Transgenic banana could feed millions

RIU

Validated RNRRS Output.

A safe transgenic banana could prevent nematodes (worms) destroying around 6 million tonnes of bananas a year. This is enough to feed the 60 million people in Uganda, Rwanda, Ghana, Nigeria and Cameroon for whom banana is a staple food. Because bananas are sterile, it's very hard to breed resistance to nematodes by conventional plant breeding methods. And the chemicals that are used to control nematodes are harmful both to humans and the environment. The gene introduced into East Highland African Bananas stops the nematodes growing and laying eggs, but does not affect humans at all. This technology is already being used in the UK, and also in Uganda on local cooking bananas. The transgenic method is also being applied to develop nematode-resistant potatoes and rice.

Project Ref: **PSP20:**
Topic: **1. Improving Farmers Livelihoods: Better Crops, Systems & Pest Management**
Lead Organisation: **John Innes Centre, UK**
Source: **Plant Sciences Programme**

Document Contents:

Description

Research into Use
NR International
Park House
Bradbourne Lane
Aylesford
Kent
ME20 6SN
UK

Geographical regions included:

UK, Uganda,

Target Audiences for this content:

Crop farmers,

PSP20

A. Description of the research output(s)

1. Working title of output or cluster of outputs.
In addition, you are free to suggest a shorter more imaginative working title/acronym of 20 words or less.

Genetically engineered resistance to banana nematodes

2. Name of relevant RNRRS Programme(s) commissioning supporting research and also indicate other funding sources, if applicable.

Plant Science Research Programme (ID code PSP0033).

3. Provide relevant R numbers (and/or programme development/dissemination reference numbers covering supporting research) along with the institutional partners (with individual contact persons (if appropriate)) involved in the project activities. As with the question above, this is primarily to allow for the legacy of the RNRRS to be acknowledged during the RiUP activities.

Plant Science Research Programme grants R6743 and R8031.

Institutional partners on DFID PSRP grant R6743 and R8031:
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*4. Describe the RNRRS output or cluster of outputs being proposed and when was it produced? **(max. 400 words)**. This requires a clear and concise description of the output(s) and the problem the output(s) aimed to address. Please incorporate and highlight (in bold) key words that would/could be used to select your output when held in a database.*

The output is both a technology and a product and was generated over the 2002-2005 period.

The technology enables the reliable production of banana **embryogenic callus** and **cell suspension cultures**, which can be used for **genetic transformation**. This technology has been optimised for East Highland African Bananas (EHAB). These are AAA **cooking bananas** which represent the staple food for millions of people in Africa. Unfortunately, most EHAB are recalcitrant to callus and cell culture *in vitro* and cannot be genetically transformed. The output from this programme provides for the first time – worldwide - a technology enabling the transformation of EHAB. Banana plants are grown in glasshouses at the John Innes Centre (Norwich, UK), immature inflorescences are harvested and cultured *in vitro* to produce embryogenic callus, which is then dispersed in liquid culture and used for genetic transformation. This technology was successfully transferred to KARI-NARO (Kampala, Uganda) where embryogenic callus was produced from local cooking banana varieties.

The product comprises of transgenic banana plants with varying levels of **resistance to nematodes**. The African countries that have banana-dependent food insecure people include Uganda, Rwanda, Ghana, Nigeria and Cameroon. Banana losses to nematodes are estimated to be 6m tonnes/year representing the consumption need of 60m people in banana-dependent countries. Banana improvement by conventional plant breeding is very difficult given its reproductive sterility and nematicide chemicals are harmful to both humans and the environment. Using nematicides is also not economically feasible for poor and subsistence farmers. This situation provides a very good opportunity for a biotechnological solution. Our approach relies on introducing into banana an additional plant gene coding for a protein (called cystatin) that prevents the digestion of parasitic nematodes. The cystatin suppresses the nematode's ability to grow, lay eggs and build to population levels that damage crops. As cystatins are part of the human diet (present in cereal seeds, eggs etc.) they have no effect on our digestion or health. Additional work funded by other donors (DEFRA) has demonstrated that cystatin has also no environmental impact on a wide range of non-target organisms.

