Are diseased and blemished foodstuffs good for you? The need for plant pathology

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Background

Mankind is cropping the same 6 million square miles of land as in 1960 but feeding 80% more people. To keep pace with anticipated population increases, agricultural production from this area must triple by the year 2040[1]. Failure to achieve this will result in the destruction of substantial amounts of the world's precious native flora and fauna. Stark predictions such as this emphasise the fundamental importance of efficient use of our limited land area. Increasing salinity and soil erosion continue to reduce the potential area for agricultural production. Crop yield is also limited by drought and pest and pathogen attack. Advances in the science of crop protection have lessened the impact of the latter, yet the threat from insects, nematodes, fungi, bacteria and viruses is perpetual and pre- and post-harvest losses on a world scale are huge.

In contrast to the Developing World, where production of sufficient staple crops remains the priority, abundance is taken for granted in more-developed nations and consumer demand is now for consistently higher-quality, diverse foodstuffs, available year-round and produced in ways considered ethically and environmentally sound. The great challenge is to realise these objectives without threatening food security or facing drastic increases in food prices.

There is a feeling among the media, the public, and some circles of government, that Developed-World agriculture has reached a point in which the battle against pests and diseases is in equilibrium and further scientific development redundant. Outright condemnation of further technological development in agricultural practices is gaining a favourable political hearing. Many of these fears are irrational, being fuelled by a largely ignorant media interested in 'sound bites' and sensationalism rather than in scientific accuracy or ethical integrity. A great deal of misplaced optimism exists in the belief that a 'greening' of agriculture can meet the future requirements of farmers, environmentalists and the public. Such a romantic notion was recently described as 'a misleading and dangerous illusion'[2]. The demonisation of science, to create a popular perception that it is part of the problem rather than the solution, is dangerous and unfounded.

We should, of course, be concerned about the demands we are making on fragile ecosystems and do our best to harmonise agricultural production with environmental protection. But this will only come about through technological and scientific advances, with efficient training and advisory systems, to ensure advances are translated into tangible benefits for farmers. Ignorance is not a foundation for progress - future food security depends on scientific endeavour to overcome the daunting challenges.

Crop protection is central to the wider debate since its primary tools, pesticides and, increasingly, genetic engineering, are the cause of much consumer anxiety. With this in mind, this article aims to examine the need for further scientific research in crop protection, revealing the challenges, possible solutions and the threats of ill-conceived changes to the system.

Figure 1 The benefits of host resistance are clearly seen in two potato breeding lines resistant (left) and susceptible (right) to potato late blight.

Breeding for resistance

Conventional methods Using natural plant defences is clearly the best strategy to reduce yield losses and maintain quality. The benefits of host resistance are clear; the control measure is always in place, the risks of environmental damage are negligible and the need for pesticides is reduced. In many cases, sufficient natural resistance is found in wild plant populations. The challenge is to incorporate the trait into a crop species while maintaining satisfactory yield and quality criteria. This is a lengthy and complex process in which 'crossing the best with the best and hoping for the best' often forms the basis of the breeding strategy.

However, in recent years our understanding of plant genetics has improved greatly as advances in biotechnology have allowed detailed genotypic examination (i.e. DNA-based) rather than reliance on phenotypic markers (e.g. morphological traits). Through the application of such molecular markers, genetic maps are now available for many of the major food crops and we are able to identify and monitor the inheritance of genes or regions of chromosomes responsible for agronomically important traits. Such Marker Assisted Selection (MAS) is already having a great impact on conventional breeding through accelerating selection programmes.

Although MAS is yielding benefits for well-characterised traits or resistance based on single genes, the real leaps in understanding will only come from detailed investigation of the complex patterns of signalling, gene expression and biochemical pathways involved in host-plant resistance. Parallel studies on pests and pathogens during successful or unsuccessful colonisation of a host will also help pinpoint fundamental steps in the interaction. At SCRI, such targeted gene discovery programmes are already underway and yielding exciting data on gene expression in both host and pathogen. With time, such information will underpin plant breeding strategies, as trait specific markers for MAS or single genes incorporated through gene transfer (see below). Such work does not rely solely on molecular biology, as other

