Institution: Imperial College London

Unit of Assessment: 5 Biological Sciences

Title of case study: 5 - The development and application of successful mycoinsecticides for locust control in Africa and Australia: Green Muscle® and Green Guard®

1. Summary of the impact (indicative maximum 100 words)

Locust and grasshopper outbreaks can form swarms containing billions of insects, creating feared and damaging agricultural pests. Following research at Imperial College London, the entomopathogenic fungus *Metarhizium acridum* was developed into an oil formulated product ('Green Muscle®') that could be applied by ground-based and aerial spray equipment at ultra-low volume (ULV) rates, when locust and grasshopper populations periodically increased. Green Muscle® has since been used to treat locust outbreaks in Israel and five southern African countries. Green Guard®, an associated mycoinsecticide marketed in Australia, has been used extensively to control locusts in regions where there are land use limitations on chemical pesticides. Both Green Muscle® and Green Guard® are supplied by Becker Underwood. Besides the success of *Metarhizium* as an effective, environmentally-friendly locust control option, substantial science and enabling technology ensued, that should accelerate the development of other mycopesticides as important alternatives to currently beleaguered chemical pest control methods.

2. Underpinning research (indicative maximum 500 words)

Locusts, in their gregarious phase, can form huge groups and embark on mass migrations, travelling as vast swarms of agricultural pests. Locust swarms have the potential to affect the livelihoods of one in ten people on the planet. A single locust swarm can contain billions of insects and travel hundreds of kilometres a day. The ban on spraying toxic insecticides such as dieldrin to control locusts led to international funding to develop a biological control method. This was achieved by the LUBILOSA Programme [1, G1], a research programme aimed at developing a biological alternative to the chemical control of locusts, by developing a mycoinsecticide based on the fungus *Metarhizium acridum*. The founding partner was CABI, which collaborated with two Imperial College laboratories: the International Pesticide Application Research Centre (IPARC) and the Centre for Population Biology (CPB), both situated at Silwood Park, Imperial College.

Work at IPARC focused on (i) development of the fungal spores into a formulated product called 'Green Muscle' and (ii) improving the chances of microbial control agents working in the field through optimising application techniques to ensure that spores have a reasonable chance of reaching the biological target. The work was underpinned by IPARC's long-standing collaboration with UK manufacturers of rotary atomisers used for ultra-low volume (ULV) application of insecticides for both locusts and cotton pests. This enabled the export of over a million spinning disc sprayers for small-scale farmers in Africa and, fortuitously, research in 1993 at Imperial had focussed on the ULV application of particulate suspensions. Formulation of *Metarhizium* conidia in oil [2; and UK Patent GB2255018B] enabled spraying at ULV rates (0.5-2 litres/ha), with rotary atomisers used efficiently to spray 5 x 10^{12} conidia/ha in dry environments. 'Green Muscle' development at IPARC enabled such inter-disciplinary and education-linked research to continue, for example, with a project that evaluated its use in vehicle-mounted sprayers [Pestic. Sci., 51, 176–184, 1997].

There was an obvious need to find and identify a virulent entomopathogen [3]; the sequence of changed names used for the *Metarhizium* fungi actually reflects their importance: with international efforts only resolving the name *M. acridum*, in 2009. The standard 'Green Muscle' strain IMI330189 had been isolated from a grasshopper in Niger, and this was used for all major trials (although a different isolate showed better efficacy against Pyrgomorph grasshoppers). In the first large-scale trial in 1995 in south-east Niger, six 50 hectare plots were sprayed, resulting in over 80% reduction of the grasshopper population after 3 weeks, in contrast to significantly higher populations in plots

treated with fenitrothion, an organophosphorus insecticide [4]. Field results carried out in the late 1990s have proved equally reliable with aerial applications, usually with superior pest control to chemical standards and minimal detrimental effects on the environment [e.g. 5]. Similar results were achieved, with a different *M. acridum* isolate, in Australia (see §4). The potential for horizontal transmission (secondary cycling) due to reproduction of the micro-organism [Proc. R. Soc. Lond. B, 259, 265-270, 1995] is an added benefit, but it is dependent on environmental conditions and takes time to verify in the field. Probably of more practical significance, with *Metarhizium* and other entomopathogenic fungi, is that the relationship between dosage and efficacy can be complicated by temperature and pathogen-host attack and defence mechanisms [6]. The understanding of this is important for interpreting field trial data and 'placing' appropriate isolates for target pests.

