SESSION 4A

POST-HARVEST LOSSES FROM PESTS AND DISEASES

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RECENT SURVEYS OF POST-HARVEST PEST PROBLEMS IN FARM AND COMMERCIAL GRAIN STORES IN THE UK.

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ABSTRACT

The results of recent surveys of storage practice and pest presence in UK farm grain stores and in off-farm commercial or central stores are presented. Much of the cereal market demands pest-free grain and the extent to which the grain industry meets this stringent requirement is discussed. The implications of the MAFF Code of Practice for the Control of Salmonellae are considered. This Code was not published at the time of the surveys and stipulates the exclusion of birds and rodents from stores containing grain intended for incorporation in animal feedingstuffs. In general, the majority of stores are successful in controlling those insects regarded as primary pests but less successful in avoiding secondary insect pests and excluding rodents and birds.

INTRODUCTION

The expansion of the UK cereal industry during the decade 1975-1985 resulted in a doubling of production from 13.8M to 26.5M tonnes and an exportable surplus of 6-10M tonnes (Wilkin & Hurlock, 1986). This level of production has been maintained with an average of 22.4M tonnes for 1985-89, comprising 57% wheat, 41% barley and 2% oats (Anon., 1991). These proportions differ between the constituent countries of the UK, with more wheat than barley grown in England whereas barley is the predominant crop in Scotland, Wales and Northern Ireland.

At harvest time approximately 90% of the crop is put into farm grain stores (Taylor & Sly, 1986). By the end of September 80% of wheat and 60% of barley remains on-farm and then, between October and June, there is a fairly constant decline in stocks such that most stores are empty by July, ready for the next harvest (*Source*: MAFF Cereal Stocks Survey). In off-farm commercial stores grain may be stored for much longer, especially that sold into Intervention. The total throughput of these stores varies but was estimated to be 6M tonnes for England and Wales in 1977/78 (Taylor, 1978) and a survey by Garthwaite *et al* (1987) identified 7.4M tonnes in England in 1985/86 but the latter were uncertain what proportion of the total this represented. In the 1985/86 survey, 33% of the grain was identified as coming from harvests prior to 1985.

The historical need to prevent damage or loss of grain by protecting it against attack by mould, mite, insect, rodent or bird pests has, to a large extent, been superceeded by more stringent requirements. For example, the UK flour milling industry uses 30% of wheat production and has a general requirement of freedom from pests (*Source*: NABIM). Almost half the grain exported goes to countries that require a phytosanitary inspection to check for the presence of pests (Wilkin & Hurlock, 1986). Animal feed accounts for 40% of UK cereal production (*Source*: MAFF) and the *Code of Practice for the Control of Salmonellae* during the storage, handling and transport of raw materials intended for incorporation into animal feedingstuffs, published by MAFF in 1989, requires the exclusion of birds, rodents and insects from stores. These factors have imposed the need not only to prevent damage by pests but to provide pest-free grain. At the same time it is MAFF policy to minimise the use of pesticides.

Surveys of storage practice and pest presence in farm and commercial grain stores were carried out between 1987 and 1989. This paper presents a summary of the main results of these surveys and discusses their implications.

METHODS

Farm grain stores

A random sample of 742 farm grain stores were surveyed between April and August 1987, stratified such that there were approximately 50 farms in each of three size groups in each of five regions covering the whole of England. Size (small, medium and large) was based on area of cereal grown and defined as 5-29.9, 30-74.9 and 75ha or more, respectively. Further details of stratification are given in Prickett (1988). The sample was 1.7% of the estimated total number of farms in England that stored grain. National estimates derived from the survey data were weighted by the total number of farms in each stratum identified by the annual MAFF census.

Commercial grain stores

Commercial or central grain stores were surveyed between September 1988 and March 1989. The aim was to survey all sites in England and Wales that had a storage capacity of more than 1,000 tonnes and to inspect up to four individual stores at each site for the presence of pests. The total number of such sites that existed at the time of the survey was believed to be 179, determined from information from several sources. The actual number of sites surveyed was 171 and at 157 of these a total of 283 individual stores were inspected. External bins or silos were excluded from inspection on grounds of safety. Further details are given in Prickett & Muggleton (1991).

Pest detection

The detection methods used for insects and mites were visual observation, sieving of residues, and placement of bait-bags (Pinniger, 1975), probe traps (Burkholder, 1984) and pitfall traps (Cogan & Wakefield, 1987). Rodents and birds were assessed on the basis of animal sighted or recent physical signs, such as droppings. Pests were recorded as present or absent and no attempt was made to assess the size of populations.

RESULTS

Grain storage

National estimates of total cereal storage capacity and the types of storage facilities are given in Table 1. The majority (86%) of farms that grew grain had their own grain store and the raised total quantity of wheat, barley and oats taken into these stores from the 1986 harvest was 18.5M tonnes, 88% of the 21.0M tonnes harvested. The weighted average tonnage stored was 90t, 288t and 1,058t on small, medium and large farms respectively. The total on-farm storage capacity was estimated to be 21.2M tonnes, with 66% of this being floor-stores, 23% internal bins and 11% external bins or silos. A small proportion of farms (15%) intended to use all their stored grain on the farm, nearly all of whom were small farms; most farms (85%) intended to sell all or part of their grain. At 23% of farms there had been a carry-over of grain from the previous harvest and 16% of farms had taken grain in from elsewhere for drying or storage. Three-quarters (77%) of the farms were mixed rather than purely arable and this was reflected in the fact that 68% bought-in animal feed.

The estimated total storage capacity in commercial grain stores was 4.5M tonnes, 83% of this being floor-stores, 4% internal bins and 13% external bins or silos. At the time of the survey 2.4M tonnes was in store and throughput during the previous 12 months was 4.9M tonnes, giving a total content and throughput of 7.3M tonnes, with an average of 41,000 tonnes per site. Home-grown grain was received direct from farms at 98% of sites and from other stores at 33%; imported grain was stored at 5.5% of sites but only 0.6% stored exclusively imported grain; and Intervention grain was present at 30% of sites. Infestable commodities other than cereal grain were stored at nearly two-thirds (62%) of sites and consisted mostly of rapeseed and pulses. When asked about the intended market for the grain in store, most site managers identified several markets. Those most frequently specified were export (67% of sites), feed mill (65%), flour mill (41%) and malting (37%).

TABLE 1. Raised estimates of storage capacity on farms in England and in commercial grain stores in England & Wales.

	Farm stores Small	Farm stores Medium	Farm stores Large	All farms	Central sites
Total number	17,394	12,887	12,509	42,790	179
Capacity (tonnes)	1.9M	4.3M	14.9M	21.2M	4.5M
Floor stores (%)	46.1	57.1	70.6	65.6	83.2
Internal bins (%)	32.9	28.2	20.5	23.2	3.6
External bins (%)	19.9	14.0	8.9	11.0	13.3
Other (%)	1.1	0.7	0.1	0.3	0.0
Throughput (tonnes)	1.6M	3.7M	13.2M	18.5M	7.3M

Physical control methods

The extent to which physical methods, such as controlling the temperature and moisture content of the grain, and pesticides are used to protect the grain is shown in Table 2. Almost all farmers (97%) said that the grain store had been cleaned to remove residues before the harvest was taken in. Grain cleaning and drying to prevent the development of mould and mites occurred on 59% and 81% of large farms respectively, but the frequency dropped to 15% and 19% for small farms. Similarly, grain cooling to prevent insects from breeding was more common on large farms (72%) than on small ones (50%), but most common at central sites (91%).

Insecticides

Insecticide use followed the same pattern as that for physical methods, being more frequent on large farms than on small ones. Overall, insecticide treatment of the fabric or structure of the store was carried out on 52% of farms, whereas only 10% of farms applied insecticide to the grain itself. Almost all grain treatments were in stores where the fabric was also treated. A much greater percentage of central sites (72%) applied insecticide to the grain than did large farms (20%). Allowing for whether the whole of a bulk was admixed, or just the surface was treated, an estimated 9% of farm-stored grain and 23% of centrally-stored grain was treated with insecticide. In both farm and commercial stores, approximately 95% of fabric treatments and 80% of grain treatments were said to be prophylactic rather than to control an existing infestation.

TABLE 2. Physical and chemical methods used to maintain the quality of stored grain (percent of premises).

	Farm stores			All	Central
	Small	Medium	Large	farms	sites
Store cleaned pre-harvest	92.8	99.1	99.5	96.6	-
Grain cleaner used	14.8	28.2	59.0	31.8	59.2
Grain dryer used	18.7	49.9	81.4	46.4	65.7
Grain cooled/aerated	48.8	64.0	72.2	60.2	90.6
Insecticide treatment*:					
Fabric of store	27.9	59.2	78.3	52.1	85.8
Grain (all or some)	2.1	9.6	20.2	9.7	71.6
Total, fabric or grain	28.2	60.3	81.6	53.4	94.1
Rodenticide treatment	67.5	83.3	85.5	77.5	97.7

* Pirimiphos-methyl was the most common insecticide, used in about 75% of treatments. For further details of insecticide use, see Prickett (1988) and Prickett & Muggleton (1991).

Pests

The percentage of farms where the different types of pest were detected are shown in Table 3. Beetles have been grouped as primary pests (those that may cause serious and damaging infestation) and secondary pests (those that are usually associated with poor hygiene or mouldy grain, but nevertheless may lead to rejection of grain offered for sale). The genera included in each grouping are given in the foot-note to the Table. One or more of the primary beetle pest genera occurred in 9.7% of farm stores and an estimated 7.8% of farm-stored grain from the 1986 harvest was put into these stores, amounting to 1.4M tonnes. Secondary beetle pests and moths were found two to three times more frequently than the primary pests and more often in small farms than large ones. Psocids, which may become a nuisance when present in large numbers, were detected in about half the stores. Mites were widespread, present in 72% of stores and there was little evidence of a difference in frequency between the farm sizes. Rodent presence was detected in 70% of stores, comprising 53% with rats and 59% with mice, whilst bird presence was noted in 62% of stores - 31% with pigeons and 53% with sparrows.

The three primary insect pest genera, *Oryzaephilus*, *Cryptolestes*, and *Sitophilus*, occurred with similar frequencies (Table 4) and, in each case, they were more common on mixed farms (those growing cereal and keeping livestock) than on purely arable farms. One or more of these pests were found on 70 out of 584 mixed farms and on 5 out of 158 arable farms, giving significantly different ($p<0.05$) weighted percentage occurrences of 11.9% and 2.4% respectively.

TABLE 3. The frequency with which pests were detected in farm grain stores (percent of farms).

Pest	Farm stores Small	Farm stores Medium	Farm stores Large	All farms
Primary beetles (a)	11.4	9.3	7.7	9.7
Secondary beetles (b)	29.7	20.4	12.8	21.9
Moths (c)	36.7	23.6	21.4	28.3
Psocids	50.8	59.1	46.2	51.9
Mites (d)	73.5	71.5	69.2	71.6
Rodents	69.4	68.8	73.6	70.4
Birds (e)	58.4	63.5	64.4	61.7

(a) *Oryzaephilus, Cryptolestes, Sitophilus*; (b) *Ahasverus, Typhaea*; (c) *Endrosis, Ephestia*; (d) *Acarus, Glycyphagus, Tyrophagus*; (e) Pigeons, sparrows.

TABLE 4. The occurrence of primary insect pests on arable and mixed farms (percent of farms).

Pest	Arable	Mixed	All farms
Oryzaephilus	1.0	6.0	4.8
Cryptolestes	1.3	5.7	4.6
Sitophilus	0.8	5.3	4.2
Any of the above	2.4	11.9	9.7

See text for number of arable and mixed farms

Pest data for commercial or central stores are given in Table 5, on both a site and individual store basis. The pest groupings are similar to those for farm stores except that spider beetles (Ptinidae) have been included because they were found frequently. The percentages for pests found in stores are lower than those for sites, reflecting that pests found at a site were not necessarily present in all stores at that site. Primary beetle pests were detected in twice as many stores (27%) as were secondary beetle pests (12%). Ptinidae were found in 36% of stores and moths in 17%, whilst psocids and mites occurred in 55% and 81% respectively. Rodents, noted in 71% of stores, comprised rats in 33% and mice in 61% whilst birds, recorded in 46% of stores, comprised pigeons in 34% and sparrows in 24%.

In Table 6, insect occurrences have been partitioned by whether they were found only in the grain; in the grain and on the structure; or only on the structure. Occurrences in the grain are those detected by the use of probe traps or pitfall traps placed in the grain or by bait-bags placed on the grain. Occurrences classed as on the structure are those detected by bait-bags placed on the structure, by visual observation, or by the sieving of residues. The three beetle groups and psocids were detected more often in the grain than on the structure. The proportion of detections that were in the grain, rather than on the structure only, was approximately 85% for each of these four groups. Moths showed a different pattern and were found in the grain in 39% of the stores where they occurred.

TABLE 5. The frequency with which pests were detected in commercial grain stores (percent of sites and percent of individual stores).

Pest	Sites (N = 157)	Stores (N = 283)
Primary beetles (a)	39.5	26.5
Secondary beetles (b)	17.8	11.7
Spider beetles (*Ptinidae*)	49.0	35.7
Moths (c)	25.5	16.6
Psocids	65.0	54.8
Mites (d)	87.3	81.3
Rodents	79.0	71.4
Birds (e)	59.2	46.3

(a) *Oryzaephilus, Cryptolestes, Sitophilus*; (b) *Ahasverus, Typhaea*; (c) *Endrosis, Ephestia, Hofmannophila*; (d) *Acarus, Glycyphagus, Tyrophagus*; (e) Pigeons, sparrows.

TABLE 6. The occurrence of insects in the grain and on the structure of commercial grain stores (percent of stores).

Pest	Grain only	Grain & structure	Structure only	Location uncertain
Primary beetles	17.0	5.3	3.5	0.7
Secondary beetles	8.1	1.1	1.8	0.7
Spider beetles	23.0	6.4	4.9	1.4
Moths	3.2	2.8	9.2	1.4
Psocids	24.7	18.0	9.2	2.8

In response to questions on insect detection at commercial sites, managers at 94% of sites said that grain was checked for pests upon intake. Grain had been rejected upon intake because of infestation at 59% of sites - 80% of these had rejected grain from farms and 23% from other stores. Insect traps were used in 26% of stores to monitor the grain for pests and 80% used spear or vacuum sampling, giving an overall 92% of stores monitoring the grain. An insect and/or mite infestation was said to have occurred at 51% of sites during the previous 12 months, 23% having had an insect infestation and 40% a mite infestation.

DISCUSSION

The results show that the majority of stored grain was protected by physical control methods, such as store cleaning or manipulating the temperature and moisture content of the grain, and by treating the structure of the store with insecticide. Only 9% of farm-stored grain and 23% of grain in commercial stores was treated with insecticide. One measure of the success of this approach is that in 90% of farm stores and 73% of commercial stores no primary beetle pests were found, indicating that the majority of the industry is able to satisfy market demands for pest-free grain. However, there are still some problems that need to be addressed, including the development of insecticide resistance, the effective application of insecticides, the presence of secondary pests and the exclusion of rodents and birds from stores.

The percentage of farm grain stores with primary beetle pests (9.7%) is very similar to that found in previous surveys. In 1977 a survey of 368 farms in 12 English counties detected one or more of the primary pest species in 13.0% of stores (Anon., 1981). A more limited survey in 1980 of 129 farms in eastern England found these species in 8.5% of stores (Wilson, 1983). During this period, 1977 - 1987, the proportion of farms using insecticide in the grain store increased appreciably. In 1976/77 the percentages of small, medium and large farms using insecticide were 11%, 41% and 61% respectively (Taylor & Lloyd, 1978) and in 1986/87 (the current survey) these percentages had risen to 28%, 60% and 82%. Thus, despite increased insecticide use, there is very little evidence of any decrease in the frequency of pests.

The extent to which this may be due to the presence of insecticide resistance is unclear. Primary pests collected during the surveys were tested for resistance using discriminating doses of insecticide that were just sufficient to kill all individuals of normal susceptibility, following the general procedures set out in FAO Method No. 15 (Anon., 1974). The results of these tests showed that in *Oryzaephilus surinamensis* resistance to organophosphorus insecticides is widespread and more common in commercial stores than in farm stores, but that in *Cryptolestes ferrugineus* resistance to these insecticides is rare (Prickett *et al*, 1990). The resistances detected by the discriminating dose tests may not necessarily enable the insects to survive properly applied field treatments at the recommended dose but their presence greatly reduces both the safety margin between control success and failure and the effective life of a residual treatment.

In the 1980 farm survey, primary pests were found in 7% of stores that had used insecticide and in 9% that had not used insecticide (Wilson, 1983). Subjecting that data to Fisher's Exact Test shows that these rates are not significantly different ($p=0.96$). Wilson commented that those farms which both used insecticide and were infested gave support to the view that pesticides may not always be used in the most effective manner. The occurrence of primary pests in commercial grain stores has been examined in the light of this comment. To minimize differences other than insecticide use, stores were selected where: a) all grain had been cooled, b) all three methods of detecting insects in grain (pitfalls, probe traps and baitbags on the grain) had been used during the inspection, c) either all the grain in store had been admixed or none had been treated and d) if the grain had been treated it was a prophylactic treatment and not because of known infestation. These criteria were satisfied by 112 stores - 39 with treated grain and 73 with untreated grain. The treatments were with either chlorpyrifos-methyl, etrimphos, methacrifos or pirimiphos-methyl. *O. surinamensis* was detected in the grain in 8% of the treated and 7% of the untreated stores; *C. ferrugineus* in 3% and 14%; and *Sitophilus* spp in 3% and 10% respectively. One or more of these three pests occurred in the grain in 10% of treated stores and 22% of untreated stores. Statistical comparisons showed no significant difference between rates for treated and untreated grain ($p>0.05$ in all cases). These results are of concern not only because insects appear to have survived insecticide treatment, but also because the presence of primary insects in the grain, whether it was untreated or treated prophylactically, suggests that the stores were insufficiently monitored to detect the presence of these pests.

