Stored products research in Europe – a very personal perspective!

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Abstract

The general consensus is that there are about 50 countries in Europe. There are no discrete boundaries and some countries may be both in Europe and another continent. In this short presentation, I want to dip into the history of stored products research over the past 50 years or so in this diverse geographical and political area. It is curious how the emphasis of the research has changed but perhaps more often been cyclical with areas being topical and novel, falling out of fashion, and then being "rediscovered" often with scant recognition for what has gone before. The trap of pretending that there was no research prior to the advent of electronic publication of journals and especially of abstracting services has reinforced the opinion that is apparent in much literature of the past 10-20 years that nothing before about 1970 actually happened. It may also be related to the geographical locations where research is undertaken and the accessibility, often determined by the language, of the research to a global community. The current levels of research activity are driven and limited by funding, political factors and perceived necessity. These are debatable subjects at best. So, where are the primary targets for research in the future or have the problems really been solved? This presentation will attempt to sample and illustrate how the nature of research may follow advances in methodology, how it has perhaps been a consequence of failure to appreciate what has gone before, and is likely to continue changing with demand. How and where will this be achieved?

Keywords: Food security, Insecticides, Biological control, Insect pests, Fungal infestations.

1. Introduction

Europe is an amazingly diverse continent considering its size and position. It has played a key role in human history although it is not the source of the human species, which is Africa, nor the source of agricultural life, predominantly Asia (although there are reasonable claims for the present day Israel to have been an early site of wild grain consumption), Central America and the Andean slopes. It has a lesser latitudinal range than South America or even Australasia, extending from about 35° N to about 70° N (save for a few islands such as Svalbard or Franz Joseph Land at about 80° N) and includes less than 7% of the world's land area. It is only a little larger than Australasia, half the size of South America and less than 25% the area of Asia. Its climate is temperate, much colder in the north than the south, but not as extreme as found for example in N America. Its boundaries are vague; Turkey is in both Europe and Asia, and some other Middle Eastern countries (Israel or Syria for example) as well as Russia, are sometimes included in Europe or Asia or both! Most authorities include about 50 countries in Europe, but the precise number depends on what you believe or accept!

This relatively modest area includes as many countries as Africa or Asia and at least twice as many as North America. They have their own governments and, until quite recently, their own currencies. Most have their own language, and I, like many of my fellow UK citizens, speak only one European language other than English – and that badly.I am relieved and slightly ashamed that I stand here in Portugal speaking English that most of you can comprehend; half the people in Europe can speak English although only for about 12% of the population is it a native language (European Commission, 2009). I will return to this subject later.

Europe does have a large population of around 750 million people (United Nations, 2009). To feed this population from its small land area is a major challenge especially as large northern tracts are relatively unproductive and certainly unsuitable for cereal or pulse production. It has used its relative wealth to protect its food and develop food security measures as its population has grown. Several European countries have also governed, alternative words could justifiably be used, various parts of the globe far

away. One might start with the Romans and Greeks in classical times but more recently the Austrians, and then the Germans, French, Dutch and British. One of the more desirable consequences has been the willingness of many of the latter group to invest expertise and funding in support of agriculture, including storage systems, in parts of their former empires so that work on stored products has not solely been based or targeted at domestic problems.

The consequences of these situations are that research has taken place in different countries with different cultures and, despite their geographical proximity, with relatively limited exchange of information. One of the benefits of the European Union has been the sharing of expertise, development of broadly based projects, and access to funding opportunities. To some extent this may be at the expense of targeted funding within the individual countries but it has brought countries with limited resources into the picture so that research can be funded from a central source or on a collaborative basis.

In the following pages, I want to briefly and imperfectly review some of the changes which have taken place, postulate what has brought them about, and consider the consequences in terms of the changing pattern of research activity in Europe. I acknowledge that it is an entirely personal view, it may well have a somewhat "anglocentric" stance and I have drawn freely on my association with the Journal of Stored Products Research as a source of information. I am aware that the data are imperfect but, as I shall explain, attempting to impose pseudo-rigour is not helpful.