The outputs from this project provide an example of how transgenic technology can be adapted to meet the needs of the poor. A parallel strategy is described in proforma dossiers No19 and No21 on genetically engineered rice and potato for nematode resistance, respectively.

5. What is the type of output(s) being described here?
Please tick one or more of the following options.

Product	***Technology***	***Service***	***Process or Methodology***	***Policy***	***Other Please specify***
x	*x*				

6. What is the main commodity (ies) upon which the output(s) focussed? Could this output be applied to other commodities, if so, please comment

Banana, more specifically cooking bananas from Uganda also called East Highland African Bananas (EHAB) are the main commodity for which the approach is relevant.

7. What production system(s) does/could the output(s) focus upon?

Please tick one or more of the following options. Leave blank if not applicable

Semi-Arid	***High potential***	***Hillsides***	***Forest-Agriculture***	***Peri-urban***	***Land water***	***Tropical moist forest***	***Cross-cutting***
			x				

8. What farming system(s) does the output(s) focus upon?
Please tick one or more of the following options (see Annex B for definitions).
Leave blank if not applicable

Smallholder rainfed humid	***Irrigated***	***Wetland rice based***	***Smallholder rainfed highland***	***Smallholder rainfed dry/cold***	***Dualistic***	***Coastal artisanal fishing***
x			*x*			

*9. How could value be added to the output or additional constraints faced by poor people addressed by clustering this output with research outputs from other sources (RNRRS and non RNRRS)? (**max. 300 words**). Please specify what other outputs your output(s) could be clustered. At this point you should make reference to the circulated list of RNRRS outputs for which proformas are currently being prepared.*

These outputs can be clustered with others focusing on banana improvement through classical breeding or biotechnology. Stacking transgenic nematode resistance with other traits (GM or not) such as bacterial and fungal resistance could significantly enhance banana productivity and hence benefit poor and subsistence farmers in Africa, South Asia and South America.

Value could be added by clustering with outputs from other banana transformation projects or research programmes using transgenic approaches for nematode resistance in other crops. This includes outputs from RNRRS sources described in proforma dossiers No19 (“Genetically engineered resistance to rice nematodes”) and No21 (“Genetically engineered resistance to potato nematodes”). This also includes outputs from non-RNRRS sources focusing on GM banana research in National Research Programmes (Uganda, India, Mexico etc.) or CGIAR Centres such as IITA.

Validation

B. Validation of the research output(s)

***10. How** were the output(s) validated and **who** validated them?*
Please provide brief description of method(s) used and consider application, replication, adaptation and/or adoption in the context of any partner organisation and user groups involved. In addressing the “who” component detail which

group(s) did the validation e.g. end users, intermediary organisation, government department, aid organisation, private company etc... This section should also be used to detail, if applicable, to which social group, gender, income category the validation was applied and any increases in productivity observed during validation ***(max. 500 words)****.*

Validation of technology

The callus and cell culture technologies developed for Ugandan cooking bananas (EHAB) have been validated through repeated use by scientists at the John Innes Centre (JIC) and the Kawanda Agricultural Research Institute (KARI) including Dr. Philippe Vain (JIC) and Priver Namanya (KARI). Embryogenic cell suspensions cultures have also been used successfully as target material for genetic transformation at JIC. This work is currently being summarised in a scientific publication to be submitted for review.

Validation of product

Ugandan cooking banana plants (Matoké type) containing an additional cystatin gene were assessed for nematode resistance in bioassays undertaken by scientists at the University of Leeds (by Prof. Howard Atkinson's group). Transgenic banana plants containing and expressing different cystatin genes were challenged with *Meloidogyne incognita* and exhibited levels of resistance. This was the first demonstration world-wide of the value of transgenic East African Highland Bananas (EHAB).

