HGCA

PROJECT REPORT No. 6

THE CONTROL OF INSECTS IN EXPORT GRAIN

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The control of insects in export grain

by

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INTRODUCTION

The export of grain from the United Kingdom has expanded greatly during the 1980s. Initially, a trade in barley to Eastern European countries was established but the market is now much wider and buyers of UK grain are spread throughout the world. Current levels of cereal production provide an exportable surplus of around 8-10 million tonnes and this level of availability looks likely to continue for some time into the future.

Historically the UK was always a net cereal importer and, consequently, grain handling facilities at ports have been in the form of intake silos with only limited ability to outload. As a result the early export efforts were concentrated on small, often unregistered, ports which loaded vessels of around 1000 tonnes. These shipments were distributed via the European inland waterway system or trans-shipped to larger vessels at ports such as Rotterdam. In the early years the network of small ports, mostly along the east coast of the country, worked effectively and provided an export route with minimum capital expenditure. However, more recently the size of cargoes has increased greatly and a number of deep-water berths are now being used to load export grain. In some cases large silos have been purpose built and in others existing silos have been adapted to outload grain.

Freedom from infestation has always been a quality requirement of export grain. This can take one of two forms: either a contractual requirement or a phytosanitary requirement prohibiting the presence of certain specific pest species. The latter is an arrangement between governments and is administered by an appropriate official body. In the UK the task of providing phytosanitary certificates for export grain is undertaken by the MAFF, and Ministry staff must inspect grain during loading to confirm that none of the specified pests are present before a certificate can be issued. Where no certificate is required the grain is generally inspected by cargo superintendents who check for the presence of any insects.

The system of inspecting grain during loading was satisfactory with small cargoes when individual lorry loads could be inspected and cleared for tipping. It became much more difficult to inspect grain at the new, larger facilities. For example, these silos were often filled over a period of weeks before a ship was loaded so that it was not possible to ensure that all grain was checked by MAFF staff or cargo superintendents during intake. Therefore, the grain had to be examined as it was outloaded onto the vessel. Generally this involved collecting samples from a conveyor belt linking the silo and ship. Unfortunately, if infestation was discovered during loading it had to be assumed that, by the time the conveyor could be stopped, some pests would have reached the ship. In this case the only resort was to fumigate the cargo; an expensive, dangerous and not entirely reliable procedure.

Another problem that arose, particularly over the issue of phytosanitary certificates, was the availability of Ministry staff. The new export silos were organised to work long hours and at least 6 days a week. It became increasingly difficult to ensure that MAFF staff would be available at all times and this began to cause the trade some difficulties.

One possible alternative method of ensuring freedom from infestation could be to admix a suitable pesticide with the grain. There are a large amount of data available to show that several pesticides will control all grain pests likely to be present in UK grain[1]. Such treatments are relatively inexpensive and would fit in readily with out-loading operations at many of the port silos. It is not surprising, therefore, that during 1983-4 a number of treatments were under-taken to ensure that any insect and mite pests in grain at the time of loading were killed during transit.

Although the admixture of a pesticide with grain appears to offer many advantages there are a number of technical difficulties that could seriously limit the use of the technique. Most assessments of pesticides intended for use as grain protectants have been aimed at determining the period of protection offered by a single treatment, hence the speed of action has not been important. Speed of action is also effected by the temperature of the grain. This is not very important when considering long term protection but could be of great significance when complete kill of insects is needed over a limited period of time. Obviously the temperature of grain and the length of voyage must influence the effectiveness of any treatment applied to export grain. Unfortunately, there are a lack of data on the effects of temperature on the speed of action of grain protectants or on the likely range of temperatures of UK grain as supplied for export.

The work reported in this paper was carried out to investigate the speed of action of pesticides applied to grain and to attempt to define the conditions under which treatments would and would not prove successful in disinfesting exported grain. The investigations fall into two categories: laboratory trials of pesticides at a range of doses and temperatures, and field investigations at port silos to collect data on practical operating conditions and on the seasonal variation in temperatures of grain at ports. In ideal circumstances the field investigation would have been carried out before the laboratory work was started but this proved impractical and the two parts of the project were carried out simultaneously.

PRACTICAL INVESTIGATIONS

Aims and objectives

Visits were made to several port silos and grain trading companies in order to collect the following information:-

1) Details of export grain contracts, with particular reference to infestation and requirements for treatment.

2) Range of markets supplied and likely voyage times.

3) Method of treating grain and the range of chemicals used.

4) General details about the export grain trade and the views of silo staff on infestation problems and the methods currently used to inspect and certify cargoes of grain.

5) Details of the range of grain temperatures found during the year and advice on methods of collecting further temperature data.

In addition visits were made to the two major servicing companies involved in the treatment of grain at port silos.

Methods of collecting information

The managers at 4 silos were contacted and interviews arranged. A visit was also made to the commercial headquarters of two grain trading companies as well as short visits to several other ports.

At two ports the silo managers agreed to collect some temperature records of grain destined for export and in another case arrangements were made for MAFF staff to monitor temperatures of grain at the silo.

Information collected

General details:- All people who were contacted during the information gathering exercise were extremely helpful and co-operative. Several people went to great lengths to provide details of their commercial operations which proved most valuable in building up a picture of the working of the export grain trade.

There was a universal view that infestation in export grain could not be tolerated and all exporters appeared to expend substantial resources in attempts to prevent insects entering their premises or being loaded onto ships. All port silos sampled incoming grain for quality including infestation. Any infested loads were rejected but this policy could be relaxed at times of supply shortage. There was a wide-spread view that farmers were still not sufficiently aware of their obligations to supply pest-free grain and a feeling that MAFF should do more to make farmers understand the quality standards needed for export.

The silo managers were almost unanimous in their assertions that grain was only treated with a pesticide if this was a contractual requirement and the customer was bearing the cost. Exceptionally, admixture was used to ensure freedom from infestation in grain loaded onto vessels. There were also strong feelings that if a treatment was carried out, the issuing of a phytosanitary certificate should be a formality.

There was some concern over the role of MAFF in carrying out phytosanitary inspections. In general the trade did not feel that the Ministry took sufficient account of the needs of the trade and felt that more formal liaison should take place. ADAS advisers involved in phytosanitary work were regarded with the greatest of respect but some of the casual staff now employed were much less highly thought of, and some examples of problems caused by their inexperience were quoted. The trade view was that as they were paying for this service they expected only the best quality of staff to be provided.

The contractual requirements for grain to be treated seemed usually to be drawn up by the agents of the importing country. These sometimes specified the chemical to be used and the dose to be applied but often merely asked for the grain to be treated. In the latter case the choice of pesticide was usually made on commercial grounds. It did not seem at all clear if any checks were made by importing countries on the pesticide used or on the quality of the treatments.

Export grain was always treated by a servicing company although one silo manager expressed an interest in carrying out his own treatments. The managers of two servicing companies involved in treating grain confirmed the information about how pesticides were chosen. Pesticidal emulsions are used exclusively but the precise method of application varies between sites. The servicing companies regard grain treatment as a routine operation with few special problems. However, they did point out that denaturing treatments carried out using coloured dye, showed up losses of dye and operator contamination. No detailed records were kept of rates of application but general checks on the amount of pesticide used versus the tonnage of grain treated suggested that dosage rates were usually within + or - 10%.

Voyage times:- An estimate of voyage times to various customers for UK grain was obtained from East and South coast ports. There was generally good agreement between the estimates provided by the managers of different silos. The shortest voyage time, for trips to Rotterdam, was always less than 48 hours but, as this grain was invariably trans-shipped, it was never treated with a pesticide. Voyage times for other destinations were as follows:-

Russia 4.5 - 7 days (Baltic); 15 days (Black Sea)

Italy	11.5 days
Spain	8 "
Algeria	12.5 "
Israel	11 "
Saudi Arabia	14 "
Poland	5-8 "
Libya	10 "
South Korea	40 "
China	40 "

Temperature of grain:- Little if any data were available on the temperature of grain as it was loaded onto ships at ports. Therefore the work had to rely on the collection of temperature records during the course of the project. Some information was collected at three ports and further data may be collected as part of another investigation. However, sufficient data are available from two ports to offer a reasonable picture of the range of temperatures.

At one port in Ipswich, temperature data were collected by the silo staff over the period August to December. The temperature of the grain in some lorry loads was recorded as they entered the silo immediately before transfer to a vessel. Between 67 and 168 temperature readings of individual loads were recorded each month. The monthly mean of these results is given in Figure 1. The variation about the mean was about + or - 4°C.

Records of the temperature of grain as it was loaded onto vessels was obtained at Hull over the period April to June. Between 10 and 35 readings were taken per month. The average grain temperature for April was 8°C, rising to 12.5°C in May and 14°C in June.