Since insects can hide in cracks and crevices in walls and floors and develop in the residues that accumulate there, an important part of pest control is the elimination of these harbourages and the removal of residues. Most of the farm stores were empty at the time of the survey and therefore the occurrence of primary pests in 9.7% of stores reflects the extent to which they were present on the structure or in residues. These pests were detected in the structure of 8.8% of commercial stores - 33% of the detections. Further examination of the farm survey data showed that primary pests occurred in 5.3% of stores that were cleaned by vacuum, in 11.9% cleaned manually and in 10.9% of those that were not cleaned. The figure for vacuum cleaned stores is significantly lower ($p<0.05$) than that for the two other groups, which do not differ from each other. This indicates that manual cleaning is not very effective and greater attention to store cleaning and eliminating harbourages would reduce the threat of infestation.

The five-fold greater occurrence of primary beetle pests on mixed farms than on arable farms requires further investigation. Barker & Smith (1990) found that in Manitoba, Canada, *C. ferrugineus* occurred more often than expected on farms where there were livestock. They suggested that bought-in animal feed can sometimes contain stored-product insects and thereby introduce pests to the farm. Wilkin & Hurlock (1986) reported that, during 1981-85, a substantial proportion of certain food commodities imported into the UK were infested and that grain pests were regularly imported. They commented that some of the infested commodities were used in the manufacture of animal feed. Thus it seems likely that the higher frequency of pests on mixed farms may be attributable, at least in part, to infested animal feed.

Secondary beetle pests, *Ahasvera advena* and *Typhaea stercorea*, were found in farm stores more commonly than were primary pests, but the reverse was true for commercial stores. These species are regarded as quarantine pests by some countries that import grain and are sometimes confused with primary pests. It is therefore disturbing that in commercial stores the majority of occurrences were detected in the grain. It is equally disturbing to note that, comparing occurrences in treated and untreated grain as was done above for primary pests, there was no significant difference ($p>0.05$).

Mites were shown by Griffiths *et al* (1976) to be a common feature of stored grain during a survey of farms in 1973/74, but they did not specify the frequency with which one or more of the genera *Acarus*, *Glycyphagus* or *Tyrophagus* occurred. The data from that survey have been re-examined recently and the overall frequency for these three genera was 227 out of

236 farms or 96% (Muggleton, pers.comm.) whereas the figure for the 1987 survey was 72%. Whether this demonstrates a decrease is uncertain because the farms visited in 1973/74 were not a random sample and included farmers that had requested visits from MAFF staff. Mites collected during the recent surveys were tested for resistance by exposing them to 8mg/kg of pirimiphos-methyl applied to wheat (Stables & Wilkin, 1981). This is equivalent to twice the recommended field dose. Resistance was detected in 16% of the populations collected from farm stores and in 64% of the populations collected from commercial stores (Starzewski, 1991). The higher frequency in commercial stores probably reflects the greater use of insecticide in those stores and the concentration of grain from many different sources. Since pirimiphos-methyl is the most commonly used insecticide in grain stores (Prickett *et al*, 1990), these findings have serious implications for the successful control of mites.

The difficulty of excluding rodents is exemplified by their presence being noted in nearly three-quarters of grain stores despite the use of rodenticide in the majority of stores. The surveys did not investigate whether rodenticides were used in the most effective manner, whether rodents were resistant or whether stores were proofed against rodents but each of these aspects may have contributed to the level of rodent presence noted. Certainly the presence of birds in over half the stores suggests that buildings will need to be better proofed against vertebrate pests to meet the new requirements in the Code of Practice for the Control of Salmonellae.

In conclusion, the surveys have demonstrated a considerable investment in pest control by the grain industry with the result that the majority of stores are free from primary insect pests. However, the existence of laboratory-detected resistance in these pests may signal problems for the future. The frequency with which other insects, mites, rodents and birds were detected suggests that there is scope for a heightened awareness amongst store managers of the need for adequate control of these pests.

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CURRENT TRENDS IN THE PROTECTION OF STORED CEREALS IN THE TROPICS BY INSECTICIDES AND FUMIGANTS

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ABSTRACT

Economic change and environmental concern both have major roles to play in determining how and with what chemicals stored cereals will be protected. In tropical, developing countries both these factors affect the future of pest control in farm and central storage.

In central storage, increasing development of resistance to phosphine and contact insecticides, the uncertain future of the fumigant methyl bromide due to its role in the depletion of atmospheric ozone and cost constraints should lead to a more careful and cost conscious application of pest control measures.

On small farms, particularly in Africa, storage is increasing as a result of market liberalisation. This will result in the need for increased usage of dilute dust insecticides. Furthermore, improvement of small scale storage structures may allow the use of phosphine formulations to proliferate, with a concomitant increase in problems due to resistance and safety.

INTRODUCTION

In developing countries huge quantities of cereals, particularly maize, rice, sorghum and millet are stored on farms and in large scale storage facilities. Nearly all developing countries are in the tropics and in climates that encourage the rapid growth of insect populations. Thus effective pest control is crucial and is a burden borne across a variety of income groups, including resource poor farmers, commercial operations and national marketing boards. In central storage, the principal means of pest control is by fumigation, with ancillary use of contact insecticides for protection against reinfestation. This contrasts with farm storage where fumigation of grain has not been a widely available option and when chemicals are used for grain protection they are usually low-strength dust formulations of contact insecticide.

PEST CONTROL IN CENTRAL STORAGE

Bag storage in hessian, jute or polypropylene bags is the most common storage technique in developing countries. With the exception of animal feed, which in any case tends not to be treated with pesticide, produce is rarely stored in bulk. In the few instances where bulk storage is practised, products may be fumigated or treated directly with contact insecticide dust or spray at the time of loading.

Fumigation

Fumigation remains the only means of disinfesting bag stacks of grain *in situ*, and is therefore of world-wide importance. In developing countries the commonest method of fumigation is the treatment of bag stacks under gas-tight sheets. Phosphine and methyl bromide are the only gases which continue to be used to any extent. Grain marketing organizations that originally used methyl bromide, later changed to phosphine, because it was easier to use, requiring less equipment for application and safety purposes. In many countries, methyl bromide application is restricted to specific purposes, to satisfy contract requirements, in circumstances where phosphine is not appropriate or where there is an advantage in completing the fumigation within 24 hours.

In many developing countries there is now easy access to phosphine preparations. This has led to their use by those with little understanding of the fact that insect eradication can only be achieved within reasonably gas-tight enclosures (Halliday *et al.* 1983). The great increase in the use of phosphine in the 1970s and 1980s, often under conditions of inadequate sealing, resulted in repeated exposure of insects to sub-lethal fumigant concentrations. This led to survival of insects and the development of fumigant resistance which is now widespread (Taylor, 1989). In most countries, the magnitude of resistance is still not sufficient to cause insect survival in field treatments, provided the recommended fumigant application rate and exposure period are used under gas-tight conditions. Currently, a minimum exposure period of five days at adequate concentration is necessary to avert or delay the development of phosphine resistance.

Fumigating whole stores, rather than covering individual bag stacks with gas-tight sheets, is practised in South Asia. Since most stores do not retain gas sufficiently well for effective fumigation, this technique has been instrumental in the development of phosphine resistance (Tyler *et al.*, 1983). In Pakistan, where whole-store fumigation has been practised for many years, phosphine resistance has increased so that fumigation exposure periods have to be extended in order to obtain control; some samples of *Tribolium castaneum* required exposure for 12 days at a standard dosage of 0.33 mg/litre (Mahmood *et al.*, 1992). Although there have been attempts in West Africa to design and build stores that are sufficiently gas-tight for effective fumigation, there is little evidence that they are being regularly used for this purpose.

Winks (1987) considered that it was necessary to prepare for the 'phosphine resistance era'. This theme has been taken further in recent recommendations made by the Association of South East Asian States (ASEAN) Food Handling Bureau, for fumigations involving phosphine (Annis & van Graver, in press). These authors recommend that phosphine should be used only under strictly gas-tight conditions, that have been pressure-tested, and where a total fumigation time of 10 days is available, including preparation and terminal airing. To ensure effective fumigation of bag stacks a plastic groundsheet beneath the stack is secured with adhesive to the stack covering sheet, which is tailored to the shape and size of the stack. At least one country in South East Asia has indicated its intention to adopt this sealed sheeted-stack technique of fumigation for national grain stocks. Implementation of the method will be more costly than the traditional sheeted-stack techniques and it may be some years before it is widely used.

For many years, methyl bromide has been a valuable alternative fumigant to phosphine, particularly where short exposure periods are essential. For example, Thailand which exports about four million tonnes of cereal grain each year uses methyl bromide to treat all of this produce immediately before shipment. Very recently however, methyl bromide has been identified for its capability to cause depletion of stratospheric ozone, raising doubts regarding its continued availability as a fumigant (Andersen & Lee-Bapty 1992). Decisions to limit the use of methyl bromide, under the Montreal Protocol Agreement are expected in November 1992. Irrespective of these decisions, it is likely that increasing pressure will come from environmental organizations to reduce atmospheric emissions from all uses of methyl bromide, including use for commodity fumigation.

Many developing countries rely on agricultural exports for a major proportion of their foreign exchange, and any factor affecting these exports, such as a ban on quarantine fumigation with methyl bromide, would have very serious consequences. No new fumigants which could be substituted for methyl bromide have been registered for many years, and research on controlled atmospheres, with carbon dioxide and nitrogen, has shown that neither of these can be used cost-effectively for the short-period treatments in which methyl bromide is widely employed.

The use of controlled atmosphere storage in developing countries is not widespread. Traditional hermetic storage in pits is practised on a small scale but more modern techniques have generally not been introduced since nearly all these are appropriate to bulk storage, which is rarely practiced in developing countries. One exception is the use of sealed bag-stack storage in South East Asia, pioneered by the Australian Centre for International Agricultural Research (ACIAR). In this case bag stacks are sealed into plastic envelopes, placed under a partial vacuum, to test for leaks, and then gassed with phosphine or, more commonly, carbon dioxide (Annis *et al.*, 1984). Only in Indonesia is this system used on a fully operational basis. Very good results have been achieved for the storage of milled rice stocks for periods of up to two years (Nataradja & Hodges, 1989).

Contact Insecticides

Insecticides are applied with the intention of reducing the frequency of fumigation when grain is stored in the medium or long-term or of obviating fumigation in short-term storage. The actual extent of pesticide usage is not known; manufacturers' sales figures are unlikely to be a reliable guide since few pesticides are sold exclusively for use in storage.

Only a limited number of pesticides are available for use in central storage. While individual countries differ in terms of which pesticides and which formulations are registered, those available are organophosphorous compounds (e.g. fenitrothion, pirimiphos-methyl, dichlorvos, chlorpyrifos-methyl), synthetic pyrethroids (e.g. permethrin, bioresmethrin) or carbamates (e.g. carbaryl, bendiocarb). The use of mixtures to broaden the spectrum of pests controlled is rare, although a combination of pyrethroid/organophosphorous insecticides, applied at ultra low volume, has been used in Senegalese stores. In Mali this treatment failed to show any residual efficacy.

In developing countries it appears that emulsifiable concentrates are the most commonly used pesticide formulations employed in stores, primarily because they are widely available for crop protection. Flowable concentrates and wettable powders are generally not available. Under many conditions the choice of formulation may make little difference to pest control efficiency since on absorbent surfaces such as whitewash, plaster, concrete, brick, jute or hessian, they are lost rapidly so that there is minimal residual action (Holborn, 1963; Chadwick, 1984; Webley & Kilminster 1980; Hodges & Dales, 1991). Webley (1985a) has stated that there is probably no truly residual spray on concrete. Adverse temperature and humidity conditions may also contribute to the reduced efficacy of pesticides in the tropics.

The development of resistance to contact insecticides is well known in strains of many species of storage insects; resistance to malathion is now so widespread (Champ & Dyte, 1976) that this pesticide is now little used. Current methods of application, in which a high dose of pesticide is applied and allowed to decline in concentration over a long period, would appear to encourage the development of resistance. In Indonesia, the National Logistics Agency (BULOG) is aware of the need to limit this effect and it avoids over-use of one compound by changing its operational pesticide fairly frequently.

The most widely used method for applying insecticides in bag stores is to spray store and stack surfaces with a dilute residual insecticide using knapsack sprayers or, more commonly, power sprayers. The normal procedure is to a) treat empty stores to destroy any residual infestation present in cracks and crevices; b) at the time of fumigation, to apply a spray treatment to store structures in order to kill all pests not under the gas-proof sheet, and c) at intervals after fumigation to respray store and bag stack surfaces to limit the rate of reinfestation.

The justification for surface spraying in stores is based almost completely on a great many laboratory studies on the effects of pesticide on storage insects. Unfortunately, there has been almost no effort to demonstrate that the actual application of pesticides in stores limits pest increase and that the use of pesticide is more cost effective than reliance on fumigation alone. McFarlane (1980) considered that the surface spraying of bag stacks of milled rice may be of no benefit under tropical conditions. Recent studies on milled rice stocks in Indonesia have been unable to demonstrate any delay to refumigation as a result of respraying store and stack surfaces. It was concluded that reliance on fumigation alone, with a concurrent non-residual spray treatment, would be more cost-effective (Hodges *et al.*, in press).

At the time bag stacks are constructed, each layer of the stack may be dusted or sprayed with insecticide. Although this technique has often been recommended, it would seem to be rarely used because it is both a very time-consuming operation and hazardous to store labourers.

Insecticide admixture has been advocated as a good technique for the protection of bagged commodities (Webley, 1985b) and it certainly has the advantage that insects are likely to have prolonged contact with the treatment. In consideration of a stock protection strategy in South East Asia, Annis and van Graver (1987) recommended admixture of grain protectants for storage of grain for 3-9 months, this duration being the maximum period of biological efficacy for the dose of protectant used. Longer periods would unduly increase the possibilities for the development of insect resistance. Many countries would permit the admixture of insecticides; however, this option is rarely used due to logistical difficulties, double handling costs and in some cases a reluctance to apply pesticide directly to food. A recent variant of admixture is to treat the insides of bags with a controlled release formulation or to implant in bags strips of plastic tape from which the pesticide is released slowly. To date trials of this method using slow release formulations of malathion or chlorpyrifos have not shown much potential as a stock protection system in large scale storage (Grant *et al.*, 1990).

Fogging of stores to kill flying insects has been advocated but is also rarely used. A variation of this is the

"Pestigas" system, developed by Wellcome, in which insecticide concentrate is delivered into stores, in a carbon dioxide stream, from nozzles located at eaves height. However, for the protection of durable food crops, this method appears to have been used only experimentally. Suharno *et al.* (1987) suggested that the system retards insect population growth to about the same extent as conventional spraying on a three-weekly routine. In view of the fact that conventional respraying is unlikely to be cost-effective (Hodges *et al.*, in press) and that "Pestigas" is in any case a more expensive option, its adoption is unlikely to be justified. However, if tested in relatively airtight stores its performance might be somewhat better.

PROTECTION OF FARM STORED GRAIN

In much of the developing world, particularly in Africa and South Asia, up to three quarters of the durable crop production may be stored in small quantities on smallholder farms, mostly for home consumption. Farm storage losses have, in general been quite low (Tyler & Boxall, 1983) because of the inherent resistance of local varieties to indigenous pests, short storage periods or climatic factors which are adverse to pest proliferation. Consequently, there has been very little use of insecticides on the farm.

The recent trend of governments in developing countries to introduce radical trade liberalisation policies has led to the relaxation of controls on agricultural marketing. Private traders are replacing governmental organisations as the primary buying agents for grain, thus reducing the quantities handled by central storage agencies. These changes are providing incentives for farmers to increase production and to retain the produce on the farm for long periods, in order to gain the benefits of higher selling prices as the post-harvest season progresses. Increased production is very much dependent on the cultivation of high yielding varieties (HYV), which are generally very susceptible to storage insect pests. Farmers are now turning to insecticides to enable them to maintain their stored produce in good condition.

For many years, chemical companies have produced dilute insecticide dusts for use on small farm and this formulation continues to be the one most commonly used. However, dilute dusts which have an acceptable shelf life are extremely difficult to formulate, so that few of these products are available commercially. The active ingredients most commonly employed are pirimiphos-methyl and fenitrothion. For control of the Larger Grain Borer *(Prostephanus truncatus)* in Africa it is recommended that these organophosphorus compounds are combined with a pyrethroid, either permethrin or deltamethrin, to which this pest is particularly susceptible (Golob, 1988).

Few farmers can afford the luxury of purchasing chemicals, even relatively cheap dilute dusts. In the past twenty years there has been an explosion in research undertaken to identify cheap, locally available alternatives, particularly compounds of vegetable origin. When tested in the laboratory and small-scale field trials, several plants have been shown to be efficacious, including *Azadirachta indica* (neem) and *Acorus calamus* (sweetflag) (Golob & Webley, 1980). However, there have been no attempts to scale up these investigations, to determine the cost-effectiveness or practicability of using such materials. More importantly there has been a dearth of information concerning the toxicological hazards of most of the plant extracts. Unless this information becomes available, it will remain difficult to recommend the use of these extracts for crop protection in the developing world.