Key personnel:

- Roy Bateman, CABI Bioscience (1989-2003), Imperial College, then Honorary Senior Lecturer, Division of Ecology and Evolution, Department of Life Sciences, Imperial College London (2003-present)
- Matthew Thomas, Research Fellow, then Lecturer, CPB and CABI Bioscience, Imperial College London (1991-2005)
- Simon Blanford, PhD student (1995-1998), research fellow (1999-2002), Department of Life Sciences, Imperial College London

3. References to the research (* References that best indicate quality of underpinning research)

[1] * Lomer CJ, Bateman RP, Johnson DL, Langewald J, Thomas M., '*Biological Control of Locusts and Grasshoppers'*, Annual Review of Entomology, 46, 667-702 (2001). DOI, **141 citations (as at 19/07/13)**

[2] * Bateman, RP; Carey, M; Moore, D; Prior, C., '*The enhanced infectivity of Metarhizium flavoviride in oil formulations to desert locusts at low humidities'*, Annals of Applied Biology, 1222, pp 145–152 (1993). DOI, **150 citations (as at 19/07/13)**

[3] Bateman RP, Carey M, Batt D, Prior C, Abraham Y, Moore D, Jenkins N, Fenlon J., '*Screening for Virulent Isolates of Entomopathogenic Fungi Against the Desert Locust, Schistocerca gregaria Forskal'*, Biocontrol Science and Technology**,** 6, 549-560 (1996). DOI, **27 citations (as at 19/07/13)**

[4] Kooyman, C; Bateman, RP; Langewald, J; Lomer, CJ; Ouambama, Z; Thomas, MB., '*Operational-scale application of entomopathogenic fungi for control of Sahelian grasshoppers'*, Proc. R. Soc. Lond. B, 264, 541-546 (1997). DOI, **26 citations (as at 19/07/13)**

[5] Langewald J, Ouambama Z, Mamadou A, Peveling R, Stol I, Bateman R, Attignon S, Blanford S, Arthurs S, Lomer C , '*Comparison of an organophosphate insecticide with a mycoinsecticide for the control of Oedaleus senegalensis (Orthoptera: Acrididae) and other Sahelian grasshoppers at an operational scale*', Biocontrol Science and Technology, 9, 199-214 (1999). DOI, **26 citations (as at 19/07/13)**

[6] * Blanford S, Thomas MB, Langewald J, '*Behavioural fever in the Senegalese grasshopper, Oedaleus senegalensis, and its implications for biological control using pathogens*', Ecological Entomology, 23, 9-14 (1998). DOI, **54 citations (as at 19/07/13)**

Grants:

[G1] **LU**tte **BI**ologique contre les **LO**custes et les **SA**uteriaux (LUBILOSA): was a research and development programme funded (approximate total £10.4m) by the Governments of: Canada, the Netherlands, Switzerland and the UK. It was implemented by: CABI, CILSS-AGRHYMET, GIZ, Imperial College (IPARC and CPB) & IITA.

4. Details of the impact (indicative maximum 750 words)

Because the use of a mycoinsecticide in the context of locust control was such a novel concept at the time, LUBILOSA scientists were obliged to undertake an extended transition from research to the 'near marketplace'. The large trials in Niger of 'Green Muscle' (§ 2) were all publically funded, as were toxicology, ecotoxicology, registration support and even initial branding: functions normally

carried-out in the 21st century by private enterprise. The pattern of public-funded research being taken up by small companies now appears to be conforming to another trend: over recent years these have been in turn acquired by major agro-chemical companies. The withdrawal of many conventional chemicals, for various environmental, toxicological and regulatory reasons, has created a heightened need for biopesticides, so in retrospect the importance of this work extends well beyond just locust control.

Green Muscle®

The company Biological Control Products (BCP), a leading producer of biopesticides in Africa, commercialized *Metarhizium* for the locust control market as 'Green Muscle', first in South Africa and subsequently in other southern and eastern African countries. The company was taken over by the U.S. crop-technology company Becker Underwood in 2010, which was in turn bought by BASF in 2012. The company continues to supply Green Muscle® for the central & southern African market [A]. The product is marketed as '*an alternative to chemical pesticides*' that works in '*complete harmony with the environment'*, and it is '*recommended by the Food and Agriculture Organisation of the United Nations for use in ecologically sensitive areas*' [A]. The impact of Green Muscle includes:

- In 2009, the bio-pesticide was used to treat around 10,000 hectares of wetlands infested with red locusts (*Nomadacris septemfasciata*) - this was to prevent a full-blown invasion that could have affected the food crops of around 15 million people - whilst still protecting wild animals including: elephants, hippos, and giraffes, in the Iku-Katavi National Park, Tanzania [B]. It was the first time that biopesticides had been used on such a large scale against locusts in this region and the Food and Agriculture Organization of the United Nations (FAO) organized and coordinated the campaign together with the International Locust Control Organization for Central and Southern Africa (IRLCO-CSA) [B, C]. Aerial survey and control operations were run over a few weeks in Malawi, Mozambique, Tanzania and Zambia, to get the locust threat fully under control [B, D, E].

- A plague of locusts broke out in Southeastern Egypt and Northeastern Sudan in February 2013. Within a month, the plague had reached Cairo and, by 4th March, it had reached Israel. In Israel, the plague was treated with the bio-pesticides Green Muscle, which largely controlled the outbreak within the first week [F].

Green Guard®

The LUBILOSA Programme was regularly reviewed by Dr. Richard Milner of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, who subsequently promoted the mycoinsecticide technology in Australia as Green Guard® [G]. In an article describing the Green Guard® pesticide, the relation between Green Guard® and Green Muscle® is explicitly described: '*Much of the basic technology used to develop Green Guard® was derived from a collaboration with the LUBILOSA group working in Africa and England to develop Green Muscle™, a similar product registered in parts of Africa and produced under licence by Biological Control Products in South Africa*' [G].

