Application for permission to carry out field trial with GM wheat plants with increased photosynthetic efficiency

Key Points

- **Rothamsted Research has applied to Defra for permission to conduct a field trial of GM wheat plants that have been engineered to carry out photosynthesis more efficiently, i.e. to harness light energy in a more efficient way.**
- **The increased photosynthetic efficiency has the potential to result in higher yields in the GM plants in the field.**
- **The trial aims to test the efficacy of these plants in field conditions.**
- **Wheat yields have plateaued globally and there is a pressing need to develop new higher yielding wheat varieties using the same amount of resources and land.**
- **Scientists from Rothamsted Research, the University of Essex and Lancaster University have been working on understanding photosynthesis and improving its efficiency for more than 25 years.**
- **The research is funded by the Biotechnology and Biological Sciences Research Council (BBSRC) and the United States Department of Agriculture (USDA) as part of the International Wheat Yield Partnership Consortium.**
- **A public consultation on this proposed field trial has now begun and is available on the Government (Defra) website.**

- Ensuring food and nutritional security is a major challenge given the projected need to increase world food production by 40% in the next 20 years and 70% by 2050.
- Wheat is one of the major grain crops worldwide and provides approximately one-fifth of the total calories and protein consumed globally.
- Wheat yields have reached a plateau in recent years.
- A promising route to increase wheat yields is to improve the efficiency by which light energy is converted to wheat biomass in the process called photosynthesis.
- Photosynthesis is the major determinant of energy conversion efficiency.
- Traditional breeding and agronomic approaches have maximised light capture and the proportion of total biomass allocated to the grain.
- Genetic modification is a promising approach to improve the efficiency of photosynthesis and in this project it is being explored to achieve higher wheat yield potential.
- This is a small scale proof of concept field experiment to test the potential of the GM plants to carry out photosynthesis more efficiently and deliver higher yields in relevant field conditions.

Questions and Answers

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A) General

1. **Why are increases in wheat yields needed?**

- Ensuring food security is a major challenge given the projected need to increase world food production by 40% in the next 20 years and 70% by 2050. Wheat is one of the major grain crops worldwide and provides approximately one-fifth of the total calories of the world's population. In the UK grain yields (farm gate) have increased from about 7 to 8 t/ha over the past 20 years, however wheat yields in the UK and other high yielding environments have reached a plateau in recent years. Global average yields are around 3 t/ha.

2. **Which ways have been tried so far to increase wheat yields?**

- Yield increase is a key target for wheat breeders using traditional approaches, selecting for total biomass or harvest index (ratio of grain to straw), a component of the first green revolution. To our knowledge, yield increase itself has not been targeted by GM means.

3. **Why do you need to do this experiment?**

- We have successfully developed GM wheat plants that result in increased photosynthetic efficiency and higher yields in the laboratory. A publication will be submitted in November to Philosophical Transactions of the Royal Society – an Enhancing Photosynthesis special issue.

- We wish to test this under relevant 'real-life' conditions in the field to see if this can provide a viable solution to achieve a transformational increase in wheat yields.

4. **Why do you have to use GM: is there another way to improve the efficiency of photosynthesis?**

- Whilst there is some natural variation in photosynthesis it is rather limited. GM will enable the introduction of more extreme variation and offers the potential for more radical improvement.

5. **Can we not just get altered photosynthetic efficiency through conventional breeding of wheat varieties?**

- The recent increases in photosynthesis observed to date via conventional breeding have been very small e.g.in the order of 1% per year or less. In order to achieve the increases that will be needed to for the future we need much larger increases – 3% and above. One way to achieve this is to target photosynthesis specifically – as we have done with SBPase. This is a targeted approach which has the potential to enable the production of higher yielding wheat in a shorter time period.

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6. **What is the nature of the genetic modifications you have made?**

- One of the determinants of crop yield is the photosynthetic capacity of the crop over the season. Sedoheptulose-1,7-biphosphatase (SBPase), an enzyme involved in the process of photosynthesis, has been shown to play a major role in the control of the efficiency of this process. Professor Christine Raines at the University of Essex has been conducting research on SBPase for over 25 years. GM wheat plants with increased SBPase protein levels and activity, grown under greenhouse conditions, showed significant differences compared to controls including: enhanced photosynthetic activity, increased vegetative biomass, and an increase in both number and total mass of seeds per plant (Raines, Parry *pers comm*). This application seeks permission to investigate the effects of up-regulating the levels of SBPase in wheat plants in the field.

- We have produced two types of plants, one in which two extra gene copies of SBPase are functional and one in which six extra copies of the SBPase gene are functional.

