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THE DEVELOPMENT OF AN INTEGRATED STORAGE STRATEGY FOR MALTING BARLEY

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THE DEVELOPMENT OF AN INTEGRATED STORAGE STRATEGY FOR MALTING BARLEY

Edited
by

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Contents

Abstract

This report describes experiments to determine the best storage strategy to break dormancy, preserve germination and discourage infestation in malting barley. The objectives of this project were to establish a model for time/temperature combinations required to break dormancy in the most difficult variety (Triumph) and calculate subsequent germination loss during cool storage. These predictions were combined with calculations and experiments on insect increase to determine the infestation potential of different strategies during the phases of dormancy break and subsequent cooling The effects of sudden cooling on germination were examined to check for 'secondary dormancy' and the dormancy of the most troublesome varieties was compared to check that the model was representative. Information on current storage practices were collected, to see if these were compatible with the proposed strategy. Finally, commercial-scale trials in the north and in the south of the country were carried out, in order to validate some of the storage strategies for malting barley.

Predictions based on laboratory work indicate that dormancy can be broken so that germinative energy rises from 10% to 95% in 24 days at 30°C and 12% moisture content (m.c.) or 12 days at 40°C and 11% m.c. Higher final germinative energies are achievable at lower temperatures but longer storage times. For instance, it takes 50 days to break dormancy at 20°C or 80 days at 15°C.

Calculations based on speed of insect development and fecundity show that lower temperatures gave greater safety margins between insect development time and break of dormancy. Saw-toothed grain beetles were the quickest developing insects at high temperatures with little margin for error between dormancy break and development times. Most strategies allowed theoretical insect development after dormancy break and during cooling. Rust red grain beetles were the greatest threat at 35°C, saw toothed beetles at 25-30°C with few insects developing at 20°C where grain weevils predominated.

Laboratory experiments at 20, 30 and 40°C simulating times for dormancy break, cooling and subsequent storage showed that at 40°C, no insects tested were able to survive. At 30°C, moderate insect numbers developed during dormancy break and cooling but they failed to survive in subsequent storage. At 20°C, few saw-toothed beetles developed during dormancy break and cooling and none survived storage but large numbers of grain weevils developed and half of them survived storage.

A sudden drop in temperature did not induce secondary dormancy and the prediction model for germination changes at steady temperature was effective during a change of temperature.

The varieties Triumph, Blenheim and Pipkin were identified as barleys more prone to dormancy. Triumph emerged from dormancy more slowly than Blenheim or Pipkin. For a given change of temperature the rate of emergence from dormancy increased by the same factor for all three varieties.

A survey of maltings storage showed that most storage has aeration but virtually none has automated control. Most grain was stored for over ten months, showing the

potential to minimise carry-over stocks. Most grain was initially stored at the optimum temperature for insect development.

Experiments in cooling 1,000 t bins in the south of England showed that initial cooling to 15-20°C in tall silos was as fast as expected and as fast as in flat stores but subsequent cooling to 10°C was unexpectedly difficult. Hot barley cooled by upward aeration late in the year required special measures to avoid roof condensation. Neither grain weevils nor saw-toothed beetles survived the storage strategy at initial temperatures of about 22°C but at just under 40°C, there was development of grain weevils after three to four months.

Similar experiments in the north of England showed that monitoring grain temperature off the drier was essential to control the initial warm storage temperature. Although storage temperatures were higher than the recommendations based on laboratory work, maltable barley was still produced. A 'dryeration' effect reduced moisture contents to 10-11% during cooling, further protecting the barley from loss of germinative capacity. Higher differential settings on the fan control reduced moisture pick-up. The high temperatures (above 40°C) at the northern site killed all insects. Downward air flow avoided condensation in the roof space but the disadvantage of downward air flow was that regions of low airflow between the vents at the base of the site were the last to be cooled and were also more difficult to cool.

Storage of malting barley between 25°C and 35°C to break dormancy before cooling is a high risk strategy which encourages infestation. This risk can be minimised by using the information on dormancy break, germination loss, cooling rates and insect increase that is contained in this report. Ultimately the data could be made available in the form of a decision support system for maltsters. Automated fan control, purpose built for the malting industry should be developed alongside such a decision support system.

1. Background and objectives

The UK malting industry produces malt throughout the year and so malting barley is traditionally stored for extended periods, often up to 18 months. This ensures a continuous supply of the desired varieties and a ready stock of barley in which the natural dormancy has decreased and germination reached an acceptable level.

Dormancy is broken by storing the grain at elevated temperatures achieved after drying. The lower the temperature, the longer the period of storage required. Once dormancy has been broken, the barley must then be cooled to protect against germination loss and infestation.

Prolonged storage is expensive in capital costs and wasteful of storage facility requirements. It also significantly increases the risk of insect and mite development with consequent damage and losses. The current, industry-favoured strategy to protect against infestation has involved the direct admixture of residual, organophosphorus contact pesticides to the barley, usually as it is loaded into store. However, pesticides degrade rapidly at high temperatures, sometimes necessitating repeat treatments, thus increasing the costs of treatment, handling, residue analysis monitoring and increasing the risk of exceeding the maximum residue limit. There are also pollution implications of disposing of pesticide-loaded effluent from the steeping stage during the malting process.