Cystatin genes were also introduced into another type of AAA bananas (Cavendish) leading to levels of resistance to *Radopholus similis*. This work was published in a peer-reviewed international scientific journal:

Atkinson HJ, Grimwood S, Johnston K and Green J (2004) Prototype demonstration of transgenic resistance to the nematode *Radopholous simils* conferred on banana by a cystatin. Transgenic Research 13:135-142

The efficacy of cystatin proteins against a wide range of nematode species and the generic value of using cystatin-based transgenic approaches for nematode control have been extensively documented through peer-review publications from H. Atkinson's group:

Lilley CJ, Urwin PE, Johnston KA, et al. (2004) Preferential expression of a plant cystatin at nematode feeding sites confers resistance to *Meloidogyne incognita* and *Globodera pallida*. Plant Biotechnology Journal. 2:3-12.

Atkinson HJ, Johnston KA, Robbins M (2004) Prima facie evidence that a phytocystatin for transgenic plant resistance to nematodes is not a toxic risk in the human diet. Journal of Nutrition 134:431-434

Atkinson HJ, Urwin PE, McPherson MJ (2003) Engineering plants for nematode resistance. Annual Review of Phytopathology 41:615-639.

Urwin PE, Green J. and Atkinson H.J. (2003) Expression of a plant cystatin confers partial resistance to Globodera, full resistance is achieved by pyramiding a cystatin with natural resistance. Molecular Breeding 12:263-269.

Urwin PE, Zubko EI, Atkinson HJ (2002) The biotechnological application and limitation of IRES to deliver multiple defence genes to plant pathogens. Physiol. And Molecular Plant Pathology 61:103-108.

Urwin PE, Troth KM, Zubko EI, *et al.* (2001) Effective transgenic resistance to Globodera pallida in potato field trials. Molecular Breeding 8:95-101.

Urwin PE, Levesley A, McPherson MJ, et al. (2000) Transgenic resistance to the nematode Rotylenchulus reniformis conferred by Arabidopsis thaliana plants expressing proteinase inhibitors. Molecular Breeding 6:257-264

Lilley CJ, Devlin F, Urwin PE, *et al.* (1999) Parasitic nematodes, proteinases and transgenic plants.

Parasitology Today 15:414-417.
Urwin PE, McPherson MJ, Atkinson HJ (1998) Enhanced transgenic plant resistance to nematodes by dual proteinase inhibitor constructs. Planta 204:472-479.
Vain P, Worland B, Clarke MC, *et al.* (1998) Expression of an engineered cysteine proteinase inhibitor (Oryzacystatin-I Delta D86) for nematode resistance in transgenic rice plants. Theoretical and Applied Genentics 96:266-271.
Urwin PE, Lilley CJ, McPherson MJ, *et al.* (1997) Resistance to both cyst and root-knot nematodes conferred by transgenic Arabidopsis expressing a modified plant cystatin. Plant Journal 12:455-461.

*11. **Where and when** have the output(s) been validated? Please indicate the places(s) and country(ies), any particular social group targeted and also indicate in which production system and farming system, using the options provided in questions 7 and 8 respectively, above **(max 300 words)**.*

The tissue culture technology to initiate embryogenic callus and cell suspension cultures were developed and validated at the John Innes Centre (UK) during the 2001-2002 period. These technologies were subsequently transferred to the Kawanda Agricultural Research Institute (Uganda).

Genetically transformed cooking bananas containing an additional cystatin gene against nematodes were produced during the 2002-2004 period at the John Innes Centre. The University of Leeds conducted all glasshouse trials of GM bananas. These plants have not yet been evaluated in the developing world as the DFID PSRP came to an end in 2006 coinciding with banana plants being clonally propagated *in vitro* for field trial. The Kawanda Agricultural Research Institute has agreed to test these GM banana plants in Uganda but needs support. In addition, improving nematode resistance using a generic cystatin-base approach could impact on a broad range of nematodes and therefore be relevant to many African, Asian and South-American countries growing bananas for local consumption.