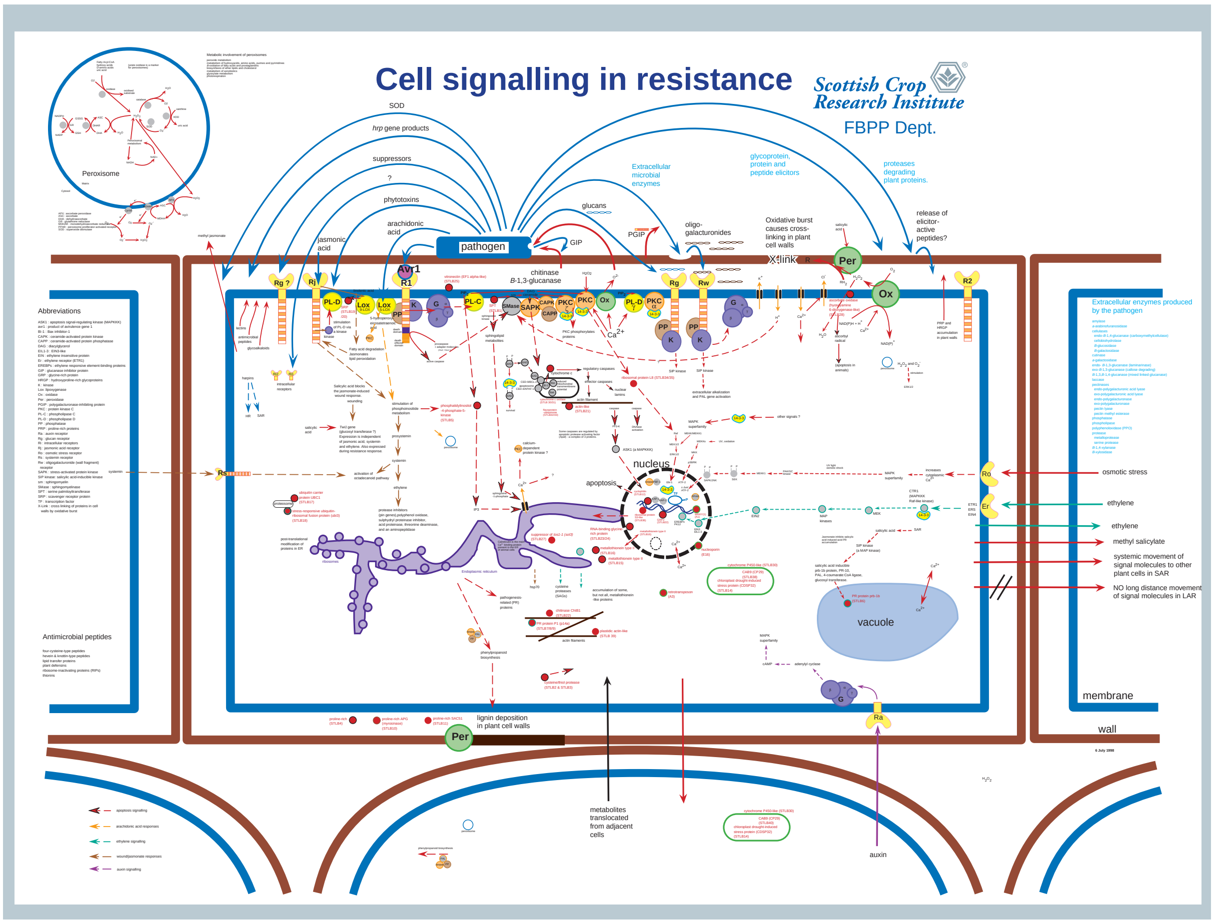

Figure 2 In this diagrammatic representation of host-plant cells, only a portion of the complex response to pest or pathogen attack is shown.

specialist knowledge is fed in at every step. For example, resistant germplasm must be tested for stability, its utility in other climates, and careful deployment is needed to ensure it is effective and durable in the field. We are already involved in a world-wide programme to test the stability of quantitative resistance to potato blight in tropical, sub-tropical and temperate regions. Identification and exploitation of sources of resistance among wild relatives is vital and, at SCRI, the Commonwealth Potato Collection is proving an excellent genetic resource.

Gene transfer Traditional means of gene transfer within a plant species (crossing and repeated backcrossing) have been augmented by an ability to create wide interspecific crosses by tissue-culture techniques such as embryo rescue or protoplast fusion. In addition to this, through advances in biotechnology over the past 18 years, the ability to move individual genes, or groups of genes, across genus or even kingdom boundaries is now feasible. 'Genetic engineering' (genetic enhancement or manipulation) will certainly play a key rôle in the future of global food production, but still faces many scientific and socio-political challenges. Such a quantum leap in technological capabilities naturally evokes both positive and negative feelings. The technology offers the potential to provide secure and stable food supplies with minimal environmental damage, but doubts about the ethics, environmental impact, suitability for developing nations, and fears of dependency on enhanced crop varieties must be recognised and addressed before widespread adoption is possible. In terms of public acceptance, it is vital that consumer fear is allayed by communicating the results of thorough, independent scientific assessments of risk in a balanced way. This must include the extensive data from testing prior to release and monitoring over several years after release (see article on page 44).