- In order to be able to select in the laboratory plants that have the extra SBPase copies vs those that do not have them, an additional gene that confers herbicide resistance has been inserted in the plants. This gene, called *bar,* confers resistance to herbicides with the active ingredient glufosinate ammonium, but this has been used only to select transgenic plants in the laboratory and this trait will not be utilised in the proposed field trials.

- Apart from the expected characteristic of enhanced SBPase expression and, under glasshouse growth conditions, increased total biomass and dry seed yield (unpublished data) these plants are indistinguishable from non-GM control plants. No other changes to the plant morphology or development have been observed.

- The inheritance of SBPase over three generations follows normal rules of Mendelian genetics.

7. **What exactly will you be measuring in the field in terms of determining increase in yields?**

- We will determine total aboveground plant biomass and grain yield on an area basis at full maturity. We will also measure the number of wheat ears on an area basis and the grain number and weight per ear. From this data we will estimate the harvest index, which is the proportion of biomass allocated to the grain.

- We will assess development of the GM and control crop at all stages.

8. **Do you anticipate any compromise between yield and nutritional value? Will you be monitoring for this? Could there be any unexpected consequences for the plant due to the increased efficiency of photosynthesis (trade-offs) and will you be measuring for these? If so how?**

- We do not anticipate any trade-offs caused by the overexpression of SBPase. Plants will be fertilised to adequate levels and according to typical agronomic practice at the Rothamsted farm, thus nutrients will be in plentiful supply. One could argue that increased production of biomass may require greater nutrient inputs or could potentially result in lower nitrogen content in the grain, leading to lower quality. We will monitor for grain quality by assessing nitrogen content in the grain.

9. How novel is the approach? Has it ever been tested in the field before? Conceptually at least even if not with the same genetic modification.

- This approach is novel for wheat in the field. Tobacco and soybean plants with additional functional copies of SBPase have previously been grown in the field. Wheat plants with additional copies of SBPase have previously been grown in the glasshouse.

10. How important is this research?

- This research is very important at three levels: a) ***scientifically***, as the potential delivery of wheat plants that can perform photosynthesis more efficiently and result in increased yields in the field would be a significant break-through b) ***economically,*** because wheat is a major commodity crop globally c) ***for public good,*** because of the benefits that this research will confer both to **food security globally** and **the environment**.

11. How have you communicated this research and the possibility of a field trial?

- We have been working on this area of research for the last 25 years and information has been available on the websites of all partner organisations over the years.

12. Will the public be consulted?

- As part of the Defra process, there is a period of a public consultation. People can make representations to Defra on any environmental risks that it is thought might be posed, by the field trial. These will be considered by ACRE.

- ACRE is a statutory advisory committee appointed under section 124 of the Environmental Protection Act 1990 to provide advice to government regarding the release and marketing of genetically modified organisms (www.defra.gov.uk/acre/).

13. Why is there a need to carry out this research in the UK?

- This research could benefit global crop farmers and the environment.

- The UK has world-class plant scientists who are at the forefront of developing scientific and technological advances that can make agriculture more efficient and sustainable.

- This research contributes to promote the UK's competitiveness, investing in biotechnology and therefore ensure long term benefits to the taxpayer.

14. Are there any similar experiments being carried out anywhere else in the world?

- Potentially yes. At later stages of the research project there are plans to conduct field trials testing for the effect of the same genetic modification in wheat plant varieties that are adopted for the mid-west environment in the USA.

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B) Health and Safety

1. **Will the trial be safe?**

- Rigorous regulations govern the planting and management of GM crop trials in the UK. The Government's independent group, ACRE (the Advisory Committee on Releases to the Environment), will be risk assessing the application for permission to conduct the trial. In addition, the management and other aspects of the trial are monitored by the Animal and Plant Health Agency (APHA) who provides Defra with GM inspection and enforcement services for the deliberate release of GMOs.

- At Rothamsted Research we have an internal GM Safety Committee, which carries out thorough risk assessments of proposed field trials prior to submission to ACRE and no major safety concern has been raised.

2. **Will anyone inspect the trial?**

<u>If the trial is approved by Defra then:</u>

- The Government's GM Inspectorate of the Animal and Plant Health Authority (APHA) will conduct inspections throughout the trial. http://www.gm-inspectorate.gov.uk/

3. **Could you give us a brief overview of the process of approval for research using genetically modified organisms (GMOs)?**

- At Rothamsted, like many universities and research institutes around the world, work is taking place using GM plants and microbes for a variety of projects and to address specific scientific questions. Research is conducted in our laboratories, in our glasshouses and in some instances, in the fields of our research farm. For each of these areas where research using GMOs is undertaken, there are a series of relevant regulations that are followed and risk assessments procedures that are carried out.