An alternative to the current industry reliance on prophylactic pesticide admixture would be rapid cooling of the grain. If necessary, this could be allied to peripheral insecticidal treatments which have already been demonstrated to be effective in stores of feed wheat (Armitage *et al.*, 1994). However, the requirement to break dormancy before cooling can commence, is a complicating factor. During this phase infestations may increase unimpeded. Which strategy therefore will break dormancy sufficiently quickly while minimising the potential for infestation? Is it best to store the grain at a relatively low temperature for a long period or to store at a high temperature for a short period? An additional impediment to the use of cooling for malting barley has been the fear of imposing 'secondary dormancy'. This aspect also needed to be investigated.

The objectives of this project were :

1. To establish time/temperature combinations required to break dormancy in what is generally considered to be one of the most difficult varieties (Triumph spring barley) and calculate subsequent germination loss during cool storage.
2. To combine these with calculations of insect increase to determine the infestation potential of different strategies.
3. Using the regimes established above, to measure increase in insect population in laboratory experiments, during the phases of dormancy break and subsequent cooling.
4. To collect information on current storage practices in commercial maltings, to see if these were compatible with the proposed strategy.
5. To investigate the effects of sudden cooling on germination.
6. To compare the break of dormancy for Triumph with more recently developed, dormancy-prone varieties, to confirm it as representative of a 'worst case' dormancy scenario.
7. To carry out commercial-scale trials in the north and in the south of the country, over two successive storage seasons, in order to validate some of the storage strategies for malting barley.

As a result of the above, the aim was to identify low-cost storage techniques for the malting industry, that would ensure rapid dormancy break and preserve high germination with low infestation risk without resort to pesticides. The experiments were overseen by a steering committee comprising the principal scientific contributors to the project, representatives of the malting industry and HGCA. Steering committee meetings were held approximately bi-annually during the course of the project.

2. Determination of germination and its relevance to malting

M.Proudlove

FROM BARLEY GRAIN TO MALT

Malt is made by soaking barley grains in water (steeping), allowing them to grow (germination) and then drying them (kilning). This converts tough barley into easily crushed malt - the raw material for brewing, distilling and many other food products. In brewing and distilling, malt provides the fermentable sugars used by yeast to produce alcohol and also contributes to the final colour and flavour of the product.

Steeping

Barley arriving at the maltings is dried to between 10 and 12 % moisture content (m.c.) to maintain viability, reduce the risk of microbial attack and to maintain quality during the storage period, which may be up to 15-18 months after harvest.

During steeping, barley is immersed in water at 12-20°C, for six to eight hours (h), to start rehydration of the grain, to about 33% m.c. The water is drained and the grain air-rested for 12-14 h, during which time the embryo starts to become active. A second immersion for 8-10 h increases the m.c. up to 42% and during the second air-rest of 8-10 h, the grain 'chits' (i.e. the roots emerge). A third 4-10 h steep may follow, to bring the final moisture to 42-48%, which is necessary to ensure that the barley grain releases the starch reserves needed for fermentation. The water is changed to prevent microbiological contamination but also to remove inhibitory substances in the husk. The entire process of steeping normally takes about 48 h. Steeping is temperature dependent so that at 15°C, it takes two thirds as long as at 10°C.

Germination

This usually takes four to six days at 15-20°C. The grains produce enzymes which break down the cell walls, proteins and some starch (referred to as 'modification'). Over- and under-modification occur when too much or too little of the grain is degraded. Growing grains produce heat, so an even temperature is maintained by blowing air with controlled temperature and humidity through the malt bed. Excessive losses of starch and consequently fermentable sugars, which are used by the grain for

embryo, root and shoot growth, are prevented by regulating air flows. A moisture loss of 3-4% and root shrivelling commonly occur during germination. (Germination brings the food reserves in the embryo into a suitable state so that they are hydrolysed at mashing by the enzymes formed during malting.)

Kilning

Germination is halted by kilning; drying the germinated grain to 3-5% over 24-48 h at temperatures, initially as low as 50°C (because temperatures cannot be too high while the malt is damp otherwise the enzymes will be killed) and rising to 100°C, depending on the type of malt required (lager, ale, stout). Most of the malt's colour and flavour is produced during kilning.

It is vital that malting barley should be alive (viable) and capable of germinating, to produce the degree of modification specified by the brewer or distiller. Like most seeds however, barley will show some degree of dormancy which prevents it germinating in the ear but dormancy may persist after harvest and this must be overcome before the grain may be used for malting. A balance must therefore be reached between maintaining viability, breaking dormancy and avoiding 'water sensitivity' (where the grain may 'drown' if exposed to too much water during steeping) as well as avoiding storage losses caused by pests.

GERMINATIVE CAPACITY

This shows how many grains are alive. Results would ideally be in the range 99-100% but the barley may be accepted above 95%.

Method

Two replicates of 200 grains or corns, obtained using a sample divider were steeped for two days in 200 ml of fresh 300g/l hydrogen peroxide solution at 18-21°C for two days. The liquid was strained off and replaced with fresh hydrogen peroxide for a further day. Those corns which had not developed both root and shoot (acrospire) growth were separated and counted and the husks covering the embryos peeled. This was achieved by inserting the tip of a dissecting needle under the husk and sweeping it round. The brownish skin covering the germ was removed by rubbing with a finger to expose the pure white tissue. The peeled corns were then incubated on two Whatman No. 1, 85 mm filter papers moistened with 4 ml distilled water in a closed 90 mm

petri dish for one day at 18-21 °C and the corns showing acrospire or root growth recorded.