LABORATORY EXPERIMENTS

Aims and objectives

The laboratory experiments were intended to determine the time needed to achieve complete kill of insects when exposed to grain treated with one of the pesticides currently approved for this use in the UK. Gross measurements of time in days were considered to be sufficiently accurate for the purposes of this work. Assessments were carried out with 5 species of grain pests and at a range of temperatures which were considered likely to cover the seasonal variation in grain temperatures. Work was not carried out above 20°C as such data is already available from earlier work[1]. Dosage rates of full, half and one quarter of the approved rate were used to cover the possibility that treatments do not always achieve the full dose.

Materials and methods

i) Grain:- English wheat, variety Avalon, with a moisture content ranging between 14-15% (as determined by BS 4317:3:1987) was used as a substrate for all tests. Before use the grain was sieved and winnowed to removed as much chaff and dust as possible.

ii) Insects:- Laboratory strains of the following insects were used:

Oryzaephilus surinamensis (the Saw-toothed Grain Beetle)
Sitophilus granarius (the Grain Weevil)
Cryptolestes ferrugineus (the Rust-red Grain Beetle)
Ahasverus advena (the Foreign Grain Beetle)
Tribolium castaneum (the Rust-red Flour Beetle)

The insects were bred in the laboratory at 25°C and 70% r.h. on the appropriate food medium and adult insects, approximately 2-4 weeks old were collected from the cultures and used for testing. Non-specific organophosphorus resistant strains of *O. surinamensis*, *T. castaneum*, *C. ferrugineus* and *S. granarius* were used as such strains are commonly found infesting UK grain. The resistance status of the strain of *A. advena* is unknown but these insects had been in culture for many years in the laboratory without exposure to pesticides.

iii) Pesticides and methods of treatment:- Commercial emulsifiable concentrate formulations of chlorpyrifos-methyl (Reldan), etrimfos (Satisfar), methacrifos (Damfin) and pirimiphos-methyl (Actellic) were used. These were diluted in water according to the manufacturer's recommendations and applied at the following intended doses:-

chlorpyrifos-methyl: 4.5, 2.25 and 1.13 mg/kg
etrimfos: 4.2, 2.1 and 1.05 mg/kg
methacrifos: 4.75, 2.38 and 1.19 mg/kg
pirimiphos-methyl: 4.0, 2.0 and 1.0 mg/kg

The pesticides were sprayed using a hand-held paint spray gun onto 25 kg batches of grain as they were being tumbled in a concrete mixer. The grain was tumbled for a further 5 minutes after treatment to ensure good mixing. This method of treating grain had previously been calibrated and was known to apply close to the intended dose[2].

Immediately after tumbling, samples of the treated grain were removed for biological and chemical assessment.

iv) Assessment of grain:- Samples of each batch of treated grain were removed and analysed for pesticide residues by GLC using the "Panel" method[3].

The speed of action of the pesticides was assessed at 5°C and uncontrolled relative humidity, 10 and 15°C at 75% r.h., and 20°C at 70% r.h. Fifty-gram aliquots of treated grain were set up in 120 ml wide-mouthed glass jars, the inside necks of which had previously been treated with PTFE suspension to prevent insects escaping. The jars of grain were then allowed to equilibrate overnight at the test temperature.

Batches of 20 insects were counted from the cultures, placed in glass tubes and conditioned at the appropriate test temperature for at least one hour. The insects were then added to the treated grain. Batches of each species of insect were also set up on untreated grain to act as controls and exposed at all test temperatures.

Three jars of each insect/pesticide/dose/temperature combination, plus the appropriate controls, were examined after 48 hours exposure. The grain was tipped from the jars onto a tray and the insects separated from the grain. The insects were categorized as either dead (no discernible movement) or alive (some obvious movement noted). A further three jars were then examined at daily intervals until complete kill was obtained or until 10 days exposure, which ever was sooner.

Each combination required more than 10,000 insects and, on some occasions, in order to maximise the data obtained whilst limiting the amount of unnecessary experimentation, a restricted number of replicates were used. Assessments were first made with grain treated at full dose, then at quarter dose and finally at half dose. In this way it was possible to eliminate some tests at half dose. For example, if 100% mortality was recorded at quarter dose after 2 days exposure, it was assumed that half dose would be at least as effective. On a few occasions, limitations on the supply of insects restricted the number of replicates set up at full dose.

Results

The data obtained during the laboratory tests are summarised in Figures 2 to 11. These show the mean percentage mortality of the three replicates for each temperature/pesticide/insect combination as well as control mortalities. In most cases counts were carried out until 100% mortality was achieved or the 10 day assessment period had ended. There were however, a few occasions when insufficient replicates were available to allow counts to be continued throughout the 10 day period. Generally, the results that were obtained on these occasions give a clear indication whether or not complete kill would have been obtained within 10 days.

At the two lower temperatures the results were sometimes erratic. This is probably an indication of the pesticide being marginally effective.

The results for chemical analysis of the treated grain are given in Table 5. Generally between 62 and 80% of the intended dose was recovered from the grain with the exception of methacrifos where only between 40 and 72% was recovered. Previous work with this chemical has indicated that it is particularly difficult to apply to grain under laboratory conditions.

The main objective of this work was to provide practical information on the time taken for treatments to give complete kill of insects in grain at various temperatures. Therefore, the results have been summarised in Tables 1 to 4 to show the number of days needed to give complete kill for each species/temperature/pesticide/dose combination. These show that at 20°C and 15°C the full dose of all pesticides gave complete kill of all species within 4 days. At lower temperatures all chemicals acted more slowly although the effect varied between species. For example *S. granarius, C. ferrugineus* and *T. castaneum* always became more difficult to kill as the temperature was reduced. With the other species the effect only became marked at 5°C or at reduced doses.

The results of the laboratory tests contain a large amount of data and it is difficult to make comparisons. Therefore, a further summary has been produced in which each pesticide was scored according to the number of days taken to achieve 100% kill at full dose at a particular temperature. Where a pesticide failed to achieve 100% kill within 10 days, a score of 11 was used. In cases where counts did not continue throughout the 10 day period and 100% mortality was not reached extrapolation was used to calculate an appropriate score. This only occurred in 6 cases out of the 80 insect/temperature/pesticide combinations. Table 6 shows the relative order of effectiveness of each pesticide against each species at each temperature. The relative performance of each combination of pesticide/temperature/species and dose was calculated by adding together the number of days needed for 100% kill for all of the species and is given in Table 7. Finally, the relative susceptibility of each species was assessed and is given in Table 8.

The data given in Table 6, 7 and 8 shows that the speed of kill was influenced by both the target species and temperature. There were small differences in the overall performance of the chemicals tested and they can be grouped into the following order of effectiveness:- etrimfos, chlorpyrifos-methyl, methacrifos and pirimiphos-methyl. The test method showed little difference between the susceptibility of the five species of insects at 20°C but at 5°C, *C. ferrugineus* was the most difficult insect to kill followed by *T. castaneum* and *S. granarius*.

DISCUSSION

Practical investigations

Large tonnages of grain are treated with a pesticide during loading at UK ports. However, the most usual reason for such treatments is because they are required in the terms of the contract and not to facilitate the loading of infested grain. The treatments must, however, go some way to ensuring that any insects that escape the inspection procedures will be killed. The treatments also may have additional benefits if the grain is being shipped to a developing country where infestation pressures in local storage are high. Even under tropical storage conditions a pesticide applied during loading in the UK could provide an important period of protection whilst the grain is held by the customer. The ability to apply such treatments in an economic and effective manner could prove to be an important selling point for British grain.

Factors effecting the performance of a pesticide applied to grain do not seem to be considered or understood by either shippers or purchasers of the grain. No consideration seemed to be given to grain temperature or length of voyage when planning treatments. The standards of efficacy of particular pesticides are judged in terms of their performance as conventional grain protectants or merely on commercial considerations. This could have serious consequences in cases where some infestation was present in the grain as it was loaded.

Much grain shipped to Europe, particularly that intended for trans-shipment, is not treated with a pesticide. These shipments have the shortest voyage time and would offer the shortest exposure period of any insect to the treated grain before the cargo was inspected at its destination.

The voyage times reported in this paper are all from East or South coast ports and so do not give a comprehensive picture for the whole country. However, they do provide sufficient information to allow broad generalisations to be made. Markets for which treatments are usually required, such as Poland and Russia, have voyage times and, therefore potential exposure times, of between 4.5 and 8 days for most cargoes. Grain intended for Black Sea Ports will have voyage times of more than 10 days as will grain intended for most other destinations likely to require treatment. It is also interesting to note that the longest voyage times for UK grain of about 40 days offer the opportunity for many species of insect to complete their life cycle with a subsequent 100 fold increase in numbers.

As with voyage times the data obtained on grain temperatures do not take into account factors such as regional or perenial variation. Also, wide variation in temperatures of individual loads of grain delivered to silos were noted. However, a general trend was established, with a mean temperature of about 20°C in the summer months declining steadily to about 8 - 10°C by December. The gap in the records available during January and March is unfortunate. Information from commercial grain stores suggests that the temperature is unlikely to have fallen much below 8°C, the temperature recorded when records resumed in March. However, extrapolation of the rise and fall shown by the records collected does suggest that the temperature could have fallen to 5°C during February. It is not clear if these temperatures reflect the temperature of the grain during storage or merely the results of transportation in lorries and exposure to ambient conditions. If it is the former then changes in storage practice may effect the temperature of grain delivered to export silos. However, the results do suggest that the range of temperatures used for the laboratory testing of pesticides covers the lower end of the range of grain temperatures.