- Rothamsted Research’s activities are compliant with the law and our GM Safety Committee oversees all projects that involve GMOs. There are several key pieces of legislation specifically concerned with the contained use of genetically modified organisms (GMOs). The main piece of legislation, covering both human health and environmental aspects of work in laboratories and glasshouses with GMOs, is the Genetically Modified Organisms (Contained Use) Regulations 2000, as amended (referred to hereafter as the Contained Use Regulations). In risk assessment of our procedures we follow best practice as specified by the Compendium of Guidance http://www.hse.gov.uk/biosafety/gmo/acgm/acgmcomp/index.htm that has been put in place by the Health and Safety Executive (HSE), in conjunction with the Department for Environment, Food and Rural Affairs (Defra) and the Scottish Government.

- Occasionally, a research project requires experimentation using GMOs in the field and for this approval/permission from Defra is required. The procedure is as follows: we have to carry out a full risk assessment of the project and submit an application to Defra where we describe clearly the aims of our experiment, the type of plant material and the specific genetic modifications that we have carried out. We are also required to make an assessment of the risks to human health and the environment. The application becomes publicly available on the Defra website and our application is then independently assessed by the Advisory Committee on Releases to the Environment (ACRE). During the period that the application is being considered there is also a 48-day public consultation carried out by Defra where any member of the public can comment or ask any relevant question. Once the risk assessment process has been carried out, ACRE make their recommendation to Defra who may or may not then grant a consent to conduct an experimental field trial (with specific conditions if appropriate). The trial and the management procedures are regularly inspected and reports made publicly available at http://www.gm-inspectorate.gov.uk/deliberateRelease/exptreleases.cfm

4. What security measures will you be taking?

- Completely surrounding the site will be a 2.4m high chain-link fence (with lockable double gates) to prevent the entry of rabbits, other large mammals and unauthorised persons.

5. Will you need fences and why?

- Unfortunately, in the past, GM field trials in the UK have been damaged by anti-GM protesters. Although these GM plants pose no danger to the public, we felt it necessary to put in place various security measures, including surrounding the trial by a tall fence, to prevent unauthorised access.

- This will be a controlled experiment and we want to ensure that it is conducted with the scientific rigour and high standards at Rothamsted Research.

- To do this, we need to ensure that rabbits, dogs, other large animals and people do not wander into the field and damage the experiment.

- We hope that nobody will attempt to damage the experiment as the results of this trial could be very important in determining whether this type of technology works or not.

6. What about cross-pollination and unintended spread of GM seeds?

- Although wheat pollen can be disseminated by the wind, such dissemination is limited by the relatively large size and weight of wheat pollen. The risk of cross-pollination is also reduced by its short period of viability of the pollen, the existence in the design of the trial of a non-GM wheat pollen barrier and the existence of a 20 m unplanted buffer zone surrounding the trial.

- The majority of the seed is retained in the ear of the wheat plant until harvest but a small proportion can be spilled to the ground during this process. Dispersal of seed prior to harvest by wind is highly unlikely. The risk of dispersal by wildlife is possibly but will be managed by excluding animals from the site by fencing and bird-scaring devices.

- Under experimental conditions wheat can be out crossed to wild grasses. Of these, only the genera *Elymus* and *Elytrigia* (formerly *Agropyron*) are present in the UK and there are no reports of wheat x *Agropyron* spontaneous hybrids. Wheat can also be forced using laboratory techniques to cross to rye, triticale and a limited number of other cereals but these crosses would not occur naturally.

7. Would any trace of gene transfer affect where farmers can sell their produce?

- Given the small scale nature of the proposed experiment and the presence of extensive measures to manage the minimal risk of pollen transfer the chances of gene transfer affecting farmers is exceptionally low.

- See also **6. cross-pollination**

8. **Are you going to test the safety of the wheat plants for human consumption?**

- The aim of the proposed trial is to only test the performance of the plant under field conditions and its ability to photosynthesise more efficiently resulting in higher yields.
- Plants and seeds arising from this trial will not enter the food or feed chains.
- If the trial gives successful results and there is consideration in commercialising the trait, then new GM lines will be generated, further rigorous experiments conducted and separate regulatory processes will be followed. This takes years and years and is a very thorough process.

C) Ecology

1. **How are these plants potentially better for the environment?**

- The aim of this experiment is to test if we can produce higher yielding wheat varieties, whilst using the same available land and the same or less amount of inputs (e.g. water and fertilisers) as currently used. Achieving this will contribute significantly to global food and nutritional security, whilst ensuring environmental sustainability.

