an innovative culture that embraces biotechnology, is needed to accelerate crop improvements.
- ✔ Translation of Key Exploitable Results is a priority area. Collaborative working is urgently needed between industry and the science base to overcome market failures translating research to develop climate resilient crops.
- ✔ Short term projects (3-5 years) produce fragmented 'islands' of research, a more strategic approach is needed. Public Private Partnerships (PPP) represent the best option to exploit the knowledge base to deliver 'future proof' crops.
- ✔ Low level and declining public investment in crop breeding programmes should be reversed. Crop research needs a reinvigorated strategic programme at the European level. Collaborative research and innovation projects need to be longer term (5+ years) and well-funded (€8M+) to drive translational crop research effectively.
- ✔ An enabling regulatory environment to support NGTs should be a short-term priority to accelerate the broader application of biotechnology. This will compliment conventional crop improvement pathways, to develop some new plant varieties faster, and in a more precise manner.
- ✔ In parallel, environmental risk assessments should be undertaken, and literacy programmes developed and implemented, to educate citizens and stakeholders about NGTs. This should be linked to sustainability issues, and making informed risk assessments.
- ✔ Barriers to translating public research to industry need to be better understood and addressed. Life Cycle Analysis represents an important tool to address the socioeconomic costs, risks and benefits of the proposed approaches. This will support commercial decision making.
- ✔ Issues regarding IP and benefits sharing need to be resolved for maximal use of research outputs by Industry.

Strategic research priority areas:	
Phenotyping and validation	Chlorophyll Tuning
Translation of QTLs	Moving to field trials
Computational model improvement	Phenotyping tool development
Genomic toolbox expansion	Synthetic biology approaches

‘Smart’ Crops Align with EU policy

Focusing on crop breeding to enhance photosynthesis supports the **Green Deal** and **Farm to Fork** goals, promoting sustainable production, food security, the bioeconomy and climate action. Biotechnologies are crucial for advancing both conventional and new breeding techniques, with the proposed **Biotech Law** aiding progress. Enhancing photosynthesis aligns with the **Strategic Dialogue on the Future of EU Agriculture** recommendations for innovative breeding. This approach increases productivity, reduces fertilizer use, enhances water efficiency and supports biodiversity, contributing to multiple SDGs.

Photosynthesis is positioned to be a crucial technology for crop improvement, enhancing European competitiveness and economic prosperity.



This roadmap has been developed based on:

- Literature reviews.
- Results from the H2020 projects: CAPITALISE, Gain4Crops, PhotoBoost and BestCrop.
- Opinions from online breeder and grower surveys.
- Workshops with 20+ stakeholder representatives to identify: (1) The needs of Industry & (2) The barriers to translating crop research.
- A Translational Photosynthesis workshop with 50+ academics and industry representatives.
- Social Sciences Stakeholder Engagement with consumers, farmers and breeders.

This Roadmap has been developed by the CAPITALISE project (EC Grant Agreement 862201), with contributions from the GAIN4CROPS (ECGA 862087), PhotoBoost (ECGA 862127) and BestCrop (ECGA 101082091) projects and key stakeholders. This is a summary of the more detailed European Strategic Research Agenda and Road Map to 2030.
This document can be accessed using the QR code.