The general comments by the silo managers about the need to make farmers more aware of their obligation regarding quality poses some interesting questions. It seems unlikely that ADAS having changed from offering free advice to a polciy of charging, will be in a position to provide a national campaign to encourage and assist farmers to avoid infestation. It will therefore need pressure by the shippers and silo managers to persuade farmers to ensure that they are able to meet quality standards. There would also seem to be some need to consider ways of improving liaison between the trade and ADAS, and phytosanitary inspection methods.

Laboratory trials

The pesticides used in the work were the chemicals most commonly used as grain protectants in the UK and all have been approved for that use under the Control of Pesticides Regulations 1986. Field information showed that all of these pesticides were used to treat export grain.

The full dose of each of the chemicals tested was completely effective against all the species of insect in 4 days or less at 20°C. However, reducing the temperature had a significant effect on the time taken to kill some species and this effect was more pronounced with some pesticides than others. Chlorpyrifos-methyl and etrimfos were generally least effected by temperature. Therefore, treatments with these chemicals are likely to give the best kill of pests at the lowest temperatures. However, it must also be borne in mind that the performances of the chemicals, even at full dose, will be marginal in grain destined for Poland if grain temperatures fall towards 5°C. Fortunately, during much of the year, grain temperatures seem likely to be above 10°C at which level the full dose of all pesticides are likely to disinfest grain before it reaches this destination.

Dosage rate, like temperature, influenced the action of the pesticides. Reduced dosage rates gave slower action in most cases; a point which must be noted by the companies carrying out the treatments. The dosage rates achieved during treatments of export grain have never been investigated and it was not possible to gather such information during this work. However, any underdosing could have a significant effect on the speed of action of treatments and the effect would become greatest at lower temperatures. Some further investigation in this area would seem warranted.

The work reported in this paper cannot be considered to represent a comprehensive investigation of the topic and some cautionary notes must be sounded. For example, the insects were not allowed to acclimate slowly to the low temperatures and this must have reduced their fitness compared to field strains. The relatively high control mortalities that were recorded in the long exposures at the lowest temperature are a manifestation of this problem. However, the results do not take account of the damage caused to insects by mechanical handling during loading of the ship and this probably more than compensates for the lack of acclimation.

The results do give a good, general indication of the speed of action of grain protectants at a range of temperatures and at a range of doses. This data can be used to predict the likely outcome of treatments applied to export grain provided the grain temperature and voyage time are known. The predictions would be improved by some further entomological detail. For example, work was confined to adults, which are the most visible stage, but the larvae of some species are more tolerant to pesticides and some data on the control of immature insects would be a useful addition. In the future the influence of more highly resistant strains of insects on the action of pesticides may also have to be considered.

Treating export grain with a pesticide may provide a useful way to deal with low levels of residual infestation although it should not be considered as an alternative to proper management and inspection by the silo staff. Pesticide treatments could also offer some benefits to the receiving country provided they are carried out in an effective and responsible manner. Whilst admixture treatments are unlikely to replace direct inspection of the grain by trained entomologists, they could help to overcome problems caused by the availability of staff and help to eliminate the need for fumigation when a few insects are discovered during loading and thus offer considerable cost benefits to the industry. It should also be borne in mind that in some respects the application of a pesticide is more easily checked than is the level of infestation in the grain during loading.

Suggested further studies

This study did show up a lack of information on the practical processes involved in exporting and physical condition of UK grain. This subject is worthy of more detailed investigation. The biological and chemical effectiveness of commercial treatments were not checked and consideration should be given to further work in which samples of treated grain are collected and subjected to laboratory analysis.

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Table 1 Number of days exposure needed to achieve 100% mortality of insects at 5°C

Pesticide	Applied Dose	INSECT SPECIES				
		O. surinamensis	*S. granarius*	*A. advena*	*T. castaneum*	*C. ferrugineus*
Pirimiphos-methyl	1/4	7	-	10	>10	-
	1/2	5	-	7	>10	-
	Full	3	> 10	2	9	>10
Chlorpyrifos-methyl	1/4	9	> 10	>10	>10	>10
	1/2	6	> 10	7	>10	>10
	Full	4	3	4	4	> 5
Etrimfos	1/4	2	> 10	2	>10	>10
	1/2	-	> 10	-	>10	10
	Full	3	> 5	2	> 5	3
Methacrifos	1/4	> 10	> 10	8	-	-
	1/2	5	> 10	2	-	-
	Full	5	4	2	>10	> 10

Table 2 Number of days exposure needed to achieve 100% mortality of insects at 10°C

		INSECT SPECIES				
Pesticide	Applied dose	O. surinamensis	S. granarius	A. advena	T. castaneum	C. ferrugineus
Pirimiphos-methyl	1/4	5	> 10	2	> 10	> 10
	1/2	2	> 10	-	> 10	> 10
	Full	2	7	2	3	8
Chlorpyrifos-methyl	1/4	4	9	3	> 10	> 10
	1/2	4	8	2	> 10	> 10
	Full	2	2	2	> 4	5
Etrimfos	1/4	2	> 10	5	> 10	7
	1/2	-	> 10	-	> 10	7
	Full	2	> 5	2	5	2
Methacrifos	1/4	8	> 10	5	> 10	> 10
	1/2	3	> 10	2	>10	> 10
	Full	2	3	2	4	> 5

Table 3 Number of days exposure needed to achieve 100% mortality of insects at 15°C

Pesticide	Applied dose	INSECT SPECIES				
		O. surinamensis	S. granarius	A. advena	T. castaneum	C. ferrugineus
Pirimiphos-methyl	1/4	4	> 10	3	>10	9
	1/2	2	10	2	10	> 9
	Full	2	5	2	3	> 3
Chlorpyrifos-methyl	1/4	4	4	2	> 10	10
	1/2	2	2	–	8	8
	Full	2	2	2	3	4
Etrimfos	1/4	2	> 10	2	> 10	3
	1/2	–	10	–	7	3
	Full	2	5	2	3	2
Methacrifos	1/4	5	> 10	2	> 10	>10
	1/2	3	> 10	–	10	8
	Full	2	4	2	3	2

Table 4 Number of days exposure needed to achieve 100% mortality of insects at 20°C

Pesticide	Applied dose	INSECT SPECIES				
		O. surinamensis	S. granarius	A. advena	T. castaneum	C. ferrugineus
Pirimiphos-methyl	1/4	3	8	2	>10	4
	1/2	2	6	-	6	3
	Full	2	>3	2	3	2
Chlorpyrifos-methyl	1/4	2	3	2	10	3
	1/2	-	3	2	5	>2
	Full	2	2	2	2	2
Etrimfos	1/4	2	8	2	10	3
	1/2	-	>8	-	5	3
	Full	2	4	2	4	2
Methacrifos	1/4	3	10	2	>10	>10
	1/2	2	8	-	8	5
	Full	2	2	2	4	2

Table 5 Pesticide residues detected on treated grain by chemical analysis immediately after treatment

Pesticide	Intended dose (mg/kg)		Actual dose (mg/kg)
Etrimfos	Full	4.2	3.1
	1/2	2.1	1.4
	1/4	1.05	0.69
Chlorpyrifos-methyl	Full	4.5	3.6
	1/2	2.25	1.5
	1/4	1.13	0.97
Pirimiphos-methyl	Full	4.0	2.7
	1/2	2.0	1.2
	1/4	1.0	0.82
Methacrifos	Full	4.75	2.4
	1/2	2.38	1.7
	1/4	1.19	0.57

Table 6 The relative effectiveness of the full dose of chlorpyrifos-methyl, etrimfos, methacrifos and pirimiphos-methyl applied to wheat against 5 species of insects at 4 temperatures. (Results based on the number of days taken to achieve 100% kill)

Species	Temperature	
S. granarius	20	CPM+Meth> Etrim+PM
	15	CPM> Meth Etrim+PM
	10	CPM> Meth> PM> Etrim
	5	CPM> Meth> PM> Etrim
C. ferrugineus	20	CPM+Etrim+Meth+PM
	15	CPM+Etrim+Meth+PM
	10	Etrim> Meth> PM> CPM
	5	Etrim> CPM+Meth+PM
O. surinamensis	20	CPM+Etrim+Meth+PM
	15	CPM+Etrim+Meth+PM
	10	CPM+Etrim+Meth+PM
	5	Etrim+PM> CPM> Meth
T. castaneum	20	CPM+Etrim PM Meth
	15	CPM+Etrim+Meth+PM
	10	Meth+PM> CPM+Etrim
	5	CPM> Etrim> PM> Meth
A. advena	20	CPM+Etrim+Meth+PM
	15	CPM+Etrim+Meth+PM
	10	CPM+Etrim+Meth+PM
	5	Etrim+Meth> PM> CPM

+ denotes compounds of equal performance, expressed in alphabetical order.