2. **Do you foresee any environmental problems from these GM wheat plants? For example down the food chain? Or on wild plants?**

- All material generated and used for the experiment will be destroyed at the end of the experiment following rigorous procedures and no material will enter the food and feed chains.
- Wheat is naturally self-pollinating and only under experimental conditions wheat can be crossed with various wild grasses. See also questions in previous section about cross pollination.

3. **What are the effects on biodiversity of this research?**

- This is a small-scale highly controlled experiment over the course of two years. We do not anticipate any effects on biodiversity.

D) Technical

1. **How did you make the GM plants?**

- We have produced two types of plants, one in which two extra copies of the plant gene SBPase are functional and one in which six extra copies of SBPase are functional.
- To achieve expression of the inserted sequences in the wheat plants we prepared gene cassettes that contain the SBPase gene as well as gene switches and other components that enable the selection of plants that have taken up the inserted DNA versus those that did not.
- The inserted gene is expressed, i.e. functions, throughout the wheat plant.

- The gene cassettes were inserted in the plants by direct gene transfer into specific cells of wheat seeds in the laboratory.

- We used gene-switches (genetic sequences which are responsible for turning genes on and off) to regulate when and where SBPase gene sequences and the selection marker gene sequences will give the information to make the proteins in the plant. The "gene-switches" (also known as promoters) that we used originate from genes in other plants such as maize or other organisms such viruses that affect plants e.g. the rice tungro bacilliform virus. Both of these gene-switches result in SBPase and the herbicide selection marker protein being made continuously throughout the GM wheat plant.

- The gene cassettes that carry the SBPase gene also contain an antibiotic resistance gene that helps distinguish the DNA cassette in laboratory conditions. This antibiotic resistance gene is not active in the plant. The likelihood that these elements could move to soil bacteria is being risk-assessed because theoretically there is a possibility of gene transfer. However, these genetic elements are already present in bacteria and in soil microbes in particular and we estimate the rate of horizontal gene transfer is likely to be extremely low.

- Since we have inserted a number of genes next to each other into the plant, in order to make sure that each gene stops making protein at the correct point we have inserted some genetic "end-signal" sequences in between the genes. In our system these end-signal sequences originate from various organisms including Arabidopsis*, Agrobacterium tumefaciens* and Cauliflower mosaic virus.

2. Can you see any differences between normal plants and the GM ones?

- Apart from the expected characteristic of enhanced SBPase expression and, under glasshouse growth conditions, increased total biomass and dry seed yield (unpublished data), these plants are indistinguishable from non-GM control plants. No other changes to the plant morphology or development have been observed.

3. Where did the SBPase gene come from?

- The SBPase gene comes from *Brachypodium distachyon* a plant species used as a model in laboratory experiments and is a distant relative to wheat. The common name of this plant species is stiff brome.

4. Could the genetic changes end up in other organisms and cause problems?

- The chances that this could happen are exceptionally low given the scale of this experiment and with the safety measures in place.

- SBPase occurs naturally in all plants and is an enzyme which takes part in the Calvin-Benson cycle which makes sugars using the energy produced from absorption of sunlight. To the best of our knowledge there is no published toxicity or allergenicity data for SBPase. At the levels expected to be generated by these plants and because the grain will not enter the food or feed chains, we consider the potential toxic or harmful effects to be negligible.

5. Will your experiment be legal?

- Yes. GM experiments are allowed in Europe as long as the strict regulations to ensure safety are followed. This GM field trial will only proceed if it is authorised by Defra after a careful evaluation of the evidence.

E) Logistics

1. Where is the trial taking place?

- The GM field trial, if approved, will take place on the experimental farm at Rothamsted Research in Harpenden, an agricultural research establishment that receives strategic funding from the Government via the Biotechnology and Biological Sciences Research Council (BBSRC).

- The experiment will be conducted in a dedicated location in the Rothamsted farm in Harpenden, designed to address biosafety and security considerations.

- Rothamsted has many experimental plots covering the whole estate, of which this trial forms one very small part. Some of these experimental plots have been running continuously for more than 170 years, helping to shape our knowledge of agriculture and ecology.

- These Long Term Experiments, a UK national capability funded by the BBSRC and Lawes Agricultural Trust, are unique and precious. They provide valuable data for current research at Rothamsted, as well as being an invaluable UK and international resource.

2. Will I be able to come and look at it?

- Yes, it will be possible to see the trial but you will require permission from Rothamsted Research in order to do this.

- The plot is surrounded by a perimeter fence that has been erected to prevent the entry of rabbits, other large mammals, and unauthorised people to ensure the experiment is conducted with the scientific rigour and high standards expected at Rothamsted Research.

