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FUNGICIDAL CONTROL OF BOTRYTIS ON COLD-STORED WHITE CABBAGE

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Summary Spreading soft rots caused by Botrytis cinerea are the predominant type of spoilage in the long-term cold storage of white cabbage. Two fungicides, thiabendazole and dicloran, applied after harvest as dusts, have been used successfully to control Botrytis in several commercial trials of five to seven months' duration. After preparation of the white cabbage for market at the end of the storage period, a significant (P=0.01) increase in the marketable yield of 9%-26% was obtained, despite other deterioration from bacterial soft rots, black speck, rots caused by Alternaria brassicicola and a range of physiological disorders.

Résumé La propagation de pourritures humides provoquées par le Botrytis cinerea est le type de détérioration le plus prédominant chez l'emmagasinement frigorifique à long terme de choux blancs. L'application en forme de poudre de deux fongicides, le thiabendazole et le dicloran, après la récolte, s'est montrée effective dans le contrôle de "botrytis" dans plusieurs essais commerciaux, pendant une période de 5 à 7 mois. Après la préparation de choux blancs au marche à la fin de la période d'emmagasinement, on a obtenu une significative (P=0,01) augmentation (9%-26%) du rendement de bon débit, malgré la parution d'autres formes de détérioration provenant de pourritures humides bactériennes, les petites taches noires, les pourritures provoquées par Alternaria brassicicola et une série de désordres physiologiques.

INTRODUCTION

The most important factor limiting the successful long-term commercial storage of white cabbage is spoilage by the grey mould fungus, Botrytis cinerea (Derbyshire, 1973; Kear and Symons, 1973; Geeson and Robinson, 1975). Infection sometimes takes place at the stalk, and the characteristic, spreading brown soft rot can render the whole head unmarketable. More usually, however, rots start on the senescent or wilted outer leaves, or on bruised tissue of the stored head, which can be trimmed at the end of the storage period to give a clean, marketable cabbage. Even at the optimum storage conditions of 0-2°C, and relative humidities approaching saturation (Burton, 1973), which can only be achieved for long-term storage (six to seven months) by refrigeration, Botrytis can spread in store, albeit slowly, and form nests of decay. Other rots sometimes occur, caused by *Alternaria brassicicola*, a *Phytophthora* sp., *Fusarium avenaceum* and pectolytic bacteria (pseudomonads), and their symptoms and occurrence, and those of other diseases, are comprehensively reviewed by Geeson and Robinson (1975).

Other losses of stored white cabbage include those from evaporation, senescence of the outer leaves, re-growth of the stem, and a range of internal blemishes (Geeson and Robinson, 1975). Black speck, a stippling of small necrotic lesions that can enlarge and coalesce, is an important example of these internal blemishes, and though its exact cause is unknown, it has been suggested that guttation injury plays a part (Strandberg *et al.*, 1969) or that strains of the cauliflower mosaic virus or the turnip mosaic virus are causal (Natti, 1958, amongst others).

As the primary aim of successful storage is to reduce the predominant type of spoilage, the control of *B. cinerea* was thought necessary. Careful harvesting and handling help to lessen rotting, by reducing mechanical damage which predisposes white cabbage to infection, but it is not the only factor involved, as rotting still occurs in commercial stores over six months' storage, even with careful handling. Furthermore, it is not always possible to handle carefully under commercial conditions. Consequently, a chemical control of grey mould rot on stored white cabbage was considered, which would reduce the extent of soft rotting on each head and possibly the incidence of *Botrytis* infection as well. *B. cinerea* is readily controlled *in vitro* and on a variety of hosts by the currently available broad-spectrum benzimidazole fungicides, viz., benomyl, thiabendazole, thiophanate-methyl and carbendazim, and trials with these fungicides, applied as post-harvest dips, were carried out (Kear and Symons, 1973, and unpublished data), as an extension of the A.D.A.S. work with benomyl on carrots and celery (Derbyshire, 1973). Post-harvest dips were not, however, successful, as the incidence and severity of lesions similar to black speck appeared to be increased by the dips and it was thought that the benzimidazoles, particularly benomyl, were phytotoxic. Penetration of the dips was usually deep within the head, and the necrotic blemishes that occurred often made the whole head unmarketable (Kear and Symons, 1973). For these reasons, a dry formulation of a suitable fungicide, that would not penetrate into the cabbage, was sought. Until recently, quintozene dust was used on stored white cabbage in the Netherlands (Whitwell, 1971) and East and West Germany (Vogel and Neubert, 1964; Struck and Grutz, 1972), but its use is being reviewed because of its possible carcinogenicity. It has never been adopted in the U.K. for cabbage storage and is also under review here. Of the benzimidazole fungicides only thiabendazole is formulated as a dust, thermal dusting tablet (smoke) or for ultra-low volume (ULV) application. Dicloran, which is highly active against *B. cinerea*, is also formulated as a dust, and from a preliminary small-scale trial (½ tonne) in the 1973-74 storage season it was shown that dicloran and thiabendazole dusts controlled grey mould rot and increased the marketable yield compared with the untreated control. The dusts were tested on a commercial scale in 1974-75, together with the thiabendazole smoke and ULV treatments which, although easier to apply than the dusts, gave variable results and were only partially successful.

METHOD AND MATERIALS

In the four trials in 1974-75, five to eight tonnes of cabbages for each trial were stored in slatted, ½t bulk bins. The cabbages for the trials were grown in the area south of King's Lynn and in the Spalding area of Lincolnshire, using standard cultivation procedures, and the cultivars are given in Tables 1-4. The cabbages were harvested at the end of November or beginning of December before the first serious frosts, and all harvesting and handling was carried out under commercial conditions. The cabbages were cut in the field by hand so that usually four, loose outer wrapper leaves were left on the dense head, with a stalk of approximately 2cm.

The exception to this was Trial 3 in which stalks of up to 30cm were left, as it was thought by the farmer that this would prevent rotting into the head from the stalk. The four consignments of cabbage for the trials were stored at three storage sites, two in Norfolk (Trials 1 and 3 with pre-packers) and one in Birmingham (Trials 2 and 4 with a cold storage company). At the storage site, outer leaves were trimmed until the storage head, composed of white to pale green leaves, was reached. Each cabbage was visually examined and excessively bruised or rotten leaves were trimmed out, or the cabbage was excluded from the trials. Immature cabbages (low density) were also excluded. The cabbages were treated and placed into store, usually within a week of harvesting.

The fungicide dusts used were thiabendazole (30% a.i., Rothwell Plant Health Ltd) and dicloran (4% a.i., Boots Co. Ltd) applied as a light covering at 750g per tonne of cabbages. Kaolin Light B.P. (Boots Co. Ltd), applied at the same rate, was used as a positive control. An untreated control was also included. The cabbages were treated in single layers on pallets by dusting one half of the cabbages, turning them over, and then treating the other half. This was time-consuming and unrealistic commercially. Consequently, dusting was also carried out while cabbages were being trimmed and loaded into bulk bins by dusting the bin, and alternating a layer of cabbages with a dust application. The fungicidal dusts were applied with a fiddle-brush duster (hand duster K6 type, Kyoritsu Noki Co. Ltd, Tokyo, Japan). The bulk bins, which had previously been washed with detergent and dried, were overwrapped with clear polythene (500 gauge) in two of the trials (Nos 2 and 4), to increase the relative humidity (r.h.) within each bin to nearly saturation. The bins were placed in a storage chamber at 1-3°C and an ambient r.h. of 90-95%. The experimental design was a randomized block with three replicate bulk bins for each treatment. Samples of 90-120 cabbage heads per treatment were taken at the end of the storage period of 25-30 weeks for a detailed assessment of each cabbage. In Trial 3 an additional mid-term assessment was made after 20 weeks.

A record of the ambient temperature and relative humidity within each storage chamber was made throughout the storage period, together with a record of the temperatures in several bulk bins by the use of thermistor probes. The weight loss of the cabbages occurring throughout the trial (mainly evaporative losses) was found by placing three weighed sample nets containing five cabbages into each bulk bin. Disease assessment was carried out after harvest and at the end of the trial, and any leaves showing spreading soft rots were removed and weighed. The causal agents of the rots were identified during the assessment, and isolations were made for further identification, if necessary. Further trimming was carried out to remove stalks, and leaves with necrotic lesions which were not obviously pathological in origin, including black speck, to give marketable heads of usually Class 1 Standard (Anon., 1974). The marketable yield of the sampled cabbages, the weight of diseased leaves, and the further trimming loss, were expressed as a percentage of the head weight after storage. A preliminary investigation of the residues of thiabendazole was made after removal of four outer leaves. Residues were determined in three of the trials, at the start of the storage period, after 18 weeks' storage, and at the end of the storage period.

RESULTS

The main causes of deterioration of stored white cabbage in the four trials, and the effects of thiabendazole and dicloran on soft rotting, are described below. More detailed results of the trials are presented in Tables 1-4 and yield advantages are summarized in Table 5.