GERMINATIVE ENERGY

A measure of whether grain is dormant and will not grow in the allotted time even given sufficient air, temperature and water is obtained by germinating 100 corns in 4 ml of water. Barley would not be malted below 95% germination. When 8 ml of water is added to the grain, the results are described as 'water sensitivity' and give the maltster an idea of how the grain should be treated in steeping. For instance, a low percentage germination using 8 ml of water means the grain will drown if it is steeped for too long. Values of 50-60% would be the minimum requirement. If not enough water was to be added, patches of endosperm would not break down, an inhomogeneous modification would occur during germination and the malt would become 'sticky' and give run-off problems in mashing so the full extract potential of the malt will not be achieved.

Method

Two Whatman no 1, 85 mm filter papers were placed in the bottom of a 9 mm petri dish and either 4 ml or 8 ml of water added. To this was added 100 corns obtained from the sample using a sample divider. These were placed on the paper so that each made good contact. In the 8 ml test, the ventral side only touched the paper to avoid drowning the embryo.

The dish was covered with its lid, ensuring that loss of moisture was prevented by a good seal. Alternatively, this was achieved using a plastic re-sealable bag. The samples were incubated inside a dark cabinet at 18-21°C and the corns which are chitted at 24 h and 48 h from the start of steeping were removed, to prevent excessive moisture uptake.

The cumulative percentage of corns chitted each day were recorded and the counts at 72 h for the 4 ml test taken as germinative energy and for the 8 ml test as water sensitivity.

3. A model of dormancy and viability based on laboratory data for integration with insect development calculations

J.L.Woods

INTRODUCTION

This part of the report, establishes the time needed for barley to remain at a variety of temperatures before cooling can commence, thus providing the basis of calculations about pest increase during this phase. It also predicts subsequent germination loss as the grain is cooled and stored at low temperature.

The change in germinability of malting barley can be considered as a combination of two processes:

(i) A break of dormancy where the percentage of the viable seeds that can germinate under given conditions (germinative energy), is increasing.

(ii) A loss of viability (germinative capacity) where the number of seeds that can ultimately germinate, in the absence of dormancy, is declining.

This is illustrated in Fig. 3.1. The combination of the two effects results in the characteristic germination history curve, which predicts the overall germinability, germinative energy - g as a product of the percentage viable, germinative capacity - g_v and the percentage to have broken dormancy - g_d.

PREDICTION METHOD

The changes in g_v and g_d with time are predicted using probit analysis. This assumes that the lengths of time to loss of viability and to break of dormancy are normally distributed. The values of g_v and g_d are calculated from the probability function:

$$p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{\frac{-X^2}{2}} \, dX$$

where $X = (t - t)/\sigma$

The value of σ for viability loss is given by Ellis and Roberts (1980) as :

$$\log_{10} \sigma_v = 9.983 - 5.896 \log_{10} M - 0.04\ T - 0.000428\ T^2$$

The value of σ for break of dormancy is taken from the Newcastle work on the variety, Triumph (Briggs and Woods, 1993; Woods *et al.*, 1994) as :

$$\log_{10} \sigma_d = 1.91 - 0.0352\ T$$

The standard deviations, σ_v and σ_d have the units of time and define the rates of the two processes. It should be noted that σ_v is a strong function of moisture content and temperature, while σ_d is a function of temperature only. The model reflects the experimental finding that moisture content does not significantly affect rate of break of dormancy.

CHANGES IN STORAGE

In order to predict germinability changes during 'warm' storage prior to cooling the following assumptions were made:

(i) The required germinability is a minimum of 95%.

(ii) A typical worse-case dormancy level is 10%. In barleys collected with the objective of acquiring dormant samples in the 1990 and 1991 harvest, four out of 33 were below 10% at levels of 6%, 8%, 6% and 8.5%.

(iii) The initial viability was 98%. This viability refers to a value based on an ageing test and is not derived from values in the hydrogen peroxide test (Chapter 2 - germinative capacity). The value is based on five barleys tested at 38°C, one of which was replicated at four moisture contents. All values were above 98%.

(iv) The mean moisture content in storage was 12% (wb). Due to variations in drier performance 11% and 13% were also examined.

(v) All germination values refer to the 4 ml, 3 day, IoB test (Anon., 1991), outlined in Chapter 2 under germinative energy.

Based on these assumptions and the double probit analysis, the effect of temperature and moisture content on storage time is illustrated in Table 3.1. At 12% moisture content the germinability can be raised from 10% to 95% in 19 days at 35°C. However, regions of the store at 13% moisture content would suffer too much viability damage to attain 95% germinability. At 13% m.c., 95% is just about achievable by 28 days at 30°C. At 11% m.c. it is possible to go to 40°C and break dormancy in 12 days.

From these predictions, 24 days at 30°C and 12% m.c. would give a germinability rise from 10% to 95%. Any barley at 13% m.c. (24 days at 30°C) would have a slightly lower germinability calculated to be 93.6% (not shown on Table 3.1).

The results of Table 3.1 also show that at lower temperatures and longer times it is possible to achieve higher germinabilities. This is due to the sensitivity of viability loss to temperature.

CHANGES DURING COOLING

The data on the 15, 10 and 5°C cooling front completion times (Wilkin *et al.*, 1990, p.36) are utilised to predict worse case viability loss during ambient cooling after warm storage (30°C, 24.2 days). Predictions for grain at 12% and 13% are presented in Table 3.2 for the case of 6.8 $m^3/h/t$ (4 cfm/t) fan capacity and starting date 1st August. Given 24.2 days warm storage the 1st July start date was not considered.