- There is a public footpath, which runs about 50-80 metres from the fence and there will be information points around to inform members of the public what the trial is about.

3. How big is it?

- The area for the proposed field trial, including controls and spacing between GM plots will cover 13.5m x 18m (243 m^2). It will comprise eight 1.8 x 6m plots (86.4 m^2) planted with GM wheat plus four 1.8m x 6 m plots of non-GM controls. Each plot will be separated from each other by 0.5m and from the edge of the trial by a wheat pollen barrier of at least 3m which will completely surround the outer perimeter of the trial. This in turn, is surrounded by a 20m unplanted area which will be kept free from weeds.

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4. How long for will the trial be carried out? i.e. How many seasons, how many replicates?

- If approved, the trial will be carried out over a period of two years in the spring/summer seasons of 2017 and 2018. The plants will be sown in March/April and harvested in Aug/Sept.

F) Finance/Commercialisation

1. **How much will it cost? Who will be paying for it?**

- The proposed field trial is one component of a three-year research project that includes experiments in the laboratory and the glasshouses in three different research organisations in the UK (University of Essex, Lancaster University and Rothamsted Research). The total value of the research project for the three years is £865,884.5. The cost for the proposed field trials is £30K per year.

2. **How can this experiment bring value for the UK taxpayers?**

- This research has been undertaken for many years in the lab and the glasshouses of the partner organisations. This experiment will assist in determining whether this technology could provide environmental and financial benefits for the economy and the taxpayers by improving wheat production, a staple cereal crop.

3. **Have you received industry funding for this work?**

- No. The research project is funded by the Biotechnology and Biological Sciences Research Council (BBSRC) and United States Department of Agriculture (USDA ARS) as part of the International Wheat Yield Partnership (IWYP) consortium activities. This particular research project is funded under IWYP with the following contributions: UK, BBSRC: (£695,933); USA, USDA $294,350. The IWYP public and industrial partners are numerous and are all listed here http://iwyp.org/partners/ Private partners are members by paying a small yearly fee to help offset administrative costs of IWYP. A few function as **non-voting members** of the executive board and **serve in an advisory capacity**. Although their input is sought, they do not make selections or final decisions. Research funding is solely from public funders in many countries, their individual agencies make final funding decisions based on recommendations of IWYP, and therefore research results and outputs are open access and nonexclusive.

- Rothamsted Research does receive some funding from industry, but not for this project specifically.

- Our overarching philosophy at Rothamsted Research is that we need to work with government policymakers, non-government organisations (NGOs), agribusinesses and farmers if we are to deliver the knowledge, innovation and new practices to increase crop productivity and quality, and to develop environmentally sustainable solutions for agriculture.

- Working with industry is a must if we are to turn our scientific knowledge into technologies that can benefit farmers, because it is only industrial partners that have the necessary infrastructure to develop and distribute innovative technologies to those who need it.

- However, at Rothamsted Research we also recognise that the UK taxpayer is the main funder of our research. We recently conducted a formal public dialogue in order to listen to the views of the public and those of the stakeholders of Rothamsted Research on our collaborations with industry and to receive their input in developing guiding principles of how we should work with industry. More information on the outcomes of the dialogue can be found here: http://www.rothamsted.ac.uk/news/public-dialogue-guiding-principles-rothamsted-research%E2%80%99s-work-with-industry

4. Who owns the existing patents in this area, and who will own the results of this research?

- This is a proof of concept experiment as part of the regular research practice. The organisations involved in the research project hold no IP for commercialisation.

5. Are there any potential economic returns from this research, and who will gain from it?

- This is a small experimental field trial to test for the first time the efficacy of this characteristic in wheat plants in field conditions. This is an early stage of the research project and quite upstream of commercialisation. In the long run, the potential for economic returns from the research project as a whole for farmers internationally and taxpayers will only be able to be predicted once the research project has been completed and the results will have been fully analysed.

6. How will you ensure this doesn't just line the pockets of industry and reaches those who will benefit from the technology but may not be able to afford it?

- This project is quite upstream of commercialisation. However, in general, when licensing our technology to commercial producers, our primary goal is to ensure maximum benefit to society. We therefore take steps to ensure that licensees achieve this.

7. Is there a market for this potential product?

- This project is quite upstream of commercialisation. However, yes, theoretically there is as wheat is a main commodity crop globally.

8. Are you going to put the knowledge gained from this trial in the public domain?

- Yes, the results will be published after peer review in the appropriate scientific journal and we will make them accessible on our website. We will also communicate them in dissemination events at each of the institutions.