In the past, fumigation has not been widely promoted for use on farm because of the potential hazards to both untrained users, neighbours and livestock. A further factor has been the inability of farmers to provide or understand the need for gas-tight enclosures. High boiling point liquid fumigants such as ethylene dibromide, carbon tetrachloride and carbon disulphide were marketed in developing countries in quantities appropriate for small-holder farmers. Carbon disulphide was widely used at farm level in Swaziland to fumigate grain stored in gas-tight metal tanks, but during the 1970s was progressively replaced by phosphine. Now, with the more widespread use of metal storage bins, the use of phosphine fumigation has increased. The smallest packs of phosphine fumigants supplied by manufacturers have usually been sufficient for the treatment of approximately 10 tonnes of grain, significantly more than most farmers would wish to treat. Recently, a new formulation known as the 'Tiny Bag' has become available, which produces three grams of phosphine. The product is intended for small-scale users and could provide farmers with a much safer option than using individual tablets taken from larger packs. Nevertheless, unless small-holder fumigations are done under sufficiently gas-tight conditions there will be increased risks of poisoning and further development of phosphine resistance.

Many countries do not possess pesticide legislation nor do they have facilities for testing and registering chemicals that the industry attempts to introduce. There is often unrestricted access to chemicals, for example, in West Africa tablets of aluminium phosphide as well as a variety of emulsifiable concentrates can be purchased over the counter from general stores and petrol service stations. The United Nations Food and Agriculture Organisation (FAO) assists governments to design appropriate pesticide legislation and this initiative is helping to combat the problems of misuse. When a compound is approved as a grain protectant its use is governed by specifications issued by the Codex Alimentarius Commission.

PEST CONTROL IN THE FUTURE

In parts of the developing world there will be some shift from large scale to farm storage. Pesticide use in the future will be determined by the cost consciousness of the user as well as by environmental considerations. Changes that are likely to occur are as follows:

- methyl bromide is likely to be severely restricted because of its effect on ozone depletion;

- phosphine will remain the major gas for fumigation but the development of resistance in insect populations will increase unless improved pest management practices are widely implemented;

- the spraying of store surfaces with residual insecticide will decline because it is generally not cost-effective; the procedure also promotes insecticide resistance;

- smallholder storage practices on farms will improve and this will entail the use of better storage structures, increased use of dilute dusts and a gradual proliferation in the use of fumigation. However, there will be a need for an improvement in extension effort in order that farmers fully understand that poor application techniques lead to a waste of resources and the development of insecticide resistance.

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THE INFLUENCE OF STORED FOOD ON THE EFFECTIVENESS OF FARM RAT CONTROL

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ABSTRACT

Rodenticide treatments against farm rats were carried out using difenacoum and bromadiolone inside and outside the area of known difenacoum resistance in central-southern England. Estimates were made of the numbers of rats present during the course of treatments and bait markers were used to estimate the amounts of bait consumed by survivors. Only approximately 10% of survivors consumed sufficient bait to kill fully susceptible animals. The presence of difenacoum resistance thus did not significantly effect treatment outcome. The presence of stored cereal significantly reduced treatment effectiveness. This effect was not apparent when changes occurred in food availability. This study has shown that strategies can be developed that are specifically targeted at the extensive and intractable problem of stored cereal infestation by rats.

INTRODUCTION

The poor performance of second-generation anticoagulant rodenticides, such as difenacoum and bromadiolone, against farm rats (*Rattus norvegicus*) in Hampshire has previously been ascribed to the presence of difenacoum-resistant individuals (Greaves *et al.*, 1982a). Recently, however, the original data used to compare the length of anticoagulant treatments in Hampshire, England with those against warfarin-resistant populations in Powys, Wales were reanalysed by Quy *et al.* (1992). They found that some differences between the two areas were only explicable in terms of variation in behavioural responses towards bait and suggested one potential cause of such behavioural differences was the availability of alternative food. In general, the greater the availability of such food the less likely are rats to consume bait. This study has been undertaken to measure the influence of both difenacoum resistance and alternative food availability on treatment effectiveness. It compares treatments in the area of Hampshire where difenacoum resistance is known to be widespread with treatments in the adjacent county of West Sussex. Here difenacoum resistance is unknown but the ecology of farms is more like those in Hampshire than the farms in Powys considered previously.

Stored cereal is a major potential source of food on many farms. Prickett (1988) found 53% of farm grain stores to be infested with rats. Extensive problems also exist in commercial grain stores with 41% of sites and 33% of stores infested (Prickett & Muggleton, 1991). These problems persist despite use of rodenticides on 78% and 98% of farm and commercial grain storage sites respectively. There is thus considerable potential for improving the management of rat infestations in and around grain stores. There have, however, been no studies of possible strategies specifically targeted at such infestations. The study reported here provides some of the data required to develop such strategies.

METHODS

A total of 42 rodenticide treatments were carried out on farms in a replicated experimental design. Each replicate consisted of 6 treatments; three inside the area of known difenacoum resistance in the county of Hampshire (Greaves *et al.*, 1982b) and three in the adjacent county of West Sussex which is outside the known area of difenacoum resistance. One of each of three kinds of treatment was performed in each area for each replicate. These treatments were: a) seven weeks of laying baits containing 50ppm difenacoum, b) seven weeks laying baits containing 50ppm bromadiolone c) three weeks of laying unpoisoned baits followed by four weeks of baiting with bromadiolone (to measure bait consumption in the absence of mortality).

For the first three weeks of the treatments all baits contained 100ppm of the bait marker decachlorobiphenyl (DCBP) and during the final four weeks all baits contained 100ppm of the bait marker 2,2',4,4',5,5'-hexachlorobiphenyl (HCBP). Baits consisted of 90% pinhead oatmeal, 5% sucrose, 2.5% pure corn oil, 2.475% polyethylene glycol 200, and 0.025% triethanolamine. They were formulated to contain either 50ppm difenacoum or 50ppm bromadiolone and 100ppm of either DCBP or HCBP. Baits were tested for palatability, bioavailability and homogeneity.

Sites were found through contacts in the local farming communities and the presence of rats confirmed during a preliminary visit. Selected farms were allocated to one of the three treatment types. Each farm was surveyed to determine the size of the infested area and a map was drawn of the farm buildings and adjacent land. The distribution of potential food sources for rats was indicated on this map in terms of presence or absence within a grid of $10m^2$ squares. These food sources fell into three categories: stored produce, animal feeds or standing crops in fields adjacent to the farm buildings. Stored produce was further sub-divided into stored cereal (wheat, oats or barley), stored seeds (e.g. linseed or grass seed), and other stored produce (e.g. peas or beans). An additional food type, related to stored cereal, was waste cleanings or whittlings. Animal feeds were either silage (maize or apple but not grass as this was considered to have little attraction to rats), commercial feeds (pellets or cattle cake) or on-farm feeds (crushed cereals). Standing crops were either cereal (barley or wheat) or associated with game cover (maize, kale or artichokes). There was thus a total of nine different categories of food supply. Any potential food that appeared to be unavailable to rats, for instance in rodent proofed grain silos, was not included in the assessment of food availability. All major changes that took place in the availability of food during a treatment were also recorded. A major change was defined as the complete arrival or removal of food to or from a $10m^2$ grid square and movement of food between grid squares.

During week 1 of each trial live-capture cage traps were set for four consecutive days throughout the infested area. Up to 20 animals were removed and housed individually in the laboratory. All these animals were subjected to the blood clotting response test for warfarin resistance (Martin *et al.*, 1979). Any warfarin-resistant individuals were then given a blood clotting response test for difenacoum resistance (Gill *et al.*, in press). During week 2 a pre-treatment census was performed using the tracking plate method developed by Quy et *al.*, (in press).

Bait was laid throughout the infested area, including along any infested hedgerows leading away from the farm buildings, for seven consecutive weeks from the Monday of week 3. Baits were placed in wooden bait boxes. Some baits laid indoors were placed in trays rather than boxes. All bait points initially had 100g of bait. The number of bait points varied between 20 and 94 while bait point density varied between 103 and 236 per infested hectare. This variation reflects the sizes of infested areas and the decisions of the experienced operators involved. The amounts of bait eaten from each bait point were recorded every Wednesday, Friday, and Monday. If all bait was consumed from a bait point the amount laid there was doubled. Conversely, if no bait was removed from a point for two consecutive days the amount of bait laid was reduced by 50% to a minimum of 25g. At the beginning of the fourth week of baiting all bait was removed and replaced with either difenacoum or bromadiolone formulations containing 100ppm HCBP. After the seven weeks of baiting had been completed all baits and bait containers were removed.

Mid-treatment censuses were carried out using the tracking plate method during the third and sixth weeks of baiting. A post-treatment census was carried out during the week following the seventh week of baiting. Daily estimates of the size of the population present on each farm were obtained by linear interpolation between each of the successive census estimates. The experimental design did not allow for estimates of recruitment to the population during the course of treatments through either reproduction or immigration. Hence, the effectiveness of each treatment was estimated in terms of the maximum number of animals that survived. This estimate was derived by expressing the size of the population at the post-treatment census as a percentage of the pre-treatment census. Any treatments for which population size had increased between the pre-treatment census and the post-treatment census were considered to have left 100% of the original population alive at the end of the treatment.

During the week following the post-treatment census live traps were set to catch up to 20 survivors which were tested for resistance to warfarin and difenacoum as described above. During the following three weeks Fenn Mk IV spring traps were used to provide a further sample of surviving animals for analyses of bait markers.

Laboratory studies have shown that a close relationship exists between the amounts of DCBP and HCBP consumed and residues recovered from whole bodies using gas chromatography (CSL, unpublished). The recovery rate is approximately 46% for DCBP over a wide range of exposures (R^2 = 0.99) and 55% for HCBP (R^2 = 0.98) with a detection limit of approximately 0.5g of bait containing 100ppm of marker eaten by a 200g rat. The residues recovered from the bodies of survivors were thus used to estimate the amounts of bait that these animals had eaten during the seven week baiting period. Only data from 432 survivors of the first five replicates (30 treatments) have been processed to date.

All percentages were arcsine square-root transformed before statistical analyses to stabilise variances. In the text, table and figures, mean and standard errors are presented for untransformed data to ease interpretation. All two by two χ^2 tests include Yate's continuity correction. All quoted significance levels are for two-tailed tests.

RESULTS

Infestation characteristics

The mean size of infested areas on 21 Sussex farms of 0.25±0.02ha was not different to that of 0.28±0.02ha for 21 Hampshire farms (t = 0.91, *NS*). Similarly there was no difference in the mean estimated initial rat population sizes of 104.3±17.0 and 94.2±15.4 rats per farm in Sussex and Hampshire respectively (t = 0.44, *NS*). Difenacoum resistance was detected on 19 of the Hampshire farms but none of the Sussex farms. The only clear difference regarding food availability was the presence of stored cereal on 14 (66.7%) Hampshire farms compared with only 6 (28.6%) Sussex farms (χ^2 = 4.68, P = 0.031).

Treatment outcome

The mean estimated maximum percentage of the initial population present at the end of the treatments was 59.2±7.7% in Hampshire compared with 29.5±8.5% in Sussex (t = 2.41, P = 0.020). An estimated 57.9±8.8% of the initial population survived on farms where difenacoum resistance was present compared with 33.2±7.9% on the other farms (t = 2.04, P = 0.048). Treatment type did not significantly effect treatment effectiveness ($F_{2,39}$ 0.64, *NS*). If difenacoum was less effective than bromadiolone against difenacoum-resistant animals then a significant interaction would be expected between treatment type and the presence of difenacoum resistance but this was not the case in a two-way analysis of variance ($F_{1,24}$ 0.13, *NS*). The only significant effect of food availability was 61.1±9.0% maximum survival in the presence of stored cereal compared with only 29.2±7.1% in its absence (t = 2.83, P = 0.007). Effectiveness was not influenced by the occurrence (n = 11) or absence (n = 31) of major change in food availability during the course of treatments (t = 0.32, *NS*).

A four-way analysis of variance was performed to examine the effect of four factors on variation in estimates of maximum survival: the type of treatment, the presence or absence of stored cereal on the farm; the presence or absence of major change in food availability during the course of the treatment; the presence or absence of difenacoum resistance amongst rats on the farm. Only the presence of cereal significantly influenced maximum survival as a main effect ($F_{1,27}$ 6.85, P = 0.014). Treatment type ($F_{1,27}$ 1.45, *NS*) and presence of difenacoum resistance ($F_{1,27}$ 2.7, *NS*) were insignificant as main effects and neither contributed to any significant second order interactions. While change in food availability made an insignificant contribution as a main effect ($F_{1,27}$ 2.34, *NS*) it exhibited an interesting two-way interaction with the availability of stored cereal ($F_{1,27}$ 6.25, P = 0.019). Table 1 shows that in the absence of stored cereal the occurrence of major change in food availability made no difference to effectiveness. However, for treatments in the presence of stored cereal the eight where change occurred were more effective than the other 12 (t = 2.36, P = 0.030). Stored cereal was available throughout the treatments on seven of the eight farms where both major change occurred and stored cereal was present. On the other it was introduced during the course of the treatment. On none of the farms where stored cereal was present and major change occurred did complete removal of cereal occur, although in all but one instance there were changes in cereal availability.

Table 1. Differences in maximum estimated percentage survival in the presence and absence of stored cereal and whether or not major change occurred in food availability during the course of treatments.

	Maximum percentage survival			
	No change in food availability		Major change in food availability	
	n	*Mean±SE*	*n*	*Mean±SE*
Stored cereal absent	19	25.4±7.5	3	52.8±18.8
Stored cereal present	12	76.2±10.1	8	38.4±13.7

Patterns of bait consumption

The average consumption of bait per rat for each day of each treatment was calculated by dividing the total bait consumption recorded between visits by the number of days between visits and by the estimated size of the rat population present on that day. Figure 1 shows that for the 28 treatments where either bromadiolone or difenacoum baits were laid for seven weeks there was a difference in the pattern of bait consumption between the 13 in the presence and the 15 in the absence of stored cereal.

Bait consumption was significantly higher over the first 2 days on farms without stored cereal (t = 3.05, P = 0.007). After four to seven days bait consumption began to decline in the absence of stored cereal, presumably as some animals succumbed to the treatment. Bait take on farms in the presence of stored cereal declined after 9 to 11 days of baiting. Bait consumption per rat appeared to increase again after 16 days of baiting in the absence of stored cereal. This increase was not apparent in the presence of stored cereal.

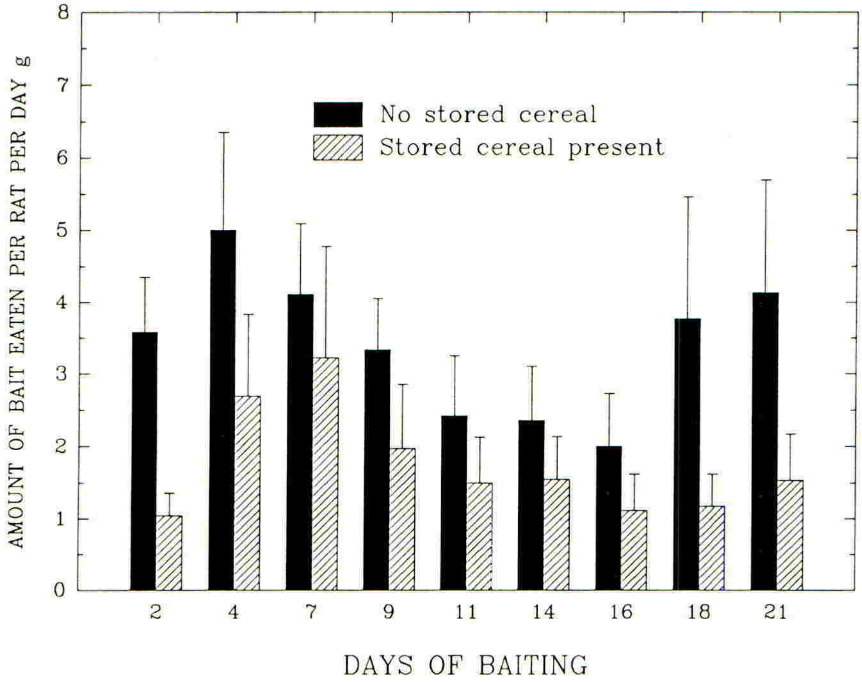

FIGURE 1. Differences in patterns of treated bait consumption over first 21 days of baiting for 15 treatments in the absence of stored cereal and 13 in its presence.

<u>Bait consumption by survivors</u>

Figure 2 shows the estimated amounts of treated bait consumed by 432 survivors of the first five replicates of the study. Forty-eight (11.1%) of survivors had eaten 20g or more of bait. Only three of these were survivors of treatments in Sussex and no survivors of Sussex treatments had eaten more than 50g of bait. Forty-five (18.1%) of survivors of treatments in Hampshire had eaten more than 20g of treated bait (approximately a lethal dose for a fully susceptible animal, see below).