2. Sources of information

Many of the statements made in this paper are based upon my own experience of meetings, papers, reviews and invaluable personal contacts with people from Europe and, of course, much further afield as well. I began research, not actually associated with stored products, some 43 years ago so I have watched and participated in the changes in scientific research and communication through a dramatic and prolonged period.

To try and get some sort of quantitative basis for my arguments I have utilised publications in the "Journal of Stored Products Research (JSPR)" at three periods of time, 1967-68, 1987-88 and 2007-2008. This opens the door to bias since it was first published in the UK by Pergamon in September 1965 although the very first Advisory Board had representatives from 12 other countries, including 6 from Europe. I acknowledge that the editor and her Associates were all working at the Pest Infestation Laboratory in Slough, UK, but by 1967 the journal was already pretty well established. Using abstracting services is not helpful as coverage of journals in the 1960's was extremely patchy and using journals published in one country and not in English adds at least a similar problem to using JSPR. The Journal of economic Entomology has consistently published papers of high quality back to 1908 but most, at least in the early days, were from North American authors and therefore not relevant to a commentary on activity in Europe.

An alternative source of information would be international symposia but they are often dominated by attendees from the country or geographical region in which they are located or, if not dominated, then at least the local scientific community is unusually well represented (e.g. Zuxun et al., 1998; Credland et al., 2003). This is, of course, a very good reason for moving conferences, such as that opening today, to different locations in different continents. It does however mean that consideration of attendance at such meetings provides no more objective data than from publications.

I therefore acknowledge a problem but there is no simple solution which would provide an overview of activity in Europe prior to about 1970 – and herein lies a different problem addressed later in this paper. So, accepting the limitations of the data source, what can be concluded about the history and development of stored products research in Europe?

3. Subjects of research over the years

It is curious how topics appear to have risen and fallen in popularity or importance as measured by the proportion of papers published on them.

In 1967 and 1968, publications were dominated by papers dealing with the rather basic biology of pest insects; mites and fungi were rather rarely mentioned or studied in Europe, there being only a single paper published from a European author on mites in JSPR during this period (Ždárková, 1967) and not one paper on mycological or microbiological problems (Fig. 1). Fumigants including phosphine, nicotine

and sulphuryl fluoride and residual insecticides, notably malathion and fenitrothion, were the subjects of several papers.

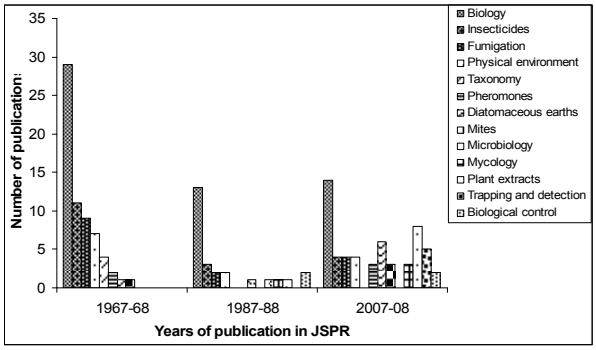

Figure 1 The broad areas into which publications in the Journal of Stored Products Research fell during three separate two-year periods of publication, 1967-68, 1987-88 and 2007-08.

Twenty years later, 1987-88, among the 28 papers published in JSPR by authors based in Europe, the dominance of papers dealing with pest biology remained. Only two papers dealt with fumigation and four with insecticides. One paper was published on fungal toxins (Bacha et al., 1988) and one on microbiology (Lacey, 1988).

The situation changed dramatically in the following 20 years although in 2007-2008 there were still more papers dealing with biology than any other (general) subject. The key change was an altogether more diverse range of interests that were included with subjects not previously represented appearing. Of course occasional papers on these subjects had appeared previously but not in the years sampled. More papers dealing with plant extracts (other than nicotine or pyrethrum) than either fumigants or insecticides were published, and several papers on diatomaceous dusts raised their profile significantly. Papers dealing with trapping and the modelling of conditions in stored commodities were also more common than previously. Four papers were published on mites and another four on fungi associated with stored products, not all with their toxin production.