Just as significant are the scientific questions to be answered as this new technology is taken forward. Identification of target genes is, of course, fundamental to the process. To date, the approaches have been relatively crude, few natural pest or pathogen genes have been identified and those advanced to commercial production primarily produce toxins or antifeedant molecules against insect pests. More subtle approaches using viral coat protein genes to mimic the widely applied phenomenon of cross-protection are being applied, but we need to learn more of the complexity of host/pathogen interactions to enable progress. Very sophisticated methods of isolating genes involved in natural defence responses are currently being used at SCRI. A knowledge of the complex signalling pathways involved is emerging and will enhance our ability to manipulate host/pathogen interactions through transgenic approaches which may not involve gene transfer between species. Over-expressing or silencing of existing plant genes may, for example, provide a way forward.

The path to successful commercialisation involves gene discovery, confirmation of function, efficient transformation protocols, control of expression and assessment of the optimal deployment strategy to avoid breakdown of resistance and escape to the environment. All areas, incidentally, in which SCRI has proven expertise. It is only stable, well-funded and independent research teams, with a holistic view of the field, that have the necessary skills for the task. A moratorium on biotechnology research will only stifle progress, reducing the competitiveness of UK science, shifting the responsibility for refinement and development work from the public to the private sector, preventing inward investment to 'UK Crop Protection Research Ltd' and putting our growers at a disadvantage in international markets[3].

Figure 3 Without fungicides, raspberries rapidly become infected with grey mould.

The future of pesticides

Compared with natural plant resistance, the application of synthetic biocidal compounds to crops is very inefficient. It is costly, application times are restricted by weather conditions, much of the product (95%) misses both the target organism and even the crop, while some are highly toxic with risks to the user and the environment. In addition, efficacy frequently declines as pesticide resistance builds in the target organism. Moreover, there are few agrochemicals active against bacterial pathogens and none against viruses *per se*, which cause considerable problems in the tropics. So why are biocides used? The answer is quite simply that they are an absolute necessity in the majority of cropping systems; the extent of their use is testament to that fact. Consider the control of potato late blight caused by the fungus *Phytophthora infestans*. At present, potato growers in the United Kingdom spend *c*. £150 per hectare on chemical control of blight and very conservative estimates suggest around $1 billion is spent annually world-wide. Chemical sprays are not applied, as is sometimes perceived, out of a wanton disregard for the environment, but out of necessity to reduce yield losses. Failure to control blight in a commercial crop on the central lowlands of Scotland will result in severe financial loss, but in a vital staple crop in the S. American highlands, the price can be measured in human life.

The pressure for farmers to reduce inputs of 'synthetic' products for the perceived benefit of health, the environment and promote 'sustainability' is increasing, and some fail to understand why we cannot ban the use of all pesticides and become 'organic' tomorrow. Such simplistic solutions are rife amongst those that Norman Borlaug (Nobel Laureate and architect of the 'Green Revolution') described as "the extreme elitists and doom-sayers in the environmental movement in affluent countries who have never personally experienced poverty nor have produced a single ton of food"[4]. Limited organic production is feasible, particularly in annual crops, because of the premium prices paid willingly by some consumers and through the benefit of being surrounded by pesticide-treated crops which are relatively free of pests and pathogens. This latter point is analogous to human immunisation against disease (e.g. whooping cough); the risk of disease in a few untreated children is low, so long as the majority are immunised. The epidemiological consequences of widespread organic growing need careful consideration as pest and pathogen populations would be certain to increase as a result, thus increasing the threat, both within organic production systems, and on surrounding farms. Even organic organisations have acknowledged the difficulty with some diseases such as late blight and permit the use of a calcium hydroxide and copper sulphate mix called Bordeaux mixture. This is a product of the late nineteenth century, deemed 'traditional', and therefore judged acceptable by organic organisations. However copper sulphate is neither organically 'natural' nor particularly safe.

Figure 4 Cabbage white caterpillars, the bane of every gardener, can rapidly devastate a crop.