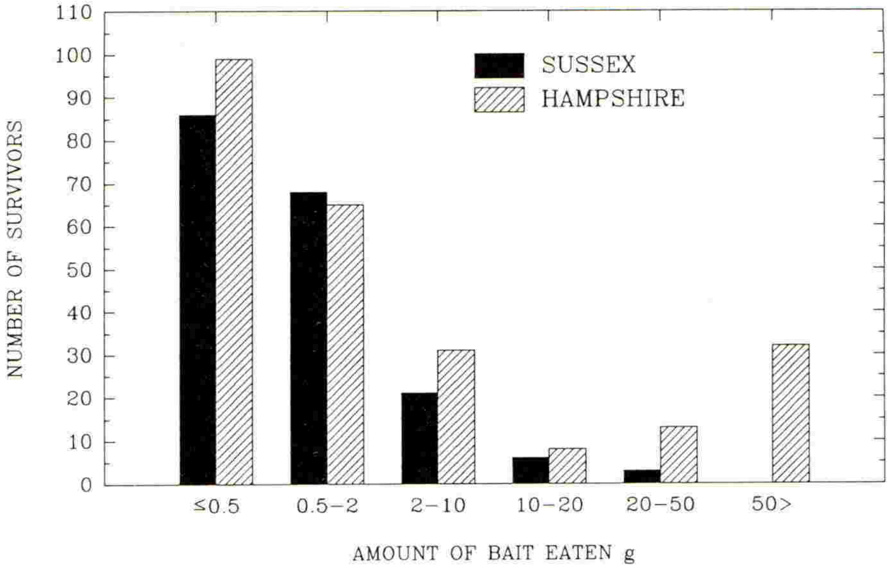

FIGURE 2. The estimated amounts of treated bait eaten by 432 survivors of treatments in Sussex and Hampshire

DISCUSSION

This study is unique in the detail of monitoring undertaken and the number of comparable treatments performed. As a consequence quantitative data are, for the first time, emerging on the relationship between individual differences in bait consumption and the outcome of treatments at the level of populations. This is particularly apparent in the analyses of bait marker residues in the bodies of survivors. Both DCBP and HCBP have been used previously as qualitative markers (Buckle *et al*., 1987). Used quantitatively they represent much more powerful analytical tools. The LD50 of both difenacoum and bromadiolone for fully susceptible rats are equivalent to a 200g individual eating 20-30g of bait containing 50ppm of active ingredient over a four day period, allowing for sex specific toxicities (Greaves & Cullen-Ayres 1988). The 18.1% of survivors on Hampshire farms that consumed more than 20g of treated bait thus represents the approximate contribution of second generation anticoagulant resistance to reduced treatment effectiveness. It is therefore not surprising that resistance does not contribute significantly to differences in treatment outcome at the level of populations once other factors are controlled for. Similarly, in these circumstances, it might be expected that there would be no apparent difference in the effectiveness of difenacoum and bromadiolone against populations containing difenacoum-resistant animals. The cause and effect relationship between the presence of difenacoum resistance and impaired effectiveness of second-generation anticoagulants proposed by Greaves et al. (1982a,b) thus now seems premature. Indeed Greaves & Cullen-Ayres (1988) suggested that the resistance factor possessed by difenacoum-resistant strains was insufficient to generate the apparent practical problems without invoking additional behavioural or ecological explanations.

Quy et al. (1992) inferred that reluctance to consume bait made a substantial contribution to poor effectiveness of treatments in Hampshire. The bait marker analyses confirm that the majority of survivors failed to consume sufficient bait to kill susceptible animals. We thus need to understand why these animals are apparently reluctant to consume substantial quantities of bait if we are to improve treatment effectiveness. The different patterns of bait consumption in the presence or absence of stored cereal begin to show how ecological factors can influence the behaviour of individuals. Furthermore, these different patterns are reflected at the level of treatment outcome given the impaired treatment effectiveness in the presence of stored cereal. A major difference in treatment effectiveness between Hampshire and Sussex farms is thus explicable in terms of the higher prevalence of stored cereal in Hampshire. Such a difference might also be expected in relation to the predominantly livestock rather than arable farms in Powys, Wales.

What is it about the presence of stored cereal that results in many rats failing to consume substantial quantities of bait? Whole cereals are known to be highly attractive foods for rats (e.g. Palmateer, 1974). It may simply be that the treated baits used in this study failed to compete with a highly attractive alternative food. Another feature of stored cereals, however, is that they tend to be consistently available in the same place for many months from harvest until they are moved off the farm, often not until the following spring. Animals thus have the opportunity to become adapted to a food source that is not only attractive but also consistently available. Against this predictability perhaps the novelty represented by baits elicits not only disinterest but active avoidance. If there is a major change in food availability against this previous background of environmental consistency then interest in any potential food may be enhanced. Such an interpretation is consistent with a risk-sensitive model of foraging behaviour (e.g. Caraco, 1980). This could explain the increased effectiveness of treatments when major change in food availability occurs in the presence of stored cereal. In no case did the observed major change in stored cereal availability involve complete removal. It thus seems likely that consistency rather than just attractiveness contributes to the influence of stored cereal on bait consumption and thus treatment effectiveness.

There is some evidence that the use of poison baits imposes selection pressure favouring individuals that exhibit heightened neophobic responses towards novel foods such as bait (Mitchell *et al.*, 1977). In a diverse and changing environment these animals are likely to be at a disadvantage relative to less cautious individuals. In contrast, the persistent availability of stored cereal on many Hampshire farms may allow animals to fully express neophobic responses. The major changes in food availability recorded in this study are a rather crude measure of environmental stability. In general, much greater change can be expected on farms where livestock are kept compared with predominantly arable concerns. Livestock are fed on a daily basis, food will inevitably be spilt and the general level of activity during the autumn and winter is much greater than around farm buildings that are used only for storing food and machinery. It seems likely that these differences would have existed between farms in Powys and those in Hampshire for the trials reanalysed by Quy *et al.* (1992). The observed differences in effectiveness between these areas are thus explicable in terms of the attractiveness of stored cereal and the stability of its availability.

Strategies for dealing with rat infestations associated with stored cereal begin to emerge from this study. The association of major change in food availability with enhanced success suggests that rodenticide treatments should be timed to coincide with these changes. Rodenticide treatments thus need to be integrated with grain husbandry practices. Perhaps most importantly, all attempts should be made to restrict access of rats to stored cereal, particularly that which is going to be present for many months. Commercially such practices are likely to become more important in the future as tests for grain contamination become more sensitive.

The failure of rodenticide treatments against farm rats has, in the past, often been attributed to anticoagulant resistance without adequate evidence. This study suggests that much closer attention should be paid to ecological factors in terms of the attractiveness and stability of the alternative food supply. The major impact of stored cereals in particular has not previously been recognised. This may explain why problems persist in grain stores despite extensive use of rodenticides. Potential strategies are emerging, however, that can be specifically directed towards the problems posed by rats in the presence of stored cereal. Continuing to improve our understanding of the way patterns of bait consumption by individual animals determine the outcome of treatments will be important for the implementation of such strategies.

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ALTERNATIVE STRATEGIES FOR THE CONTROL OF POST HARVEST ROTS IN APPLES AND PEARS

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ABSTRACT

The introduction of post-harvest fungicide treatments in the early 1970s in the United Kingdom considerably reduced losses due to rotting in stored apples and pears and resulted in their routine use, regardless of need, in subsequent seasons. Despite the success of such treatments in maintaining average annual losses in stored apples and pears due to rotting to below two per cent, and their obvious advantages environmentally, they are not acceptable to markets or consumers and result in higher levels of residues in the fruit, though usually below the permitted maximum residue levels. Alternative control strategies therefore have to be identified. Surveys carried out on rotting in treated stored Cox apples and Conference pears over the past ten years have identified the fungi responsible, but not the level of losses in the absence of treatment. Alternative control measures are reviewed and discussed in relation to apples and pears, including biological, cultural methods and pre-harvest orchard treatments.

The strategy of integrated control of fruit storage rots is proposed which includes a scheme for assessing the risk of rotting in Cox apples based on fruit mineral analysis, orchard factors and orchard rot history.

INTRODUCTION

The harvesting period for most British apples and pears is restricted to the period mid-September to mid-October. Efficient storage is therefore essential in order to allow the fruit industry to regulate its supply of fruit onto the UK market for most of the year and enable it to compete successfully with the ever-increasing supplies of high quality fruit from other EC countries and outside Europe. Losses due to post-harvest rots can seriously affect the economics of such storage and their effective control is an integral part of efficient storage. In the 1950s and 60s rotting due to Gloeosporium species (Preece, 1967) was the main limitation to extending the storage life of Cox apples. However, the introduction of benzimidazole fungicides (eg. benomyl, carbendazim, thiophanate-methyl) in the early 1970s as post-harvest fungicide treatments was so effective that the problem was virtually eliminated. Similarly the emergence of Phytophthora rot in the 1970s (Edney, 1978; Upstone, 1978) coincident with the introduction of bare soil management systems in orchards, was controlled by the post-harvest use of metalaxyl in combination with carbendazim. Post-harvest fungicide treatment proved so successful in controlling storage rots that, until recently, almost all apples and pears were routinely dipped or drenched pre-storage. As a result of this success all research into storage rots and alternative means of control virtually ceased. The increased public concern about the use of pesticides in food production has meant that post-harvest treatments are unacceptable to consumers and consequently to markets. There is now an urgent need to re-examine control of storage rots in the UK and to develop alternative strategies. This paper aims to review the fungi responsible for losses in store, identify available alternative methods of control and develop a strategy for control that is not dependent on post-harvest fungicides.

CLASSIFICATION OF ROT FUNGI

The main post-harvest rots can be classified into two broad categories - orchard diseases and store diseases. (Table 1)

TABLE 1. Categories of rot fungi

Orchard diseases	Store diseases
Brown rot (*Monilinia fructigena*)	Botrytis rot (*Botrytis cinerea*)
Gloeosporium rot (*Gloeosporium* spp)	Blue mould (*Penicillium expansum*)
Nectria rot (*Nectria galligena*)	Mucor rot (*Mucor pyriformis*)
Phytophthora rot (*Phytophthora syringae*)	Fusarium rot (*Fusarium* spp)
Botrytis rot (*Botrytis cinerea*)	
Black rot (*Botryosphaeria obtusa*)	
Diaporthe rot (*Diaporthe perniciosa*)	

Orchard disease rots usually result from infections that occur in the orchard, but which are latent or escape notice at harvest. Some such as brown rot require wounds for entry, but most are also capable of direct attack. These fungi are present in the orchard either as cankers or mummified fruit or in the soil. Brown rot or Phytophthora rot cause immediate rotting after infection, but Gloeosporium rot or Nectria rot require a latent phase and therefore do not appear as rots in store until several months later. In contrast, store disease rots usually only arise from infections established after the fruit has been picked and put into store. Botrytis rot is categorised in both classes; in the orchard it is visible as an eye rot, originating from infection of senescing petals on the fruit calyx, which usually dries causing a dry eye rot. Store diseases generally need wounds for entry, although Penicillium rot can also enter via lenticels on mature bruised fruit. Store fungi originate in soil, weeds, plant debris and any other form of debris such as leaves and twigs which may be introduced into the bulk bin at harvest. Dirty bulk bins contaminated with the previous season's rot debris are also a source of store disease rots. Orchard diseases are generally well controlled by post-harvest fungicides, but these are usually ineffective against store diseases either because of resistance to fungicides as in the case of Botrytis and Penicillium (Berrie, 1989), or because available fungicides are ineffective (eg. Mucor).

IMPORTANCE OF ROTTING

The main apple (Cox and Bramley) and pear (Conference) cultivars grown are susceptible to most of the storage rot fungi. A survey of losses due to rots in untreated Cox conducted in 1961-65 identified Gloeosporium rot as the main cause of the losses with levels of 30 per cent in worst affected stores (Preece, 1967). *Monilinia fructigena* (brown rot) was also important, but other rots notably *Phytophthora syringae* were insignificant or not present. The considerable advances in Cox storage technology, such as the introduction of controlled atmosphere (CA) low oxygen storage, improved fruit mineral composition and post-harvest fungicide treatments, suggest that losses due to rots are unlikely to be as great now. However, more recent information on losses in non-fungicide treated Cox is limited. Over the past ten years surveys conducted by ADAS Wye of rotting in fungicide-treated Cox fruit (Table 2) have shown that the use of fungicide drenches has maintained losses below two per cent. Brown rot still causes losses in most seasons, *Gloeosporium* is usually only present at trace levels, with *Nectria galligena* causing significant losses in wet seasons (1987/88), despite the use of a drench. In Conference pears (Table 3) *Botrytis cinerea* is consistently the main cause of rotting which was adequately controlled by the use of vinclozolin as a post-harvest drench. The temporary suspension of the approval for vinclozolin in 1990 has left the industry with no effective products to control Botrytis rot, with around 60 per cent of isolates resistant to benzimidazole fungicides (Berrie, 1989).

The susceptibility of the main fruit cultivars Cox apples and Conference pears to fungal rots and the relatively high rainfall of UK fruit production areas suggests that significant rotting is likely to occur in most seasons in long term stored fruit, such that control measures will be necessary to reduce losses and maintain the economics of storage.

A new survey in 1991/92 funded by MAFF and the Apple and Pear Research Council (APRC) of rotting in treated and untreated stored Cox apples and Conference pears will generate information on the importance of rotting over the next two seasons.

CONTROL OF ROTS BY POST-HARVEST FUNGICIDE DIPS OR DRENCHES

The development of fungicide dips/drenches to control storage rots demonstrates how research has contributed to a successful practical system for growers. Before discussing alternative control strategies it is important to explore the obvious advantage of fungicide dips/drenches and identify the problem areas that have resulted in such a successful system becoming undesirable, mainly due to the increasing public concern over the environment and the level of pesticide usage.

TABLE 2. Results of Survey in Southern England of mean percentage losses of fruit numbers due to fungal rots in apple cv. Cox's Orange Pippin treated with fungicide drenches, 1982-91

Fungal Rots	1982/3	1983/4	1984/5	1987/8	1988/9	1989/90	1990/1
Botrytis	0.1	0.5	1.1	0.6	0.4	0.3	0.3
Monilinia	0.2	0.4	0.1	0.6	0.3	0.5	1.1
Gloeosporium	0.1	0	0	0.6	0	0.1	0
Nectria	0.2	0.2	0.2	4.2	1.1	0.2	0.2
Phytophthora	0.6	0.5	0.4	0.1	0.3	0.8	0.1
Mucor	0.1	0.1	0.4	0	0	0.	0
Other rots*	0.2	0.1	0.2	0.2	0.4	0.2	0.6
Total losses due to rots %	1.5	1.8	2.4	6.3	2.5	2.1	2.2
Farms sampled	14	15	18	21	22	30	40

* *Penicillium, Fusarium, Diaporthe*

TABLE 3. Results of survey in South England of mean percentage losses of fruit numbers due to fungal rots in pear cv. Conference in the presence of fungicide drenches, 1980-91

Fungal Rots	'80/81	'82/3	'83/4	'84/5	'87/8	'88/9	'89/90	'90/91
Botrytis	1.0	2.5	1.1	1.8	0.8	0.8	0.9	2.3
Monilinia	0.4	0.4	0.3	0.2	0.5	0.1	0.6	0.2
Nectria	-	0	-	0.1	0.3	0.1	0.1	0
Phytophthora	-	0	-	0.1	0.1	0	0	-
Mucor	0.1	0.2	0.3	0.6	0.1	0.1	0.1	0.1
Other rots	0.1	0.1	0.1	0.3	0.0	0.1	0.3	0.6
Unidentified stalk end rot	-	-	-	-	0.2	-	-	-
Total losses due to rots %	1.6	3.2	1.8	3.1	2.0	1.2	1.9	3.2
Farms sampled	60	12	29	31	12	12	7	42

Post-harvest fungicide dips/drenches have provided a cheap, reliable means of rot control for the past twenty years. Such a system allows the decision on need for treatment and choice of product to be delayed until harvest. Only one treatment is necessary which is targeted on the fruit and not the orchard environment. Benzimidazole fungicides, the main chemical group used for rot control, are reported to be harmful to the predatory mite *Typhlodromus pyri* and to earthworms, both of which are vital parts of integrated orchard protection. The use of post-harvest drenches avoids the use of such products in the orchard. In Germany and the Netherlands, where the use of pre-harvest sprays for rot control is more usual resistance of Gloeosporium rot to benzimidazole fungicides has been reported. (Palm, 1986; van der Scheer & Remijnse, 1988). In the UK it would appear that restricting use of benzimidazole fungicides to post-harvest dips/drenches also reduces the risk to the operator. The use of post-harvest fungicides, however, is not without difficulties. Disposal of the large volumes (around 2,000 litres) of drenching solution, which should be changed regularly (every 200 bins) to avoid debris and fungal spore build-up presents considerable, though not insurmountable, problems. Post-harvest treatments are effective in rot control because they achieve better fungicide cover on fruit and consequently levels of residue on the fruit are higher. MAFF funded studies by ADAS Wye comparing levels of 3 pre-harvest sprays of thiophanate methyl with a single post-harvest dip (Table 4) shows that the residue resulting from the latter is approximately ten times that from pre-harvest sprays although still below the maximum residue level (MRL) permitted of 5 mg/kg. In addition the results of MAFF surveys in 1988-89 (MAFF/HSE, 1990) of pesticide residues in culinary apples (Table 5) show that fungicide residues (usually below the MRL) were detected in over half the samples. Most of these fungicide residues originated from a post-harvest treatment. The presence of a pesticide residue in food, even if well below the MRL, is sufficient to create concern in consumers, despite reassurances on safety. The possible advent of produce labelling may also contribute to the demise of post-harvest treatments. A requirement to label fresh produce with any pesticide treatment applied post-harvest might result in a demand by markets for the abandoning of such practices. Within Europe the use of post-harvest fungicide drenches on fruit are only used in the UK and France and discussion within the EC suggest that Member states may agree to a ban on such treatments in the future (Anon, 1990). Perhaps the greatest problem for the use of post-harvest treatments is the actual concept of drenching fruit with fungicide. It is simply not acceptable to consumers. Therefore, despite the obvious environmental, biological, commercial and scientific advantages of such treatments, their use is likely to decline in the future, as a result of consumer and hence market pressure. The UK fruit industry therefore has to explore alternative strategies for rot control so that it is well prepared for the future.