Initial Trimming Losses

Cabbages prepared for storage were not of marketable quality (Class 1), and if sold immediately would still have needed slight trimming to remove discoloured leaves and black speck. Samples were taken and a marketable yield of 85%-90% was obtained, for which no allowance is made in the marketable yields given in Tables 1-4. For Trial 3, long stalks were left by the grower which accounted for 11.5% of the initial trimming loss, in comparison with 1.5% for Trial 4.

Evaporative Losses

Evaporative losses were significantly different for the various storage regimens, but within an acceptable range of 0.9% $30d^{-1}$ in Trial 2 to 1.8% $30d^{-1}$ in Trial 1. The polythene covering in Trials 2 and 4 reduced the mean weight loss $30d^{-1}$ to 0.9% and 1.2% respectively, compared with Trials 1 and 3 which had means $30d^{-1}$ of 1.8% and 1.5% respectively. Any free moisture that condensed on the underside of the polythene overwrap and dripped onto the cabbages did not predispose the cabbages to more rotting, as a comparison of the pathological weight losses of samples of cabbages from the top and bottom of the bulk bin in Trials 2 and 4 showed no significant difference ($P=0.05$).

Losses from Soft Rotting

The most apparent deterioration of the untreated cabbages was the spreading, soft brown rot, caused by *Botrytis cinerea*, often covered in a greyish felt of mycelium and spores. Less important pathological spoilage was from watery, soft, brown rots, characterized by their lack of mycelium, caused by pectolytic bacteria of the *Pseudomonas marginalis* type, of which isolations were made. Bacterial and *Botrytis* soft rots spread to other cabbages to form nests of decay and the infection developed into each cabbage, often necessitating the removal of 10-15 leaves during market preparation. A mean incidence of 2.9% of the heads was completely rotten and unmarketable for the controls in the four trials; none of the fungicide-treated cabbages were completely rotten. The fungicide-treated cabbages had fewer lesions of *B. cinerea*, or none at all, and any lesions present were typically of small size. The losses from *Botrytis* soft rotting on the fungicidally-treated cabbages was significantly less ($P=0.01$) than that of the controls, and the incidence of cabbages infected by *Botrytis* was decreased by the fungicides.

Black, felt-like *Alternaria brassicicola* lesions were seen, particularly on the fungicidally-treated cabbages in Trials 2 and 4. Superficially, they were small, 5cm in diameter, but they spread deeply into the cabbage, which needed heavy trimming. In addition, a sharply defined, firm, black lesion, was found under the *Alternaria* lesions, which affected at least three of the underlying leaves. There was no indication that *A. brassicicola* was controlled by the fungicides.

Losses from Other Blemishes

After preventing the soft rots by fungicidal treatment, or by trimming the soft rot from the cabbage, other blemishes had to be dealt with before the cabbage was marketable. The outer 3-5 leaves dehydrated slightly and became senescent, and these objectionable, yellow, dry leaves had to be removed. Necrotic lesions not obviously pathological in origin, vein streaking, and black speck on the foilage had also to be removed, and the protruding stalk had to be trimmed flush with the head, in accordance with E.E.C. Standards (Anon.,1974). These trimming losses from other blemishes were of the same order for all treatments. Although black speck was often present on the outer leaves, it seldom occurred after trimming for market preparation had taken place. When rated "severe" (≥5 leaves removed entirely through the occurrence of black speck) the incidence was variable, ranging from 1.9% for all treatments (Trial 1) to 13.4% (Trial 2). There was no difference in the occurrence of severe black speck between the dust treatments and the controls. A very small percentage (0.7%) of the cabbages of Trial 2 were rendered completely unmarketable by black speck. Other internal blemishes were unimportant in the four trials.

Marketable Yield

Despite the soft rotting from A. brassicicola and pseudomonads, and the black blemishes, the fungicide dust treatments gave a high and consistent advantage in marketable yields ($P=0.01$) when compared with the controls, on the four commercial samples of cabbages. Furthermore, for Trial 4 in which the level of rotting was high, the use of a fungicidal dust kept the marketable yield at an acceptable level (16-20% total trimming loss), whereas the yield from the controls was commercially unacceptable. The yield advantage is summarized in Table 5.

Table 1

Weight Losses of White Cabbage (mean percentage) after 26 Weeks' Storage

Trial No. 1 Cv. Original Langendijk Late, Gebrs Van den Berg
Storage Site: Methwold, Norfolk

Treatment	Evaporative Losses During Storage:- Final	per 30d	Trimming Losses after Storage from:- Rots	Further Prepn for Market	Marketable Yield (excluding evap.losses)
Untreated (control)	11.2	1.8	12.9a*	10.1a*	77.0a*
Kaolin (control)	11.0	1.8	10.5a	10.3a	79.2a
Dicloran	10.2	1.7	1.6 b	11.4a	87.0 b
Thiabendazole-RPH	11.6	1.9	2.0 b	12.5a	85.5 b
Mean	11.0	1.8			
	S.E.±0.45	S.E.±0.08			

*Means with the same letter within each column do not differ significantly ($P=0.001$) based on the Newman-Keuls multiple range test.

Table 2

Weight Losses of White Cabbage (mean percentage) after 30 Weeks' Storage

Trial No. 2 Cv. Winter Keeper (Extra Late Langendijker), A.L. Tozer Ltd
Storage Site: Birmingham

Treatment	Evaporative Losses during Storage:- Final	per 30d	Trimming Losses after Storage from:- Rots	Further Prepn for Market	Marketable Yield (excluding evap.losses)
Untreated (control)	5.4	0.8	23.7a*	13.4a*	62.9a*
Kaolin (control)	6.8	1.0	29.8a	13.5a	56.7a
Dicloran	7.2	1.0	6.9 b	18.2a	74.9 b
Thiabendazole-RPH	6.1	0.9	8.5 b	12.9a	78.6 b
Mean	6.4	0.9			
	S.E.±0.62	S.E.±0.09			

*Means with the same letter in each column do not differ significantly ($P=0.01$) based on the Newman-Keuls multiple range test.

Table 3

Weight Losses of White Cabbage (mean percentage) after 20 and 25 Weeks' Storage

Trial No. 3 Cv. Decema, Elsoms (Spalding) Ltd
Storage Site: Methwold Hythe, Norfolk

Treatment	Evaporative Losses during Storage:-		Trimming Losses after Storage from:-			Marketable Yield (excluding evaporative losses)
				Further Prepn for Market:-		
	Final	per 30d	Rots	Leaves^x	Stalks^x	
After 20 weeks						
Untreated (control)	7.7	1.7	19.5a*	5.7 bc*	13.0a*	61.8a*
Kaolin (control) 1)†	8.7	1.9	20.4a	5.9 bc	12.7a	61.0a
2)	6.6	1.4	19.2a	7.2 bcd	14.4a	59.2a
Thiabendazole 1)†	5.6	1.2	2.3 b	9.4 cd	13.8a	74.5 b
-RPH 2)	6.3	1.3	2.4 b	10.5 d	13.1a	74.0 b
After 25 weeks						
Untreated (control)	8.8	1.5	25.6a	1.9a	15.6a	56.9a
Thiabendazole 1)†	9.4	1.6	4.0 b	10.5 d	12.4a	73.1 b
-RPH						
Mean	7.2	1.5				
	S.E. ±0.49	S.E. ±0.10				

Table 4

Weight Losses of White Cabbages (mean percentage) after 26 Weeks' Storage

Trial No. 4 Cv. Winter Keeper (Extra Late Langendijker), A.L. Tozer Ltd
Storage Site: Birmingham

Treatment	Evaporative Losses during Storage:-		Trimming Losses after Storage from:-			Marketable Yield (excluding evaporative losses)
				Further Prepn for Market		
	Final	per 30d	Rots	Leaves	Stalks	
Untreated (control)	8.4	1.4	34.6a*	3.7a*	7.9a*	53.8a*
Kaolin (control)	11.5	1.9	31.8a	5.1ab	8.4a	54.7a
Dicloran	7.4	1.3	5.1 c	8.0 b	3.6 b	83.3 b
Thiabendazole 1)†	5.6	0.9	13.5 b	3.5a	5.1 b	77.9 b
-RPH 2)	5.5	0.9	11.6 bc	3.7a	5.0 b	79.7 b
Mean	7.5	1.2				
	S.E. ±0.94	S.E. ±0.16				

Notes

*Means with the same letter within each column do not differ significantly (P=0.01) based on the Newman-Keuls multiple range test.

†Treatment 1) Cabbages dusted both sides on pallets
Treatment 2) Cabbages dusted when loaded into bulk bins

^{x}As the cabbages in Trial 3 had unusually long stalks, a relatively low marketable yield was found. Consequently the further trimming losses for this trial have been divided into losses from leaves and stalks. The results from Trial 4 have been divided similarly for comparison.