Current Situation

C. Current situation

*12. **How and by whom** are the outputs currently being used? Please give a brief description **(max. 250 words**).*

Technology
The tissue culture technologies developed in this programme have been used by Priver Namanya in Uganda (Kawanda Agricultural Research Institute) to produce – for the first time - embryogenic callus from local genotypes.

Product
Transgenic banana plants containing an additional cystatin gene have not yet been evaluated in the developing world as the DFID PSRP came to an end in 2006 coinciding with banana plants being clonally propagated *in vitro* for field trial. The GM banana plants are maintained *in vitro* using resources at the John Innes Centre until further

funds are secured to deliver these important outputs.

*13. **Where** are the outputs currently being used? As with Question 11 please indicate place(s) and countries where the outputs are being used **(max. 250 words).***

Technology
The tissue culture technologies developed in this programme have been used by scientists at the John Innes Centre (UK) as well as at Kawanda Agricultural Research Institute to produce embryogenic callus from local cooking banana genotypes.

Product
Products are not currently being used because of the end of the DFID PSRP funding in 2006. The Kawanda Research Agricultural Institute has agreed to test the transgenic banana plants containing an additional cystatin gene for nematode resistance in Uganda providing that funding can be secured.

*14. What is the scale of current use? Indicating how quickly use was established and whether usage is still spreading **(max 250 words).***

Technology
To date, the technologies developed in this programme have been used in the UK and in Uganda. Publication of this work should promote further use.

Product
Transgenic banana plants containing an additional cystatin gene have not yet been evaluated in the developing world because of the end of the DFID PSRP in 2006.

*15. In your experience what programmes, platforms, policy, institutional structures exist that have assisted with the promotion and/or adoption of the output(s) proposed here and in terms of capacity strengthening what do you see as the key facts of success? **(max 350 words).***

The following factors have contributed to the promotion and adoption of the outputs:

- The publication on genetically engineered nematode resistance in banana using cystatin genes (Atkinson *et al.* 2004 – see section B of this dossier).
- The Ugandan initiative on "Novel approaches to the improvement of banana production in East Africa – the application of biotechnological methodologies" implemented by INIBAP-IPGRI has provided a valuable framework for promotion and/or adoption of the technologies developed in this programme. The membership of the John Innes Centre along with NARO, IITA, KULeuven, CIRAD and the Makerere University in Uganda in this initiative has greatly facilitated the free dissemination of outputs to African partners.
- Articles in the popular press about the outputs of the programme such as "Worms beaten back in the battle for banana" (2003) New Scientist February 1st, p15 or "Going bananas" (2003) Evening News, January 25th, p3.

- Additional web-based information provided by the institutions (University of Leeds, John Innes Centre, DFID PSRP etc..) involved in this work:
  http://www.biology.leeds.ac.uk/nem/crops/crops.htm
  http://www.dfid-psp.org/Research/CropTrans2.html
  http://www.jic.ac.uk/staff/philippe-vain/banana.htm
- Presentation of the outputs at international meetings, especially those in Africa, Asia and South America:
  Atkinson HJ (2006) Prospects for transgenic control of nematodes on banana. Invited International Speaker to the annual conference of the Organisation of Tropical America Nematologists, (Costa Rica, June 2006).
  Atkinson HJ (2006) Recent Progress on Molecular Approaches to Novel Crop Resistance against Nematodes, Brazilian National Nematology Conference, February 2006 (Invited Speaker).
  Atkinson HJ (2006) Recent Progress on Molecular Approaches to Novel Crop Resistance against Nematodes. Invited international speaker to the S. Korean Government Conference on Applied Genomic (Seoul, June 2006).
  Atkinson HJ, Green J, Vain P, Pinto Y, Koyama M and Snape JW (2005) Genetically modified crops can contribute to pathways out of poverty. AAB conference, September 22nd-23rd , Cambridge, UK.
  Atkinson, H.J.; Cowgill, S.E., Green, J., and Kiezebrink, D.T. (2004) Progress and challenges in developing transgenic nematode resistant crops for subsistence agriculture. Invited presentation at XXVII ESN International Symposium Rome June 2004.
  Vain P, Worland B, Ross S, Green J, Atkinson H and Snape JW (2002) Transformation of East African Highland Banana for nematode resistance. 3nd Workshop on Biotechnology for Banana in East Africa, November 13-15th. Kampala, Uganda.
- Presentation of outputs in DFID reports:
  Vain P, and Snape JW (2004) A UK banana transformation capability for developing countries applications. In DFID PSP Annual report. CAZS, Witcombe JR and Harris D eds. p15-17.
  Vain P, and Snape JW (2001) A UK banana transformation capability for developing countries applications. In DFID PSP Annual report. CAZS, Witcombe JR and Harris D eds. Section 1, p39-40.