What has produced this changing picture which is not, at a superficial level, greatly different from that which appears to have occurred elsewhere (although fellow contributors may correct this impression)? Partly the answer may be an autocorrelation with the increasing geographical diversity of the authors (see below) so that problems encountered in and techniques applicable to non-English speaking countries begin to make an appearance. However for reasons explained later there being no simple method of data collection which would enable this to be excluded, perception might prevail. I would suggest that the primary reason for the changing picture is that prior to the 1970's or even the 1980's there were significant gaps in our knowledge of even the most important pests of stored products whether from temperate or tropical regions. Until knowledge of the biology of these pests was available, control was rather generic in nature and, of course, the hazards associated with the use of some insecticides were not widely accepted. The Environmental Defense Fund was established in the US in 1967, two years after publication of the first issue of JSPR in September 1965, and the general use of DDT was banned in the US on 31 December 1972. Bans have followed in the UK in 1984; the Stockholm convention banned all use except for vector control in 2004. Its use had, of course diminished dramatically to be replaced largely by organophosphates such as malathion and fenitrothion, and more recently by pyrethroids.

The apparent effectiveness of insecticides for grain protection limited the demand for research on the biology of the pests but restrictions on the use of some compounds was an incentive to find out more about them. Hence the growth in biological studies and the continued interest as more focussed and selective control agents have been employed. The wide application of synthetic pyrethroids such as deltamethrin (often in K-Obiol) and permethrin which have markedly differential effects on different pests of stored products (e.g. Arthur, 1997) are one such case.

At the same time limitations on the use of grain protectants and especially the withdrawal of methyl bromide were introduced. Production and use of methyl bromide was banned by the Montreal Protocol of 1992 and European Union member governments agreed to phase out use of methyl bromide by 2005. However some countries sought 'critical use' exemptions and the use of the pesticide therefore continued. Exemptions were granted initially but there were none in 2009 in the EU so its use has been successfully phased out. This has left phosphine as the fumigant of choice and research has again concentrated on its differential effects on pest species (e.g. Pimentel et al., 2007) but awareness of resistance problems in many areas (e.g. Mills, 2001; Benhalima et al., 2004) has been growing steadily. In the UK the only organophosphates that can now be applied to grain are pirimiphos-methyl and chlorpyrifos-methyl. Diatomaceous earths have been used as alternatives but their effectiveness varies with many factors. Hence the reliance on physical controls such as temperature regulation have become of paramount importance and modified atmospheres are perceived as perhaps the next generation of broad control measures. In general terms, the same pattern is applicable in Europe as a whole; insecticides are rather rarely used, especially on food commodities and research is concerned with optimising the effect of alternatives.

An additional aspect has been the level of activity under aid programmes. There have been extensive research programmes looking at aspects of stored-product, primarily food, protection in developing countries including valuable work associated with East and West Africa, parts of South America but rather less towards the Far East or southern Asia. These programmes flourished in the late 1980s but appear to be diminishing in the current economic climate and their short-term future appears somewhat bleak. EU funding has provided some protection against the plight of individual countries but even here there appears to be increasing pressure on the funding available. The consequence has been a recent retrenchment with more research on important but local problems, collaborative studies with other parts of the world, especially North America, and perhaps a greater tendency to undertake research which is relatively cheap to undertake involving minimal technological input. Even the Consultative Group on International Agricultural Research (CGIAR) and its institutes (outside Europe) are showing aspects of financial constraint (CGIAR, 2008). One consequence of this change has been the growth of interest in plant derivatives other than pyrethrum and nicotine which have long histories of usage. Collaborative work with scientists in developing countries has resulted in a proliferation of papers on plant extracts, many actually from the plant family Labiatae (e.g. Keita et al., 2001; Stella Nerio et al., 2010). Although touted as potentially valuable and effective, most have not had their toxicological effects determined and scant regard has sometimes been paid to their application in areas other than where they are grown. Bluntly whilst some may in the future have local importance, they are, in my opinion, unlikely to be adopted in many developed countries for several reasons – unproven toxicity, the effects of residual product, cost, effectiveness in a several 1000 ton grain lot, the importance of minimising (often to zero) insect remains, etc.

