The survival of four species of adult grain store beetles at constant temperatures between −6 and +10 ℃

D M Armitage, L Dixon and P Hart[1]

Abstract

The mortality was determined of *Oryzaephilus surinamensis*, *Sitophilus granarius*, *Cryptolestes ferrugineus* and *Typhaea stercorea* between −6 and +10℃, after acclimation at 1℃ per day from 20℃ *T stercorea* was the least hardy under all conditions and *C ferrugineus*, the longest-lived below 0℃ The expected time for 1% survival varied from 28 days at −6℃ to 514 days at 10℃ for *O surinamensis*, from 35 days at −6℃ to 470 days at +10℃ for *S granarius* and from 81 days at −6℃ to 247 days at 10℃ for *C ferrugineus* *T stercorea* failed to survive acclimation to −6℃ and 1% survival time varied from 11 days at −4℃ to 187 days at +10℃

Three strains of *S granarius* showed significantly different survival at 0℃, so the expected time for 1% survival of the hardiest was 55% higher than that of the least hardy laboratory strain, which was also the heaviest

Introduction

Hitherto, cooling grain by aeration in the British climate has been considered mainly as a means of preventing insect increase This is achieved by lowering grain temperatures using ambient air, below the minimum for reproduction of the species concerned before they can complete their life cycle (Burges and Burrell, 1964) However research in southern England (Armitage and Llewellin, 1987) has shown both that it is possible to reduce grain temperatures below 5℃ by December and that this will kill all *Oryzaephilus surinamensis* L and *Sitophilus granarius* L in the grain mass before Spring, when the grain is sold

This approach offers considerable economies over the prophylactic use of insecticides It is also useful when considering how to combat insecticide resistant animals, especially when currently in Britain, only three closely-related chemicals are currently approved and marketed for use on grain in storage Minimising the use of pesticides will also help reduce the residues on food It is therefore important to develop an integrated strategy for grain storage that will be as reliable as chemical treatment

To provide more precise data on the survival of the strains of insects used in the farm scale tests already reported Armitage and Llewellin, (1987), they were exposed to a range of temperatures likely to occur in British grain bulks after acclimation as this greatly increases their survival time (Evans, 1983) As well as *O surinamensis* and *S granarius*, *Cryptolestes ferrugineus* Steph and *Typhaea stercorea* (L), commonly encountered in British stores, were used In addition, 3 strains of *S granarius* were exposed at 0℃, as laboratory strains have been found to be more succeptible to cold than field strains (David et al, 1977)

Methods

The insects used included three strains of *S granarius* The first had been in culture since 1952 when a Russian strain was united with one from the U K, collected in 1948, the second strain was collected in 1987 in an intervention store (Manby) and the third was collected in 1982 (Field) The other species comprised, *T stercorea* 'Datchet' collected in 1980, *C ferrugineus*, cultured since before 1958 and finally a field strain of *O surinamensis*, collected in 1981 The tests described were carried out in 1986 and 1987

The weevils were bred upon whole wheat, the other species on a mixture of 5 5 1 by volume of wheatgerm, oats and yeast To the *T stercorea* only was added 15 mls of water and a small wad of damp cotton wool, to provide the high r h and associated mould growth that this species seems to need (Jacob, 1989) Batches of 50 adults of each species were counted out from cultures maintained at 25℃, 70% r h They were collected from 8 − 10 week old cultures, originally set up with 100 adults Each batch of insects was transferred to an 8 × 2 5 cm tube two-thirds filled with 15g of wheat, previously conditioned to an m c in equilibrium with 70% or 50% r h as required (Pixton and Warburton, 1971) Ten percent of the wheat was coarsely kibbled, as ground grain enhances the survival of these insects at low temperatures (Granovsky and Mills, 1982) The ends of the tubes were capped with a circle of gauze to allow ventilation

[1] Central Science Laboratory, Ministry of Agriculture, Fisheries and Food, Sand Hutton, York YO4 1LZ UK