Table 3.2 shows that the predicted loss in viability is considerable and most of this occurs during the 24 day period at 30°C from the time the fan is started to the arrival of the 15°C front. In reality, the traverse time of the front is 8.7 days and therefore the grain will be at near the mean ambient temperature within this time. Given that loss of viability increases by a factor of ~4 for a 10°C temperature rise, this is very significant.

In Table 3.3 the loss in viability is re-calculated assuming a 20°C front arriving in 8.7 days, followed by the 15, 10 and 5°C fronts. The predicted loss in viability is greatly reduced.

DISCUSSION

The major cost associated with dormancy is the need to carry over stocks of barley from one season to the next. The prime objective is therefore to produce maltable

barley quickly. Within the constraints adopted in this analysis a 24 d storage at 30°C would be the quickest 'safe' treatment. From the previous dormancy project (Briggs and Woods, 1993), a number of barleys stored at 38°C and 12% m.c. suffered vigour loss after 10-15 days. This would support a storage regime of around 30°C at 12% m.c.

Once a quantity of barley has been processed quickly, these predictions suggest that storage of subsequent lots of barley at lower temperatures for longer periods would give higher germinabilities. However, this would require a high degree of control of temperature into store. A single temperature process with a subsequent cooling/holding period may be more manageable.

It might be economically justified to dry the first batch of barley to 11% and break dormancy in 16 days at 35°C. This may be easier to achieve than a high degree of temperature control into store.

These results give the range of options for a warm storage dormancy break, based on the laboratory data of Briggs and Woods (1993).

Table 3.1.
Time in days to break dormancy at a range of storage temperatures and moisture contents.

°C	MC = 11%			MC = 12%			MC = 13%		
	t_{10-95}	g_{max}	t_{max}	t_{10-95}	g_{max}	t_{max}	t_{10-95}	g_{max}	t_{max}
10	115	97.6	176	116	97.4	168	118	96.9	161
15	77	97.6	116	78	97.2	110	79	96.7	105
20	52	97.4	76	52	97.0	72	54	96.3	68
25	35	97.2	49	35	96.7	46	37	95.7	44
30	23	96.9	32	24	96.1	30	-	94.6	28
35	16	96.3	20	19	95.0	19	-	92.5	17
40	12	95.3	13	-	92.8	12	-	88.1	11
45	-	93.0	8	-	88.3	7	-	79.3	6

t_{10-95} time to increase germinability from 10% to 95%

g_{max} maximum germinability that can be achieved at a given temperature

t_{max} time to achieve g_{max}

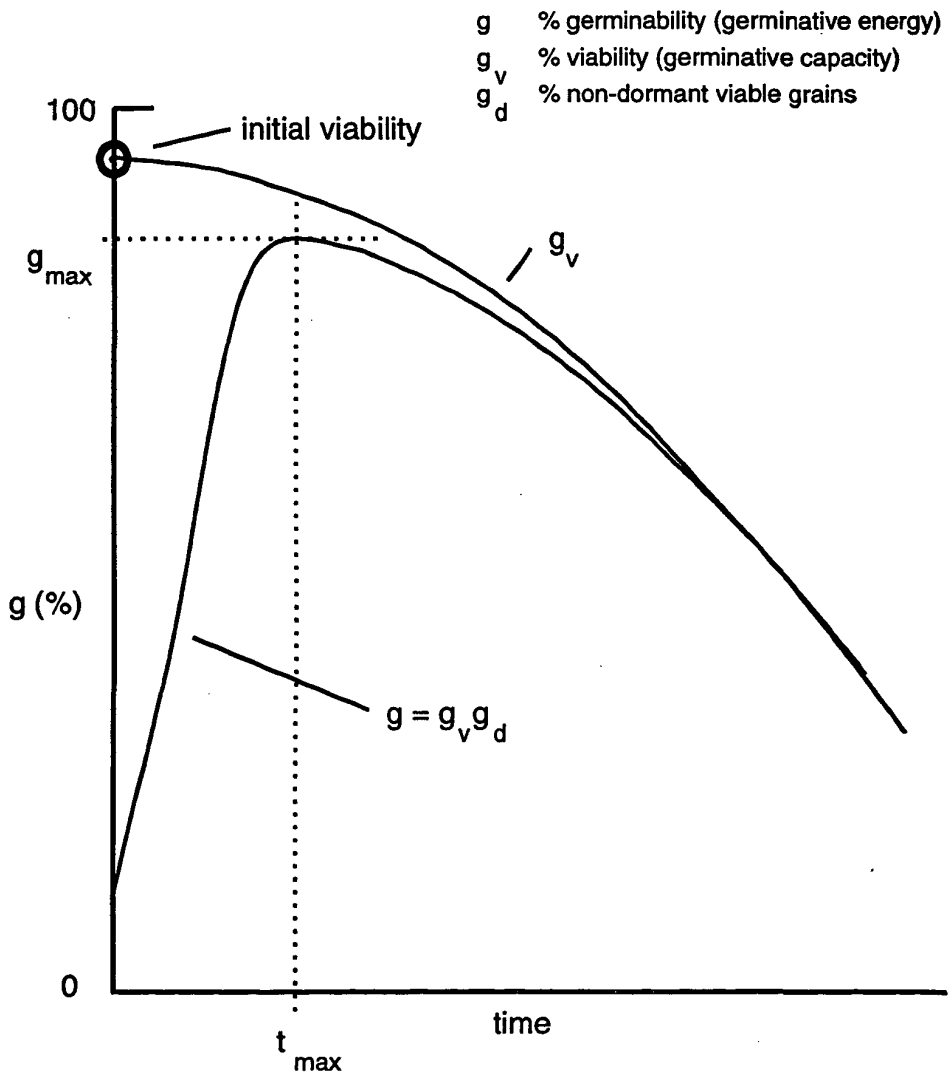
Table 3.2.
Dormancy and viability changes during cooling (6.8 m^3/h/t, start date 1.8)