4. Where has research been based in Europe?

Using the same source of information as before there has been a dramatic change in the sources of published papers (Fig. 2). It should be remembered that JSPR was published in the UK and was predominantly in English although I note that a paper in French on parasites and predators of bruchids (de Luca, 1965) appeared in the very first issue. More than half the papers in 1967-68 were from scientists in England and almost all the rest from outside Europe. The only non-UK European papers were from Israel, Czechoslovakia, Germany and Norway (still the only paper published in the journal from a Norwegian source (Sømme, 1968). By 1987-88 at which time the journal was well established and with a truly international advisory board and Regional Editors in the UK, Australia and the US, there was little change in the minimal European representation outside the UK but there were now twice as many papers from outside Europe as from the UK. The big change came over the next 20 years when coverage suddenly exploded in Europe; 16 different European countries, not unfortunately including Portugal, were represented and their papers far outnumbered those from the UK although collectively Europe is greatly outnumbered by papers from other parts of the world.

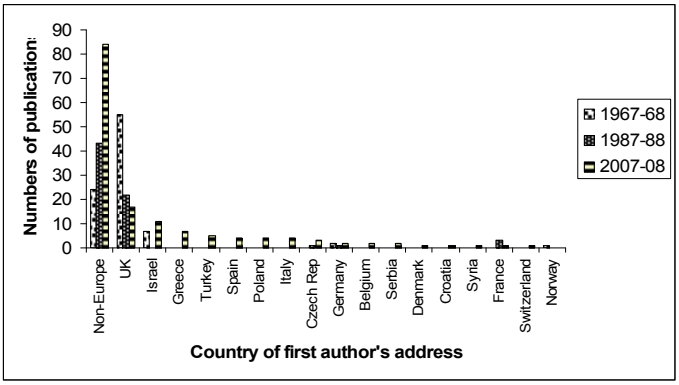

Figure 2 The geographical sources of manuscripts in the Journal of Stored Products Research fell during three separate two-year periods of publication, 1967-68, 1987-88 and 2007-08. Sources are based on the address of the senior (first author) when the work was undertaken.

One is therefore led to ask what has produced the recent explosion of work across Europe, but overall the demise of Europe as a contributor to stored products research on a global front? I would suggest that the answer lies on two fronts –language and money!

5. The importance of language

I now wish to bring down the wrath of the conference onto my head! I believe that it is impossible to produce genuinely objective data to support the argument that I propose here because of the number of confounding variables, so I stress that the views here are my own. It is my belief that English has become the language of science in the late 20th century. We all take rapid travel, electronic communications, the internet, email, etc. for granted so the world of science has been driven to move to a universal language – which may in the 21st century become a form of Chinese, so those of you younger than me, be prepared! In the early and mid-20th century publications on many subjects including stored-product protection were written in native languages. The distribution of journals in paper format was expensive and, of course, subscriptions of libraries and research institutions tended to be based on the local language with, perhaps, one or two subscriptions to journals in foreign languages, frequently English, French or German. The consequence was that relatively important work was "hidden" or unavailable, rather parallel to the lack of awareness of Mendel's seminal studies on inheritance which were also lost for 40 years at the end of the 19th century. Furthermore, abstracting and indexing services were entirely paper based so that finding published material on any subject was extremely time consuming and often required some knowledge of at least one foreign language, usually English for non-native speakers. Progressively, as transport and communication became easier so conferences, such as the 1st International Working Conference on Stored Product Entomology (IWCSPE) held in Savannah, USA in 1974, the 2nd in Ibadan, Nigeria (1978), the 3rd in Manhattan, Kansas, USA (1983), and the 4th International Working Conference on Stored Product Protection (IWCSPP) in Tel Aviv, Israel (1986) became increasingly important as venues for information exchange and it was invariably the case that papers were presented in English. Only when the 5th IWCSPP was held in Bordeaux in 1990 were a few papers delivered in French; this typifies the problem of a small continent like Europe having a richness of entrenched languages. However my general argument is that as communication improved so the shift towards a common language accelerated and because of the major influence of North America, Australasia and the British Empire in the 19th and early 20th centuries, the common language was English, with French, German and a little Spanish also occurring. Outside Europe, in the Far East, oriental languages, in particular Mandarin, Cantonese and Japanese were used and an almost separate scientific culture was established.