Table 5

Increased Marketable Yield after Storage for the Fungicidal Dusts in the Four Commercial Trials of White Cabbage

Trial No.	Storage Period (weeks)	Yield Advantage relative to untreated (%w/w)	Reduction in Rots relative to untreated (%w/w)
1	26	9.3*	11.1*
2	30	13.9	16.0
3	20	12.5	17.2
	25	16.2	21.6
4	26	26.2	24.5

* For comparison, all the yields from dust treatments at any one trial have been averaged. They were not statistically different (P=0.01)

DISCUSSION

It is clear that by using the fungicidal dusts, dicloran (4%) or thiabendazole (30%), a significant reduction (P=0.01) in soft rotting from Botrytis, and a significantly increased marketable yield of stored white cabbage (P=0.01), is obtained, after five to seven months' storage, compared with the controls. Other advantages are that a mid-term trimming to remove soft rotting is unnecessary, thus saving a labour intensive practice and its cost. Mid-term trimming is often carried out by farmers, particularly those using the Dutch stacking system with forced ventilation. Optimum temperatures of 0-2°C cannot be maintained for six months with this system and rotting occurs earlier and more severely than with refrigerated storage so that the use of these fungicides would be advantageous. The stored product is more pleasant to handle in the packing station, giving better labour relations. Moreover, the trimmed cabbage has lost less leaves and therefore has a better colour and shape with important marketing consequences (Anon.,1974).

There was no difference between the two methods of application of the thiabendazole dust in controlling the Botrytis soft rotting, or in the resultant marketable yield (Tables 3 and 4), so that the faster, more commercial method of dusting layers of cabbages in the bulk bin, can be used. A further development would be the continuous application of fungicidal dust on a conveyor belt in the pack-house. The internal blemishes that appeared to be aggravated by the use of fungicidal dips in previous work (Kear and Symons,1973) were not increased with the dust treatments. The level of infection of stored white cabbage was also low throughout the country this year, as shown in Trial 1, and it is quite possible that with higher levels of infection, a greater marketable yield will result.

Although the exclusive use of thiabendazole or dicloran has given rise to tolerant strains of B. cinerea in other crops, their chemistry and modes of action are different. Thiabendazole is an inhibitor of nucleic acid metabolism in the nucleus (Bartels-Schooley and MacNeill, 1971), whereas dicloran allows normal nucleic acid metabolism but blocks protein synthesis in the ribosomes (Sharples, 1961). This could be exploited to minimize the occurrence of tolerant strains by alternating the fungicides after two or three years.

After market preparation of the cabbages, residues of <6ppm of thiabendazole were found, which remained fairly constant throughout the six months' storage period. This residue level is considered acceptable and a limited clearance has been given under the Pesticides Safety Precautions Scheme. A full clearance is being sought for both thiabendazole and dicloran, which are safe compounds, with low mammalian toxicity. Thiabendazole is already in accepted use for oral administration as an anthelmintic, and as a food additive. All dusted outer leaves would have to be removed, but this would be carried out anyway during market preparation.

The use of polythene overwraps on bulk bins in two of the trials reduced evaporative losses during storage, but the saturated relative humidities did not predispose the stored cabbages to more rotting, which is in accordance with the findings of other authors (Van den Berg and Lentz,1974, amongst others).

White cabbages intended for long-term storage should be handled and harvested with great care to minimize mechanical damage and prevent an early onset of rotting. Whilst we do not disagree with this maxim, we have found that growers cannot often afford to handle carefully as this slows the work rate, which is of particular importance if piece-work is involved. By using fungicidal dusts a grower with a small harvest team can still retrieve the situation and consider long-term storage of white cabbage with good yields. The increase in yields that result from fungicidal use more than offset the cost of the fungicide and its application.

References

ANON (1974) E.E.C. Standards for cabbage (round-headed), Ministry of Agriculture, Fisheries and Food

BARTELS-SCHOOLEY, J. and MACNEILL, B.H. (1971) A comparison of the modes of action of three benzimidazoles, Phytopathology, 61,816-819

BERG, VAN DEN L. and LENTZ, C.P. (1974) High humidity storage of some vegetables, Canadian Institute of Food Science and Technology Journal, 7,260-262

BURTON, W.G. (1973) Environmental requirements in store as determined by potential deterioration, Proceedings 7th British Insecticide and Fungicide Conference, 3,1037-1055

DERBYSHIRE, D.M. (1973) Post harvest deterioration of vegetables, Chemistry and Industry, No.22,pp.1052-1054 (November 17th, 1973)

GEESON, J.D. and ROBINSON, J.E. (1975) Damage will mean trouble in store, Commercial Grower, No.4147,pp.1245-1246 (June 27th, 1975)

KEAR, R.W. and SYMONS, J.P. (1973) Post-harvest deterioration of stored Dutch white cabbage, Mededelingen van de Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent, 38,1549-1560

NATTI, J.J. (1958) Cabbage mosaic and leaf spotting in storage, New York Agricultural and Experimental Station Farm Research, 24,13

SHARPLES, R.O. (1961) The fungitoxic effects of dicloran on Botrytis cinerea, Proceedings 1st British Insecticide and Fungicide Conference, 2,327-336

STRANDBERG, J.O., DARBY, J.F., WALKER, J.C. and WILLIAMS, P.H.(1969) Black speck, a nonparasitic disease of cabbage, Phytopathology, 59,1879-1883

STRUCK, P. and GRUTZ, E.M. (1972) [Successful storage of white cabbage], Gartenbau, 19,201-202

VOGEL, G. and NEUBERT, P. (1964) [Results from the use of Phomasan (pentachloronitrobenzol) during cabbage storage], Deutsche Gartenbau,11,205-208

WHITWELL, J.D. (1971) Winter storage cabbage, Agricultural Development and Advisory Service Quarterly Review,pp.38-48

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IMPROVED SPRAY SCHEME OF FUNGICIDES ON FLOWERING STRAWBERRIES FOR BOTRYTIS FRUIT ROT CONTROL

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Summary Strawberry fruit rot, at harvest and during transport, mainly results from *Botrytis cinerea* infections during flowering and can be reduced by treating the flowers. Fungicide analyses of the different flower parts (sepals, petals, etc.) revealed that, one day after spraying, all these flower parts contained a sufficient amount of fungicide (> 100 ppm) to prevent fungal growth. A few days after spraying however new flowers arise from buds which are only externally covered with the fungicide. The internal flower parts contain no fungicide and are susceptible to infection during several days up to the next weekly spray. In a glasshouse experiment using artificial infections the effect of spraying fungicides during flowering twice a week was investigated. The plots treated twice a week contained a lower degree of fruit rot than plots sprayed once a week.

Résumé La pourriture des fraises, qui se manifeste à la récolte et au transport, est surtout provoquée par des infections de *Botrytis cinerea* durant la floraison. La lutte contre cette infection florale consiste en des traitements hebdomadaires. L'analyse des différentes parties des fleurs (sépales, pétales etc.) a révèlé que toutes ces organes floreaux contenaient une quantité suffisante de fongicide, pour prévenir la croissance du champignon (> 100 ppm). Quelques jours après le traitement de nouvelles fleurs surgissent provenant de boutons qui ne sont recouverts qu'extérieurement. Les parties florales internes ne contiennent pas de fongicide, elles sont susceptibles et des infections peuvent avoir lieu durant plusieurs jours jusqu'à la pulvérisation suivante une semaine plus tard. Dans une expérimentation en serre et en utilisant des infections artificielles nous avons étudié l'effet de pulvérisations aux fongicides exécutées deux fois par semaine pendant la floraison. Les parcelles traitées deux fois par semaine contenaient une quantité de pourriture inférieure comparées aux parcelles traitées une fois par semaine.

INTRODUCTION

Fruit rot of strawberries is mainly caused by *Botrytis cinerea*. The fungus may infect various parts of the flowers soon after the buds open, causing either an agressive blossom blight or a latent infection which at favorable conditions can give the typical grey mould rot (Jarvis & Borecka, 1968). Direct infection on the ripe berry is also possible to a certain extent (Hennebert & Gilles, 1958). This problem is discussed elswere (Kamoen & Jamart, 1975).

In the present paper an improved flower treatment is studied for a better control of pre- and post-harvest fruit rot.

METHODS & MATERIALS

Strawberries under glass or in the field were treated with dichlofluanid or benomyl once or twice a week. To prevent high residues on harvested fruit half the normal fungicide concentrations were used for the twice weekly sprayings. For dichlofluanid 25 and 12,5 g/are Euparen (50 % a.i.) was used and for benomyl 8 and 4g/are Benlate (50 % a.i.) Each treatment was applied on four plots of 16 plants.

Botrytis infections on flowering plants were effected by spraying a spore suspension over the plants with a hand sprayer. The amount of post harvest rot was examined after three days conservation. The ripe berries were separately put on filterpaper on tables in the laboratory.

Analyses of flower parts were made be means of bioautography on thin layer chromatograms (Jamart, Kamoen, Moermans, 1975). Small flower parts of about 10 mg (e.g. one petal leaflet) were macerated in 0,2 or 0,5 ml ethyl acetate. Appropriate amounts were spotted on the thin layer plates.