Biotechnological solutions should be addressing local needs and have a strong biosafety background. This requires an assessment under field conditions in different locations, using different production systems and over several years by national programmes. Further diffusion to growers via participatory breeding schemes can further contribute to the evaluation and ensure that transgenic plants are fit for purpose. The attitude of local governments towards biotechnologies is also a key factor for success. In this regard, the Ugandan government is committed to fund biotechnology-based approaches to enhance cooking banana production.

Current Promotion

D. Current promotion/uptake pathways

*16. **Where** is promotion currently taking place? Please indicate for each country specified detail what promotion is taking place, by whom and indicate the scale of current promotion **(max 200 words).***

The technology is promoted worldwide through peer-reviewed scientific publications, web-based information and the Ugandan initiative on the application of biotechnological methodologies (see section C of this dossier).

The product (*i.e.* transgenic cooking banana plants with levels of resistance to nematodes) are not currently being used in developing countries. However, the Kawanda Agricultural Research Institute has agreed to test these plants in Uganda providing that funding can be secured.

Proforma dossier No19 and No21 provide examples of promotion and uptake pathways for transgenic rice and potato plants containing additional cystatin genes for nematode control, respectively.

17. What are the current barriers preventing or slowing the adoption of the output(s)? Cover here institutional issues, those relating to policy, marketing, infrastructure, social exclusion etc. ***(max 200 words)****.*

Technology

There are no barriers to the adoption of tissue culture and transformation technologies as the know-how is freely available and actively disseminated through the Ugandan biotechnology initiative (see section C of this dossier). The technological outputs do not bring additional intellectual property right constrains to existing transgenic strategies for banana improvement.

Product

The end of the DFID PSRP funding in 2006 has stopped the planned translational research to developing countries. Current barriers are:

- Lack of funding to enable the maintenance of expertise and ouputs (*i.e.* transgenic banana clones with anti-nematode transgenes) in the UK.
- Lack of funding to carry out field trials in Africa. The Kampala Agricultural Research Institute has offered to test these banana plants in Uganda but needs support.
- The impact of nematodes is generally underestimated by both international and national research institutes which consequently lack activity in this area. This represents an excellent opportunity to valorise the outputs from the DFID-funded science based in this area of research to benefit the poor.
- The absence of biosafety regulations and of the means to implement them prevents the evaluation and release of GM crops in many African countries.

18. What changes are needed to remove/reduce these barriers to adoption? This section could be used to identify perceived capacity related issues ***(max 200 words).***

No changes are required for the adoption of the banana tissue culture and transformation technology by the international scientific community. However, many changes are needed to remove or reduce the barriers to the adoption of GM crops in Africa and to a lesser extend in Asia. Helping African countries to develop and implement biosafety regulations is a pre-requisite. Developing transgenic strategies with a strong poverty focus (*i.e.* with relevant traits in relevant species) and a public-good approach are also key. Evaluation of the GM crops by participatory breeding after initial testing by national programmes could help to demonstrate the benefits to poor or subsistence farmers. Maybe more consideration should also be given to the voice of developing world farmers

who would like to explore for themselves the potential benefits of biotechnologies to improve their livelihood.