Overlying this progressive shift was a dramatic revolution in the transmission of information. Until the late 1960's virtually all written information had to be transmitted in conventional post; manuscripts were submitted to journals as multiple hard copies. The first notable change was the introduction of facsimile (fax) machines for document transmission; although relatively cheap, fax machines only became widely

available in the 1960's and it still took 6 minutes to transmit a single sheet of A4 in 1968 and 3 minutes in 1976! In turn the fax machine was replaced by email which really became widespread from the early 1980's. The internet which became more widely available in developed countries in the 1990's has revolutionised publication and abstracting services. Many journals now only accept manuscript submission online by using the internet. Many of us take it for granted that we can download papers from a very wide range of journals published across the globe, though most by only a few publishers, straight into our own offices. Subscriptions to paper copies continue to decline and some journals are now only published electronically. If we want to know about work published on any subject, we search international databases such as the ISI Web of Knowledge in the UK, Scopus, Current Contents and Current Abstracts, PubMed, etc. So suddenly the whole world of scientific knowledge is potentially available at your desk top. This in turn puts even more pressure on dissemination not being limited by language so virtually all mainstream journals now publish almost exclusively in English and many offer translation services for those unable to write in English effectively.

6. Money talks

It is very hard to get authentic data on investment into research in any particular area which does not have boundaries which are clearly demarcated. Furthermore, many countries contribute substantial sums to central pools such as the CGIAR so expenditure is not limited to that directly invested by the governments or agencies in their own countries.

For example, in the UK support for research on stored products has shrunk dramatically. The Natural Resources Institute was the last vestige of a succession of bodies including the Tropical Stored Products Centre and Tropical Products Institute which undertook wide ranging research in many areas. It was privatized and then downsized dramatically in 2001 leaving a valuable but relatively tiny shadow of the activities 10 and more years previously. Research at The Pest Infestation Laboratory (PIL) initially focused on protecting the security of foodstuffs held under wartime conditions. It was established on the Slough site in 1940 as the UK government realized the problems encountered when they started to create food stockpiles for the War: medium-term storage of British grains was one thing, long-term storage of foods imported from the tropical and subtropical climes of the British colonies was another. So, from the start, PIL entomologists were dealing with problems on imported food stocks as much as those on home-grown cereals (Haines, pers. comm.). After its initial establishment by the Department of Scientific and Industrial Research it was transferred through various agencies to and of the Ministry of Agriculture, Fisheries and Food (MAFF), becoming ultimately the Central Science Laboratory, and an Executive Agency of MAFF in 1992, relocating to York in 1996 and most recently becoming an Executive Agency of the Department for Environment, Food and Rural Affairs (DEFRA). Last year it became an integral part of the Food and Environment Research Agency (FERA), itself an Executive Agency of DEFRA. Although food security falls within their current remit, investigation of problems associated with stored durable commodities scarcely features in their current programmes (FERA, 2009). Almost all their research is now concerned with the pests of growing crops.

Therefore the two largest bodies traditionally working on stored products in the UK have shrunk to minimal size. If one took out their contributions to stored-product research in the UK over the past 70 years, whether dealing with national or international problems, there would be precious little left. If one adds to that the recently announced cuts of over £900 million from the budget for UK universities, the plight of stored products research is self-evident.

Conversely, despite the prevailing global economic conditions and particular problems in parts of Europe (such as Greece), France, Germany and the US are investing in higher education and research (Spencer, 2010) so there is the potential for more research activity elsewhere. The Institut National de la Recherche Agronomique (INRA), and the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), for example, support substantial research as do comparable agencies in other European countries. Furthermore the EU research framework programmes are well supported and FP7 expenditure is projected to increase year on year with a total budget of 5200m€, although only a small portion of this is directed towards research with any stored products element. It does, however, have the capacity to spread research activity within the EU and collaborating countries.

The overall picture is of a relative decline in UK involvement, compared with the past, but prospects of growth more widely although we can be sure that funding will always be challenging.