Plague locust (*Chortoicetes terminifera*) populations in Australia are present more regularly than most African locust species and there is a greater environmental pressure to develop alternatives to chemicals [G]. Control of locusts using Metarhizium/Green Muscle® is more expensive than control using chemical insecticides. Therefore it is mainly used on properties with certified organic production, including cattle, and in other areas, such as water-courses, where chemical pesticide use is restricted or undesirable. Constraints on the use of chemical insecticides are increasing and having a biological control agent is critical to ensuring the continued effectiveness of the Australian Plague Locust Commission (APLC) locust management programme [H]. The APLC began using Green Guard® operationally in 2000 and, since then, it has been used '*extensively where there are land use limitations on chemical pesticides*' [I]. Green Muscle® is mainly aerially applied [J].

During the period 2004-2008, 33,350 ha was sprayed with *Metarhizium*; for the period 2008-2010 it was 30,120 ha, with an additional 9,630 ha treated by the South Australian Department of Primary

industry and approximately 11,000 ha treated by the Victorian Department of Primary Industries during a 2010 outbreak. Green Guard® was a recommended pesticide during the 2010-2011 locust campaign in New South Wales [K]. Although more expensive than chemical insecticides, the area treated with Green Guard® has generally increased as a proportion of the total area. Green Guard® has also been used in East Timor and China and is also now marketed by Becker Underwood [L].

Mycoharvester

A 'spin off' technology from the development of *Metarhizium acridum* was the development at Imperial College of a device to collect separated conidia from the culture substrate (usually grain) in a pure form, to aid both drying (which enhances conidial shelf life) and formulation stability. This equipment was later further developed and named the 'Mycoharvester' [M]; it is now used by others working on fungal pathogens and more than 100 machines have been sold around the world.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Becker Underwood 'Green Muscle®' page, http://www.beckerunderwood.com/productsservices/biological-crop-protection/bio-pesticides/green-muscle/ (archived at https://www.imperial.ac.uk/ref/webarchive/44f on 7/11/13)

[B] Food and Agriculture Organisation of the United Nations press article, 'Red Locust disaster in Eastern Africa prevented', 24/6/09, http://www.fao.org/news/story/en/item/21084/icode/ (archived at https://www.imperial.ac.uk/ref/webarchive/54f on 7/11/13)

[C] 'Fungal pesticide saves crops from locusts',http://www.scidev.net/global/biotechnology/news/fungal-pesticide-saves-crops-from-locusts.html (archived at https://www.imperial.ac.uk/ref/webarchive/04f on 7/11/13)

[D] 'Tanzania flexes its Green Muscle', http://www.new-ag.info/en/developments/devItem.php?a=943 (archived at https://www.imperial.ac.uk/ref/webarchive/b5f on 7/11/13)

[E] UNOCHA, Annual report of the resident/humanitarian coordinator on the use of CERF grants, page 4, https://docs.unocha.org/sites/dms/CERF/Malawi%20CERF%20Narrative%20Report%202009.pdf (archived here)

[F] 'Israel Escapes Locust Plague — For Now', Yahoo! News, 7/3/13, http://news.yahoo.com/israel-escapes-locust-plague-now-025017640.html (archived at https://www.imperial.ac.uk/ref/webarchive/94f on 7/11/13)

[G] Biopesticides: Green Guard®, http://pubs.rsc.org/en/Content/ArticlePDF/2002/PO/B200948J?page=Search (archived here)

[H] Australian Government Department of Agriculture, Insecticide and Application Technology Research, http://www.daff.gov.au/animal-plant-health/locusts/aplc-activities/research/insecticide (archived at https://www.imperial.ac.uk/ref/webarchive/64f on 7/11/13)

[I] 'Information on the Bio-insecticide Green Guard® ULV Australian Plague Locust Commission (APLC)', http://www.daff.gov.au/__data/assets/pdf_file/0010/146818/metarhizium.pdf (archived here)

[J] Hunter D, Milner R, Spurgin P, 'Aerial treatment of the Australian plague locust, *Chortoicetes terminifera* (Orthoptera: Acrididae) with *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes)', Bulletin of Entomological Research, 91**,** 93–100 (2001) (available here)

[K] New South Wales Government, 'Spraying locusts with Green Guard®', http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/355420/Spraying-locusts-with-Green-Guard.pdf (archived here)

[L] Becker Underwood 'Green Guard Technical Information' page, http://www.beckerunderwood.com/solutionsresources/blogs/becker-underwood-australia/green-guard-technical-information/ (archived at https://www.imperial.ac.uk/ref/webarchive/74f on 7/11/13)

[M] The 'MycoHarvester': Cleaning up locust control. Bateman, R. International Pest Control. April 2003 *and* http://www.mycoharvester.info (archived at https://www.imperial.ac.uk/ref/webarchive/84f on 7/11/13)