19. What lessons have you learnt about the best ways to get the outputs used by the largest number of poor people? ***(max 300 words).***

The product (*i.e.* transgenic cooking banana plants with levels of resistance to nematodes) is not currently being used in developing countries. However, the following factors are foreseen to be instrumental in getting the outputs used by the largest number of poor people:

- Demonstration of efficacy of the GM trait locally under the farming conditions of the poor.
- Scientists in national programmes committed and well resourced to complete the translational research and to further develop "home grown" technology and ownership.
- Maintenance of staff and competence in national programmes to achieve the activities described above.
- Schemes to engage with growers on the balance of benefits and risks associated with biotechnology.
- A "realistic" environment for biotechnology from a range of stakeholders including politicians and media.
- A national government with commitment to plant biotechnology and with all necessary legislation in place and active. Uganda meets these criteria.

Proforma dossiers No19 ("Genetically engineered resistance to rice nematodes") and No21 ("Genetically engineered resistance to potato nematodes") provide examples of the lessons learnt in the best ways to get GM crops containing additional cystatin gene(s) against nematodes used by the largest number of poor people.

Impacts On Poverty

E. Impacts on poverty to date

20. Where have impact studies on poverty in relation to this output or cluster of outputs taken place? This should include any formal poverty impact studies (and it is appreciated that these will not be commonplace) and any less formal studies including any poverty mapping-type or monitoring work which allow for some analysis on impact on poverty to be made. Details of any cost-benefit analyses may also be detailed at this point. Please list studies here.

The product is not currently being used in developing countries and to date, no GM banana has been released / commercialized worldwide. The impact of GM banana on poverty is therefore difficult to assess post-release. The specific issues of the benefits from transgenic nematode resistance have been considered and the extent of need in terms of nematode loses to banana is detailed in section 22 of this dossier.

Atkinson H.J. *et al.* (2005) Genetically modified crops can contribute to pathways out of poverty. *Aspects of Applied Biology* 75:109-113.

Atkinson HJ, Green J, Cowgill S, *et al.* (2001) The case for genetically modified crops with a poverty focus. Trends in Biotechnology 19:91-96.

Many studies have also analysed in general terms issues of plant biotechnology and its benefits to the poor:

Cohen JI (2005) Poorer nations turn to publicly developed GM crops, Nature Biotechnology, 23, 27-33.

Thirtle, C, Beyers, L., Ismael, Y Piesse, J (2003) Can GM-Technologies Help the Poor? The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal World Development, 31, 717–732
Lipton M. (2001), Reviving global poverty reduction, what role for genetically modified plants, Journal of International Development, 13, 823-846.
Toenniessen GH, O'Toole JC and DeVries J (2003) Advances in plant biotechnology and its adoption in developing countries. Current opinion in biotechnology 6:191-198.

21. Based on the evidence in the studies listed above, for each country detail how the poor have benefited from the application and/or adoption of the output(s) ***(max. 500 words):***

- *What positive impacts on livelihoods have been recorded and over what time period have these impacts been observed? These impacts should be recorded against the capital assets (human, social, natural, physical and, financial) of the livelihoods framework;*
- *For whom i.e. which type of person (gender, poverty group (see glossary for definitions) has there been a positive impact;*
- *Indicate the number of people who have realised a positive impact on their livelihood;*
- *Using whatever appropriate indicator was used detail what was the average percentage increase recorded*