Benomyl residue on fruits was analysed by U.V. spectrophotometry (Mestres et al 1971). Residue of dichlofluanid was analysed by gaschromatography (Vogeler & Niessen, 1967).

RESULTS

Influence of flower treatments on fruit rot

In the first series of experiments the influence of flower treatments on pre- and post-harvest fruit rot was re-examined.
Table 1 shows that if flowers are treated there is less fruit rot both at harvest and after keeping for three days. From this and other results (Kamoen& Jamart,1974, Jordan,1973, Maas & Smith,1972) it appears that post-harvest rot as well as rot in the field is mainly due to outbreaks of latent infections on the flowers.

Table 1

Influence of flower treatments on percentage of fruit rot

a) at harvest and b) after a keeping period of three days

experiment date :	19.07.74		24.07.74		04.07.73
	a	b	a	b	b
benomyl	0,5	5	2	5	10
dichlofluanid	1	1,5	0,2	3,5	6
untreated	6,3	12	8,4	6	15

Analyses of flowers after treatment

The fruit rot initiated at flowering can be reduced by spraying with fungicides once a week during flowering. Over a period of more than ten years a number of fungicides have been tested according to this weekly standard programme.

Although several fungicides are excellent products for Botrytis control, the reduction of fruit rot is never complete and often poor (see table 1 and review by Kamoen & Jamart, 1974). In order to examine if the flowers are sufficiently covered with fungicides by the normal spray dosages at flowering fungicide analyses were made of different flower parts.

The analyses revealed that one day after spraying the flower parts mostly contain a sufficient amount of fungicide ($>$100 ppm) to prevent fungal growth (table 2). A few days after treatment however new flowers arise from buds closed at spraying (see fig. 1). The protection of the new opening flowers is inadequate (table 2) since many of their internal parts contain no detectable fungicide ($<$1 ppm). These internal flower parts are susceptible to Botrytis (Powelson, 1960) and an infection can occur during several days.

Table 2

Percent flowerparts with inadequate protection during the week after a flowerspray

days after treatment:		1	3	5	6
receptacles	(internal	0	100	95	95
stamens	flower	0	100	75	90
petals	parts)	0	50	90	98
sepals	(external flower parts)	5	0	25	10
phase at treatment:		open flowers	white buds		green buds

It was shown previously by Kamoen & Jamart (1974) that, once the fungus has penetrated, the infection can be stopped only partially by a normal fungicide spray applied two days later. For a better protection of the flowers spraying about twice a week seems advisable.

Field experiments

Consequently two experiments were set up spraying once or twice a week during flowering with dichlofluanid and benomyl.

In a first field experiment treating once or twice a week no significant differences could be found between both spray schemes due to a low degree of Botrytis infection.

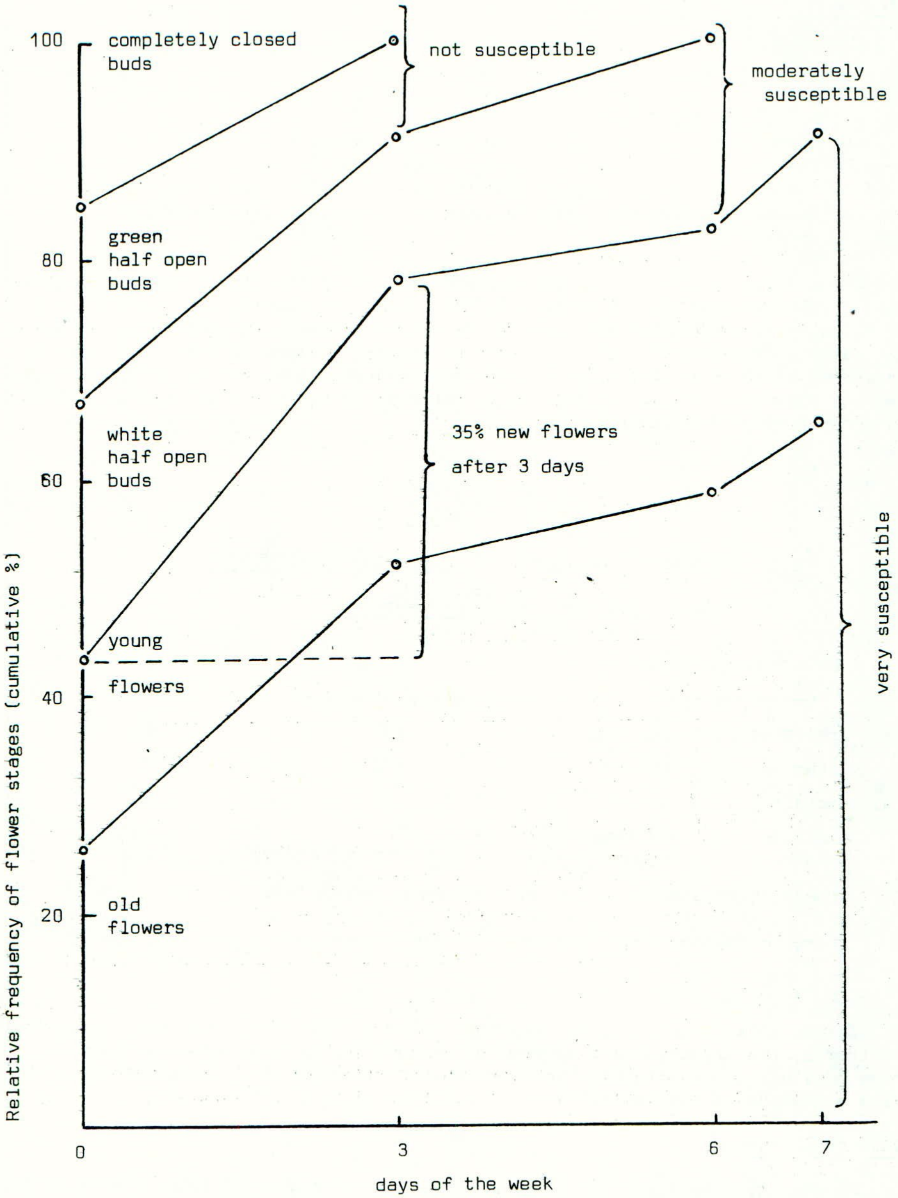

Fig. 1 : Development of buds on strawberry plants during one week at full bloom.

A new experiment was set up this year in a glasshouse. In order to increase the infections, Botrytis spore suspensions were sprayed every week on Thursday morning on the flowering plants c v. Senga gigana.
(a) Plots treated once a week were sprayed on Monday i.e. four days after and three days before the infection
(b) Plots treated twice a week were sprayed on Monday and on Thursday afternoon about six hours after the infection on Thursday morning.
(c) Control plots without fungicide treatment received an artificial infection on Thursday as well.

Tables 3 & 4 give a survey of the results of treatments with dichlofluanid and benomyl respectively. With both fungicides the amount of rot following two treatments a week was significantly less ($\alpha = 0,05$) than that following a single treatment (°).

Table 3

Percent rot and yield per plant on plots treated once or twice a week with dichlofluanid

treatment	% rot	yield g/plant	number of fruits/plant	mean weight of the plants
once a week	3.6	172	17.6	497 g
twice a week	1.1	150	16.5	493 g

Table 4

Percent rot and yield per plant on plots treated once or twice a week with benomyl

treatment	% rot	yield g/plant	number of fruits/plant	mean weight of the plants
once a week	2.4	210	19.3	830 g
twice a week	0.9	201	19.0	830 g

(°) On the control field the percent fruit rot was 9.7 %, it is significantly different ($\alpha = 0.01$) from rot on treated plots.

In relation to yield, however, whereas the use of benomyl had no siginifcant effect, the use of dichlofluanid significantly (α = 0,01) lowered the production of fruit compared with the control plots, which gave 18.5 fruits and 225 g/plant. The low yield of dichlofluanid treated plots is probably due to the phytotoxicity of dichlofluanid in glasshouse. This is also demonstrated by the weight of the plants after harvest (table 3 & 4, control = 925 g/plant).

The residue on the fruits was analysed at harvest. There were no significant differences between the residues on fruits from fields treated once a week at normal spray concentration and fields treated twice a week at half spray concentration.

DISCUSSION

The origin of strawberry fruit rot caused by Botrytis flower infections has been known for nearly twenty years (Hennebert & Gilles, 1958) and it has been confirmed repeatedly.Consequently standard spray schemes were tested using all kinds of fungicides and spraying mostly once a week during flowering. In several cases only a moderate reduction of the fruit rot was obtained in comparison with untreated strawberries, despite the good knowledge of the infection mechanism and the diversity of fungicides tested.

From analyses of the flowerparts it appears that young flowers are unprotected for several days between the weekly treatments. In order to increase the flower protection spraying twice a week seems advisable.

We tried to confirm our statements based on analyses of the flowers by practical field experiments. However, to prove the superior protection of spraying twice a week, artificial infections just between the weekly treatments are necessary. In a first field experiment without artificial infections the differences of fruit rot were not significant. In a second glasshouse experiment with artificial infections there was less fruit rot spraying twice a week than spraying once a week and the differences became significant.