> denotes a decending order of effectiveness

Table 7 The overall effectiveness of 4 pesticides at 4 temperatures in giving complete control of 5 species of stored grain beetles. (Score made up of the sum of the number of days taken to achieve 100% mortality)

Pesticide	Temperature	Score	Total
Methacrifos	20	12	
	15	13	73
	10	16	
	5	32	
Pirimiphos-methyl	20	13	
	15	14	85
	10	21	
	5	37	
Chlorpyrifos-methyl	20	10	
	15	11	68
	10	21	
	5	26	
Etrimfos	20	12	
	15	14	66
	10	18	
	5	22	

Table 8. The effects of temperature on the action of pesticides against 5 species of insects. (Score based on the sum of the number of days taken to achieve 100% mortality with each of the pesticides tested)

	Temperature			
	20	15	10	5
Species	Total scores			
O. surinamensis	8	8	8	15
C. ferrugineus	8	8	24	36
T. castaneum	11	12	18	29
S. granarius	12	16	18	26
A. advena	8	8	8	11

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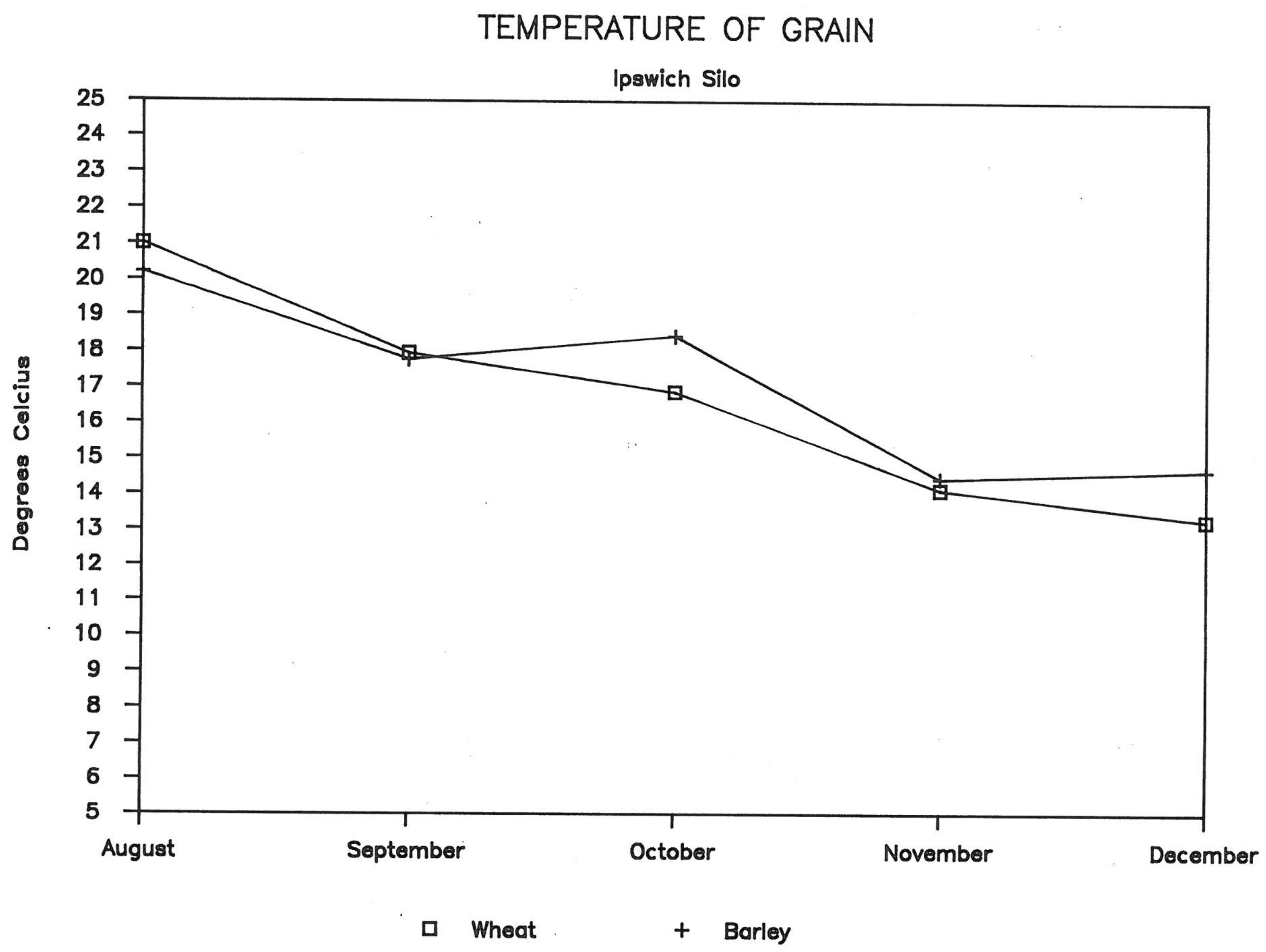

Figure 1. Temperature of grain at the Ipswich grain silo.

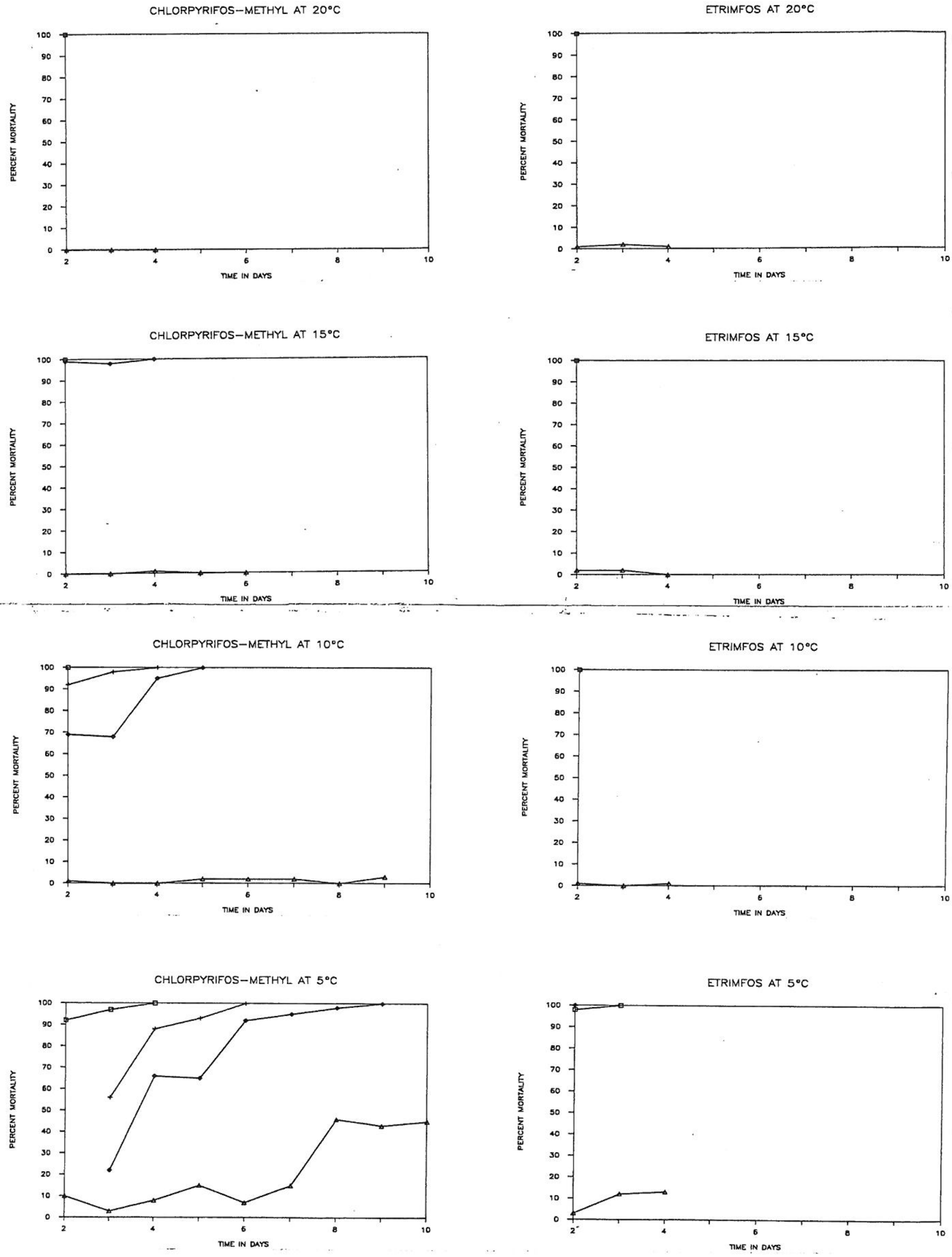

Figure 2. Percentage mortality of *O. surinamensis* exposed to grain treated with chlorpyrifos-methyl and etrimfos.