7. Where will or should money be spent?

At the moment, in 2010, most of Europe, certainly those parts where research takes place at a significant level, is perfectly capable of dealing with the safe storage of most of its food. Yes, there are particular problems which are being dealt with at a local level such as the storage of cheese in Spain (Sánchez-Ramos and Castañera, 2009 or hazelnuts in Turkey (Kibar and Ozturk, 2009) but the major food materials are not subject to insoluble problems. Consequently, most people do not see or foresee a problem worth worrying about. However, it is entirely predictable that phosphine resistance will continue to spread, that resistance to the remaining chemical protectants will spread, and sooner or later, there will be another major problem if not crisis in food security. It will not arise instantly but grow insidiously causing an increase in price as availability of high quality food declines. Politicians and funding bodies, at least in the UK, are usually more responsive to immediate than future problems so obtaining funding to solve future problems is hard.

I hold the view that the introduction of any foreign material to bulk stores of grain in Europe and probably other developed countries will be barred in the foreseeable future. I do not think this is a view that I hold alone. Therefore we need to identify tools to see us through the immediate future and longer term objectives.

I would argue that we are right to be looking at alternatives to current fumigants and chemicals now. Alternative fumigants such as sulfuryl fluoride have a long history and are not new; its effects on insect eggs, admittedly of different species, is studied regularly but intermittently (e.g. Outram 1967, Bell and Savvidou, 1999, Baltaci et al., 2009). Much the same can be said for other compounds and one must question whether such a long "gestation period" might indicate very limited potential.

Diatomaceous earths are currently valuable but I would predict a growth in resistance although there are relatively few published reports of it at present. Variable tolerance among Tribolium confusum du Val populations was established 9 years ago (Rigaux et al., 2001) and Vayias et al. (2008) demonstrated resistance development in T. confusum in the laboratory over relatively few generations. Nevertheless, the Woodstream Corporation still advertises in 2010 that "Insects cannot develop resistance, no build-up of chemical immunity" to its Safer Brand product called Concern® which contains "diatomaceous earth (85%) - all natural". Fields (1998) provided a more considered appraisal of their advantages and disadvantages in the 7th of this series of conferences in Beijing.

Any chemical additive, natural or synthetic, has problems and I would concur with the view that physical methods, perhaps allied with varietal control, will inevitably become the methods of choice in Europe in the future. This is probably the explanation for the increasing number of studies of modified atmospheres, vacuums and even irradiation as methods of control, allied of course to temperature and moisture content regulation.

Detection, monitoring and trapping are integral parts of effective control by any means and increasingly effective methods are being developed. This must continue alongside modeling of population and even individual insect movements in stores which are integral to monitoring efficiency. However I would argue that further biological studies of the familiar pests of most major crops stored in Europe are probably of limited practical value although they may be interesting in their own right. There is probably little to be discovered that will contribute to the increased efficiency of control in the immediate future.

There is a different argument in the context of storage in developing countries. High technology storage structures and the equipment for regulating physical conditions are generally expensive. There are exceptions such as the use of solar heat and relatively inexpensive storage means (Murdock and Shade, 1991) but they are unlikely to be solutions in many situations. In my view, the best hope is that European contributions will work alongside or educate scientists from developing countries. This is not intended to be patronising at all but to try and ensure that efforts are directed into sensible paths; simply watching them repeat the errors of creating problems with additives would be an inappropriate contribution. Hence, widespread support for the use of plant extracts without an appreciation of the source, toxicity, side effects, persistence, cumulative or synergistic effects, etc. is not really helpful and could easily lead to misdirected effort. Collaboration and education would appear to be the most productive ways forward in the short term rather than trying to export technology.

It would be remiss not to say something about the impact of threatened climate change. I do not think it is important for my purpose today to debate the causes but I do think we should be aware of the overall rise in temperatures in Europe and disruption of weather patterns we have regarded as normal. These changes will impact on the successful cultivation of crops, the variety which is grown in any one area and the conditions in which the products enter stores. They may also impact on the pest species we consider most important but there have been shifts in the past. The introduction of combine harvesters and consequent damage to wheat grains led to a reduction in the incidence of *Sitophilus granarius* (L.) in the UK and its replacement by *Cryptolestes ferrugineus* (Stephens) and *Oryzaephilus surinamensis* (L.). *Typhaea stercorea* (L.) and Ahasverus advena (Waltl) have become more common and in general species of tropical or very warm temperate origin have become more common at the expense of species regarded as typical of cooler northern areas (Armitage, 2004). Since storage conditions are generally controlled, I do not see any major rapid changes which might be needed in the near future as a direct consequence of climate change, but a watching brief is essential. However a recent extended review of the impact of climate change on food security worldwide provides a wider perspective (CGIAR, 2009).