In this way an improvement of the strawberry spray scheme is demonstrated theoretically by means of flower analyses and in a practical way by means of a glasshouse experiment.

Acknowledgements

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References

HENNEBERT, G.L. & GILLES, G.L. (1958). Epidémiologie de Botrytis cinerea Pers. sur fraisiers. Meded. LandbHogesch. OpzoekStns, Gent, 23 (3-4):864-888

JAMART, G., KAMOEN, O. & MOERMANS, R. (1975). Quantitative determination of methyl 2-benzimidazolecarbamate by bioautography on thin layer chromatograms. Neth.J.Pl. Path.81 (1): 42-44

JARVIS, W.R. & BORECKA, H. (1968). The susceptibility of strawberry flowers to infection by Botrytis cinerea Pers. ex. Fr. Hort. Res., 8:147-154

JORDAN, V.W. (1973). The effects of prophylactic spray programmes on the control of pre- and post-harvest disease of strawberry. Pl. Path. 22:67-70.

KAMOEN, O., & JAMART, G. (1974). Problems of Botrytis fruit rot control on strawberries. Meded. Fak.Landb.Wet.,Gent, 39 (2):1107-1119.

MAAS, J.L. & SMITH, W.L. (1972). Preharvest fungicide treatments for increasing yields and controlling pre- and postharvest fruit decay of strawberry. Plant Disease Reptr. 56 (4): 296-299.

MESTRES, R., TOURTE, J. & CAMPO, M. (1971) Dosages des résidus de benomyl dans les fruits et les légumes. Trav. Soc. Pharm. Montpellier, 31 (1):49-56.

POWELSON, R.L., (1960). Initiation of strawberry fruit rot caused by Botrytis cinerea. Phytoptahology 50 : 491-494.

VOGELER, K. & NIESSEN, H. (1967). Kolorimetrische und gaschromatographische Bestimmungen von Rückständen in Pflanzen nach Anwendung von Euparen. Pflanzenschutz-Nachrichten "Bayer", 20 (2): 534-549.

NOTES

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THE CONTROL OF STORED PRODUCT MITES BY CONTACT ACARICIDES

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Summary A number of pesticides have been assessed for effectiveness against *Acarus siro*, *Tyrophagus putrescentiae* and *Glycyphagus destructor*. The most effective compounds which controlled all three species were certain insecticides normally used against stored-product insects. However, the practical value of one of these compounds, lindane + malathion, is severely restricted due to the widespread distribution of lindane resistant strains of *A. siro* and *G. destructor*. Practical trials have shown that treatments with pirimiphos-methyl or bioresmethrin + pb will control mites in the fabric of buildings and in stored grain and these compounds will also control lindane-resistant strains.

INTRODUCTION

Mites of the family Acaridae are well known pests of stored food. As early as 1918 NEWSTEAD and DUVALL reported that serious infestations of mites occurred in Canadian wheat stored in warehouses at Liverpool for 18 months. VEBER (1925) found that *Acarus siro* (L.) was one of the most common grain pests in Eastern Russia. In Poland, BOCZEK and GOLEMBIOWSKA (1959) observed that *A. siro* and *Glycyphagus destructor* (Schrank) occurred in large numbers in grain. Numerous other reports from countries including Canada, Taiwan, Eire and France, confirmed that serious mite infestation can occur in stored grain.

Modern grain storage practice seems to have done little to reduce mite problems. In a recent survey of farm-stored cereals in England and Wales 95 per cent of the grain examined was found to be infested with mites (GRIFFITHS *et al*., 1975). The numbers present varied considerably but in one case 1.5 million *G. destructor* per kg of barley were found. The survey also showed that at least some grain in most bulks or bins examined had a moisture content of more than 14 per cent and, therefore, provided a suitable environment for the development of mites. A wide range of stored foods are susceptible to damage by mites particularly those of a farinaceous nature such as compounded animal feedingstuffs. Other products which may be damaged by mites include oil seeds, cheese, dried meats and even sugar.

Many species of mites infest stored food but the genera *Acarus*, *Tyrophagus* and *Glycyphagus* contain the most important pests. Their morphology and ecology differs considerably from other mite pests such as the plant mite of the family Tetranichidae. They respire cutaneously and require a relative humidity of more than 65 per cent for survival and about 90 per cent for optimum breeding. However, most species are well adapted to live in temperate climates being able to complete their cycle at about 5°C and to survive long exposures to 0°C.

Heavy infestations of mites can cause serious damage which is by no means confined to the food consumed. Some species have very strong smells and can impart a taint to infested goods. Mites in grain tend to be selective feeders, concentrating on the germ and thus destroying the ability of seed to germinate. In Britain several thousands of tons of grain are rejected annually due to the presence of mites. The rejected grain has to be disinfested before being acceptable and even then may be down-graded. A large cheese factor considered that the annual cost of removing mites from infested cheeses before sale amounted to more than £20,000. Additionally, mites are known to cause allergic reactions in workers handling infested produce and feed containing mites can affect animals.

One method to avoid a serious mite infestation is to dry produce and to reduce the relative humidity in stores. However, practical or economic reasons often make this impossible. A relative humidity of more than 85 per cent must be maintained during the maturing of cheese, thus offering ideal conditions for the development of mites. If grain is dried to less than 14 per cent moisture content serious mite infestations will not develop but the EEC intervention scheme and the British grain trade accept grain at up to 16 per cent moisture content. In any event, surface layers of stored grain tend to absorb moisture from the atmosphere during the damp winter months.

Chemical control using contact acaricides has been used for many years, but compared to the large amount of data available on the effectiveness of pesticides against insects, there is little information about the effectives of acaricides on mites. This is probably due to the difficulties in handling and confining mites and assessing their response to pesticides.

Over the past ten years the Pest Infestation Control Laboratory has carried out research into the control of mites using contact acaricides. The present paper summarises some of the results obtained in laboratory and field experiments.

LABORATORY TESTS

Evaluation of pesticides

Two screening tests have been employed to select materials showing promise in controlling stored-product mites. Initially, chemicals under test were mixed with flakes of wheat germ and A. siro were confined on the treated food for 6 weeks at 17.5°C and 75% r.h. Large doses of pesticides were needed before results were obtained, even with the most effective compounds. The materials tested included the organochlorine insecticides DDT, dieldrin, aldrin and lindane, and the acaricides intended to control mites on growing plants diphenyl sulphone, fluorbenside, tetradifon, chlorbenside and dinocap. All the acaricides intended for use against plant mites were ineffective against A. siro as was DDT but lindane, aldrin and dieldrin showed promise.

An improved technique was used for later tests in which the pesticide was sprayed on to whole wheat (WILKIN and HOPE, 1973). Using this method results were obtained after a 14-day exposure and at dosage levels close to those used in practice. The pesticides examined were mainly compounds with a relatively low mammalian toxicity and, therefore, having potential for use in food stores. The results are given in Table 1 in which the compounds are arranged in order of effectiveness. A compound was only considered effective if all the mites were killed during the 14-day exposure period. Six chemicals were effective against all three species but of these only lindane + malathion, pirimiphos-methyl and bioresmethrin are readily available.

Resistance to lindane

In recent years a further complication in controlling mites has arisen. The effectiveness of lindane, once the most widely-used acaricide for stored produce, has diminished and on several occasions mites have survived despite the application of the recommended dose. Laboratory tests of these survivors, in which mites were exposed to a range of doses of lindane, confirmed that strains of both A. siro and G. destructor have developed resistance to lindane. The response to lindane of susceptible and resistant strains of A. siro and G. destructor is compared in Fig 1.

Resistance was initially detected in a cheese store (WILKIN, 1973) but a large number of strains showing a marked resistance to lindane has now been collected from farms and warehouses throughout Britain. Several other species of mites are able to survive treatments with lindane but whether this is due to the species being naturally tolerant or whether it is due to the development of resistance has not been determined.

Lindane-resistant strains of A. siro and G. destructor have been examined for cross-resistance to bioresmethrin and pirimiphos-methyl. The effectiveness of these pesticides against resistant and susceptible strains is shown in Table 2. The strain of A. siro used in these tests was not killed by 100 ppm lindane and was therefore more resistant than the strain used to obtain the data in Fig 1.

The results of the laboratory screening tests show that only a limited number of pesticides have a broad spectrum of activity. The range of useful compounds is reduced still further by resistance to lindane. However, two materials, bioresmethrin and pirimiphos-methyl, already used to control stored-product insects, show considerable promise as acaricides even against lindane-resistant strains.

PRACTICAL TRIALS

In farm stores

Residual populations of mites are commonly found in empty stores and thus pose a serious threat to any infestible products subsequently placed in the premises. In particular, empty farm grain stores frequently harbour large populations of mites in residues of grain and the fabric of the building. These mites are difficult to detect by normal inspection techniques and are often not removed by cleaning. Therefore, trials have been carried out to assess the value of treating farm stores with acaricides in protecting stored products from mite attack.