□ = Full dose　　+ = Half dose

◇ = Quarter dose　　△ = Control

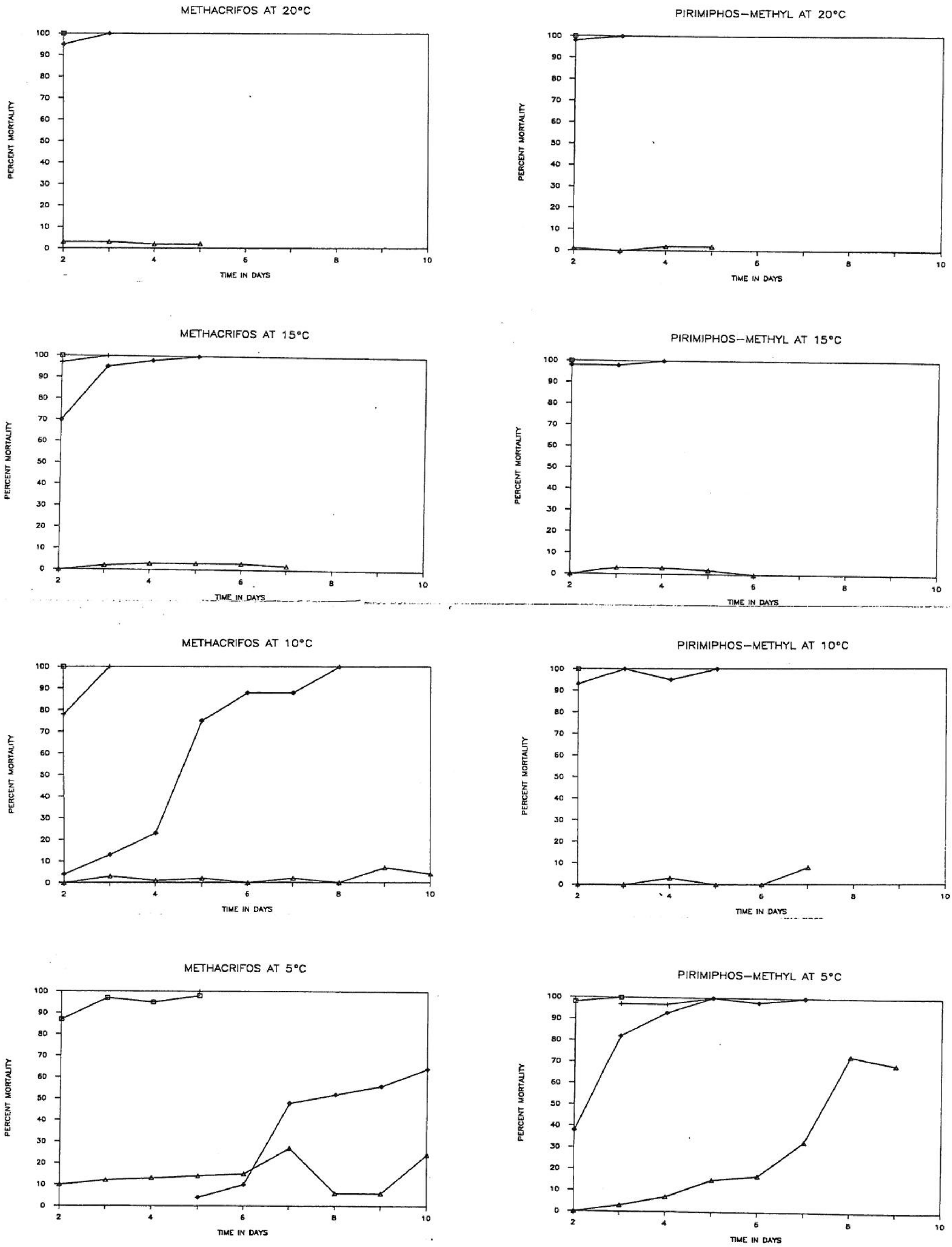

Figure 3. Percentage mortality of *O. surinamensis* exposed to grain treated with methacrifos and pirimiphos-methyl.

□ = Full dose + = Half dose

◇ = Quarter dose △ = Control

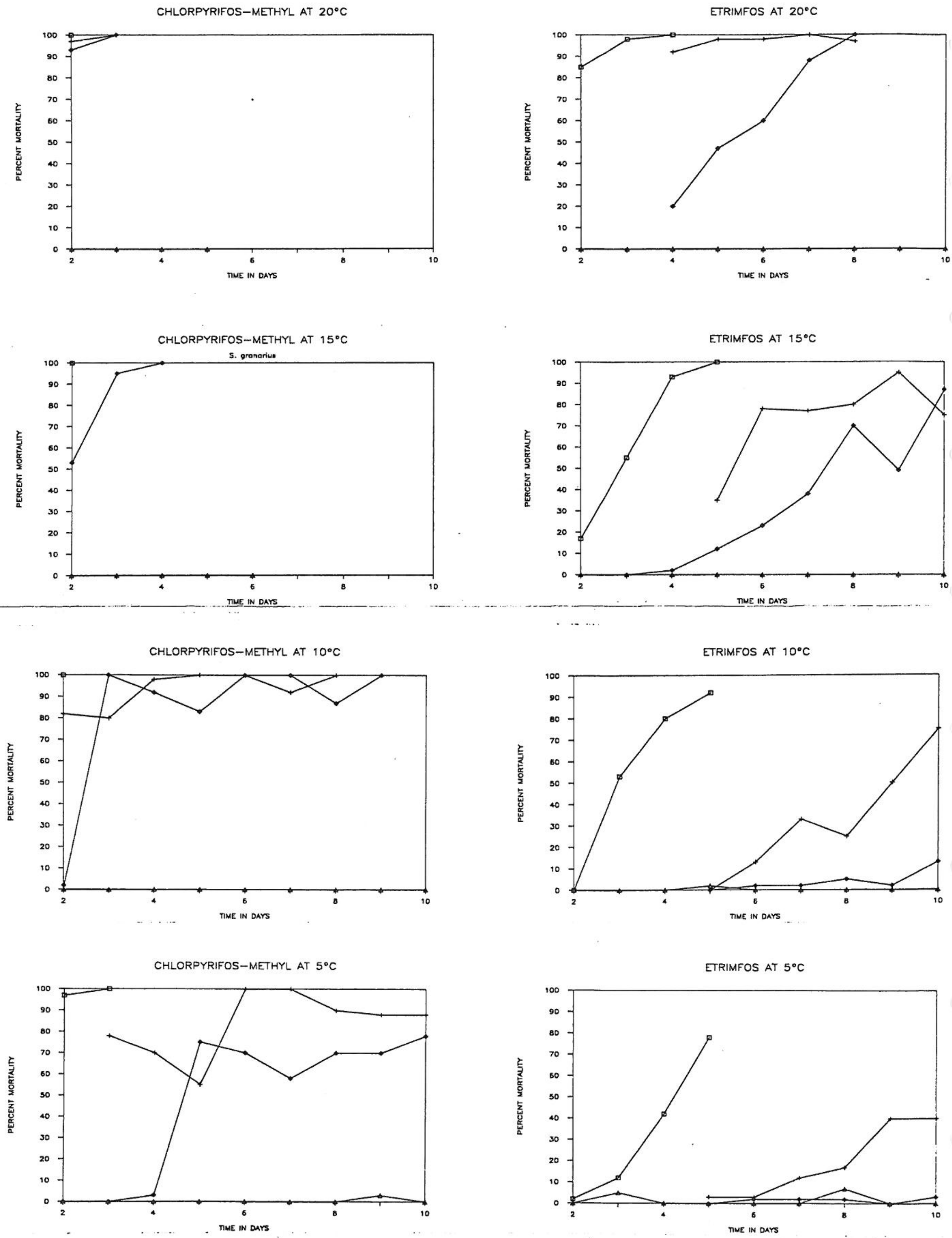

Figure 4. Percentage mortality of *S. granarius* exposed to grain treated with chlorpyrifos-methyl and etrimfos.

