AMBER. **A**pplication and **M**anagement of **B**iopesticides for **E**fficacy & **R**eliability

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AMBER: background on biopesticides

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Falling availability of conventional pesticides is putting farmers and growers under pressure

The number of conventional chemical pesticides being used by farmers growers has fallen sharply in recent years due to a combination of: (i) loss of pesticides as a result of more stringent EU rules on pesticide safety (Regulation (EC) No 1107/2009), driven by long standing concerns about human and environmental health, and including the introduction of hazard criteria in addition to risk, and more stringent operator exposure criteria (Tilman, 1999; Millennium Ecosystem Assessment, 2005); Pesticides Safety Directorate, 2008a;b); (ii) pressure from supermarkets for fresh edible produce with zero detectable pesticide residue, which restricts the time period when pesticides can be applied; (iii) control failures resulting from the evolution of heritable resistance to some pesticides in target P&D populations (van Emden & Service, 2004; Hajek, 2004). Since 1998 the number of chemical actives approved for use in the EU has fallen from >900 to 330 and this decline is continuing (Philips-McDougall, 2013). Adopting new types of synthetic chemical pesticides can help, but it will not address all the issues (e.g. zero residues), and there has been a significant slowdown in the rate at which new pesticide active substances are being developed by agrochemical companies, which means that new chemical actives are appearing too slowly to replace the ones being phased out. In 2000 there were 70 new active ingredients being developed by agrochemical companies around the world, while in 2012 there were only 28 (Philips-McDougall, 2013).

IPM: the way to make crop protection more sustainable

There are no 'silver bullet' solutions to developing more sustainable systems of P&D management. Rather, a series of innovations must be developed to meet the different needs of growers according to their local circumstances. Progressive growers are already using Integrated Pest and Disease Management (IPM), a systems approach in which different crop protection tools (chemical, biological, physical and cultural controls, alongside plant breeding) are combined with careful monitoring of pests and their natural enemies (Flint & van den Bosch, 1981; Prokopy, 1993; OECD, 2014). IPM aims to keep pests below their economic injury level while preventing adverse effects from injudicious pesticide use (Pretty, 2008) and it is a key feature of the EU Sustainable Use Directive on pesticides (2009/128/EC) (European Commission, 2009). In the protected edible crops sector, and on an increasing number of protected ornamental and hardy nursery stock crops, there is now a high dependence on the use of "macro" biological control agents (arthropod predators, parasitoids and entomopathogenic nematodes) for control of invertebrate pests as part of IPM (van Lenteren, 2000), but there is still a requirement for other alternative pest management agents that are compatible with the IPM approach.

Biopesticides are a broad group of mass-produced, plant protection agents based on living organisms or their products. There are three main types: microorganisms, botanicals (plant extracts), and semiochemicals, (note that metazoan organisms are not included in the definition of a biopesticide) (for a detailed review see Bailey *et al*., 2010; Gwynn, 2014):

- Micro-organisms. Bacteria, fungi, oomycetes and viruses are all used for the biological control of pests, plant pathogens and weeds.

  - Arthropod pest control. At the moment, the most widely used microbial biopesticide against insects is the insect pathogenic bacterium *Bacillus thuringiensis* (Bt) which produces an insecticidal protein crystal during bacterial spore formation that can be sprayed against pest targets. The same protein can be expressed in genetically modified crops and – outside of the EU (which has not adopted GM crop technology) has had a major impact on the control of caterpillar pests of broad acre crops including maize, soya and cotton. Baculoviruses are most commonly associated with causing disease in lepidopteran larvae, but are also found in diptera and some hymenopteran hosts such as sawflies. Each baculovurus type has a very high degree of host specificity. As an example, the *Cydia pomonella* granulovirus (CpGV) is used as a commercial biopesticide against codling moth on apples. At least four different species of insect pathogenic fungi are commercially available as biopesticides: these pathogens have contact action, and infect when their spores attach to the insect integument, and then germinate and grow through to the haemocoel where they proliferate and kill their hosts.
  - Control of plant diseases. Micro-organisms used against plant pathogens include the fungus *Trichoderma*, which is an antagonist of *Rhizoctonia*, *Pythium*, *Fusarium* and other soil borne pathogens (Hermosa *et al*., 2012). *Trichoderma* has multiple modes of action, including antibiosis, mycoparasitism, competition (associated with an ability to colonise the rhizosphere), and induction of host-plant resistance. The bacterium *Bacillus subtilis*, which is used against *Botrytis* on strawberries and other crops, is currently the most widely used (in terms of area applied) biopesticide in the UK (Fera Pesticide usage Survey, 2014). As well as possessing antifungal activity, it is reported to be an elicitor of host plant resistance and can promote plant growth. Other examples include *Coniothyrium minitans*, which is a mycoparasite applied against *Sclerotinia sclerotiorum*. *Gliocladium catenulatum* (= *Clonostachys rosea*) parasitizes hyphae of *Botrytis cinerea*, while *Ampelomyces quisqualis* is a parasite of a range of powdery mildew species.
  - Recently, bioherbicides based on fungi such as *Chondrostereum purpureum*, have been developed that can infect multiple weed species, and use of bioherbicides is set to increase in the future, particularly considering the serious problems that are occurring with herbicide resistance in some weed species such as blackgrass.
- Botanicals. Plants produce a wide variety of secondary metabolites that have activity against crop pests and / or diseases, some of which are already being produced as commercial biopesticides. One of the most widely used botanicals is neem oil, an insecticide extracted from seeds of *Azadirachta indica*. Essential oils from citrus and other plants are being used as biopesticides of both pests and diseases, while an extract from giant knotweed (*Reynoutria sachalinensis*) has been developed as a biofungicide for control of powdery mildew. A range of plant compounds is also being developed as novel herbicides, for example sarmentine, which is extracted from Indian long pepper.
- Semiochemicals. These are chemical compounds produced by one organism and which induce a behavioural change in organisms of the same species or a different species. The most widely used semiochemicals for crop protection are insect sex pheromones, which are deployed in pest monitoring, mating disruption and trapping. Mating disruption is used on nearly 700,000 ha and has proved to be very useful for managing pests of orchard crops including light brown apple moth, carnation tortrix moth and apple leaf rolling midge. An aggregation pheromone of thrips has also been found to be useful as a monitoring tool for economically important species such as western flower thrips; there is also good evidence that it can make mass trapping of thrips significantly more effective.