In one experiment an empty modern farm granary of about 600 tons capacity was treated with lindane + malathion shortly before harvest. The premises had a previous history of infestation and had a heavy residual population of A. siro, G. destructor and Tyrophagus longior. Laboratory tests on the A. siro and G. destructor showed them to be susceptible to lindane. The degree of infestation was measured by estimating the numbers of mites congregating on fishmeal baits over a 24-h period. Before treatment the farmer thoroughly cleaned the granary, reducing but not eliminating the infestation. However, the application of lindane + malathion emulsion at the rate of 270 mg/m^2 + 810 mg/m^2 dramatically reduced the number of mites. Fourteen days after treatment the only mites found were associated with a small heap of debris missed during the cleaning. Before any grain was brought into store this area was cleaned and re-treated.

The subsequent harvest remained free from infestation for three months despite a moisture content of about 16% A light infestation of A. siro which then developed on the surface of some bins of wheat could possibly have been introduced by rodents or birds.

Serious mite infestations also occur during the maturing and storage of traditional cheeses. In the past such infestations were kept at bay by the application of 0.5% lindane dust to the surface of the cheese but the widespread resistance to lindane has led to a complete breakdown of control. However, laboratory tests showed that pirimiphos-methyl would control cheese mites including those able to survive large doses of lindane. Field trials have, therefore, been carried out to assess the effectiveness of this compound under practical conditions.

A small farm store used to mature Cheddar cheeses produced on the premises and having a heavy infestation of Acarus chaetoxysilos Griffiths, A. farris and T. longior was used for a trial. The building was maintained at 12°C and 85% r.h.; conditions required for maturing cheese but also providing an ideal environment for mites. Pirimiphos-methyl emulsion, diluted to 2%, was applied to half the store, after removing the cheese, at the rate of 440 mg/m^2. The other half of the store was left untreated as a control. Baiting, before and after treatment, showed that the mite population in the treated half was reduced to zero within two weeks whereas numbers in the untreated portion remained unchanged. Cheeses subsequently stored in the treated half remained mite free throughout the three-month storage period.

One advantage of this method is that direct application of a pesticide to cheese is avoided so that the risks of gross pesticide residues in food is reduced. Only limited uptake of pirimiphos-methyl occurs in cheese placed in contact with treated shelving. THOMAS and ROWLANDS (1975) found that, in Cheshire cheese stored for 3 months on a board treated with 440 mg/m^2 pirimiphos-methyl, residues were confined to the outer 4 mm of the cheese in contact with the treated surface and never exceeded 13 ppm.

Control measures based on pirimiphos-methyl have now been widely and successfully adopted by the cheese industry.

In farm-stored grain

The admixture of insecticides is widely used to disinfest stored grain and protect it from further attack by insects. However, there is little data on the value of this method in controlling grain mites and therefore some trials have been carried out to assess the effect on mite infestations of admixing suitable compounds with stored grain.

Initial trials (WILKIN, 1975) showed that lindane + malathion admixed at 2 ppm + 9 ppm or pirimiphos-methyl at 4 ppm controlled infestations of T. longior, G. destructor, A. Farris and A. siro in farm-stored barley. With either treatment no reinfestation occurred during the 4.5 months storage period. However, the problem of the resistance to lindane amongst mites has markedly reduced the effectiveness of lindane + malathion. Therefore, a further trial was carried out in which bioresmethrin was admixed with wheat infested with A. siro.

Three bulks of wheat, each of about 30 tonnes and heavily infested with A. siro, were treated with bioresmethrin + piperonyl butoxide. The grain was turned using augers and the diluted emulsion added at the rate of 1.5 pints per tonne using an electrically-operated, hydraulic sprayer. The individual bulks were treated with different doses, these being 4 ppm + 20 ppm, 2 ppm + 20 ppm and 2 ppm + 2 ppm bioresmethrin + p.b. The grain had an average moisture content of 15.5 per cent and a temperature of about 15°C and these conditions remained almost constant throughout the trial.

Before and after treatment mite numbers in the grain were assessed by sieving 250 g samples collected from various parts of the bulk with a sampling spear, and counting the live mites in the sievings. During two of the treatments the mite numbers were also estimated in samples collected from the grain flow during conveying.

The average number of live mites found in the samples is given in Table 3. The reduced mite numbers in samples collected during treatment compared to the pre-treatment level is due to the action of conveying, even though the grain had only travelled through a short auger. The three treatments were equally effective in controlling A. siro but the 4 ppm + 20 ppm treatment appeared to produce a more rapid kill. The different ratios of p.b. did not effect the action of 2 ppm bioresmethrin against mites. This confirmed laboratory results which showed bioresmethrin at 2 ppm was equally effective with or without p.b. (WILKIN and HOPE, 1973). Chemical assessment of the residues of bioresmethrin + p.b. in samples of grain collected during and after treatment confirmed that the intended dose was applied and very little breakdown occurred during the 56 and 77 days storage period. A heavy mite infestation was present in the store, particularly in untreated grain residues, which provided a reservoir for reinfestation. However, no evidence of reinfestation was found in the treated bulks and the trial ended with the wheat being sold virtually free from mites.

DISCUSSION

Mite infestations are commonly made up from several species and, in any event, the identification of mites to species under field conditions is virtually impossible. Therefore, any control measures should be effective against a wide range of species. The laboratory experiments showed that few pesticides met this requirement. Almost all the acaricides intended to control plant mites proved ineffective against the stored product species, clearly demonstrating the wide biochemical differences between the two groups. However, the most effective pesticides were among insecticides with some already being used in food stores to control insects. In particular, lindane + malathion, chlorpiriphos, chlorpiriphos-methyl, phenthoate, pirimiphos-methyl, phoxim and bioresmethrin produced complete kill of all three species of mites tested at dosage levels likely to be used under practical conditions. Five of these compounds have not yet been introduced for use in food stores and some may never be. The number available for practical use is seriously restricted.

The development of resistance to lindane by A. siro and G. destructor has further reduced the range of pesticides available. Lindane + malathion, which was a particularly effective acaricide, together with lindane were the most widely-used materials to control stored-product mites in the United Kingdom. However, the levels of resistance and the widespread distribution of resistant strains has virtually ruled out further use of these materials. Fortunately, the lindane-resistant strains can be controlled by certain organophosphorus compounds or the synthetic pyrethroid, bioresmethrin.

Under practical conditions treating the fabric of a store with an acarcide can be most beneficial in preventing the subsequent infestation of clean goods put into store. In cheese stores such treatments were very effective against heavy infestations of several species of mites known to be able to survive high doses of lindane. The cheeses were protected despite being stored under conditions which favour the rapid development of mites. However, the effectiveness of treatment can be reduced if conditions of storage permit the reintroduction of mites.

Established mite infestations in farm-stored grain can be effectively controlled by admixture of a suitable acaricide and this treatment also confers a considerable degree of protection against reinfestation. The trials with pirimiphos-methyl and bioresmethrin + p.b. were very successful but in both cases about two weeks was required to reduce the population to a very low level. This slow response is often found in the practical control of mites and may be due to the relatively low temperatures at which infestations occur. The technique for admixture is already widely accepted against insects and in any case treatments with pirimiphos-methyl at 4 ppm and bioresmethrin + p.b. at 4 ppm + 20 ppm could be expected to control many stored grain insects in addition to mites.

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References

BOCZEK, J. and GOLEMBIOWSKA, Z. (1959) Investigation on the distribution of mites connected with the storage of food productions in Poland. Roczniki Naul Polnicych, 79A, 969-988.

GRIFFITHS, D.A., WILKIN, D.R., SOUTHGATE, B.J. and LYNCH, S. (1975) A study of mites in bulk grain stored on farms in England and Wales. Annals of Applied Biology. (In press)

NEWSTEAD, R. and DUVALL, H.M. (1918) Second memorandum on Acarids (mites) occurring in stored grain and flour. Report of grain pests (war) committee No. 4, 1-11.

THOMAS, K.P. and ROWLANDS, D.G. (1975) The uptake of pirimiphos-methyl by Cheshire cheese. Journal of stored Product Research, 11, 53-56.

VEBER, I.K. (1925) An investigation of grain stores to ascertain the extent of their infestation by grain pests. Defénse des plantes ii, 3, 153-154.

WILKIN, D.R. (1973) Resistance to lindane in Acarus siro from an English cheese store. Journal of stored Product Research, 9, 101-104.

WILKIN, D.R. (1975) The effects of mechanical handling and the admixture of acaricides on mites in farm-stored barley. Journal of stored Product Research, 11, 87-95.

WILKIN, D.R. and HOPE, J.A. (1973) Evaluation of pesticides against stored product mites. Journal of stored Product Research, 8, 323-327.