□ = Full dose + = Half dose

◇ = Quarter dose △ = Control

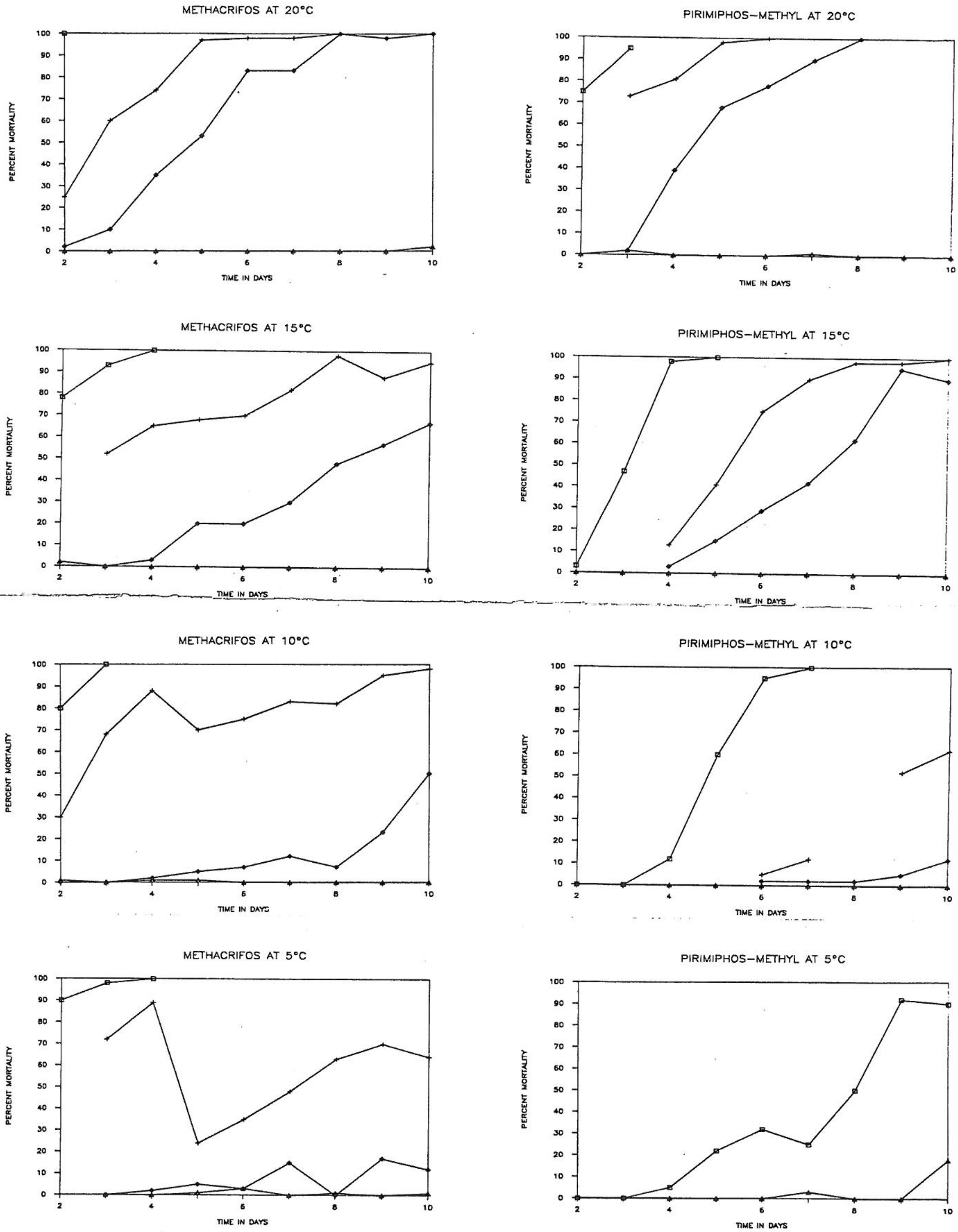

Figure 5. Percentage mortality of *S. granarius* exposed to grain treated with methacrifos and pirimiphos-methyl.

□ = Full dose + = Half dose

◇ = Quarter dose △ = Control

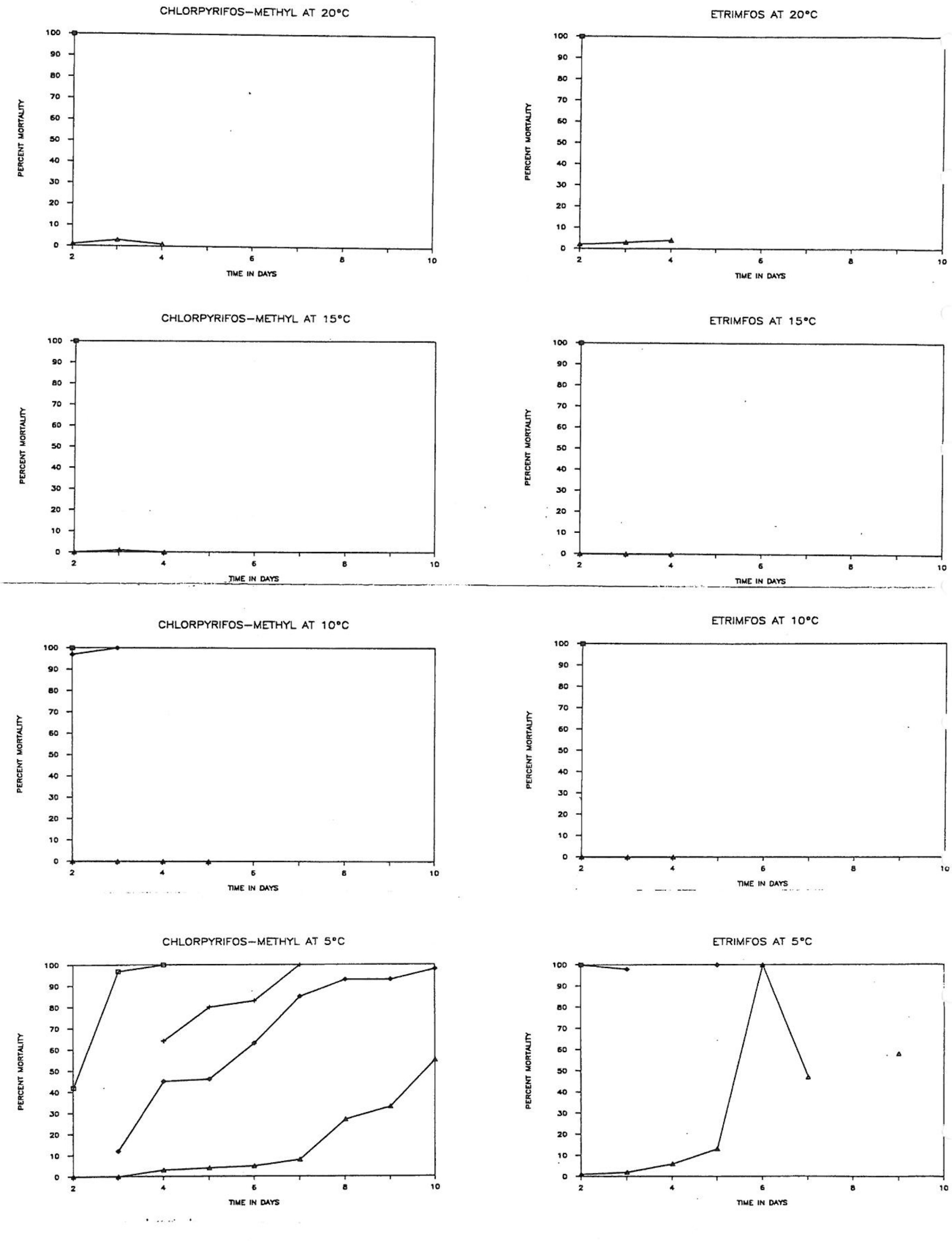

Figure 6. Percentage mortality of *A. advena* exposed to grain treated with chlorpyrifos-methyl and etrimfos.