To date, no GM banana has been released / commercialized worldwide therefore only pre-commercialisation data are available. However, the socio-economical and environmental impact of other GM crops - such as insect resistant *B.t.* cotton and *B.t.* maize - currently commercialised in developing countries - such as China, India or South Africa - has been the subject of many studies (Carl E. Pray *et al.* 2002, Five years of Bt cotton in China – the benefits continue, The Plant Journal 31:423-430 ; http://www.isaaa.org/). It is estimated that China has enhanced its farm income from biotech cotton by $4.2 billion in the 1997-2004 period. In 2005, 6.4 million small farmers were growing *B.t.* cotton in China. However, benefits of a different type of *B.t.* cotton in India have been less clear, highlighting that GM approaches should be tailored to local environments (such as high pest and pathogen pressures), agronomic practices and needs.

Environmental Impact

H. Environmental impact

24. What are the direct and indirect environmental benefits related to the output(s) and their outcome(s)? ***(max 300 words)***

This could include direct benefits from the application of the technology or policy action with local governments or multinational agencies to create environmentally sound policies or programmes. Any supporting and appropriate evidence can be provided in the form of an annex.

FAO has identified our approaches as the best prospect for biosafe banana nematode control. The use of

pesticides is not appropriate for most poor or subsistence farmers who lack both training in proper chemical use and protective clothing. Nematicides also belong to the most hazardous WHO classes a & b and are used routinely on banana plantations with considerable harm to human populations (*i.e.* in Ecuador) plus widespread environmental harm. However, pressure to use nematicides is likely to intensify when other approaches fail to be effective. Cystatin-based transgenic approaches can deliver alternative and generic approaches to chemical control of nematodes in banana with considerable environmental benefits. In addition, most bananas are sterile due to their triploid nature providing a natural containment system to prevent gene flow through cross-pollination.

All GM banana field trials will be carried out under secure conditions and experiments can be terminated before fruit has set. The latter measure ensures fruit pilfering cannot occur.

25. Are there any adverse environmental impacts related to the output(s) and their outcome(s)? ***(max 100 words)***

The cystatin-based approach to control nematodes will have no adverse environmental impact. Additional work from the University of Leeds (and funded by other donors) has demonstrated that cystatins have no environmental impact on a wide range of non-target organisms. This work has been published in the following peer-reviewed articles:

Celis C, Scurrah M, Cowgill S *et al.* (2004) Environmental biosafety and transgenic potato in a centre of diversity for this crop. **Nature** 432:222-225.
Cowgill SE, Danks C, Atkinson HJ (2004) Multitrophic interactions involving genetically modified potatoes, nontarget aphids, natural enemies and hyperparasitoids. Molecular Ecology 13:639-647.
Cowgill SE, Atkinson HJ (2003) A sequential approach to risk assessment of transgenic plants expressing protease inhibitors: effects on nontarget herbivorous insects. Transgenic Research 12:439-449.
Cowgill SE, Bardgett RD, Kiezebrink DT, *et al.* (2002) The effect of transgenic nematode resistance on non-target organisms in the potato rhizosphere. J. of Applied Ecology. 39:915-923.
Cowgill SE, Wright C, Atkinson HJ (2002) Transgenic potatoes with enhanced levels of nematode resistance do not have altered susceptibility to nontarget aphids. Molecular Ecology 11:821-827.

Currently, no efficient mean of producing GM banana plants free of selectable marker genes exists and herbicide resistance genes are often used to recover transgenic plants during the transformation process. In GM bananas, these herbicide resistant genes do not pose a problem of horizontal gene transfer as plants are sterile and cannot cross-pollinate with wild relatives.

26. Do the outputs increase the capacity of poor people to cope with the effects of climate change, reduce the risks of natural disasters and increase their resilience? ***(max 200 words)***

The principal and direct consequence of nematode damage is to stunt root systems. This makes plants are less able to obtain water and nutrients from soil. Common symptoms of nematode attack are wilting and mineral deficiencies. Our approach could help poor farmers to cope with environmental pressures which can be amplified in cases of droughts associated with climate change.