TABLE 1. The effectiveness of various pesticides against *Acarus siro*, *Tyrophagus putrescentiae* and *Glycyphagus destructor* after 14 days exposure at 17.3°C and 75% r.h. The dose in ppm used is given in brackets

Organo-phosphorus compounds	Pyrethroid	Others
Effective against all three species		
Chlorpiriphos (2)	Bioresmethrin (2)	Lindane + malathion (2.5 + 7.5)
Chlorpiriphos-methyl (2)	Bioresmethrin + p.b. (2 + 20)	
Phenthoate (10)		
Pirimiphos-methyl (4)		
Phoxim (2)		
Effective against *T. putrescentiae* + *G. destructor* (not *A. siro*)		
Malathion (10)	-	-
Fenitrothion (2)		
Iodofenphos (10)		
Tetrachlorvinphos (20)		
Effective against *A. siro* + *G. destructor* (not *T. putrescentiae*)		
-	Pyrethrins + P.b. (2 + 20)	Lindane (2.5)
Effective against *G. destructor* only		
Bromophos (12)	-	-
Dichlorvos (2)		
Ineffective against all three species		
-	Pyrethrin	Bromopropylate (10)
	Bioallethrin	Carbaryl (5)
	Bioallethrin + p.b. (2 + 20)	Quinomethioate (10)
		Piperonyl butoxide (2)

Data from WILKIN and HOPE (1973)

TABLE 2. The effectiveness of a range of doses of three pesticides against lindane resistant strains of A. siro and G. destructor

Pesticide	Dose (ppm)	A. siro		G. destructor	
		Susceptible	Resistant	Susceptible	Resistant
Lindane	2.5	+	0	+	0
	25	+	0	+	0
	50	+	0	+	0
	100	+	0	+	0
Pirimiphos-methyl	1	0	0	+	+
	4	+	+	+	+
Bioresmethrin	2	+	0	+	+
	4	+	+	+	+

+ = 100% kill after 14 days exposure

0 = Less than 100% kill

TABLE 3. The mean numbers of A. siro /kg in samples collected from bulks of wheat

Bioresmethrin + Pb (ppm)	Before treatment	During treatment	Days after treatment					
			3	7	14	28	56	77
2 + 2	4235	1376	42	83	24	1	4	0
2 + 20	4235	1100	20	95	53	0	3	3
4 + 20	4235	-	-	9	-	1	4	-

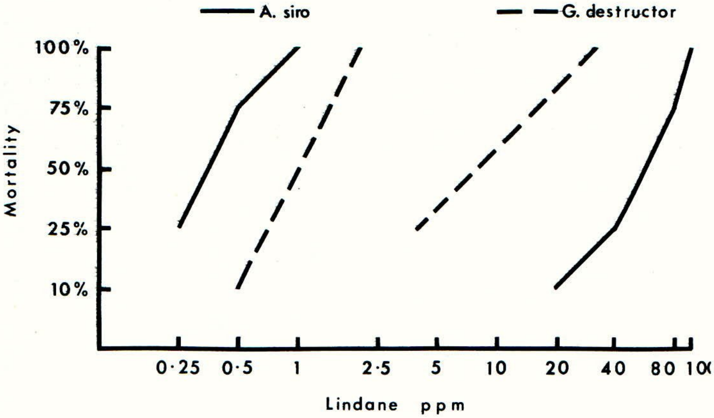

Fig 1. The effectiveness of lindane against resistant and susceptable strains of _A.siro_ and _G.destructor_.

NOTES

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AN ASSESSMENT OF RESIDUAL INSECTICIDE TREATMENTS FOR THE CONTROL OF THE SAW-TOOTHED GRAIN BEETLE (*Oryzaephilus surinamensis*) IN FARM GRAIN STORES

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Summary A series of trials have been carried out to assess the effectiveness of single applications of residual insecticides for the control of *Oryzaephilus surinamensis* in farm grain stores. The insect populations were assessed by the use of count areas, bait traps and visual inspection and the persistence of the insecticides was determined by bioassay.

Surviving insects were detected up to 3 months after treatment in all but one of the treated grain stores. The relationship between these survivors and the subsequent infestation of the new harvest, together with the implications for the control of insecticide-resistant *O. surinamensis* are discussed.

INTRODUCTION

Pre-harvest spraying of grain stores to control the Saw-toothed grain beetle (*Oryzaephilus surinamensis*) is widely practised in the United Kingdom but the variable results obtained and the relative merits of the various insecticides used often raise questions of doubt about the efficacy of the practice. During the last ten years trials have been carried out by this laboratory to assess the effectiveness of single applications of a residual insecticide. These trials have been briefly reported in Pest Infestation Research (GREEN et al. 1965, TYLER et al. 1966, 1968, GRADIDGE et al. 1970, WILKIN et al. 1970 and PINNIGER et al. 1975) and it is felt that the techniques used and the results obtained can now be evaluated.

METHOD AND MATERIALS

Trials procedure

The insecticides and formulations used in the trials are listed below (Table I). The treatments have been as comprehensive as possible under the practical limitations of commercial grain storage and were well within the capabilities of a conscientious servicing company or grain store manager. In most cases cleaning of the grain store before treatment was thorough and residues were removed where possible. In many premises, however, inaccessible residues and any old infested grain were treated with insecticidal dust or liquid fumigants.

TABLE I

Insecticides and formulations used for residual treatments

Bromophos	w.p.
Fenitrothion	w.p
Iodofenphos	w.p.
Lindane	smoke, w.p.
Malathion	smoke, dust, w.p.
Phoxim	e.c.
Pirimiphos-methyl	e.c., w.p.
Pyrethrins	Oil solution

The experimental treatments were carried out one or two months before harvest. Commercial formulations of insecticide (cleared by the Pesticides Safety Precautions Scheme for commercial or experimental trial use in grain stores) were applied with a motorised knapsack sprayer, a small pressure sprayer being used in confined areas. The application rate was usually 5 litres/100 m^2 (1 gal/1000 ft^2) but this rate was halved for large areas of metal and doubled for very porous surfaces with the insecticide concentration adjusted to give the same overall insecticide deposit. A small hand-operated duster was used to treat some of the inaccessible dead spaces.

Use of bait traps

Accurate assessment of residual infestation levels and the subsequent effects of the treatment on the population is critical for comparative trials. A commonly used method is to record the live, affected and dead insects which accumulate on pre-determined count areas over fixed periods of time. Using this method earlier trials provided useful information on the toxicity of the insecticides and the level of kill obtained. However, very light infestations and pockets of post-treatment survivors could often remain undiscovered even with additional inspection of the building. A simple bait trap technique was therefore developed to provide more detailed population assessments.

The bait traps consist of plastic mesh bags containing food. When placed in the grain store environment they will arrest the movement of wandering insects and are believed to attract others from their harbourages. After a predetermined exposure period the insects are sieved from the bait simply by shaking the bag. The technique is described more fully by DYTE et al (1975). In certain situations bait traps can be inserted into dead spaces and crevices which are impossible to inspect visually. The use of bait traps in the more recent trials has often resulted in the discovery of pockets of surviving insects which would otherwise have remained undetected (TABLE II).

TABLE II

Detection of Residual Infestation

	A	B	C
TYPE OF GRAIN STORE	Metal bins in an old brick granary	Metal bins in a modern concrete and asbestos building	Metal bins in an old brick granary
NUMBER OF BAIT TRAPS USED	15	11	16
NUMBER OF O. surinamensis PER TRAP BEFORE TREATMENT	Up to 5,000/week	Up to 200/week	Up to 12,000/week
INSECTICIDE (Applied at 470 mg/m^2)	Fenitrothion w.p.	Pirimiphos-methyl e.c.	Pirimiphos-methyl e.c.
NUMBER OF LIVE O. surinamensis IN BAIT TRAPS AFTER TREATMENT OF THE GRAIN STORE	Continuous low catch (1 or 2/week) for 12 weeks in bait traps in the vicinity of dead spaces between bins and granary wall	None detected except 14 insects in one bait trap in an area which had been missed in the treatment. After local spraying no further insects were found	Continuous low catch (1 or 2/week) for 12 weeks in bait traps in the vicinity of dead spaces and in outbuildings
LIVE INSECTS DETECTED BY VISUAL INSPECTION	None after 3 weeks	None	None after 3 weeks

Determination of deposit by bioassay

It is also important to assess accurately the insecticide deposit. Filter papers were attached to the granary structure and removed after treatment for analysis by GLC. This initial deposit was subject to physical and chemical degradation and the length of life of the insecticide is an important factor influencing the effectiveness of a treatment. A standard bioassay has been developed to compare the persistence of insecticide deposits. Adults (2-4 week old) of a laboratory strain of the Confused flour beetle (Tribolium confusum) are confined on treated surfaces for 24 hours and the mortality of the insects is recorded 24 hours after removal. For comparative purposes the effective residual life of an insecticide is defined as the period during which the deposit achieves 100% kill of the test insects.

The effectiveness of grain store treatments must, ultimately, be measured by the degree of protection afforded to grain subsequently kept in the treated grain store. Observations were made on newly harvested grain for at least 4 months so that any developing infestation would be recorded.

RESULTS AND DISCUSSION

General comparisons between the insecticides used are difficult because of the widely differing conditions and level of infestation in the grain stores.