The hard truth is that to feed 5.8 billion people, current intensive agricultural practices are reliant on pesticides. Pressure for drastic reductions, without sufficient research into alternative crop protection strategies (such as host resistance), will create more problems than they solve. Inevitably, we would see reductions in yield and quality, more stocks rejected by retailers, an impact on import and export markets, and increased food prices.

We must continue to refine the use of current compounds through improved modelling of epidemics to allow a move from prophylaxis to the much vaunted integrated crop management (ICM) programmes, where all methods of control are combined in an optimal manner[5]. Such ICM approaches are particularly relevant in the tropics where crops are threatened by a complex of many pests and diseases and control of any one without consideration of the others will likely fail. One only has to look at the difficulties in controlling rice plant-hoppers in Indonesia where, after initial success, insecticide-based control failed because the natural predators of the plant hoppers were also killed.

Although the trend has been towards the development of increasingly safe chemicals, there are still some highly toxic compounds in use. Soil sterilants are particularly toxic and compounds such as aldicarb are routinely applied to the soil prior to carrot production to prevent the nematode-induced 'fanging' of carrot

Figure 5 Both virus and aphid vector must be understood to prevent viral damage such as this on raspberry.

roots. Methyl bromide is damaging to the ozone layer yet each year, 70,000 tons are applied to agricultural soils to fumigate against nematodes and other soil-borne pests and pathogens. A reduction in the use of such compounds is clearly advisable and research is needed to optimise targeting and development of other means of control.

Monitoring of pests, pathogens and vectors

Effective breeding programmes and optimised pesticide applications may be rendered futile by the fact that pests, pathogens and their vectors are, genetically speaking, a 'moving target'. Only by knowing the distribution, diversity and ecology of these organisms, can we evaluate current problems, predict future threats and apply rational control strategies.

Despite the efforts of regulatory authorities, the changing world climate and increasing world trade in plants have resulted in pest and pathogen introductions in new biogeographic environments. There are all too many examples; the inadvertent introduction of *P. infestans* and Dutch Elm Disease into Europe; the 1995 outbreak of bacterial brown rot of potatoes which, in The Netherlands caused emergency EU legislation; the pine wilt nematode, indigenous to N. America, which devastated hundreds of thousands of trees in China and Japan, and the multi-billion dollar trade deal between China and the USA which was threatened by Karnal bunt of wheat.

Figure 6 Early detection of the pathogen, *Phytophthora fragariae* var. *rubi*, in raspberry propagation material will help prevent devastation such as this.

The maintenance of a critical mass of trained staff is vital to prevent such introductions and minimise the impact of any outbreak. The development of new tools to aid diagnostics and monitoring is also essential. For example, at SCRI, new PCR-based diagnostics for *Phytophthora* diseases in soft fruit are allowing rapid detection and identification of the disease and, in the long term, will be used in international quarantine programmes to monitor propagation stocks and prevent disease outbreaks.

As well as preventing new problems, we must evaluate changes in current pest, pathogen and vector populations. Monitoring of the virulence of UK cereal pathogen populations has, for example, improved breeding strategies and allowed advisors to recommend cereal cultivars according to current pathogen populations. Careful studies on the build-up of resistance to pesticides has extended the life of many key products. The phenylamide fungicide, metalaxyl, for

Figure 7 Blemish diseases, such as common scab, are increasingly important as tubers are sold pre-washed

example is a vital product in the control of potato late blight and was used extensively until resistance in the fungal population threatened its efficacy. Changes in patterns of usage by alternating products and mixing with other active ingredients have been successful in extending its use. Bt toxin (a 'natural' insecticide from the bacterium *Bacillus thuringiensis*) is either applied to the crop as a spray or introduced into crop plants through genetic engineering. In either form, its use must be carefully managed to prevent build-up of pest resistance. A refinement of such monitoring is the development of predictive models of epidemic development which incorporate information on pest/pathogen incidence, epidemiological data, plant resistance, weather conditions and pesticide efficacy to allow optimal integration of all control measures.