ALTERNATIVE METHODS OF ROT CONTROL TO POST HARVEST DIPS/DRENCHES

Methods of controlling rots can be categorised as DIRECT METHODS that are aimed at inhibiting the fungus itself and INDIRECT METHODS that enhance the resistance of the fruit to fungal attack.

Direct methods

Other post-harvest treatments

Post-harvest heating to kill or weaken rot fungi offers a pesticide-free method to control post-harvest rots. The technique aims to eliminate fungi on the fruit surface or within the sub-epidermal tissue, without causing damage to the fruit. In the UK limited studies demonstrated that

TABLE 4. Comparison of residues resulting from pre-harvest post-harvest treatment with thiophanate methyl expressed as total carbendazim in apple peel or flesh at various sampling times, (ADAS, Wye, 1990)

	Total carbendazim mg/kg					
	Pre-harvest spray			Post-harvest dip		
Sampling time	Peel	Flesh	Whole apple	Peel	Flesh	Whole apple
Harvest	1.3	n.d*	0.2			
After dipping				14.4	0.3	2.1
After 5 mths store	1.6	n.d	0.2	16.9	n.d	2.3
After 5 mths store + washing	1.1	n.d	0.2	13.7	n.d	2.0

*n.d = not detected (limits of detection = 0.8 mg/kg)
MRL carbendazim = 5 mg/kg

temperatures of 45°C for ten minutes reduced Gloeosporium rot on Cox apples (Edney & Burchill, 1967) but while the technique offers an alternative to pesticide use, the economics and the likely practical difficulties would make its wide-scale adoption difficult.

The use of thermo-nebulisation techniques for fogging fruit in stores, once they have been loaded have shown promise in investigations in Europe (Bompeix *et al*, 1986; Nguyen-Thé *et al*, 1988). Such a method, provided adequate cover could be achieved, would overcome the difficulties of fungicide drench disposal, but would still be confronted with consumer opposition to the concept of post-harvest fungicide use. Likewise, the use of chlorine drenches, though effective in eliminating surface spores of many storage rots, particularly *Penicillium* and *Mucor* (Sholberg & Owen, 1991) may also present environmental difficulties.

Pre-harvest fungicide sprays

The effectiveness of pre-harvest sprays of captan or benzimidazole fungicides (Burchill & Edney, 1972) and dichlofluanid (Edney and Burchill, 1968) in controlling storage rots on Cox apples, mainly *Gloeosporium*, *Nectria* and brown rot, was demonstrated in the 1960s and 70s in the UK. In Europe more recent studies have shown tolyfluanid also to be effective (Creemers, 1989), but other fungicides such as fenarimol or bitertanol used for the control of apple scab (*Venturia inaequalis*) were found to be ineffective (Palm, 1986). One of the main disadvantages of the use of pre-harvest sprays is the risk of key rot fungi, such as Gloeosporium, developing resistance to the fungicides used. Benzimidazole-resistant strains of Gloeosporium have already been identified in Europe but not, so far, in the UK. Late orchard sprays particularly of captan leave visible deposits on the fruit creating concern among fruit pickers. In addition the benzimidazole fungicides are reported to have harmful effects on the orchard predatory mites *Typhlodromus pyri* and on earthworms (Kennel, 1989). However, recent studies by ADAS Wye to examine the effects of pre-harvest sprays of captan or thiophanate methyl applied at rates recommended on the product label, have not shown any significant reductions in numbers of *Typhlodromus pyri* (Cross & Berrie in lit) or earthworms (Berrie, 1992) after two seasons of treatment.

TABLE 5. Working party on Pesticide residues: 1988-89. Residues in UK produced culinary apples (24 samples)

Chemical	No. samples with residue	Concentration range mg/kg
carbendazim (MRL* = 5)	12	0.6-1.8
diphenylamine (CAC♦ MRL = 5)	7	0.5-2.9
metalaxyl (CAC MRL = 0.05)	4	0.05-0.17
vinclozolin (MRL = 1)	3	0.5-0.6
phosalone (MRL =2)	1	0.2

*MRL = Maximum Residue Level in mg/kg
♦CAC = Codex Alimentarius Commission

Information on the effectiveness of pre-harvest sprays for control of pear storage rots in the UK is limited. Preliminary studies in 1991 by ADAS Wye, funded by Apple and Pear Research Council, suggest that sprays are much less effective for controlling Botrytis rot on Conference pears and may need to be applied very near harvest to increase efficacy.

Cultural methods

Many storage rot fungi survive in the orchards on cankers, mummified fruit, leaf debris or in the soil. Removing such inoculum sources, picking low hanging fruit separately or mulching herbicide strips to reduce soil splash will decrease the risk of introducing rot fungi into store. Bulk bins contaminated with the previous season's mummified rots are also a source of rot inoculum particularly *Penicillium* or *Botrytis*.

Biological control

Biological control can in theory be achieved by the use of resistant cultivars, natural plant products or microbial antagonists.

The main apple and pear cultivars grown in the UK, Cox, Bramley and Conference pears, are susceptible to most of the main rot fungi. Breeding programmes at HRI East Malling are screening for resistance to storage rots, but it will be some time before new cultivars which combine resistance to rotting with the required commercial attributes contribute significantly to the UK Market.

The use of naturally occurring anti-microbial plant products has undergone limited investigation overseas (Culter *et al*, 1986). In the UK, Swinburn (1973) has implicated benzoic acid in Bramley in controlling Nectria rot, but little other research has been carried out.

The use of microbial antagonists has been more widely investigated particularly abroad. On apple and pears antagonistic yeasts and bacteria have been identified as giving control of *Penicillium expansum* and *Botrytis cinerea* (Janisiewicz, 1988; Janisiewicz & Roitman, 1988). Such control methods show promise and require further investigation, but are not without difficulties. Formerly the cost of developing biocontrol agents was economically prohibitive, but now with the many problems associated with pesticides this approach may be more attractive. Despite being natural, biocontrol agents are still subject to the same registration requirement as pesticides, and may also suffer from the possible need for produce labelling to record treatment.

Indirect methods

Fruit quality

The importance of the correct mineral composition of apples in maintaining fruit quality and resisting rotting in store is now well understood. Calcium levels are of particular importance; this mineral acts in two ways. Firstly, calcium stabilises the cell wall of the apple maintaining fruit firmness by resisting degradation by enzymes that occur naturally in fruit. Secondly, it also renders the cell wall more resistant to the cell wall degrading enzymes produced by rot fungi (Sharples & Johnson, 1977; Sams & Conway, 1985; Conway *et al* 1991). Fruit of the correct mineral composition are more resistant to lenticel-invading fungi such as *Nectria galligena* or *Gloeosporium* sp (Sharples, 1980).

Many rot fungi particularly brown rot, Penicillium and Mucor rots invade fruits through wounds, either naturally occurring such as cracking or russeting, or those resulting from poor handling at harvest. Good supervision of pickers at harvest can minimise fruit damage and ensure that only sound fruit is selected for long term storage. Careful handling of fruit bins can also minimise damage and avoid fruit being contaminated with soil, which might introduce *Phytophthora syringae* or *Mucor* into store. Preliminary studies at HRI East Malling funded by the APRC (Johnson, 1992, personal communication) shows that considerable reduction in rotting can be achieved simply by good supervision of pickers and selective picking of fruit.

Picking date

The fruit must be picked at the correct state of maturity in order to be suitable for long term storage. Late picked fruit may be over-mature and therefore more liable to rotting. In addition, the longer the fruit remains on the tree, the greater the risk of infection by rot fungi particularly those disseminated by rain.

Store conditions

The development of low temperature, controlled atmosphere (CA) storage for Cox has considerably reduced the level of rotting in store. Low temperatures maintain fruit quality by suppressing senescence and fungal growth. Reducing the oxygen concentration also suppresses fruit senescence (Sharples, 1982; Sams & Conway, 1985). Low oxygen, especially at concentrations of one per cent or less can significantly reduce growth, sporulation and germination in most post-harvest fungi. Experiments at ADAS Wye compared rotting in Cox stored in air or CA (Table 6) following treatment with or without a pre- or post-harvest fungicide. All fungicide treatments reduced rotting, but the greatest reduction occurred in CA storage compared to air. A similar reduction in rotting has been found by Edney, (1964) and Bompeix (1978). To maximise the effect of storage conditions, the store must be loaded quickly and the store conditions rapidly established.

TABLE 6. Control of storage rots in Cox's Orange Pippin with pre-harvest sprays or post-harvest treatments and stored in air at 3-3.5°C or controlled atmosphere storage (1%CO_2. 2% O_2 at 3.5-4.0°C)

Treatments	% rotting (assessed in February) Controlled atmosphere	Air
Untreated	5	16.5
captan orchard spray (3 sprays)	1.2*	6.2*
thiophanate methyl orchard spray (3 sprays)	0.4*	8.8*
thiophanate post-harvest drench	1.3*	9.6*
metalaxyl + carbendazim post-harvest drench	0.9*	8.3*
SED (27 residual dof)		
Fungicide treatment	2.53	
Storage regime	1.60	
Treatment x storage	3.58	

*significantly different from untreated P = 0.05

STRATEGY FOR ROT CONTROL

There are several alternative approaches for tackling the problem of storage rot control. The use of cultural control to reduce orchard inoculum or ensuring correct harvest date, achieving the recommended standards in fruit mineral composition and use of optimum storage conditions individually will not be entirely effective in controlling rots. Similarly, adopting routinely the use of pre-harvest fungicide sprays to reduce rotting, while contributing significantly to control of storage rots, has many disadvantages. However, combining such techniques in an integrated system provides the best strategy for prevention and control of storage rots. MAFF funded research is at present developing a system of rot risk prediction. For apples, this is based on orchard rot history, fruit mineral analysis, and a pre-harvest assessment of orchard disease inoculum levels and fruit quality to determine the likely risk of rotting. In this way problem orchards can be identified and allocated for early marketing while other orchards with a low storage rot risk may only need protective orchard sprays for adequate rot control. For pears, where the main rot is Botrytis rot, developing a rot risk prediction system is more difficult and requires further research.

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SESSION 4B

ADVANCES IN THE SAFER FORMULATION, PACKAGING AND APPLICATION TECHNOLOGY OF PESTICIDES

CHAIRMAN	DR B. T. GRAYSON
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FUTURE FORMULATION TRENDS - LIKELY IMPACT OF REGULATORY AND LEGISLATIVE PRESSURE

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ABSTRACT

Regulatory and legislative pressures are accelerating the trend to develop safer formulations. Particular emphasis is being placed on the need for products which are safer in handling and use and which minimise environmental impact. These pressures coupled with the need to reduce contaminated packaging waste are leading to the closer integration of formulation, packaging and application technologies to provide safer delivery systems.

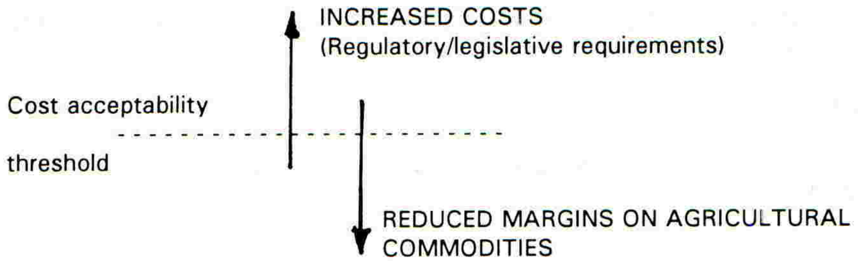
At the same time regulatory demands are making it more difficult for new compounds to achieve registration and in consequence opportunities exist to develop safer formulations of existing compounds and to improve their biological efficacy. The evaluation of adjuvants and their incorporation where feasible into crop protection products will become increasingly important.

Lower prices for agricultural commodities will reduce farmer margins and put lower thresholds on the cost acceptability of crop protection products. The formulation chemist must help develop safer products which are cost effective and cost acceptable.

INTRODUCTION

The role of the crop protection industry is to provide cost effective products for farmers and growers as aids to good husbandry. Changes in regulatory and legislative demands are adding to the cost of development of new products and in many cases to the cost of the products themselves. At the same time the Common Agricultural Policy (CAP) in Europe and pressures from GATT are reducing the margins on agricultural commodities.

Formulation is an essential part of the development of any crop protection product and influences factors including, safety, efficacy and cost. This short paper discusses the dilemmas of the formulation chemist and the industry as a whole in providing safer, cost effective/cost acceptable products in the remainder of this decade and beyond. If the cost of any product is perceived to be above the threshold for farmer/grower acceptance then the product will not be used. As a consequence new safer or more effective products may not gain market acceptance.



REGULATORY AND LEGISLATIVE PRESSURES

My remarks here relate mainly to the situation within Europe, particularly in the UK.

The EC Registration Directive (Uniform Principles) is becoming established. There are increased demands for data to register new products (active materials and formulated products) and maintain registrations on existing products. Particular emphasis is placed on environmental and residues data requirements. Issues relating to inerts will require closer attention.

General environmental concerns have resulted in closer control of water and air quality and in respect of pollution in general. Of relevance to formulation and packaging issues is legislation to control packaging waste, in particular contaminated waste.

In the UK, the Health and Safety at Work Act and the derived COSHH Regulations have brought product handling practices during application into focus. Issues relating to the permeation of protective clothing and the dermal toxicity/irritancy of products are being addressed.

Regulations and codes of practice relating to the transport and storage of products are being tightened. Problems that can arise from fires involving crop protection products were highlighted in a incident in Switzerland back in 1986. EC Regulations demand that a product should have a flash point of more than 55°C to be classed as non-flammable. Certain transport regulations, for example the International Marine Dangerous Goods Regulations (IMDG), define the flammability limit at 61°C. An appropriate target value for the industry is a minimum flash point of 64°-65°C.

On the question of margins on agricultural products, the MacSharry proposals have been reflected in reductions in effective subsidy payments. This is pressure under GATT to further reduce price support. The net effect is a reduction in farmers' margins: current CAP reforms are intended to reduce cereal prices by 29% over the next 3 years.

PROBLEMS TO ADDRESS

Over the past decade the number of new compounds registered for commercial use in Western Europe has been significantly reduced as a result of regulatory pressures. Increasing regulatory demand will increase further the cost and time to clear new compounds. It is, therefore, essential that further formulation effort is devoted to ensuring that best use is made of existing registered compounds as well as new compounds under development.

There are five main areas to be addressed:-

i Need for safer formulations to minimise problems in transport, storage and general handling.

ii Need for formulations/packs which reduce handling risks during application and minimise disposal problems. Here issues relating to the disposal of containers and used spray/product are under close scrutiny at the present time. Shelf life is also a pertinent question.

iii Environmental concerns - the issues here relate to inerts and application techniques other than hydraulic spraying.

iv Need to optimise the activity selectivity of any new or existing compounds.

v Need for coformulations either to meet marketing need or to combine active materials of differing modes of action to delay the onset of resistance.

Increasing data requirements for inerts will present difficulties There is the need to ensure that all inerts, surfactants and solvents in particular are supported by an adequate data package in respect of their toxicology, ecotoxicology and environmental fate. Situations may arise where the need for additional data to support the continued use of well established inerts may not be justifiable on cost grounds. More than ever there is the need for formulation chemists to work closely with suppliers particularly of surfactants and solvents to establish that adequate data bases for a particular inert exists and can be maintained at the beginning of any development exercise. It is important that we as formulation chemists do not use inerts which provide for greater hazards or problems than the active material itself. It is encouraging to note that the Uniform Priciples directive has a list of banned inerts rather than a list of approved inerts.

The need for additional data to support the registration of formulated products themselves must not be overlooked. Although our task here is by no means as onerous as in the case of our toxicological or residue chemistry colleagues, additional work will be required.

BASIC REQUIREMENTS OF A FORMULATED CROP PROTECTION PRODUCT

It is the responsibility of the formulation chemist to design any product to provide the best fit of relevant factors which include:-

* physical and chemical properties of the compound
* safety/environment
* registration requirements
* biology (activity/crop selectivity)
* application
* marketing/user preferences
* cost
* suitability for large scale manufacture
* shelf life.

The issues of particular interest in this paper are those relating to safety/environment, registration and cost/efficacy coupled with the need for coformulations. As far as the safety and environment issues are concerned the formulation chemist cannot work alone. There is and must be a close working relationship between formulation chemist, packaging technologist and applications engineer to provide safe and effective delivery systems for crop protection products.