8. Changes in methodology

Research is a somewhat cyclical activity in that new methods provide a means of approaching old problems in a new way. Previously insoluble problems are sometimes amenable to solution as methodologies develop. Both situations are applicable in the context of stored-product research in Europe.

I have said that I consider that relatively little research on the basic biology of pests of commodities stored in Europe is now justified. I stand by this but acknowledge that the identification and classification of pests, including potential pests, will be informed by the use of molecular methods. At present only the genera *Tribolium* and *Callosobruchus* have been investigated in any depth although there are individual papers concerning other genera such as Acanthoscelides and Bruchidius (Kergoat et al., 2005). I would suggest that the concentration on *Tribolium* and *Callosobruchus* has more to do with their use in other fields of biology, as model organisms, than their role as stored-products pests. There are no papers on *Oryzaephilus* or *Cryptolestes* despite their importance in Europe and virtually nothing on Sitophilus beyond an interesting paper by Hidayat et al. (1996) in which molecular data were shown to confirm some morphological distinguishing characters of S. oryzae (L.) and S. zeamais Motschulsky (but not in Europe). The complete genome of *Tribolium castaneum* (Herbst) has been published but whether any of the impressive body of information which that represents will solve the world's food security problems, I doubt. Nevertheless the fact that *T. castaneum* is a pest will be used to justify subsequent research and the title of the Nature paper (*Tribolium* Genome Sequencing Consortium, 2008, "The genome of the model beetle and pest *Tribolium castaneum*") with the genome sequence is evidence for my view! Let me say, however, that I am sure that the work will have major impacts elsewhere and I do not denigrate the effort or importance of the genome in other areas of scientific research.

Very much more likely to be of importance is the use of molecular data for identifying past or present infestations at very low levels in grain bulks. Enzyme-linked immunosorbent assays (ELISA) have been tried for many years and crop up intermittently. Brader et al. (2002) demonstrated the power of the method over a number of alternatives and it had a recent revival in the work of Atui et al. (2007) but it has never been taken from proof of concept to practical application. Efforts to utilise DNA technology to date have concentrated on Tribolium not only because of its pest importance but also because of its importance as a model insect and the availability of Genbank sequences (Nowaczyk et al., 2009). The potential sensitivity of such tools is already known (Balasubramanian et al., 2007) but there are many hurdles to overcome before they are commercially important. Nevertheless, it is pretty safe to predict that complete automation and rapid multiple sampling will be possible before long.

An entirely different but equally probable application of molecular developments is in the world of proteomics or metabolomics. Techniques employing mass spectrometry and large arrays to identify the sources of proteins or other metabolites and thereby identify their source has been demonstrated in the context of some foods (e.g. Mora et al., 2009; Ocana et al., 2009) and their application to the identification of pests or pathogens such as fungi in stored food must have considerable potential which does not yet appear to have been explored. Only two papers have apparently considered this approach

thus far (Park et al., 2008; Campbell, 2008) although the fundamental techniques are well established in European research laboratories.

Another area for development which has been explored in the recent past is means of detecting the presence of insects or pathogens either by their volatile chemical signature (electronic noses, e.g. Magan and Evans, 2000) by the sound (e.g. Hagstrum et al., 1990) which they make when feeding (acoustic detection) or by imaging methods (optical or spectroscopic detection, e.g. Perez-Mendoza et al., 2003; Fornal et al., 2007). At different times the feasibility of each has been shown but their practical application currently remains elusive; as Bengston said in 2005, "use of these techniques remains largely experimental"! However rapid advances in powerful techniques including nanotechnology may yet see one or more of these methods emerge into the mainstream. Europe has contributed and will doubtless continue to do so in the development and application of diverse novel methods.