Biopesticides used against plant diseases tend to be used as preventative treatments and are normally applied in an inoculative strategy, in which control is partially dependent upon growth and reproduction of the microorganism population within the immediate vicinity of the target (Eilenberg *et al*., 2001). Biopesticides used against invertebrate pests tend to be used as curative treatments, and in this case the decision to apply the control agent is based on monitoring information about the pest population size. Biopesticides applied against invertebrates tend to be used in an inundative strategy, in which the agent is applied in large numbers into the close vicinity of the target pest. The intention is to achieve rapid pest control, control is not reliant on the reproduction of the control agent to any significant extent within the environment (Eilenberg *et al*., 2001). Therefore, persistence is short, and the agent has to be reapplied frequently to maintain its effectiveness in the crop environment.

Biopesticides have a range of attractive properties for IPM (Chandler *et al.,* 2011).

- In addition to their ability to control pests and diseases, they produce little or no toxic residue, and partly for this reason they are usually considered to be minimal risk products for human and environmental safety.
- Biopesticides can often be applied with existing spray equipment, and some microbial biopesticides can reproduce on or near to the target pest / disease, giving a degree of self-perpetuating control.
- Many biopesticides are residue-exempt and they are not required to be routinely monitored by regulatory authorities or retailers. Re-entry and handling intervals are becoming more important considerations when selecting a plant protection product for use, especially in protected crop and many biopesticides have a zero or low re-entry and handling interval.
- As alternatives to conventional chemical pesticides, they can help reduce the selection pressure for the evolution of pesticide resistance in pest populations, and there is good evidence that some microbial biopesticides can stop the expression of resistance once it has evolved (Raymond *et al*., 2006, 2007; Jung & Kim, 2007; Farenhorst *et al*., 2009, 2010).
- The risk of pests and disease developing resistance to biopesticides is often considered to be low, certainly for those agents that have multiple modes of action. However, in principle there is always a potential for a target pest / disease to develop resistance or tolerance, dependent upon the size of the selection pressure, and hence we think it is good practice to adopt an anti-resistance strategy when using biopesticides.
- Biopesticides often have good compatibility both with biological pest control agents (natural enemies) and with conventional chemical pesticides, so they can be readily incorporated into IPM programmes.
- Fast acting bioinsecticides can also be useful as a second line of defence or supplementary treatment. In pest management, there are often times in the season when the invertebrate pest population starts to run away from the ability of a predator or parasitoid to control it. In such situations, a bioinsecticide can be used to hold back the population development of the invertebrate pest and allow the predator or parasitoid to “catch up”. Having this back-up often makes the difference between success and failure of IPM in protected crops.
- The costs of developing a biopesticide are significantly lower than those of a conventional chemical pesticide, which should encourage companies to develop a wide range of products (Glare *et al*., 2012).

There is clear evidence that – when used under the right circumstances - biopesticides can make a valuable contribution to crop protection as part of an IPM programme (Lacey & Shapiro-Ilan, 2008). However, there are disadvantages of biopesticides compared to conventional chemical pesticides and a balanced approach to evaluating them is required. The downsides to using biopesticides include the following:

- a slower rate of control and often a lower efficacy and shorter persistence;
- greater susceptibility to adverse environmental conditions (Chandler *et al*., 2008);
- because biopesticides are not as “robust” as conventional pesticides, they require a greater level of knowledge on behalf of the grower to use them effectively (Glare *et al*., 2012).

Biopesticides have been researched for many years but until recently only a small number of niche market commercial products have been available (Marrone, 2007). However, this is changing, and the number of biopesticide products available is rising. In the UK, this increase is occurring partly through the UK authorization of products registered in other EU countries but not yet available here. At present, about 40 different biopesticide products have been authorized for use in the UK, and there are more biopesticide products available across the EU as a whole, so there is clear potential to increase the availability of products in the UK. Looking further afield, there are over 400 biopesticide substances approved for use in the USA (EPA, 2015), some of which could be suitable for the UK (evidence for efficacy is not a requirement for registration for biopesticides in the USA, so the number of USA-registered products that are potentially useful for UK crops is likely to be significantly fewer than the full 400 registered products). There has also been a significant increase in investment in biopesticide R&D by agrochemical companies who are moving seriously into the market: this has occurred largely as a response to the EU Sustainable Use Directive, which promotes the use of biopesticides and other alternatives to conventional chemical pesticides. The new investment in biopesticides R&D by large companies has created a biopesticides "pipeline" in which new products will become available on a more regular basis (Kling, 2012).

With more biopesticide products now reaching the market, the task ahead is to find ways of optimising the use of individual biopesticides in IPM in order to take full advantage of their attractive properties. Potential adopters of biopesticides can face large fixed costs of adoption that will only decrease once biopesticides are used more widely, thereby disadvantaging early adopters. The relatively low level of experience with biopesticides creates uncertainty for growers, which can act as an important barrier to the uptake of new biopesticide products (Bailey *et al*., 2010). For this reason, it is important to develop improvements in the local management of biopesticides and put them together as sets of best practice recommendations for growers in order to improve their confidence in biopesticide technologies.

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