The tubes of insects were transferred to plastic dessicators over KOH solution of the appropriate S G (Solomon, 1951) and placed in cooled incubators The temperature in these was then reduced from 20℃ by 1℃ per day until the desired test temperature was reached, whereupon 6 replicates were withdrawn for determination of insect survival Thereafter, the sampling intervals were irregular, depending on species and temperature

In assessments of survival, only those insects able to move in a co-ordinated fashion were counted as alive After initial determination, the apparently alive and dead insects from each replicate were left for re-examination after not less than 24 h These samples were then discarded, a fresh sample of 6 replicates being withdrawn for the next determination

All species were exposed at temperatures of, +10, +6, +2, −2 and −6℃ at 70% r h but only the laboratory strain of *S granarius* was used In addition *O surinamensis* was subjected to these temperatures at 50% r h , to see how much low r h depressed survival The m c of the grain in the tubes was regularly measured, gravimetrically, by drying in a ventilated oven at 113℃ for 4 h and the KOH replaced where necessary

Finally, all three strains of *S granarius* were exposed at 0℃, 70% r h , to see if they differed in their cold hardiness Twenty batches of 50 individuals of each of the 3 strains were weighed before exposure

Probit analysis was used to estimate 50% and 1% survival times using the probit (proportion surviving)- time model used by Evans (1983) These values excluded the acclimation time and where necessary are adjusted for mortality during acclimation

Results

Above 0℃, mortalities during acclimation were less than 5%, while below 0℃, they did not usually exceed 10% The untransformed survival curves (corrected for mortality during acclimation) of *O surinamensis* at 50% r h, *O surinamensis* at 70% r h , *S granarius*, *C ferrugineus* and *T stercorea* are shown in Figs 1 − 5 respectively

Of the 4 species tested, *T stercorea* was notably the least cold hardy, failing to survive acclimation to −6℃ and surviving shorter times at all temperatures than the other species (Table 1 and 2) *C ferrugineus* was the hardiest species at temperatures below freezing, but at higher temperatures the differences between this species and *S granarius* and *O surinamensis* were minor and inconsistant For instance, at 6℃, there was no difference between the E T 50 s of *O surinamensis* and *C ferrugineus* and the value for *S granarius* was only 10 days higher However, at 2℃, *O surinamensis* survived longer than *C ferrugineus* and both longer than *S granarius*

The experiment comparing the cold hardiness of the 3 strains of *S granarius* showed large differences in ET 50 between the 2 field strains and the lab strain, but not each other, however there were differences between all 3 strains in the ET 99 (Table 3) The ranking of cold hardiness was inversely related to the weights so the heaviest strain was the least cold hardy