Yet another area where there must be room for further development is in the composition of the crops themselves. This is not the place to embark on a debate about genetic manipulation or engineering and, indeed, the means of generating new cultivars is not the issue. However, growing understanding of the biochemistry, especially the gut enzyme complements of some pests allied with some form of resistance mechanism in the crop or its product to be stored will provide an adjunct to physical control methods. However, I have said before in these meetings (Credland and Appleby, 2003) that individual resistance mechanisms in a crop are likely to be no more valuable in the long term than chemicals or fumigants with a single mode of action and I stand by this assertion. Multiple mechanisms of action are far more likely to have a role into the future but are likely to be much more difficult to both understand and engineer. Europe has a long and distinguished history in the understanding of such methodologies (e.g. Hilder et al., 1987; Gatehouse et al., 1992)

I do not plan to say anything further about the sort of progress that might be made in the context of stored products and food security in developing countries. I am sure that my colleagues have or will comment on how they see both the need for collaboration with colleagues in Europe, and the areas of research which might benefit from European inputs.

9. Neglected issues

I think it only right to say something of issues I have largely ignored, and explain why. There is no doubt that mould has been a problem on stored products in the past and still is in some instances. However the fundamental control of the problem is generally well understood and physical conditions of storage are the key. Similarly, rodent infestations can have major impacts but the newer second generation anticoagulants are effective although, as with insecticides, resistance is likely to arise and proliferate. Good management of the stores allied with selective usage is probably adequate for the immediate future.

I have said nothing about biological control. It is a subject of interest to me and it clearly has a role in the management of field pests, but does it have a place in stored product pest control in Europe if contaminants of food are to be minimised? The basic concept of introducing a pathogen, whether microbial or fungal, or an animal, is anathema to most consumers despite what scientists may think. Predators or parasitoids of insect pests are other insects so, although I think they may have a valuable role in developing countries with more acute problems, and despite the protestations that I am sure I will attract, I do not see conventional biological control as playing a significant part in stored-product pest control in Europe.

There is an area which certainly will be important but which I feel unable to say anything very sensible about, but I do not want it to be overlooked. In Australia and North America, in particular, very important work has looked at the structure of stores, their design, location, orientation and so on. This work leads to other on modelling of air flow, temperature and moisture gradients, for example. With the growth in stores in Europe which will be needed to house the food for its growing population, I trust that we shall not repeat all the work undertaken elsewhere. The values of variables in the equations may be different but I am not convinced that redeveloping the models is justified.

The biggest problem that I think we face in Europe is probably the training and education of store managers. With a move to less on-farm storage and the continued growth of cooperative and commercial stores, we may need few real specialists but it is absolutely essential that growers and importers are

aware of basic requirements and know how to recognize, minimise, or better, exclude problems. But, where are the courses to train experts in Europe? It is extremely difficult to find any and I am not aware of any in the UK that provide anything like a comprehensive coverage.

So what of the future and what do I think is likely to happen?

10. To the future

I have worked in British universities and associated with scientists from many countries for 40 years, and the most important lesson to learn from that is that if you hang in there the world changes faster than you do. I have seen governments come and go, wars come and go, financial crises come and go, and often, very sadly, people come and go. I know that trying to predict what will happen tomorrow at home, never mind in Europe over the next few decades, is virtually impossible.

However, I am confident that at some time in the fairly near future the world is going to need more scientists with expertise in stored products than are currently available. I am convinced that problems of one kind or another await us all. The world's population is rapidly approaching 7 billion; it may have actually reached this figure as we speak. Europe has about 750 million inhabitants, rising steadily but declining as a proportion of the world's population because of the greater rate of increase elsewhere. There are now closer ties between many of the countries of Europe than have perhaps ever existed. Exchange of information and skills, enhanced communication both within the continent and with others further afield should leave us well placed to deal with future problems. In my opinion it is certain that we shall need to find new strategies to deal with storage problems to feed the growing number of people and that existing measures are doomed to failure in the foreseeable future. At that time, despite warnings we can give now, funding will suddenly be made available to try and conjure solutions to problems that we can predict today. I hope that we have trained enough successors to take on this task which I consider essential to avert the sort of problems that have led to conflict in the past. I urge you all, wherever you are from, to keep up your excellent work and enjoy events such as that starting here today because I think this exchange of information, education of each other, is the key to our future.

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