Stage	Duration (days)	T(°C)	g(%)	g_V(%)	g_d(%)
(a) 12% moisture content					
Warm storage (t_{10-95})	24.2	30	95.0	96.7	98.1
up to arrival 15° front	24	30	94.6	94.6	100.0
up to arrival 10° front	40	15	94.1	94.1	100.0
up to arrival 5° front	104	10	93.2	93.2	100.0
(b) 13% moisture content					
Warm storage (t_{10-95})	24.2	30	93.9	95.5	98.2
up to arrival 15° front	24	30	91.0	91.0	100.0
up to arrival 10° front	40	15	89.7	89.7	100.0
up to arrival 5° front	104	10	87.6	87.6	100.0

Table 3.3.
Dormancy and viability changes during cooling with 20° front (6.8 m^3/h/t, start date 1.8)

Stage	Duration (days)	T(°C)	g(%)	g_V(%)	g_d(%)
(a) 12% moisture content					
Warm storage (t_{10-95})	24.2	30	95.0	96.7	98.1
up to arrival 20° front	8.7	30	96.0	96.0	99.9
up to arrival 15° front	15.3	20	95.7	95.7	100.0
up to arrival 10° front	40	15	95.3	95.3	100.0
up to arrival 5° front	104	10	94.5	94.5	100.0
(b) 13% moisture content					
Warm storage (t_{10-95})	24.2	30	93.9	95.5	98.2
up to arrival 20° front	8.7	30	94.1	94.2	99.9
up to arrival 15° front	15.3	20	93.5	93.5	100.0
up to arrival 10° front	40	15	92.5	92.5	100.0
up to arrival 5° front	104	10	90.7	90.7	100.0

Fig 3.1
Germination history of a barley in storage



4. Calculations for the development of three species of insects during the various temperature/time combinations required to break dormancy and cool the grain

D.M.Armitage

INTRODUCTION

In this chapter, the predictions of time needed to break dormancy and to cool the barley are used as the basis of calculations of the number of insects developing during these storage phases

To prevent the development of insects in stored grain, it is usual to cool grain as soon as it goes into store so that the grain temperature is reduced to below the reproduction threshold of insects before eggs laid are able to develop into adults. However, this approach is not appropriate for dormant malting barley where, if dormancy is to be broken in an acceptable time, it must be first held at a relatively high temperature, before cooling can take place. The advantage of the short time available for insects for egg-laying and development while dormancy is broken at a high temperature must be balanced against the disadvantage of their increased fecundity at this high temperature.

CHOICE OF STRATEGY

Methods

These calculations are based on the methods outlined by Wilkin *et al.* (1990) (p.70)
where:- n = (d-t)e
n = number of insects developing
d = time for cooling front to pass through the grain
t = time for insects to complete development
e = number of eggs laid per day

For successive cooling fronts, the actual time taken by the cooling front to travel through the bulk (d2) is converted to 'biological units', equivalent to days of the first cooling period - d2 x t/t2
t2 = time for insects to complete development at the lower temperature

The calculations are based on the data in Appendices A-C, including some extrapolations due to the gaps in the data. The figures for *O. surinamensis* includes a range of values. The higher values are based on unpublished oviposition data by Jacob (CSL) while the lower figures are derived from the work of Beckett and Evans (1994). The latter is based on progeny developing per female and not on eggs laid. In some cases data are only available for a r.h. of 70 % and this has been used for the calculations at the lower relative humidities, although there is likely to be a decrease in fecundity with decreasing moisture contents. In *S. granarius* and *C. ferrugineus*, there is quite dramatic increase of development time with decreasing moisture, but this effect appears much less marked with *O. surinamensis* which is unfortunately the species which poses the greatest threat to products stored at relatively high temperature. Development of *S.granarius* ceases at temperatures above 30°C. The moisture content/ equilibrium relative humidity figures are taken from unpublished work by Henderson (CSL, Slough) and are based on the ISO standard for moisture determination.

Insects developing during dormancy break

Table 4.1 complements Table 3.1 giving the time to break dormancy and compares the time taken for insects to complete their development, with the temperature/time combinations required to break dormancy. Where the latter is the smaller figure, then it may be assumed that there will be an increase in adult insects. The best strategy for storing barley will be that which allows development of the smallest number of insects both during this initial, 'holding' phase and during the subsequent cooling.

Insects developing after dormancy break and during cooling from 20-35 °C

Tables 4.2 and 4.3 complement Tables 3.2 and 3.3 which show dormancy and viability changes during cooling and shows the number of insects developing.