Food quality

There is no doubt that, in developed nations, the diversity, quality and freshness of food, especially fruit and vegetables, is continually increasing while the price falls in real terms as a proportion of income. The majority of food sales are led by a few large supermarket chains who set high standards. We increasingly regard agricultural produce in a similar way to manufactured goods, expecting a uniform size and shape and unerring freedom from disease, blemishes and pests. Misshapen or scabbed potato tubers, or a single aphid on a lettuce can result in rejection of an entire stock. This is driven by a combination of supermarket demands, EU bureaucrats and a fickle generation of consumers increasingly detached from the realities of agricultural production systems. While we would not advocate a lowering of such standards, perhaps the price of such perfection should be considered? Removal of every carrot fly, cabbage aphid or apple scab requires exceptional husbandry and intensive pesticide use. There is a conflict of interests here - demands for perfect produce and zero pesticide use are presently incompatible. In fact, public fears of pesticides are often irrational. Comparisons have been made between the doses and risks associated with consumption of 'natural' and 'synthetic' pesticides. The finding that we are exposed to 10,000 times less 'synthetic' pesticides than 'natural' pesticides (i.e. plant defence products), of equivalent toxicity[6,7] should serve not to scare us from consuming such foodstuffs, but to increase awareness of the context in which these issues should be viewed. Despite claims that pesticides are unnatural, risky, toxic and unethical, average human lifespans have more than doubled over the past 100 years, in part through medical advances but also through safer, sufficient supplies of food.

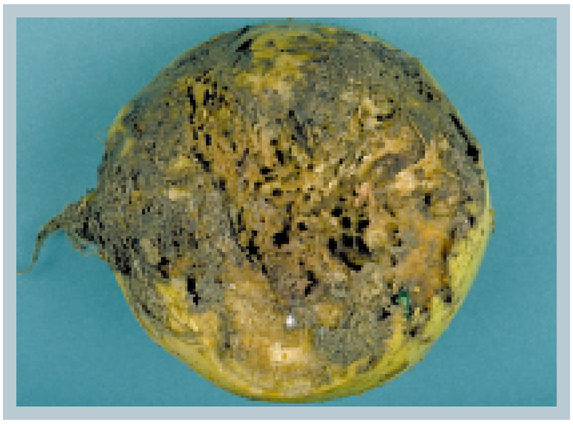

Figure 8 Like many soil-borne pests, turnip root fly is very difficult to control and may require many pesticide applications.

A double irony is that organic produce, while free of synthetic agrochemical residues, may well be detrimental to health because of increased levels of natural plant defence products and, more importantly, toxins produced by the very agents of plant disease and food spoilage which are removed by pesticides. There have been few studies on the impact of natural plant 'pesticides', but considerable work on the damage caused by toxins. A range of such toxins has been detected in foodstuffs. The best known are the aflatoxins formed in grain and nuts after infection with the ubiquitous fungus, *Aspergillus flavus*. Aflatoxins are amongst the most carcinogenic and teratogenic (causing foetal defects) substances known, yet they are entirely 'natural'. Rigorous international safety standards and procedures for screening for aflatoxins have been implemented; yet, in the UK there are still sporadic contamination problems, possibly from unregulated imports of infected foodstuff[8]. Patulin, a toxin produced by the fungus *Penicillium expansum*, has to be monitored carefully, particularly in products such as apple juice. Ochratoxins, produced by some toxigenic species of *Aspergillus* and *Penicillium*, are nephrotoxic, hepatotoxic, teratogenic, carcinogenic and immunosuppressive. They are frequently reported as contaminants on food stuffs, particularly on cereals in temperate regions, and are implicated in an irreversible and fatal kidney disease referred to as Balkan Endemic Nephropathy. Most familiar are the toxins produced by the fungus *Claviceps purpurea* which infects the grains of cereal crops, particularly rye. Toxins in rye have often been found in concentrations sufficient to induce delirium and reduced fertility.

Such Ergotism or 'St Vitus's dance' was of historical importance in Europe and may once again be increasing since the sclerotia of *Claviceps purpurea* in modern rye cultivars are smaller than those found in traditional varieties and cannot be simply sieved from harvested rye grain. We should therefore be careful in donning our rose-tinted spectacles and assuming organic produce to be more 'nutritious, healthy and safe'[9] when there is little supporting evidence[10].

Conclusions

The above discussion highlights just a few of the areas of research necessary to meet current needs and future challenges. Methods developed by the UK plant pathology community present a significant benefits to our agricultural industry, attract inward investment, develop export markets, protect the environment, and transfer technology to developing nations to solve local problems and humanitarian needs. Undermining this skill base will have serious implications. Such a resource cannot be created overnight.

There is no *status quo*. False romantic notions of medieval, subsistence agriculture will not feed an extra 5 billion mouths. We have not, and probably will not, master pests and diseases; but we do need to keep one step ahead. This will not be achieved by reducing research investment but through the maintenance of a stably funded community of scientists able to face the challenges of reducing inputs, maximising production and protecting the environment. This must be coupled with increases in training of growers, the public and, of course, future generations of scientists.

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