POTENTIAL SOLUTIONS

Means of resolving the problems raised are set out in tabular form:-

PROBLEM	REQUIREMENTS	TYPE OF FORMULATION
i Safety in transport storage and general handling	Non-flammable or non-combustible product. Low dermal toxicity. Low penetration of protective clothing.	Water based liquid formulation (of low or zero solvent content.
		WGs
	Non-dusty	Tablets
	Solids or thickened liquids rather than mobile liquids.	Gels
	EC Dangerous Substances Regulations - unclassified (where possible).	
ii Handling of products during application, disposal of containers, unused spray liquid and product	Mobile easily metered and rinsed product/ pack combinations (Dutch Covenant).	High quality liquid formulations of low dermal toxicity and good spray tank compatibility.
	Suitable for use in returnable containers.	Single phase systems, SLs, ECs, microemulsions preferred.
	Suitable for use in water soluble packs.	
	Suitable for use in direct injection spray.	
	Products of long shelf life.	

iii Environmental Issues	For conventional spray formulations use of inerts which at rates applied do not accumulate in soil or ground water.	Any type of formulation.
	Control of drift is essentially a sprayer problem (nozzle selection).	Drift control adjuvants.
	Wider use of alternative application techniques.	Seed treatments. Granules. Controlled release.
iv Activity enhancement/ modification	Improved activity/selectivity over basic formulations.	Formulations containing high levels of surfactant/oil. Oil dispersions SEs Microemulsions ECs Matrix systems Microcapsular dispersions Use of separate adjuvant.
v Coformulations	Particular emphasis on safer types of formulation (water based). Problems arise where the chemical and physical propertries are dissimilar.	SEs Microcapsular suspensions (SCs and ECs)
vi Cost	Simple formulation systems. Quick to develop and cheap to manufacture.	SCs, ECs and WPs

CONCLUSIONS/THOUGHTS ON THE FUTURE

Container disposal is perhaps at this point in time one of the most significant factors in determining which way the industry should move in developing specific types of formulation. If rinsed containers can be regarded as non-hazardous waste and the use of Small Volume Returnable containers (SVR) become accepted for use on larger farms then liquid products have an assured future.

If the disposal issues of standard type containers cannot be satisfactorily resolved then there will be a marked move to solid formulations, WGs in particular. Again the use of water soluble packaging would assume more importance.

In future formulated products must be designed in the context of 3 different types of packing.

i	Conventional	-	Liquid and Solid formulations
ii	SVRs	-	Liquids (possibility granules)
iii	Water Soluble	-	liquids
	film	-	solids (WGs WPs)

High quality liquid formulations will be required particularly for SVRs and other large containers.

Where water soluble film is used the potential for product/film compatibility with resultant spray tank problems must not be overlooked. An intriguing point to note here is the possibility of packing water-based products in water soluble film.

The development of low dose active materials will reduce both the quantity of formulation per hectare and the amount of packing material requiring disposal. The use of highly active, high cost compounds will demand that more time is spent in optimising their biological activity. The use of adjuvants in general has been the subject of a recent conference in Cambridge. I will not elaborate on this area other than to state that this area is progressively receiving more attention both in the agrochemical and surfactant/oil industries.

The comments I have made relate to products intended for hydraulic spraying. In environmental terms this application technique is by no means ideal but provides the only practical robust system for treating large crop areas. Hydraulic spraying will continue to be the norm until well into the next century. Opportunity should be taken where the properties of the compound point to make wider use of seed treatment/coating techniques and granular formulations to protect a given crop.

Many references have been made to the use of controlled release systems for crop protection. It is an area worthy of further study but the problems in our industry are much greater than those in human and animal health. Firstly our products have to work under variable conditions of temperature and humidity whereas a specific location inside a mammal or even its exterior surface provides a much more closely controlled environment. Again this is the question of the cost of the delivery system. Seed treatments and granules provide the best options for controlled release formulations in the immediate future.

To conclude it is worthwhile examining some data on formulation types in Western Europe (1989).

Figures based on metric tonnes of formulated product.

WP	29.5%)		
Dust (DP)	10.6%)	Total for dry	
Granules (GR)	12.1%)	formulations	- 54.0%
Other Dry Formulations	1.8%)		
SC	13.7%)	Total for	
SL	6.5%)	water based	
		formulations	- 20.3%
EC	24.7%)	Total for	
Unknown types	1.0%)	solvent	
		based -	25.7%
	100		100

It is revealing to note that in spite of work on alternative systems through the 1980's most of the formulations sold are still of the conventional types. Perhaps this is in part a reflection of the additional time taken to fully develop the more complex types of formulation and particularly to obtain registration.

The agrochemical industry is currently working hard on alternative types of formulation. Work on water-based systems, WGs/tablets, formulations for water soluble packaging and activity enhancement will continue throughout the 1990's. However, it will be interesting to look again at the product breakdown in terms of formulations types at the end of the decade. Although the proportion of more complex water-based, oil based and WG/tablet formulations will increase significantly, I suspect that the conventional types of formulation SC, WP and EC may still predominate. However, a proportion of those conventional formulations will be packed/distributed in water-soluble or returnable packs.

The emphasis must be on safe 'quality' formulations regardless of type. The situation will always apply where the most appropriate formulation is developed for a particular compound(s) for a given use. The emphasis will be cost efficacy/cost acceptance as well as on safety. More than ever before the formulation chemist has to make his silk purse from a sow's ear or even half a sow's ear.

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NOVEL FORMULATION AND PACKAGING CONCEPTS-CUSTOMER NEED OR MARKETING TOOL?

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ABSTRACT

In the use of plant protection products, safety for the applicator and the environment must be "Top of mind". Therefore, there is an increasing need for the plant protection industry to continue to develop new products and delivery systems which are optimised with regard to safety, environmental behaviour, biological performance and cost. Novel formulation and packaging concepts will have to make a major contribution for industry to reach these goals. By reduction of organic solvents in liquid formulations, the environmental impact and toxicity of the product may be reduced. A reduction of dermal toxicity may also be obtained by encapsulation of the active ingredient. In most situations liquid products are preferred to powders when preparing spray solutions for several reasons. The use of water soluble film to package powders provides improved worker safety by eliminating dusting during handling. User and environmentally friendly packaging systems include containers which are easy to rinse, packaging of formulations in water soluble films, and small volume refillable containers.

INTRODUCTION

Over the last decade, the plant protection industry has been faced with many changes and, today, it has to meet not only economic, but also social and environmental challenges. With a low growth market situation and increasing regulatory requirements concerning user safety and environmental compatibility of their products, innovative solutions to emerging customer needs become all important if industry players are to reach their economic objectives. From a social point of view it is necessary to inform the public on benefits and risks of products and to aim for continuous improvement of product handling systems with regard to safety for the user. The main targets concerning the protection of the environment include saving resources with better products and manufacturing processes, introducing environmentally compatible products and minimising waste by optimising production processes and packaging designs. To achieve these goals, combined efforts in research, development, production and marketing within our strategic framework will be necessary. As it will be shown by several examples, the development of new formulations and packagings can make an important contribution to the progress in the pursuit of this goal.

The core of each product is the chemical compound which is responsible for the intrinsic biological activity. However, for a safe and optimally targeted application and the development of the biological efficacy of the product, the active ingredient has to be formulated and packed properly. Therefore, the design of formulation and packagings are of fundamental importance. The formulation and packaging concept for a product depends on many factors. The physico-chemical properties of an active ingredient such as the physical state, the chemical stability and the solubility in water and organic solvents determine technically feasible types of formulations, for which the appropriate packagings have to be defined. Further important factors influencing the design of formulations and packagings of a product are the toxicological properties of the active ingredient and, of course, user's needs. As it has been shown in an earlier paper (Urech 1990), the plant protection industry has several "user" groups, namely the society, the farmers, and the regulatory authorities, which have various needs. This paper concentrates on the needs of distributors and farmers as users of plant protection products. They want economic, safe and reliable solutions to problems and no or minimal waste disposal problems. Marketing also has its need to supply the customer with new products which have competitive advantages and generate profit. For positioning a product in the market, in addition to innovations in formulations, new designs of packagings and labels further play an important role.

Today, in the European market most of the plant protection products are still sold as classical formulations such as emulsifiable concentrates (EC), soluble liquids (SL), suspension concentrates (SC), and wettable powders (WP) adding up to over 90% (Diepenhorst *et al.* 1991). Newer product forms such as water dispersible granules (WG) only slowly penetrate the market. In recent years, several active ingredients with low dose rate have been developed using typically only a few g/ha instead of kg/ha. This certainly opens new opportunities for formulation and packaging development. Indeed there has been a rapid increase in the farmer's interest in advanced types of formulations and delivery systems. Furthermore, the high development costs associated with bringing new active ingredients to the market may also push companies to investigate new formulation and packaging technologies in order to extend the life of existing products.

NOVEL FORMULATION AND PACKAGING CONCEPTS

Liquid formulations

It is recognised that liquid formulations are preferred by the farmer for preparing spray solutions for several reasons. They can be measured volumetrically, they are easy to handle, they spontaneously form stable dispersions and, given appropriate container design, most formulations are easy to rinse out of the package.

Emulsifiable concentrates (EC)

Although they are the most applied liquid formulations, EC's also have disadvantages. Some of the organic solvents used in EC's may be harmful because of their toxicity and their flammability. EC's are also coming more and more under regulatory pressure due to the organic solvents.

Suspension concentrates (SC)

These formulations have an advantage over EC's because they are water based and normally contain only small amounts of glycols as antifreeze. However, the preparation of SC's is limited to solid active ingredients having a low water solubility.

Emulsions in water (EW)

For the formulation of hydrolytically stable liquid compounds, EW's are an attractive alternative to EC's. Because they are water based they may be less hazardous for the user and the environment.

Capsule suspensions (CS)

A further step towards more safety for the user may be obtained by encapsulation of the active ingredient. As has been proven for some of our insecticides, capsule suspensions (CS) show a remarkable reduction of the mammalian toxicity compared to the EC's with respect to both oral and dermal exposure. Encapsulation of the active ingredient may also offer an advantage for compounds which are volatile.

Container designs

All liquid formulations have a disadvantage because of the difficulties to dispose of contaminated primary packaging waste. It is important therefore to ensure that single trip containers are rinsed immediately after emptying and the rinsate added to the spray tank. This requires that containers are designed to be rinsed and are easy to rinse. Clean, rinsed containers are easier to be disposed of through municipal waste channels or to be collected for controlled recycling or energy recovery. Industry is in the process of agreeing on container performance standards and specific design criteria aimed at improving handling and rinsability.

Refillable containers

Strategies aimed at reducing the number of single trip containers include the development and eventual introduction to the market of refillable containers. Mini-bulk refillable containers have long been used in the USA and Canada and have contributed to a substantial reduction in the number of single trip containers requiring disposal. Already three years ago, CIBA-GEIGY considered the possibilities of developing small i.e. 20-30 litre refillable containers for fungicides in Europe. Emerging packaging waste legislation i.e. EEC Directive on Packaging Waste, encourages the use of refillable packaging and during 1992, a number of agrochemical companies had development programmes running with small volume refillable (SVR) containers using stainless steel kegs from 10-60 litres sizes. Efforts are being made by industry to standardize fitments attaching SVR containers to sprayer transfer systems.

CIBA-GEIGY is also involved in the development of a 10 litre refillable, closed dispensing container called the 'CIBA-LINK'. The advantages of this systems are due to the fact that no investments in transfer systems or major spray equipment modifications are required. The only modification required is the fitting of a small valve either in the top of the spray tank or in the lid of the induction bowl or hopper. The 'CIBA-LINK' is quick and easy to use, simply inverting the container and engaging the dispensing head into the valve on the sprayer. Applying slight pressure opens the valve and the required amount of product can be dispensed. When the 'CIBA-LINK' is empty it is returned to the bulk site for re-filling.

Clearly the success of SVR containers will also depend on effective logistic systems and getting the economy right. We believe there is an opportunity for refillable containers and that farmers will be quick to see the benefits of such systems when they become available.

Gels (GL)

Gel formulations can be described as thickened EC's packed in water soluble bags (Dez *et al.*, 1990). In some cases, organic solvents may be replaced by natural oils. The viscosity is increased with thickeners up to a range which usually represents a compromise regarding the transport stability in the water soluble bag and the dispersibility in water. This concept offers the plant protection market a new form of product/packaging combination. The first fungicide formulated as a gel is the propiconazole GL 62.5, which was launched under the trade name PRACTIS by CIBA-GEIGY France in 1991. This product provides many benefits, which are highly appreciated by farmers. The premeasured doses in water soluble bags offer advantages in easy handling and increased user safety, and the outer package is not contaminated with product and can be easily disposed of. Because of the higher concentration of the GL 62.5 compared to the EC 500, there are also less organic solvents.

A crucial point for the success of this development was the intense collaboration of formulation and packaging specialists. The challenge for them was to identify a polyvinyl alcohol film as the primary packaging which was compatible with the solvents in the gel formulation and still had a short dissolution time in the spray tank. Furthermore, a multi compartment secondary package had to be developed which provides mechanical protection for the sachet and can be sealed against moisture.

Solid Formulations

Solid formulations have several advantages over liquid ones, in particular, regarding their environmental impact. They are free of organic solvents, easy to recollect in case of spillage, and, in general, there is less packaging waste to dispose of.

Wettable powders (WP)

These are the most common solid formulations. To obtain a stable suspension upon dilution with water, WP's have to be ground to a very fine particle size, which makes them dusty and, therefore, less safe to use, particularly when measuring out. However, worker safety may be improved by packaging the WP's into water soluble bags, which allows the farmer to use premeasured doses and the secondary package is not contaminated by product.

Water dispersible granules (WG)

WG's are slowly becoming established in the plant protection industry. In this formulation type, advantages of liquid and solid formulations are combined. Thus, WG's are easy flowing products with constant bulk density and can therefore be measured volumetrically. They are much less dusty, 2-3 times less voluminous and leave less residues in empty packagings compared to WP's. A drawback for products with high use rates may be the high price of WG's, however, the high processing costs may be balanced by reduced storage costs due to the higher bulk density. Thus, WG's are the formulation of choice for highly active solid products such as sulfonyl ureas.

Effervescent tablets (TB)

As an innovation in solid formulations, effervescent TOPAS tablets have been introduced into the market for disease control in pommefruit and vineyards (Schmutz *et al.*, 1990). As far as handling properties are concerned, tablets are clearly superior to both liquid and powder formulations. Major benefits are a premeasured dose rate, the ease of use and the empty packaging being almost free of product residues. Tablets are also particularly suited for products which are effective at low rates.

Seed treatment formulations

Tailor made formulations for seeds became established at CIBA-GEIGY during the last 10 years and are now increasingly important aspects of plant protection agents application practice. The underlying principle is obvious, placing the chemical as near as possible to where it is required to control seed- or soilborn pests for uptake by the underground parts of the plants. Thanks to the ideal placement of the product direct on the seed, benefits include a more efficient use of product, less environmental contamination and reduced exposure of non-target organisms. Therefore, from an environmental point of view, seed treatment demonstrates clear advantages over granules and soil spray. Particularly with seed treatments, there are advantages associated with indoor application and under controlled conditions by skilled operators, allowing the use of more sophisticated formulations and avoiding the variations caused by weather and different expertise. Two new products, the capsule suspension CS 400 of the insecticide PROMET, which shows reduced toxicity, and various suspension concentrates of the new fungicide BERET have recently been introduced into the market. Furthermore, polymer formulations are being developed as application tools to improve treatment quality.

Seed treatment customers have also a need for improved systems for handling chemical products. Although their needs are quite different from those of the large arable farmer, they share the problem of disposal of empty single trip containers which most often are being stained. In general, customers require high volumes such as 500 - 5000 litres per season, with the need for a closed system for the product to be pumped directly from the container to the seed treatment machine without dilution. Thus, a 500 litre tank for ready to use products was developed and introduced into the market.

CHALLENGES FOR THE FUTURE

Changing customer needs and increasing legislation concerning packaging waste have created the opportunity for companies to re-evaluate formulations and their packaging and encouraged industry to pay more attention to packaging waste management. This situation offers substantial opportunities for companies recognising these changes and which are able to innovate and, at the same time, prepared to accept risks to meet emerging customer needs to gain competitive advantage in the market place.

In the last ten years, much progress has been made in the design and development of new formulations and packagings to meet requirements for user safety and packaging waste reduction. In particular, compacted forms such as WG's are increasing in favour of WP's. Water soluble packaging provides improved user safety by eliminating dusting during handling of powders. It is also essential for gels offering an elegant solution for the handling of the viscous liquid, providing the farmer a premeasured dose and leaving packaging waste which is not contaminated. Due to concerns for environmental contamination, there will be a trend to use water based instead of solvent based formulations and there will also be a move away from liquid to solid formulations.

There is a great challenge for continuous improvement. The needs of farmers are changing to low dosage, low toxicity and more environmentally friendly products and there are concerns in the public about contamination of ground water and food with plant protection agents. The challenge for R&D is to constantly search for new active ingredients which are biologically more effective and safe. Less environmentally safe products will be phased out. However, until the older products can be replaced, new safer formulations and packagings can certainly offer an intermediary solution to increase the user safety and the introduction of refillable containers will contribute to the goal of packaging waste reduction, as well as reducing user exposure when handling concentrated products. Much is to be gained from industry working together and with governments to establish performance standards in the area of packaging waste management programmes.

In terms of overall packaging strategy, CIBA-GEIGY is committed to waste reduction and improved handling safety. A prime objective is to reduce the number of one-way containers which end up in the solid waste stream. Refillable container programmes aimed at larger growers and custom applicators will contribute to the reduction of one-way packaging and associated secondary packaging. For smaller growers and also for the use of highly active compounds, the introduction of solid formulations and gels, which can be packed in water soluble film, completes the strategy base to achieve a reduction of packaging waste. We have no illusions that developing such innovative solutions and bringing them to market in a short timeframe requires substantial money and effort as well as legislative support to encourage the implementation of emerging packaging waste reduction alternatives.