DISCUSSION

O. surinamensis was the quickest developing species and the greatest margin of safety, between the end of the warm holding phase and the start of cooling, was at 20°C while at 25°C and 30°C there was virtually no margin of safety (Table 4.1).

In theory, all strategies permitted the development of insects in the period during which dormancy was broken and the grain was cooled. Highest potential total

numbers developed at 30°C but each species peaked at a different initial temperature so that *S. granarius* did best at 25°C (Table 4.2b), *O. surinamensis* did best at 30°C (Table 4.2c) and *C. ferrugineus* did best at 35°C (Table 4.2d).

The two methods of calculating the time to pass cooling fronts through grain at 30°C both showed the potential for development of considerable numbers of insects before the grain was cooled to below their development threshold. Of the two methods, that which interposed an intermediate 20°C cooling front (Table 4.3), before the 15°C front, gave the lower estimates of insects developing than that which assumed a 15°C cooling front only (Table 4.3).

A shortcoming of the cooling calculations is that no allowance is made for the different initial grain temperatures, so that it is assumed that grain at 40°C will cool no more slowly than grain at 20°C. This is because the figures in Wilkin *et al.* (1990) were based on worst-case scenarios that made allowances for non-ideal airflow and incorporated the results of practical trials. It may be that proportional adjustments can be made to these figures which would probably result in slightly longer cooling times for grain at 40°C and shorter cooling times for grain at initially lower temperatures. However, this is not really borne out by the results from the commercial-scale tests (Chapter 9.)

The calculations of insect development are unlikely to be precisely accurate because of the incomplete data, much of the which resulted from feeding the insects on artificial media because grain may not be the optimal diet and also because different strains of the same species may have quite different biology. However these calculations are intended to show the highest numbers likely to develop and choice of the temperature/time combination giving the least numbers of insects will be the safest to use in practice, providing the conditions are also attainable during storage in maltings. The laboratory tests in this report should give some idea of the number of insects developing in practice which are supported by mortality assessments of caged insects in the commercial-scale trials.

From the point of view of pest control, the best strategy appears to be to store the grain at 20°C initially to break dormancy, if the two months required to do this is acceptable and if the cooling components of the drying equipment were capable of achieving this. Alternatively, initial temperatures above the insects threshold of 40°C or more would also prevent insect development but the threat to germination would be proportionately greater.

Table 4.1.
Comparison of days required to break dormancy at a range of temperatures and moisture contents with the time required for three species of insects (*O. surinamensis*, *S. granarius* and *C. ferrugineus*) to develop from egg to adult (extrapolations in italic).

	MC	= 11	%		MC	= 12	%		MC	= 13	%	
T (°C)	t_{10-95}	O.s	S,g	C.f	t_{10-95}	O.s	S.g	C.f	t_{10-95}	O.s	S.g	C.f
10	115				116				118			
15	77		*200*		78		182		79		*172*	
20	52	80	79.5	*105*	52	80	67.5	*105*	54	70	*69*	*105*
25	35	37	45.5	68	35	35	40.5	57	37	33*	*39.5*	54
30	23	25	33	39	24	24	30	35		23	*29*	33
35	16	24		32	19	23		29		22		27
40	12			*21*				*21*				*21*

* Insect development time lower than time required to break dormancy

Table 4.2a.
Insects developing during cooling from 20°C (6.8m3/h/t, start date 1.8)

Stage	Duration (days)	T (°C)	*O. surinamensis*	*S. granarius*	*C ferrugineus*
12 %	moisture	content			
Warm storage	54	20	0	0	0
15 °C front	24	20	1-4	8	0
10° C front	40	15		10	

Table 4.2b.
Insects developing during cooling from 25°C (6.8m3/h/t, start date 1.8)

Stage	Duration (days)	T (°C)	*O. surinamensis*	*S. granarius*	*C. ferrugineus*
12 %	moisture	content			
Warm storage	37	25	2-7	0	0
15 °C front	24	25	20-50	17	8
10° C front	40	15		24	

Table 4.2c.
Insects developing during cooling from 30°C (6.8m3/h/t, start date 1.8)

Stage	Duration (days)	T (°C)	*O. surinamensis*	*S. granarius*	*C. ferrugineus*
a) 12 %	moisture	content			
Warm storage	24	30	1-4	0	0
15 °C front	24	30	21-89	15	31
10° C front	40	15		20	
(b) 13%	moisture	content			
Warm storage	24	30	2-7	0	0
15°C front	24	30	22-93	16	45
10°C front	40	15		21	

Table 4.2d.
Insects developing during cooling from 35°C (6.8m3/h/t, start date 1.8)

Stage	Duration (days)	T (°C)	*O. surinamensis*	*S. granarius*	*C. ferrugineus*
12 %	moisture	content			
Warm storage	19	35	0	-	0
15 °C front	24	35	12-42	-	80
10° C front	40	15		-	

Table 4.3.
Insects developing during cooling incorporating a 20°C front (6.8m3/h/t, start date 1.8)

Stage	Duration (days)	T (°C)	*O.surinamensis*	*S.granarius*	*C.ferrugineus*
(a) 12 %	moisture	content			
Warm storage	24.2	30	0	0	0
20°C front	8.7	30	7-30	3	0
15 °C front	15.3	20	12-47	9	11
10° C front	40	15		14	
(b) 13%	moisture	content			
Warm storage	24.2	30	1-4	0	0
20°C front	8.7	30	8-33	4	3
15°C front	15.3	20	13-51	9	17
10°C front	40	15		14	

APPENDIX 4.1

Oryzaephilus surinamensis - time for complete development in days (t), pre-oviposition time in days (p), eggs per day (e), % mortality (m) and weekly self-multiplication rate (w) (Howe, 1956, Jacob and Fleming, 1989 and Jacob, unpub.).