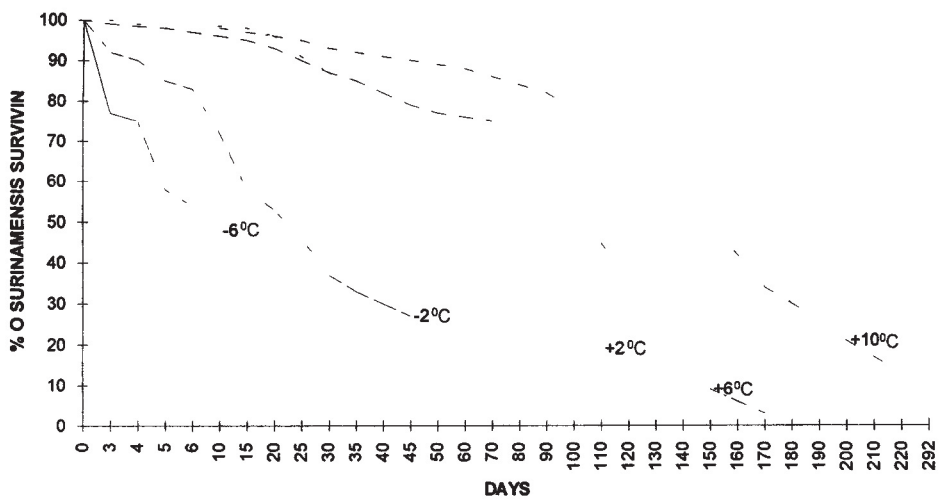

Fig. 1. Survival of adult *O surinamensis* between −6 and +10℃ at 50% r h

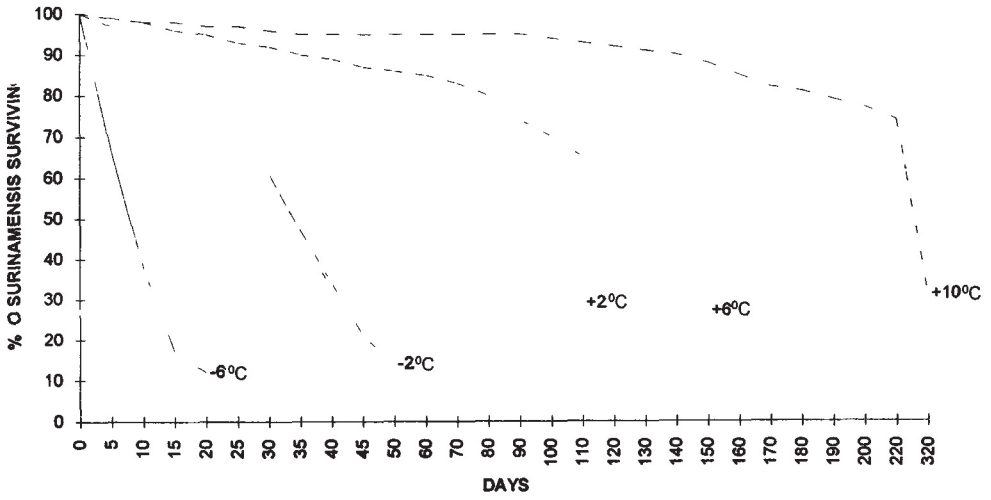

Fig. 2. Survival of adult *O surinamensis* between −6 and +10℃ at 70% r h

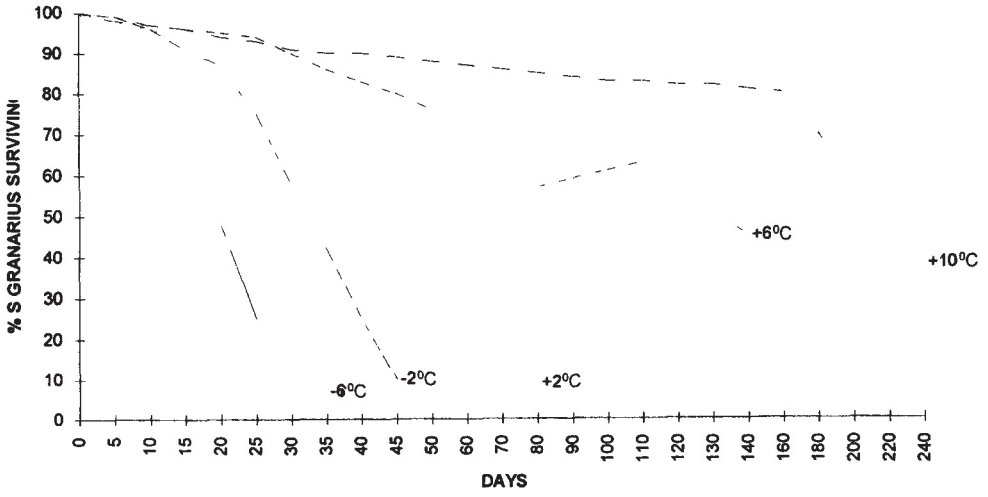

Fig. 3. Survival of adult *S granarius* between −6 and +10℃ at 70% r h

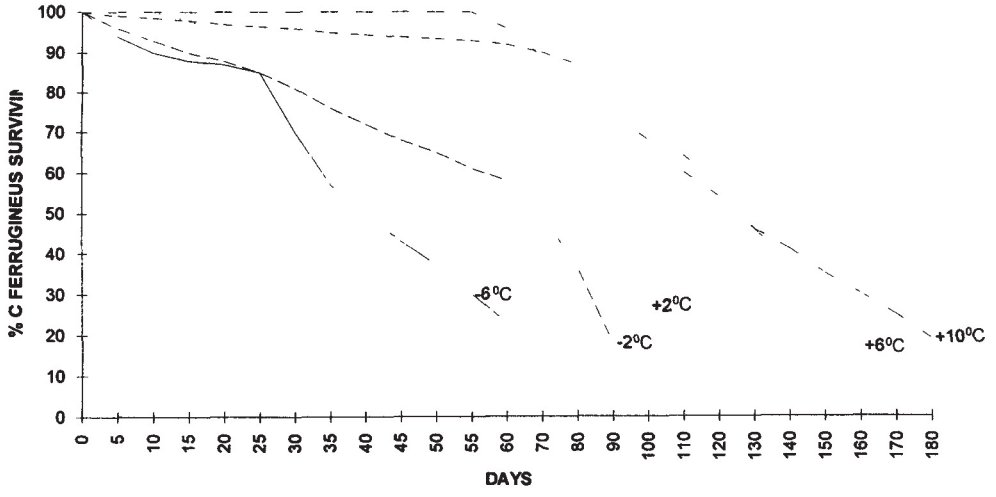

Fig. 4. The survival of adult *C ferrugineus* between −6 and +10 ℃ at 70% r h

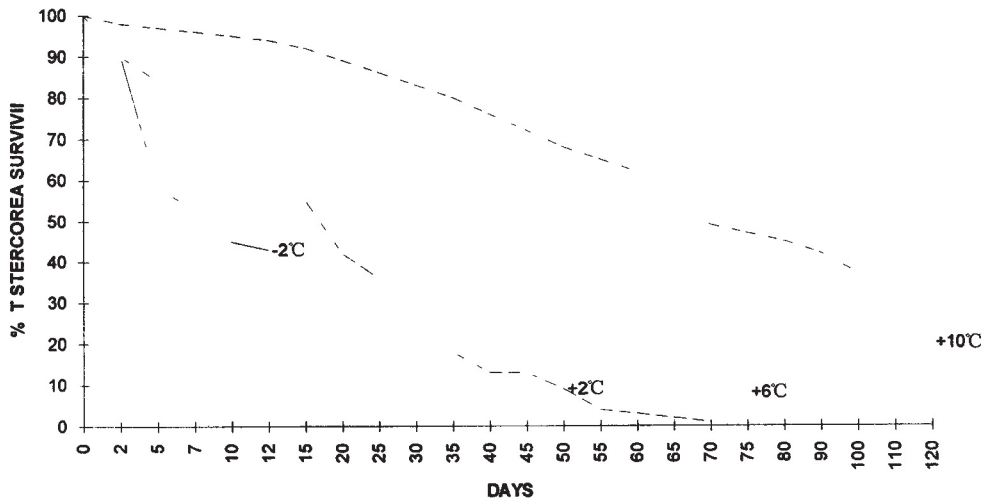

Fig. 5. Survival of adult *T stercorea* between −6 and +10℃ at 50 % r h

Discussion

The results at 10℃, the highest temperature studied, can be compared with those of Evans (1983) at 9℃, the lowest temperature he looked at The ET 50 of our *S granarius* at 70% r h was 223 days, compared to 200 obtained by Evans, a good agreement However, the ET 50 for our *O surinamensis* was 260, compared to Evans' 99 and for *C ferrugineus* our ET 50 was 98 days at 10℃, compared to 75 days at 9℃, as determined by Evans Smith (1970) found the ET50 of *C ferrugineus* at −6 ℃ to be between 3 5 − 31 days, depending on acclimation regime, compared to the 38 days of this study These differences can be attributed to acclimation regime and also probably strain

If these results are related to the survival of the same strains of *O surinamensis* and *S granarius* in English farm bins (Armitage and Llewellin, 1987), it is found that their survival at the grain surface was equivalent to constant exposure between 6℃ and 10℃ At the centre of automatically cooled bins they survived for a similar length to animals exposed to a steady −2 to +2℃