CONCLUSIONS

New formulation and packaging concepts are definitely a customer need for new and more safe plant protection products. Successfully meeting customer needs is a prime requirement for marketing success and the ability to bring innovation to the market as quickly as possible, a requirement for longer term survival. Solutions have to be offered to the farmer by new products which are optimized with respect to biological efficacy, user safety, environmental aspects and economy. It is our job to maintain our leadership role in these developments and it will be the challenge for marketing to bring these products to the farmer and familiarise him with the benefits of these new technologies.

ACKNOWLEDGEMENT

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POLYMERIC FORMULATIONS OF PESTICIDES

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ABSTRACT

Novel polymer technology has been developed to produce aqueous-based pesticide formulations. A core material is dispersed in an aqueous phase containing a polymer system designed to coat the surface of the dispersion, thus stabilising it. The core material contains the active ingredient, either alone, with solvent or in a water-insoluble polymer matrix.

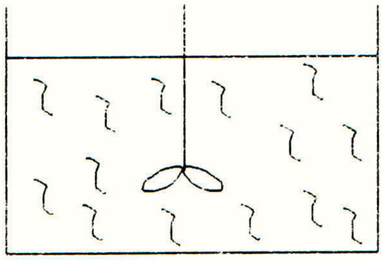
The technique is illustrated by formulations of chlorpyrifos and cypermethrin. Field trials with chlorpyrifos and a pot trial with cypermethrin clearly demonstrate improved efficacy, especially residual efficacy, over conventional formulations.

INTRODUCTION

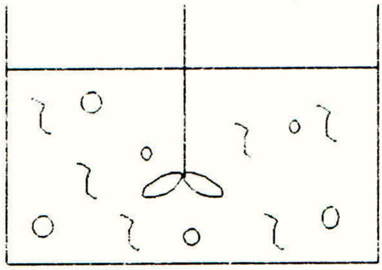
Concerns about pesticide safety usually involve two areas, the environment and the user. To protect the environment there is a general trend to use reduced levels of active ingredient. This creates a need for formulations with improved efficacy. To protect the end-user, safer formulations are required. Thus for example there is a desire to eliminate solvent-based formulations.

This paper will describe some novel polymeric formulations of pesticides, using technology patented by Allied Colloids. The formulations are aqueous-based, and show improved efficacy over conventional formulations. The technique is applicable to a wide range of active ingredients, including liquids and low melting solids which may be difficult to formulate by other techniques.

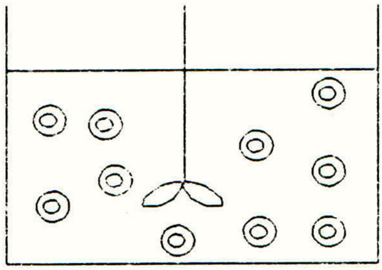
FIGURE 1.



AQUEOUS PHASE CONTAINING POLYMER



DISPERSION OF CORE MATERIAL



DEPOSITION OF POLYMER ON CORE MATERIAL, AND DISTILLATION OF VOLATILE SOLVENT (WHERE APPROPRIATE)

THE FORMULATION PROCESS

The formulation process is straight-forward, consisting of 2 or 3 stages, and is illustrated in Figure 1.

In the first stage, one or more water-soluble polymers is dispersed in an aqueous phase. The polymer system chosen may be of various types, but it must have the ability to stabilize organic droplets dispersed in the aqueous phase. Such systems include Low Critical Solution Temperature (LCST) polymers (Taylor *et al.*, 1975; Priest *et al.*, 1987). Alternatively, a coacervate-forming system may be chosen, (e.g. Nixon *et al.*, 1986).

In the second stage, a water-insoluble 'core' material is added, with high-speed shearing to the aqueous phase. The small core droplets so produced are stabilised by the polymer which deposits on the core material, forming a coating. The core material may consist of an active ingredient

a) alone (for liquids or low melting-point solids).
b) combined with a non-volatile solvent or other crystallisation inhibitor.
c) combined with a volatile solvent and a solvent-soluble, water-insoluble polymer. The polymer is chosen because of its physical compatibility with the active ingredient. In this case, the volatile solvent is distilled out in the third stage without agglomeration of the particles. The active ingredient is thus entrapped within a polymer matrix, forming a glass-like core, with a second polymer wall surrounding it. This forms a unique microcapsule/microbead suspended in water.

Applications of the technique are illustrated below.

CHLORPYRIFOS

Chlorpyrifos has been formulated by the various routes described above, using a range of stabilising polymers. The concentrations of active ingredient in the formulations have been in the range 10%-40% All formulations tested have shown an Acute Dermal LD_{50} (rat) of >2000 mg/kg.

The most interesting formulation to date is a product prepared by the distillation route, with a core of chlorpyrifos in a polymeric glass matrix, coated by a coacervate system.

Electron microscopy shows the presence of discrete spherical particles. A typical particle size distribution shows 90% < 9.0 μm and 50% < 4.5 μm.

Field trial against *Aphis gossypii* on cotton, Egypt 1991

The polymeric formulation (P) was compared with a standard commercial EC formulation. Assessments of activity were made after 24 hours and on day 3, 6, 9, 12 and 15 after spraying. The results are summarised in Table 1.

TABLE 1. Field trial against *Aphis gossypii*.

Product	Rate (g a.i./ha)	Reduction in aphid population %	
		Initial	Residual
P	240	71	59
	360	82	66
	480	90	75
	600	98	80
EC	240	70	30
	360	80	44
	480	89	57
	600	95	68

INITIAL = 24 hours after spray, RESIDUAL = 3-15 days after spray

The P and EC formulations were equivalent in knockdown activity. Results were similar after 3 days at the highest rate after which the P formulation was better at all rates tested. No phytotoxicity was observed.

Field trial against *Bemisia tabaci* in soybean, Egpyt 1991

The trial was carried out in a manner similar to that described above. Assessments were made after 24 hours and on days 3, 6, 9 and 12 after spraying. The results are summarised in Table 2.

TABLE 2. Field trial against *Bemisia tabaci*

Product	Rate (g a.i./ha)	Reduction in (nymph+adult) population % Initial	Residual
P	600	68	48
	720	76	55
	960	85	64
	1152	91	71
EC	600	62	35
	720	66	38
	960	71	43
	1152	76	48

INITIAL = 24 hours after spray, RESIDUAL = 3-12 days after spray

On this difficult-to-control insect, the P product was immediately superior to the EC, and maintained this superiority to the end of the trial at 12 days.

A second trial against *Bemisia tabaci* on cotton mirrored the results above.

CYPERMETHRIN

A 10% Cypermethrin has been formulated by the distillation route, with a core of cypermethrin in a polymeric matrix, coated by an LCST copolymer. A typical particle size distribution of the product is 90% < 1.3 μm and 50% < 0.7 μm.

Pot trial against aphids, ADAS, 1992

Winter barley seeds (cv. Bambi) were grown in pots. Immediately prior to treatment, each pot was inoculated with approximately 50 aphids from a mixed colony of *S. avenae*, *R. padi* and *M. dirhodum*.

Pots were sprayed with the polymeric formulation or a commercially available E.C. formulation. Inoculation of the pots was repeated on days 17, 37 and 43. This technique produced very high levels of aphid infestation. Assessments of the aphid population are shown in TABLE 3.

TABLE 3. Pot trial against aphids
Cypermethrin dose = 12.5g a.i./ha

Assessment time (days post insecticide)	Number of aphids per pot Polymer	E.C.	Control
0	4.0	15.0	57.5
17	22.5	95.5	165.5
37	216.0	1185.6	1856.3
43	517.5	1596.3	1325.0

The increase in residual efficacy of the polymeric formulation is clearly demonstrated.

CONCLUSION

Novel aqueous-based polymeric formulations of two insecticides have been developed. Both show improved efficacy, particularly residual efficacy, over the corresponding commercial E.C. formulations. The technique thus offers the potential of improved safety to the user, by eliminating solvents and to the environment, by reducing overall dosage.

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NEW DEVELOPMENTS IN CONTROLLED DROPLET APPLICATION (CDA) TECHNIQUES FOR SMALL FARMERS IN DEVELOPING COUNTRIES - OPPORTUNITIES FOR FORMULATION AND PACKAGING.

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ABSTRACT

The Controlled Droplet Application (CDA) of pesticides using simple hand held spinning disc applicators applying oil-based formulations at Ultra Low Volumes (ULV) of between 1 - 3 l/ha overcame a major constraint in small farmer crop protection by removing the need to fetch and carry large quantities of water to the field as required with conventional application techniques. Although the ULV technique has become widely adopted over the last 25 years in many countries, its use has been largely restricted to cotton and migrant pest control due to a lack of available ULV formulations in other crop situations. To broaden the scope of CDA and avoid formulation constraints , techniques have now been developed to also use water based spray treatments at Very Low Volume (VLV) rates of application (5 - 15 l/ha) using spinning disc sprayers. The use of water based spray treatments has necessitated the development of new spinning disc spray equipment. With recent developments in water dispersible formulations, together with prospects for better packaging, opportunities now exist to combine these developments with the logistical advantages of CDA techniques to improve safety in the use of pesticides by small farmers. The use of CDA techniques with their high work rates, ease of use and increased precision in application offers opportunities for the development of pest control programmes more appropriate to small farmer Integrated Pest Management (IPM).

INTRODUCTION

With increasing demands upon small farmers to maximise crop production it is expected that pesticide use in developing countries will increase markedly over the next few years (Hayes, 1990). Where pesticides need to be applied these products should be used as efficiently as possible and in small holder agriculture appropriate and affordable application methods are required. Traditional techniques for applying pesticides as liquid sprays (as opposed to dusts and granules) rely upon the distribution of the active material in high volumes of water, commonly 300-500 l/ha using hydraulic pressure nozzles as found on manually operated knapsack sprayers. Whilst widely used by small farmers due to their ready availability and versatility such application methods are not necessarily appropriate, particularly in semi-arid areas where water is scarce. The necessity to fetch and carry large volumes of water is labour intensive and time consuming and the sheer drudgery involved means pesticide treatments ,if made at all, are often poorly applied and frequently ill-timed (Matthews 1990).

To overcome these constraints techniques have been developed to apply pesticides in minimal spray volumes allowing treatments to be made much more rapidly and with less effort. To apply minimal spray volumes efficiently requires the use of fairly uniform droplet sizes appropriate to the biological target to ensure maximum deposition at the target site and to minimise waste. This is the principle of Controlled Droplet Application (CDA) and applies not only to pest and disease control but also weed control (Matthews 1977, Bals 1978). Simple hand held spinning disc sprayers capable of producing uniform droplets of the appropriate size (which is not possible with hydraulic pressure nozzles) have been developed for this purpose.

This paper reviews the introduction of CDA techniques using spinning disc sprayers with particular reference to small farmer cotton and the requirement to develop new spray equipment in view of recent changes in application techniques. Opportunities exist to accommodate new developments in formulation and packaging to improve safety in pesticide use and these are considered with respect to the needs of small farmers.

DEVELOPMENT OF CDA TECHNIQUES FOR SMALL FARMER USE

Hand held spinning disc sprayers were originally developed over 25 years ago to apply specific oil based formulations (requiring no mixing or dilution by farmers) at Ultra low Volume (ULV) rates of application, commonly 1-3 l/ha (Bals, 1969). Finely atomised droplets are released above the crop canopy and dispersed by the forces of wind and gravity throughout the foliage. The use of such application techniques has been most readily accepted in African small farmer cotton and migrant pest control due to the ease and speed with which spray treatments can be made; typically 1 ha can be treated in 30-45 minutes with improved precision in application. Perhaps the most successful implementation of this technique occurred in francophone sub-saharan Africa where 10 years after its introduction in 1975, 97% of all treated cotton (over 1 million hectares) was protected by ULV treatments with spinning disc hand sprayers (Cauquil, 1987). The rapid development of this technique in cotton and to a lesser extent migrant pest control has been possible due to the existence of an active extension network capable of transferring such methods directly to farmers. The agrochemical industry has also played a significant role in the development of CDA spraying by providing suitable ULV formulations and actively promoting the introduction of such techniques. In other crop situations, however, ULV formulations have not always been readily available. Their generally higher costs in comparison with conventional water dispersible formulations, such as Emulsifiable Concentrate (EC) and Wettable Powders (WP's) has led researchers to examine the possibility of using water based sprays at Very Low Volumes (VLV), typically 5-15 l/ha, with spinning disc sprayers to benefit from the logistical advantages of CDA yet avoid limitations in the availability and cost of ULV formulations.

Introduction of water based spraying

The use of water based sprays with spinning disc sprayers was first used in the early 1970's (Johnstone 1971, King 1976, Mowlam *et.al.* 1975.) to reduce expenditure on pesticides and indeed this technique has been used successfully in Malawi and Zimbabwe for control of cotton pests during the last 20 years. Bateman (1989) indicated cost savings of between 18-43% were made in comparison to ULV formulations available at that time when VLV water based spraying was first introduced into Malawi, Botswana, Zimbabwe and the Gambia. Using this technique gave comparable yields of seed cotton compared with either ULV treatments or indeed high volume knapsack applications (refer to table 1). The water based VLV technique was , however, never fully adopted in other regions of Africa in part due to the success of ULV spraying which whilst initially more expensive was certainly easier to introduce (no mixing of products, measuring or calibration). Recently, however, particularly in francophone Africa the higher costs of ULV formulations in comparison with EC's together with falling cotton prices prompted a re-examination of water based treatments at application volumes of 10 l/ha. Some problems had also been experienced with control of sucking pests (aphids,mites and whitefly) causing sticky residues on the cotton fibres and there was a desire to examine alternative spraying programmes. ULV treatments in West Africa are usually made on a calender basis with 14 day intervals between applications . The onset of spray treatments is selected according to predicted upsurges in major crop pests. With water based spray programmes it is possible to select active ingredients and dosage rates appropriate to the nature and level of pest infestation hence allowing for more flexibility in spray treatments than was possible with preformulated ULV products. Trials began in 1986 in West Africa to assess water based spraying at 10 l/ha in comparison to ULV treatments at 1 and 3 l/ha.

Table 1 Comparison of Knapsack High Volume , VLV and ULV spray treatments at Makoka, Malawi. Yields of seed cotton kg/ha.(after Matthews, 1981)

Year	Knapsack	VLV	ULV
1972	1434	-	1627
1974	1435	1636	1643
1977	1500	1351	-
1978	1156	1207	-
1979	1286	1247	-

With the use of water based treatments larger droplet sizes are normally used to reduce the effects of evaporation. This is usually achieved by increasing the flowrate to the atomiser disc. Spray passes are made every 3 rows as opposed to 4-6 with ULV treatments. Initial trials applied the same active ingredients and dosage rates at 14 day intervals for both ULV and VLV spray treatments. Results from a number of large field trials indicated that biological efficacy in controlling the major crop pests was at least comparable if not slightly better than ULV treatments.

Table 2 Comparison between ULV and VLV spray treatments in West Africa[1987-88]. Biological criteria and Seed cotton yield.- (after Cauquil, 1989.)

Country	No. of Trials	Bollworms	Aphids	Whiteflies	Mites	Yield
Benin	1	-	-	-	-	B
Cameroon	2	A,B	A,A	A,A	-	A,B
C.A.R.	1	-	-	-	A	A
Chad	1	A	-	-	-	B
Cote D'Ivoire	1	-	-	-	A	A
Mali	1	C	A	-	-	B
Togo	2	A,B	A	A	-	A,A

A - VLV superior to ULV B - VLV equivalent to ULV C - VLV inferior to ULV

Improved control of certain pests was observed with VLV treatments and it was considered that this may have been due to the use of reduced swath widths as more time is spent treating the crop and less variation in spray deposits will occur. The requirement to train farmers in the mixing of products and the use of higher application volumes was outweighed by the cost savings possible with the water based technique. Cost savings of between 14-33% were achieved in Cameroon with the large scale introduction of VLV spraying despite increased costs in spray equipment and batteries.Two spraying strategies have so far been adopted in West Africa. The first is the use of more frequent spray treatments made on a weekly basis with reduced dosage rates as opposed to fortnightly with

Table 3 Comparative costs of ULV and VLV spray treatments in Cameroon

Costs (CFA) *	1990/1 1 l / ha	1990/1 10 l / ha	1991/2 1 l / ha	1991/2 10 l / ha
spray equipment / ha	549	1 365	555	1 521
batteries / ha	283	966	297	967
insecticides / ha	14 306	10 899	14 286	7 756
Total costs / ha	15 138	13 230	15 137	10 244
(% saving)		(14%)		(33%)
Surface area (ha)	78 409	11 733	64 907	15 771

* (Central African Francs) (after Gaudard 1992)

ULV treatments at full dose. The second method is to monitor pest infestation by scouting and applying pesticides only when pest pressure reaches the economic threshold. This latter method involves the much more rational use of pesticides where active ingredients are targeted only at particular insect groups although its implementation demands a high level of farmer training by extension officers. For this reason the adoption of such control strategies is not yet possible in all areas.