°C	r.h. (%)	40	50	55	70
	m.c (%)	11	12	13	15
20	t	80	80	70	60, 62-80
	p				
	e	0.1-0.5			0.1-0.7
	m	60	60	60	40-84
25	t	37	35	33	32, 31-37
	p				
	e	1.0-1.8			1.3-2.7
	m	<15	<15	<15	15-43
30	t	25	24	23	22
	p				4-5
	e	2.1-3.7			2.7-4.0
	m	<15	<15	<15	<15
	w				2.16
35	t	24	23	22	20
	p				5-6*
	e	1.4-2.0			2.2-3.3
	m	<15	<15	<15	<15
	w				2.64*

* 33 °C

APPENDIX 4.1A

Oryzaephilus surinamensis - time for complete development in days (t), pre-oviposition time in days (p) eggs per week, mortality (m) and finite rate of population increase (w). (from Beckett and Evans, 1994).

°C	rh	40 (33)	50	55	70
	mc	11 (10)	12	13	15
20	t	96.0	76.0		75.4
	p	13	11		9
	e	0.125	0.5		1.0
	m	99	76		46
	w	1.02	1.08		1.09
25	t	39.1	35.4		34.2
	p	3	1		1
	e	3	5		8
	m				
	w	1.43	1.51		1.58
30	t	26.7	23.1		21.2
	p	0	0		0
	e	7	7		10
	m	42.5	28.2		15.0
	w	1.74	1.91		2.23
32.5	t	27	23.9		22.4
	p	0	0		0
	e	2	10		16
	m				
	w	1.74	1.91		2.23
35	t	28.1	22.7		20.0
	p	0	0		0
	e	0.2	1		4
	m	98	78		16
	w	0.93	1.31		1.79

APPENDIX 4.2

Sitophilus granarius - time for complete development (t), pre-oviposition time (p), eggs per day (e), mortality (m) and weekly self-multiplication rate (w) (Eastham and McCully, 1943: Eastham and Segrove, 1947).

°C	r.h. (%)	40	50	55	70
	m.c. (%)	11	12	13	15
15	t	*200*	182	*172*	144
	p				
	e				
20	t	79.5	67.5	*69*	56.5
	p	21	21	*21*	21
	e	0.4	0.4	*0.45*	0.5
25	t	45.5	40.5	*39.5*	36.5
	p	8	8	*8*	8
	e	0.6	0.8	*0.9*	1.1
30	t	33	30	*29*	26
	p	4*	4*	*4**	4*
	e		0.8*	*0.9**	1*

*27.5 °C.

APPENDIX 4.3

Cryptolestes ferrugineus - time for complete development in days (t), pre-oviposition time in days (p), eggs per day (e), % mortality (m) and weekly self-multiplication rate (w) (Smith, 1963, 1965.).

°C	r.h. (%)	40	50	55	70
	m.c (%)	11	12	13	15
20	t				105
	p				21
	e				0.16
	m				60
	w				1.02
25	t	68	57	54	42
	p				0.7
	e	0.9			1.5
	m	15	12	10	7
	w	1.28			1.52
30	t	39	35	33	28
	p				1.4
	e	1.5			4.2
	m	15	12	10	10
	w	1.70			2.06
35	t	32	29	27	21
	p				0
	e	2.4			5.7
	m	20	17	15	10
	w				2.64
40	t				21
	p				0.7
	e	1.2*			1.5
	m				60
	w				1.58

* 37.5 °C

5. Laboratory tests of insect increase during different malting barley storage strategies

D.M.Armitage

INTRODUCTION

Following on from the calculations of likely insect increase during dormancy break and cooling, these experiments were intended to discover how quickly insects actually increased when exposed to the temperatures and storage times needed for dormancy break and cooling. While the calculations in the Chapter 4 were often based on media other than grain, such as flour or oatmeal, in these experiments the insects had only barley to feed upon.

METHOD

Outline

Dormant samples of infested and uninfested barley were exposed in incubators to temperature/time combinations estimated to raise germination in dormant barley from 10% to 95% (t_{10-95}) and then subsequently kept at the initial temperature for the time estimated to cool the grain. Grain was sampled at the end of the 'holding' period and the warm phase to check that dormancy had been broken and to determine any increase in insect numbers. Further samplings were carried out at the end of the time estimated to cool to 10 °C, 5 °C and after six months storage. These temperatures were achieved by turning down the incubator in sharp stepwise drops.

Details

Strategies

Three were tested :-

40°C/11% m.c. (t_{10-95} = 12 days)

30°C/12% m.c. (t_{10-95} = 24 days)

20°C/13% m.c (t_{10-95} = 54 days).

Sampling schedule

a. Initial (dormancy only),

b. After t_{10-95}

c. After time to cool to 15°C (24 days).

d. After time to cool to 10°C (40 days)

e. After time to cool to 5°C (104 days)

f. After storage at 5°C for up to 6 months.