The effect of increasing r h in enhancing survival is shown by comparing the survival of *O surinamensis* at the two r h s which confirms the observations of Robinson (1928) and more recently Evans (1983) It demonstrates the importance of carefully monitoring r h in such experiments and suggests how to shorten low temperature exposures while still achieving complete mortality

Table 1. 50% survival values in days (95% fiducial limits) for acclimated adult insects of 4 species between +10 and −6℃

species	*O surinamensis*		*S granarius*	*C ferrugineus*	*T stercorea*
r h (%)	50	70	70	70	70
+10	138 (5)	257 (16)	223 (11)	97 (9)	80 (6)
+6	88 (5)	113 (5)	138 (9)	115 (5)	26 (3)
+2	53 (4)	85 (3)	45 (4)	66 (5)	22 (3)
−2	12 (2)	28 (1)	30 (1)	62 (4)	4 (1)
−6	2 (1)	10 (1)	15 (1)	38 (4)	− (−)

Table 2. 1% survival values in days (95% fiducial limits) for acclimated adult insects of 4 species between +10 and −6℃

species	*O surinamensis*		*S granarius*	*C ferrugineus*	*T stercorea*
r h (%)	50	70	70	70	70
+10	298 (11)	544 (50)	470 (32)	247 (19)	187 (17)
+6	188 (11)	234 (13)	294 (30)	206 (11)	84 (5)
+2	148 (9)	185 (11)	101 (8)	163 (15)	63 (5)
−2	65 (3)	115 (7)	55 (3)	137 (9)	11 (1)
−6	9 (1)	28 (3)	35 (4)	81 (12)	− (−)

Table 3. 50% and 1% survival values in days, (95% fiducial limits) and weight (mg) of 3 strains of acclimated adult *S granarius* at 0℃ , 70% r h

	50%		99%		wt	s d
Lab	30	(2)	61	(4)	3 3	0 004
Field	52	(2)	95	(8)	2 3	0 026
Manby	46	(2)	83	(6)	2 6	0 072

From the experiments at 0℃ with the three *S granarius* strains, it can be deduced that extra weight does not necessarily impart longer life at low temperatures Possibly the field insects are better adapted to reduce their metabolic rate than are the lab strains Although stored product grain beetles do not hibernate, Evans (1979) has noted how some strains lower their oxygen consumption with exposure to cold, an apparent adaptation

The temperature range examined in this study could perhaps be divided into 3 bands Between the chill comma and minimum breeding temperatures, the insects will be able to feed but because of the low metabolic rate, be unable to repair accumulating damage Between the chill comma temperature and their supercooling point, they will be unable to feed and therefore slowly starve At and below their supercooling temperature, death will occur when the water in their body fluids crystalises (freezes)

Evans (1983) determined that the median chill comma temperature for *S granarius* lay between 2 7 and 5 6℃ , for *C ferrugineus* it was 4 4 – 6 4℃ and for *O surinamensis*, 5 6 – 10℃ It is obviously desirable that aeration should reduce grain temperatures to these values to prevent damage by the insects which may live for extended periods above chill comma temperatures

Smith (1970) found the supercooling point of *C ferrugineus* to be – 17℃ without acclimation at an unspecified r h , while Robinson (1928) found that between 12 and 16 % m c , the supercooling point of *S granarius* was from – 9 to – 10℃ Fields (1992) gave the supercooling point of *O surinamensis* as – 16℃ These temperatures are unlikely to be achieved by aeration within the mass of British grain stores, however they may be achieved in climates such as those of Scandanavia and Canada

This study has confirmed that the variation in cold hardiness occuring within adults of a species can be as great as that occuring between species These differences can be accounted for by acclimation and r h , as well as strain It is therefore important that studies of this sort should focus on r h s and acclimation regimes strictly relevant to different climates More difficult to achieve, but equally necessary, will be a comparison of the survival of different strains and a maintenance of their cold hardiness in culture Although adults are usually identified as the hardiest stage, this is not universally so (David et al 1977) However it is appropriate that studies should continue to concentrate on adults as they are normally considered to be the stage that invades the grain after harvest

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