□ = Full dose　　+ = Half dose

◇ = Quarter dose　　△ = Control

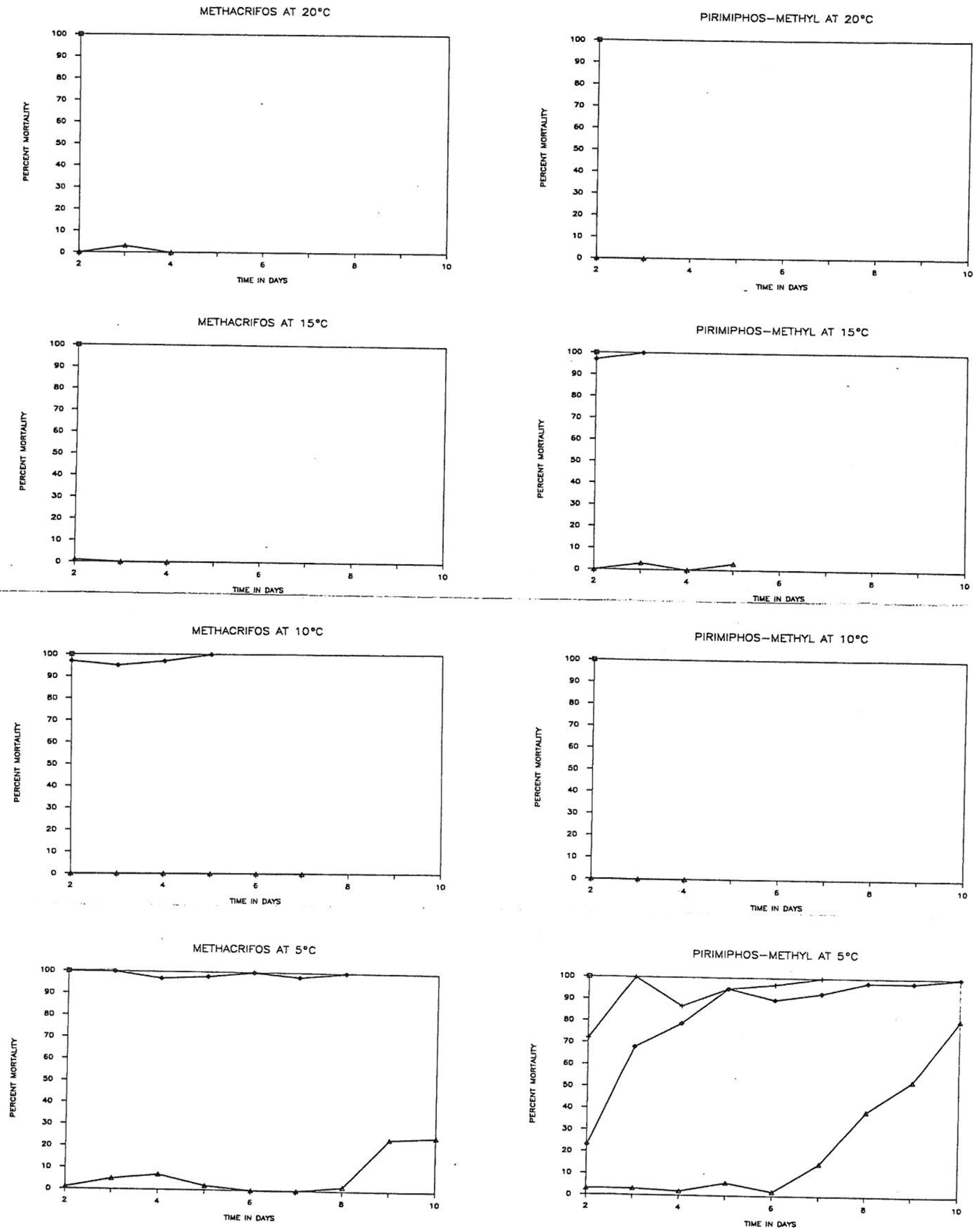

Figure 7. Percentage mortality of *A. advena* exposed to grain treated with methacrifos and pirimiphos-methyl.

□ = Full dose　　+ = Half dose

◇ = Quarter dose　　△ = Control

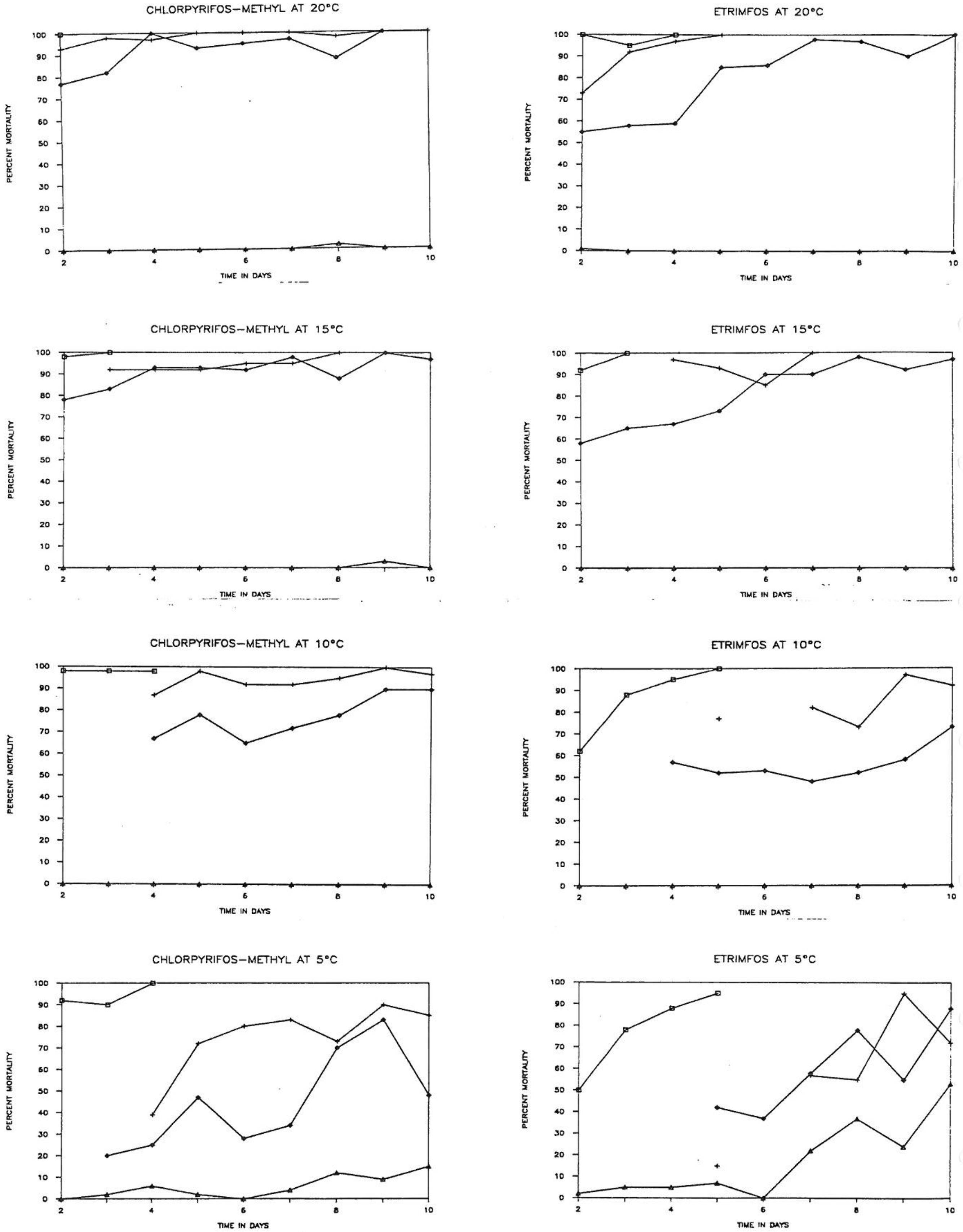

Figure 8. Percentage mortality of *T. castaneum* exposed to grain treated with chlorpyrifos-methyl and etrimfos.

□ = Full dose　　+ = Half dose

◇ = Quarter dose　　△ = Control

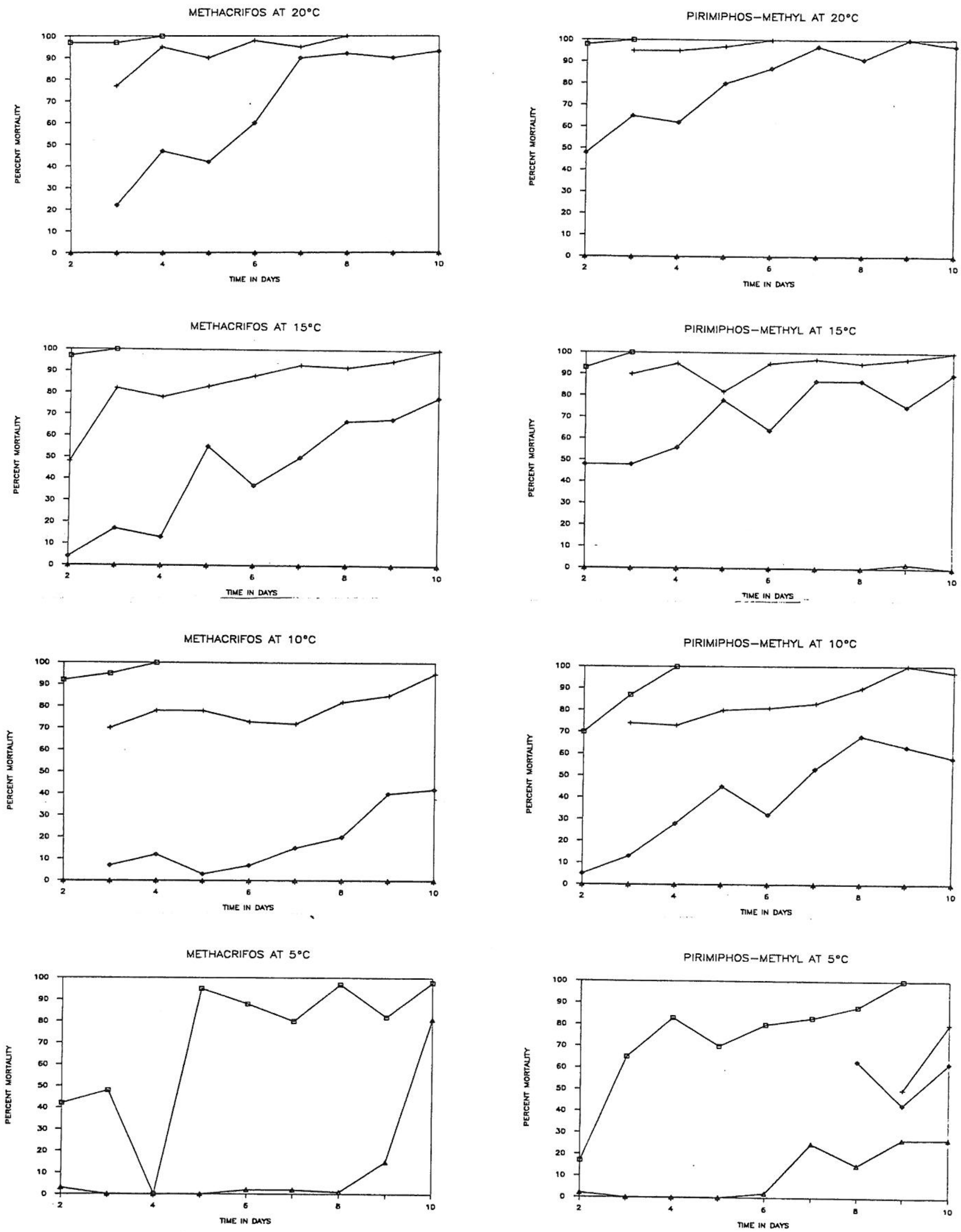

Figure 9. Percentage mortality of *T. castaneum* exposed to grain treated with methacrifos and pirimiphos-methyl.