Table 4 Comparison of costs/ha of different spray programmes in the region of Hamakoussou, Cameroon.(1990/91)

	CFA	%
ULV 1 l/ha (14 day interval / full dose)	16 893	100
VLV 10 l/ha (7 day interval / reduced dose)	12 437	74
VLV 10 l/ha (threshold intervention)	9 522	56

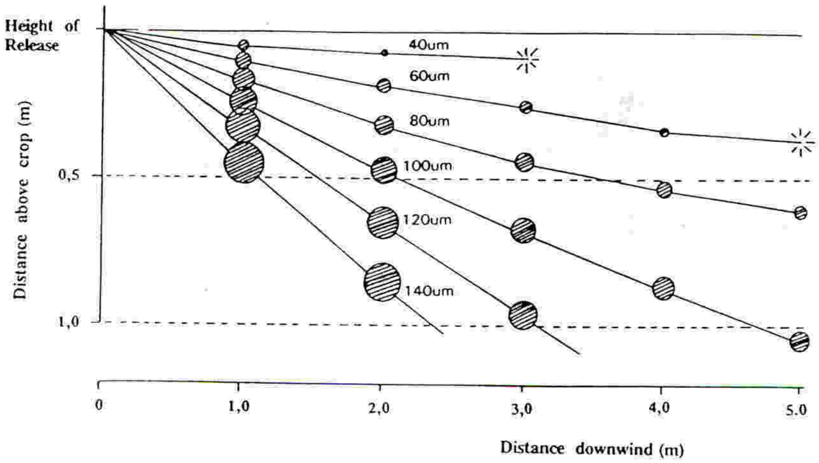
Currently a number of countries in West Africa are changing from ULV treatments to the use of VLV spraying largely due to the cost savings possible. Purchasing, for example, 1 litre of EC formulation to be made up to 10 litres with water will invariably be less expensive than using say 3 litres of a ULV formulation (despite applying the same active ingredients and dosage) due to the additional costs of using higher quantities of oil and solvent in ULV formulations. EC formulations being more concentrate can also be less expensive for transportation and being generally available from a greater number of suppliers contributes to their lower costs. This year alone it is expected that around 100,000 ha of cotton will be treated with VLV applications at 10 l/ha in West Africa.

Much of the initial development of the VLV technique used spray equipment which had been developed for ULV applications and whilst having given satisfactory biological results have suffered from a number of deficiencies. The major problems experienced have been due to high battery consumption and poor motor reliability at the higher flowrates being used. Problems have also been experienced with moisture penetration of electric motors in some older sprayer designs. Similar problems were reported during the early development of VLV spraying in Malawi, Zimbabwe and the Gambia where a number of workers concluded that improvements in sprayer design were required for this technique (King, 1976; Bateman, 1989). Moreover, spray equipment generally designed only for ULV treatments does not have the facility to select the appropriate droplet size according to the application technique in use. The choice of droplet size for ULV oil based and VLV water based treatments is quite different.

Droplet size for ULV and VLV treatments

With oil based ULV formulations which are not subject to evaporation to any significant degree, droplet sizes of 50-75μm VMD (Volume Median Diameter) have been employed to ensure adequate coverage on the crop foliage yet avoiding droplet sizes so small that they would drift uncontrollably and fail to impact on the target. Droplets of this size are, however, inappropriate with water as a carrier liquid due to problems of evaporation especially in the hot and dry climates in which they are being used. Larger droplet sizes which sediment more rapidly thus reducing the effects of evaporation are therefore more appropriate with water based sprays. However, as larger droplet sizes contain more liquid volume fewer numbers of droplets can be produced from the same volume of liquid thus higher application volumes are required to maintain droplet coverage. Figure 1 illustrates the theoretical trajectories of falling water droplets undergoing evaporation when released from a height of 1m above the crop canopy.

Figure 1 Theoretical displacement of evaporating water droplets in a 1m/sec wind. [temperature 30°C. Rel. Humidity 50% ($\delta T=7.7$)] (after Clayton, 1992)



Sprays containing water droplets under 80μm will theoretically fail to reach the target unless the atomiser is lowered to a distance of 0.5m above the canopy. Obviously these sedimentation characteristics are simplified and do not take into account turbulence and convective air currents. The addition of relatively involatile constituents in the pesticide formulation will also limit evaporation to some extent but this will vary from one product to another. Overlarge droplets are wasteful as they are poorly retained upon the plant foliage and will sediment rapidly leading to reduced swath widths and thus lower work rates. For practical purposes previous research has indicated that where water based sprays are used without the addition of an anti-evaporant then droplet sizes should be in the range of 100-150μm VMD to allow for good coverage at volume rates of around 10-15 l/ha. (Picken *et. al.* 1981; Johnstone, 1971; Bateman, 1989). For these reasons new application equipment has been developed to improve motor durability, reduce battery consumption and most importantly allow for the correct choice of droplet size appropriate to the application technique .

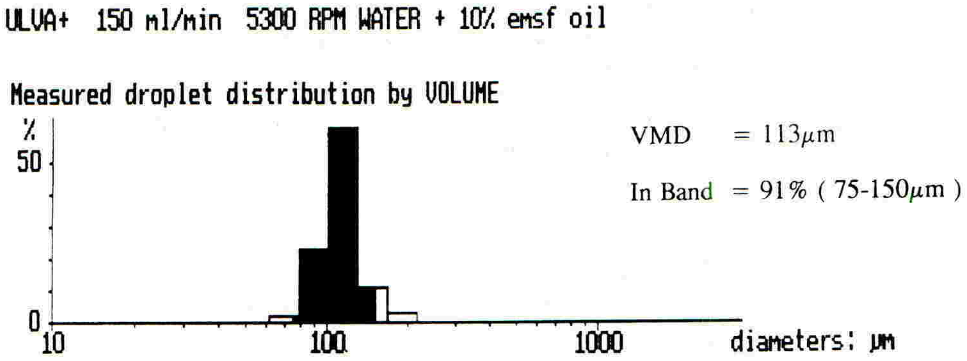
DEVELOPMENT OF A NEW HAND HELD CDA SPRAYER

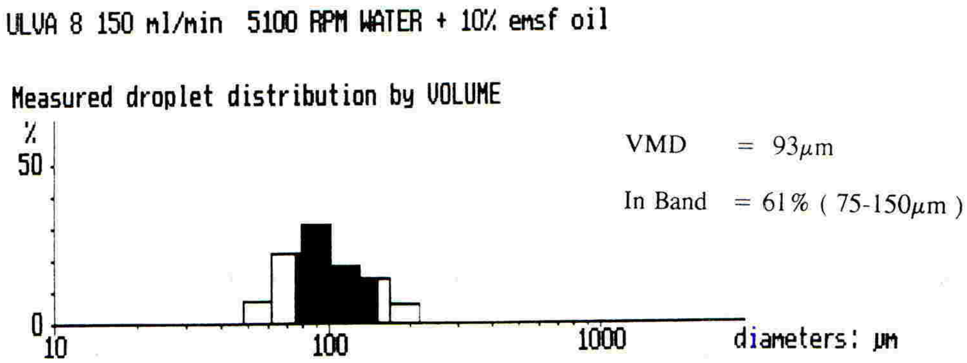
A completely new hand held spinning disc sprayer, the Ulva+ [1], has been developed

1 Trademark of Micron Sprayers Ltd.

to meet the demands of water based spraying at higher volume application rates as well as having the facility to alter droplet size according to the application technique, whether ULV or VLV. A new atomiser disc has been developed capable of maintaining good control of the droplet spectrum over a wide rate of flowrates and disc speeds. The essential feature of this new atomiser technology is the arrangement of small internal grooves for liquid distribution and 'teeth' which act as issuing points to control the break-up of spray liquid. Comparison of droplet spectra with the new atomiser and earlier disc designs indicates the improved control of droplet size now possible at higher flowrates.

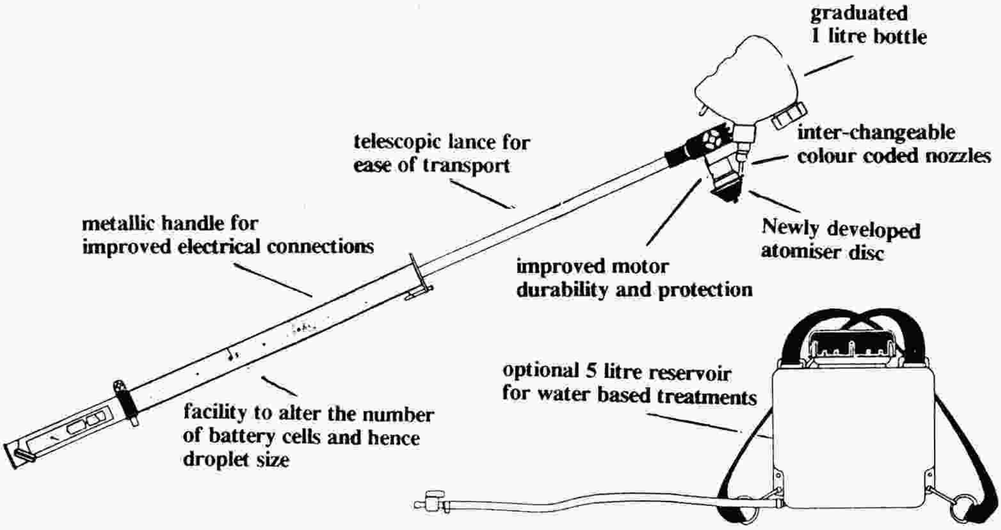
Figure 2 Comparison of droplet spectra.





The graphs illustrate the more uniform distribution of droplet sizes with the new atomiser which should allow for greater recovery upon crop foliage by reducing losses due to evaporation of spray droplets. Droplet size is controlled by adjusting the speed of rotation of the disc by varying the number of battery cells. With the new sprayer 5 batteries are recommended for VLV treatments and 6-8 for ULV treatments. Due to disc design and motor selection power consumption of the Ulva+ sprayer for VLV treatments in comparison to earlier models is greatly improved.(1.5-2.0 watts as opposed to 5-8 watts) and consequently 3-4 fold reductions in battery use have been found; typically 1 local battery is sufficient for almost 2 hectares. This sprayer, introduced early this year, is already in widespread use in West Africa for control of cotton pests using water based sprays.Trials are also being initiated on cowpea and groundnuts. A number of improvements have been incorporated in its design to increase reliability in the field and make maintenance easier.

Figure 3 Detail of Ulva+ spinning disc sprayer



PROSPECTS FOR FORMULATION AND PACKAGING

The use of water dispersible formulations with spinning disc applicators overcomes limitations in the availability of specific ULV formulations and may be more appropriate in some circumstances. Whilst Wettable powders and Emulsifiable Concentrates have been successfully used at very low volume rates more recent developments in water dispersible formulations such as suspension concentrates (SC's), micro-encapsulation (CS's) and water dispersible granules (WG's) may also be adapted for CDA use. These offer prospects for improved operator safety by avoiding the use of solvents, reducing toxicity of products to operators and possibilities for improved product handling e.g. micro-encapsulation of organophosphate insecticides can greatly reduce the toxicity of these products to spray operators (Wilkens, 1990). Other formulation techniques such as Concentrated Emulsions (EW's), Micro-Emulsions, Gels and Tablets may also be accommodated with water based CDA treatments. The use of water dispersible formulations can allow for the use of novel products such as certain microbials or organic products which cannot be formulated in oil. Prospects exist to provide pesticides in pre-measured packs for use by small farmers which would alleviate the necessity for farmers to mix products and avoid errors in dosage rate. The need for farmers to mix products is one of the major disadvantages of water based spraying as it is recognised that the necessity to handle products is one of the principle sources of operator contamination. The provision of pesticides in disposable sachets is possible with non liquid formulations. Liquid formulations can be packed in appropriate sized containers sufficient for one application (e.g. 60 - 500ml), such as, tins and bottles although care is required over their disposal. Alternatively products can be supplied in containers with appropriate measuring and dispensing facilities to reduce operator exposure to pesticides. Figure 5 summarises some of the formulation and packaging options for small farmer CDA use. Often such formulation and packaging techniques are not yet available to small scale farmers and frequently their additional cost may preclude their use in the face of cheaper but less desirable alternatives. Product specification at local and national level may be required to encourage their further introduction. One drawback of water based CDA spraying is that it allows some of the more hazardous products sometimes used with knap-sack sprayers to be sprayed at higher concentrations. The use of such products should be discouraged if their availability to small scale farmers cannot be restricted.

Although water is not the most appropriate carrier liquid for pesticides applied in relatively small droplets due to problems of evaporation there is the possibility to use spray additives to reduce the effects of evaporation and also improve spray retention on plant foliage. In Zimbabwe, for example, molasses added to water based sprays were used for this purpose and spray volumes reduced to 5 l/ha although this is no longer practised due to unavailability of molasses. The addition of emulsifiable oils has also been shown to improve recovery of spray droplets and improve retention upon leaf surfaces.(Wodegenah, 1981). There is therefore the possibility to incorporate anti-evaporants and other spray adjuvants into the spray mixes or preferably in the original product formulation to enhance activity of the pesticide. Such adjuvants are more effective if applied in a more concentrated form as occurs in VLV applications than if dispersed in high volumes. Formulation plays a key role in product efficacy and oil based ULV formulations have been shown to be more persistent than water based EC formulations without the addition of a spray adjuvant to improve retention. (Omar and Matthews, 1990)

Table 5 Formulation and packaging options for small farmer CDA application.

Formulation type [a]	Merits	Preferred packaging options	Suitability for CDA
Ultra Low [b] Volume (UL)	No mixing or dilution required by farmers	Could be pre-packed for closed transfer.	Recommended
Wettable Powder (WP)	Low cost Widely available Non liquid	Disposable sachets/ bags	Have been widely used. Problems can occur with agglomerations causing nozzle blockage or deposits accumulating on disc surfaces.
Emulsifiable Concentrate (EC)	Low cost Widely available	Appropriate sized containers.	Have been widely used. Handling concentrate can be hazardous
Water soluble Formulations. (SL) (SP) (SG)	Low cost. Completely soluble in water.	SL-small containers SP,SG -sachets.	Suitable providing products are not hazardous in concentrate mixes.
Suspension Concentrate (SC)	Usually solvent free Small particle size	Appropriate sized containers	Have been used without problems.
Capsule Suspension (CS)	Low toxicity Slow release	Appropriate sized containers	May require adequate dilution to reduce viscosity
Water dispersible Granules (WG)	Low cost packaging Non liquid	Pre-measured packs.	Suitable providing particle size is not large >50μm.

Notes: a. Water dispersible formulations may also include: Concentrate Emulsions(EW), Micro-Emulsions Gels, Tablets .

b. Oil based ULV formulations can also include particulate suspensions (FU)e.g. Powders,Microbials.

ULV formulations will continue to be used in many cotton growing areas, due to their simplicity in use, high work rates and familiarity of this technique by farmers, but in some regions will be replaced by water based treatments for reasons of cost. It is unlikely that water based VLV treatments will be generally acceptable in migrant pest control due to difficulties in obtaining and transporting even small volumes of water hence use of ULV formulations will continue to be the standard application method. Improvements in packaging of ULV formulations are also possible by providing products in pre-packed containers ready to fit directly to the sprayer. This would allow for a closed transfer system removing the need for operators to come into contact with products. It was always intended with the introduction of ULV spraying that products would be provided in this manner (Bals, 1969) although largely due to additional costs associated with such packaging this was never fully adopted. To achieve this requires only that suppliers of ULV products and equipment manufacturers standardise on a bottle thread fitting. The exception to this has been the development of the 'Electrodyn [2] ' system where products are supplied in a pre-packed 'Bozzle' which contributes significantly to improved operator safety when handling products (Smith, 1989). As with other application techniques this system has both advantages and disadvantages. By using the forces of electrostatics to deposit droplets on leaf foliage this avoids the need to rely upon the wind for droplet dispersal and impaction as required with spinning disc sprayers. This technique does, however, require even more specialised formulations which have so far only been developed for cotton and cowpea crops and are available from only one supplier. This has restricted the uptake of this technology to some extent (Matthews, 1990).

DISCUSSION AND CONCLUSIONS

The development of application equipment which permits the use of minimal spray volumes is of particular importance to small farmers as they can apply pesticides more quickly and with less effort. To apply minimal spray volumes efficiently requires the use of spray equipment capable of Controlled Droplet Application so that droplet size can be selected appropriate to the pest target. New developments in spinning disc sprayers now offer the choice of using a wider range of formulations and by overcoming problems associated with sprayer reliability and battery consumption, when applying water based sprays, should allow many more farmers to benefit from their use. Novel products such as Bio-pesticides also lend themselves to CDA spraying . Recent research has indicated that such techniques are highly appropriate for application of fungal pathogens in an oil dispersion for control of locust species (Bateman,1992). The prospects of using either ULV oil based formulations or VLV treatments with water based sprays may extend the acceptance of CDA techniques into other small holder crops. Despite encouraging results from field trials with spinning disc sprayers in crops such as groundnuts (Mercer, 1976), vegetables (Quinn *et al*, 1975), rice (Picken *et al* , 1981) and cowpea (Raheja, 1976) little large scale introduction of CDA techniques has occurred into these crops due in part to a lack of ULV formulations. Successful spray treatments have also been made in small farmer subsistence crops, e.g. millet, using hand held spinning disc sprayers although the costs of chemicals limited the acceptance of this technique (Jago, 1992). The use of CDA to apply water dispersible formulations may offer an alternative. To successfully develop appropriate crop protection programmes with CDA techniques will require the support of both local extension services and the agrochemical industry in providing farmer training and product recommendations. The use of CDA techniques offer the prospect of improved timing of spray treatments due to their high work rates. This is a crucial element in the successful implementation of Integrated Pest Management (IPM) programmes where often a rapid response to pest and disease infestations can avert the need for later more extensive intervention with pesticides.

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2 Electrodyn is a trademark of ICI Plc.

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