All treatments achieved some kill of the residual populations of O.surinamensis and in many cases spectacular accumulations of dead insects were found 24 hours after treatment. However, the results from count areas and bioassays showed differences in the residual effect of the treatments.

Persistence of deposit

The results of persistence on concrete, metal and wood surfaces as determined by T. confusum bioassay are shown in Table III. Alkaline surfaces are known to hydrolise and detoxify many insecticides (LEMON 1967) and as expected concrete surfaces were the most unfavourable. There was some evidence that wettable powder formulations were more persistent than emulsions but this may have been because the physical nature of the wettable powder makes the insecticide more readily available on porous surfaces.

TABLE III

Persistence of insecticides on structural materials as determined by T. confusum bioassay

INSECTICIDE	APPLIED DOSE mg/m^2	PERSISTENCE (WEEKS)		
		WOOD	METAL	CONCRETE
Lindane w.p.	750	4	4	1
Phoxim e.c.	100	8	4	1
Malathion w.p.	750	12	12	4
Iodofenphos w.p.	750	12	12	4
Pirimiphos-methyl e.c.	470	12	12	4
Fenitrothion w.p.	470	24	16	12

Fenitrothion is known to be one of the most persistent organo-phosphorus insecticide (LEMON 1967, PRICE and WEIGHTON 1971) and its effectiveness at the dosage of 470 mg/m^2 was confirmed by bioassay which showed that the deposit of fenitrothion remained active for at least 3 months on all surfaces tested.

The persistence of malathion, iodofenphos and pirimiphos-methyl was regarded as satisfactory for residual treatments whereas the persistence and toxicity of phoxim and lindane were unsatisfactory.

Smoke generator formulations of the insecticides generally gave a high initial kill which rapidly decreased because of uneven deposits and insecticide breakdown. Very little insecticide was deposited on vertical surfaces which were therefore non-toxic to wandering insects.

After an initial kill pyrethrins showed no residual life on any surface. This was not unexpected and showed that insects which did come into contact with the insecticide in the first few hours would not be killed by the treatment.

Although bromophos shows considerable persistence even on alkaline surfaces it is not included in Table III because of its slow action. The 24 hour exposure period was insufficient to achieve 100% mortality of bioassay insects even at dosages of 1500 mg/m^2. Although bromophos was apparently effective in controlling some infestations of O. surinamensis (GREEN et al 1970) its slow speed of action gives rise to doubts about its ability to control insects not continuously exposed to toxic surfaces.

Factors affecting insect survival

Visual inspections and bait trap counts were used to determine the extent and duration of survival after treatment. Comparisons are difficult because of the variation between sites but no treatment gave complete control of a heavy residual infestation. Results show that survival can occur in refuges or residues even after a thorough treatment with an insecticide which in the laboratory was shown to be effective. The behaviour of the insects and the persistence of the insecticide are critical factors in determining the survival of a residual insect population. Laboratory experiments have shown that the behaviour of O. surinamensis in the presence of a refuge leads to a drastic reduction in the effectiveness of a residual insecticide (PINNIGER 1974). The eradication of residual insects by a contact insecticide treatment will therefore be achieved only when all the insects come into contact with a toxic deposit. This ideal state is usually impossible to achieve in a grain store.

Our trials achieved apparent eradication in only one grain store; a lightly-infested, modern building with a sound, relatively refuge-free structure. The surviving insects detected in the other 15 trials were often associated with inaccessible residues behind bins or bulkheads. At most of the farms, insects were widely distributed over an area up to 50 metres from the source of infestation. This underlines the need to treat the outside of the grain store and all nearby outbuildings.

The monitoring of infestation in the grain stored at trial sites showed that the conditions of storage were critical if infestation was to be avoided. Table IV illustrates the relationship between infestation problems and storage practice.

Whereas sensible storage prevented surviving insects becoming established in the newly harvested grain, in cases where the new harvest was neglected, survivors of the residual treatments caused serious infestation in the new grain. In all cases where insecticide was admixed with new grain on intake no infestation was detected.

TABLE IV

Condition of Storage in Relation to Subsequent Infestation in Grain

FARM	LEVEL OF INFESTATION IN STORE	RESIDUAL INSECTICIDE (470 mg/m^2)	LIVE INSECTS DETECTED AFTER TREATMENT	CONDITION OF NEW HARVEST IN AUGUST	INFESTATION IN GRAIN IN DECEMBER
a	Heavy	Fenitrothion w.p.	In residues behind bulk-head	Hot $> 35^{\circ}C$	Heavy
b	Heavy	Fenitrothion w.p.	In dead spaces between bins and wall	Cool $< 20^{\circ}C$	No insects detected
c	Heavy	Pirimiphos-methyl e.c.	In dead spaces and outside store	Hot $> 30^{\circ}C$	Heavy
d	Light	Pirimiphos-methyl e.c.	None	Cool $< 20^{\circ}C$	No insects detected

The apparent failure of many of the residual treatments to protect newly harvested grain from infestation may give rise to some concern. However, the evidence points to the fact that although eradication is extremely difficult to achieve, a residual treatment with malathion, fenitrothion or pirimiphos-methyl can reduce a population to such a low level that O. surinamensis seldom becomes established in grain which is carefully stored. Where no residual insecticide treatment is carried out the endemic population presents a much greater hazard to incoming grain.

Insecticide resistance

The protection of grain from attack by insecticide - resistant O. surinamensis may well prove more difficult. GREEN (1975) has described the problems which may arise if strains of this insect which are resistant to malathion and other organophosphorus insecticides become established in the UK. The Ministry of Agriculture, Fisheries and Food has made a considerable effort to prevent the spread of resistant O. surinamensis. Imported cargoes are monitored and treatment is required for all ships, premises and foodstuffs found to be infested with malathion-resistant O. surinamensis. The insecticide currently recommended for residual treatments is pirimiphos-methyl. Although cross-resistance to this insecticide has been demonstrated it has so far been of a sufficiently low level to leave a reasonable margin for control at the recommended dosage rates. In the event of an outbreak of malathion-resistant O. surinamensis on British farms, we would expect that a combination of grain fumigation and residual treatments with pirimiphos-methyl would effect control.

CONCLUSIONS

Treatment of storage buildings with a residual insecticide will seldom eradicate an infestation of O. surinamensis. In many cases costly treatments which are carried out are doomed to failure because of one or more of the following factors.

1. Store design
2. Standard of hygiene
3. Thoroughness of treatment
4. Time of treatment
5. Activity of insects
6. Persistence of insecticide
7. Condition of new season's grain
8. Reintroduction of insects.

The protection of grain from attack by O. surinamensis requires an awareness of all of these factors and cannot be necessarily guaranteed by sole reliance upon pre-harvest treatment of the grain store.

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References

DYTE C E, GREEN A A and PINNIGER D B (1975). Some consequences of the development of insecticide resistance in stored product insects.
Proc. 1st int Working Conf. Stored Prod. Entomology 1974 261-271.

GRADIDGE J M G, WILKIN D R and BHARADWAJ V K (1970). Insects infesting farm stores.
Pest Infest. Res. 1969 29.

GREEN A A, KANE M J, TYLER P S and WILKIN D R (1965). Insects infesting farm stores.
Pest Infest. Res. 1965 28-9.

GREEN A A, TYLER P S, KANE M J and ROWLANDS D G (1970). An assessment of bromophos for the protection of wheat and barley.
J Stored Prod. Res. 6, 217-228.

GREEN A A (1971). The protection of cereals stored on farms.
Proc. 3rd Brit. Pest Control Conf. St Helier Pap. No. 13.

GREEN A A (1975). Resistance as a problem in the control of insects and mites infesting stored products in Britain.
Proc. 4th Brit. Pest Control Conf. St Helier Pap. No. 14.

LEMON R W (1967). A laboratory evaluation of malathion, bromophos and fenitrothion for use against beetles infesting stored products. J. stored Prod. Res. 2 197-210.

PINNIGER D B (1974). A laboratory simulation of residual populations of stored product pests and an assessment of their susceptibility to a contact insecticide. J. stored Prod. Res. 10 217-223.

PINNIGER D B, WILKIN D R, HOPE J A and WILDEY K B (1975). Insects infesting farm stores. Pest Infest. Res. 1971-73 (In press).

PRICE G N and WEIGHTON D M (1971). Fenitrothion. Its place in UK agriculture. Proc. 6th Br. Insecticide and Fungicide Conf. 2 408-18.

TYLER P S, GREEN A A, WILKIN D R and BRISTOW S G (1966). Insects infesting farm stores. Pest. Infest. Res. 1966 29-30.

TYLER P S, GREEN A A, HOPE J A and ROBBINS B (1969). Insects infesting farm stores. Pest Infest. Res. 1968 30-31.

WILKIN D R, GREEN A A, HOPE J A, KANE M J and AGGARWAL S L (1973). Insects infesting farm stores. Pest Infestation Control. Combined report of the Director of the Pest Infestation Control Laboratory 1968-70 109.