□ = Full dose   + = Half dose

◇ = Quarter dose   △ = Control

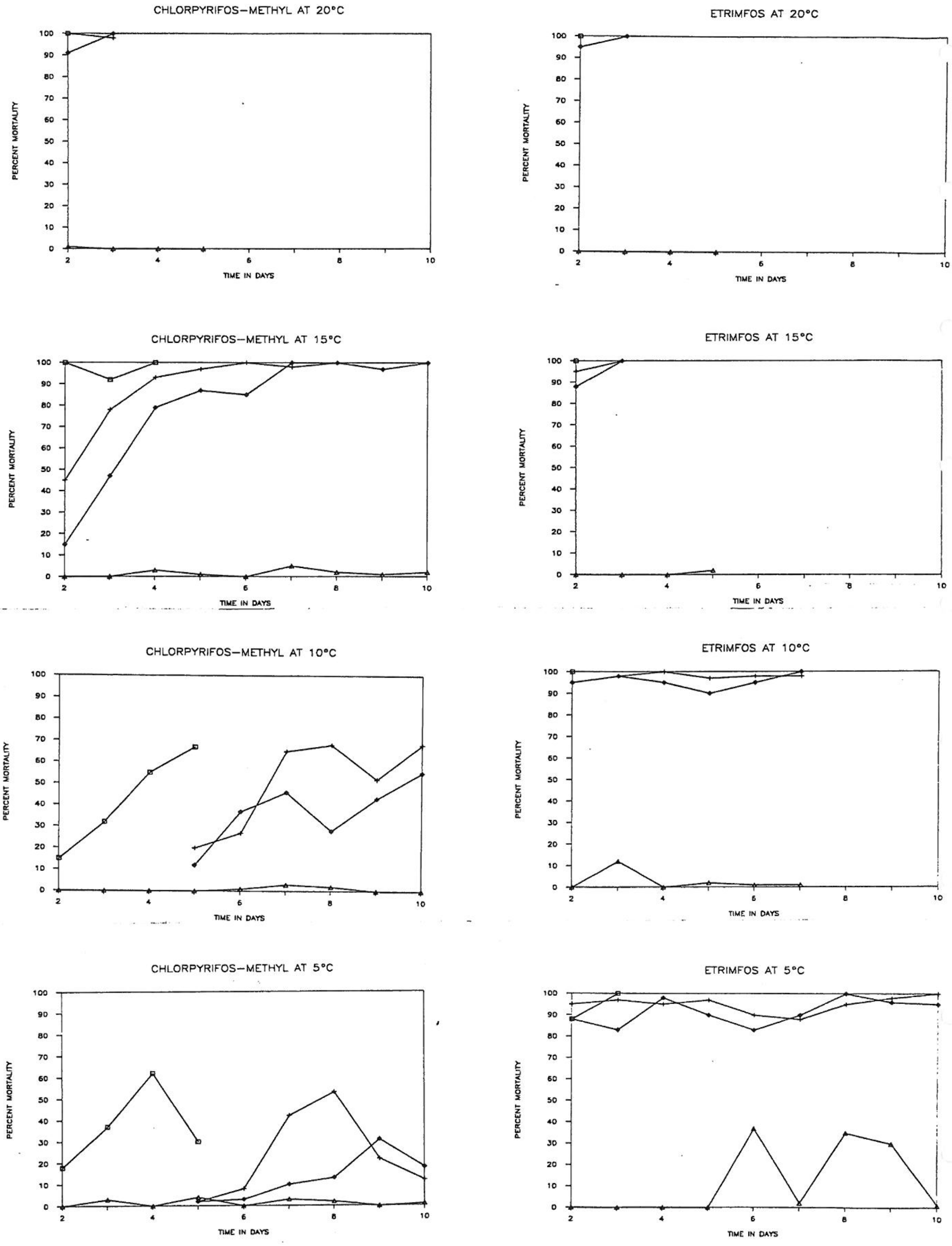

Figure 10. Percentage mortality of *C. ferrugineus* exposed to grain treated with chlorpyrifos-methyl and etrimfos.

□ = Full dose + = Half dose

◇ = Quarter dose △ = Control

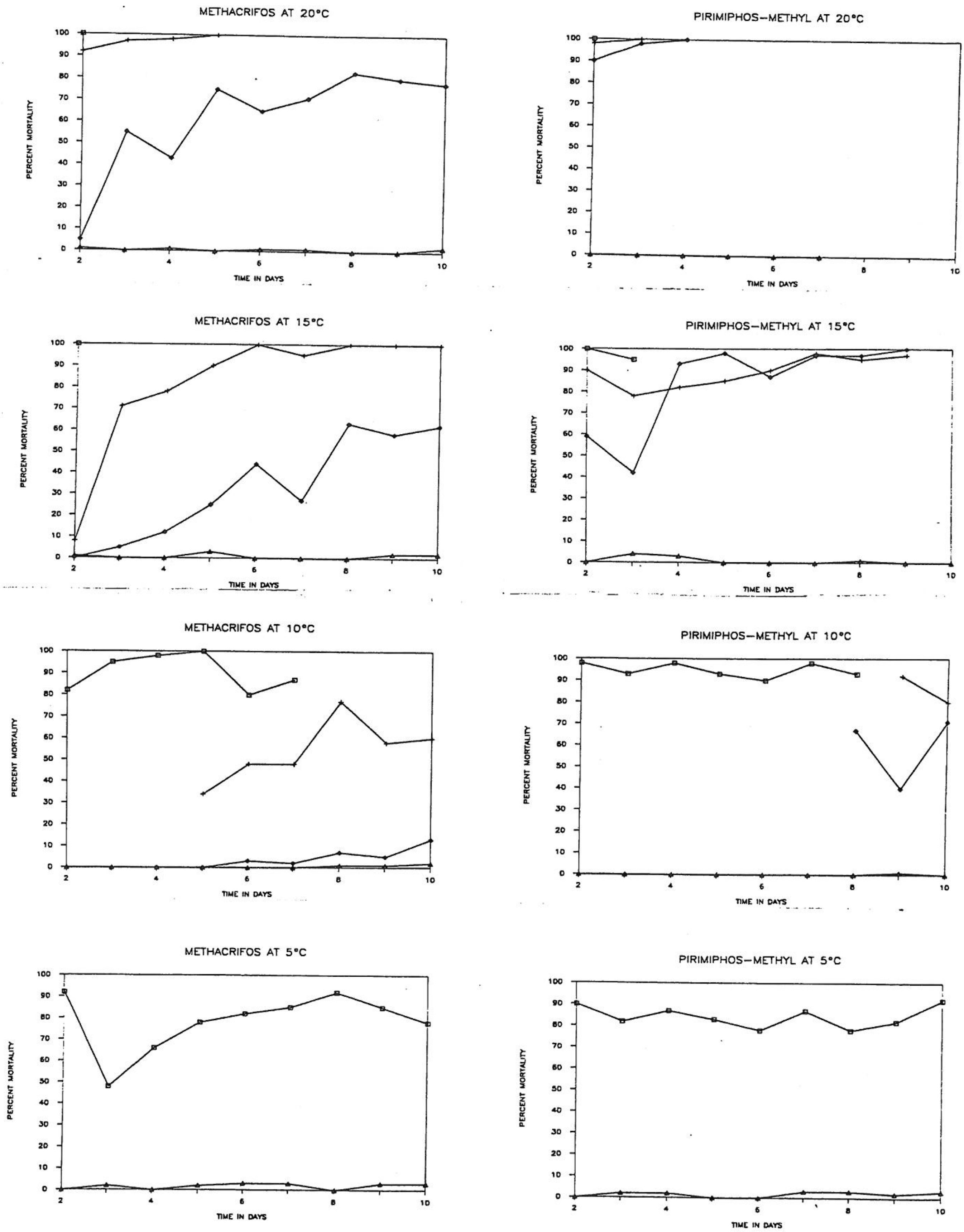

Figure 11. Percentage mortality of *C. ferrugineus* exposed to grain

□ = Full dose   + = Half dose

◇ = Quarter dose   △ = Control

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