Replication

A mixed infestation of twenty-five unsexed laboratory strain adults of *S. granarius* and *O. surinamensis* from nine and eight week old cultures respectively were used to infest ca. 75g of Camargue barley in 4 oz. jars, conditioned to the appropriate moisture content (m.c.). At each sampling period and for each strategy five of these replicates were withdrawn, the insect numbers determined and the m.c. of one of the replicates checked. An additional replicate was used for germination assessment, based on three, 100 grain samples of dormant 'Camargue'.

The experiments were carried out in unhumidified incubators and the humidities were controlled by holding the samples over potassium hydroxide (KOH) solutions of appropriate specific gravity (S.G.) .

RESULTS

Insect numbers

No insects survived at 40°C. The m.c.s measured at the sampling times coinciding with the time to break dormancy, the time to cool to 15, 10 and 5 °C and after six months' storage at 5°C were 10.3, 8.7, 8.7, 8.8 and 9.1% m.c.

At 30°C, after the time estimated to break dormancy, 80% of the original adult *O. surinamensis* had died but there were over 30 larvae/ sample to replace them (Table 1). After the time estimated for cooling to 15°C, the number of adult *O. surinamensis* had been restored to near their initial numbers and there were 15 larvae and pupae per sample. However, by now the number of dead adults had risen to 26 per sample. After this, numbers of live adults, larvae and pupae declined and there were none alive after six months' storage at 5°C. The trends were similar with *S. granarius*. The moisture contents during the experiment were in the range 11-12% m.c.

At 20°C, death of *O. surinamensis* was slower and the number of offspring produced, lower than at 30°C but the trend was the same as at 30°C (Table 2). In contrast, at 20°C, *S.granarius* did much better than *O. surinamensis* and than at 30°C. *S. granarius* had increased by 1.6x, even by the time required to break dormancy and by the time estimated for cooling to 15°C, by over 10x. This increase continued, even as the temperature dropped to 10°C, then 5°C but after 6 months at 5°C about half the *S.*

granarius had died. The moisture contents at the various samplings showed an increase to about 18% due to the activities of the insects.

Germinations

There were no problems with maintaining viability for the samples stored at 20, 30 or 40 °C. Under the same conditions, the grain quickly recovered from dormancy and slowly, as is usual, lost water sensitivity. Cooling the grain to 5°C and storing it for up to six months also had no effects on germinative properties.

DISCUSSION

The high risk strategy of keeping the grain at 40°C, to break dormancy had the apparent advantage of killing all the insects in a short time, although in practical circumstances, there must be some risk of insect development in rapidly-cooling areas of the grain. In addition, there may be some species of insects, such as *Trogoderma granarium* Everts (traditionally a maltings pest of some importance) that would be favoured by this temperature.

There was some development of both *S. granarius* and *O. surinamensis* at 30°C but this was balanced by death of the adults and there was no survival by the end of storage. This was also true of *O. surinamensis* at 20°C but an unexpected result was the explosion of the *S. granarius* population which suggests that storage of malting barley at this lower temperature before cooling is a high risk strategy as far as infestation is concerned.

These results are at variance with the estimates reported in Chapter 4 where it was suggested that *O.surinamensis* would be favoured at 30°C. Its failure to develop successfully may be accounted for by its difficulty in feeding on whole grain, whereas in all studies, on which the former estimates were based, the insects were fed on a broken substrate.

The ability of *S.granarius* to increase so well at 20°C was also unexpected. This may be partly accounted for by the swifter development times and greater productivity of the laboratory strain of *S.granarius*. However, the same strain was used in the commercial-scale experiment in the south in 1993-4 (Part 9) where it did not prosper, so the difference may also be due to accumulation of metabolic water in the laboratory experiment which increased the rate of development. On the other hand, *S.granarius*

was able to increase in 1994-5, when the grain was cooled quickly to 20°C and then remained at that temperature for some time.

Table 5.1
Laboratory experiment - Germination (%) of Camargue barley during various phases of the cooling cycle.

	40 °C			30°C			20°C		
	H_2O_2	4 ML	8 ML	H_2O_2	4 ML	8 ML	H_2O_2	4 ML	8 ML
	Capacity	Energy	W. sens	Capacity	Energy	W. sens	Capacity	Energy	W. sens
Initial				96	21	9			
After drying				91	65	16			
t 10-95	99	99	52	100	99	22	98	98	40
cool to 15°C	99	99	58	99	98	75	99	100	26
cool to 10°C	99	98	87	99	99	63	98	99	60
cool to 5°C	99	99	72	100	100	79	98	98	44
6m @ 5°C	99	99	80	100	99	81	99	99	50

Table 5.2.
Changes in numbers of *O. surinamensis* and *S. granarius* (range in parentheses) on malting barley (initial n=25 adults, 5 reps) in laboratory tests simulating cooling phases from an initial temperature of 30°C.

		O.surinamensis			*S.granarius*	
		adult		stages	adult	
	m.c.	live	dead		live	dead
t 10-95	11.8	4.0 (3-5)	20.0 (18-21)	33.4 (25-43)	15.6 (11-19)	8.0 (7-9)
Cool to 15°C	11.9	24.0 (20-33)	26.4 (24-29)	15.2 (5-24)	19.2 (13-28)	15.8 (13-17)
Cool to 10°C	11.1	18.6 (12-29)	25.4 (24-27)	3.4 (2-4)	11.4 (6-15)	29.6 (27-33)
Cool to 5°C	11.6	8.0 (3-12)	32.4 (29-40)	0	3.0 (1-4)	41.4 (35-58)
6m @ 5°C	11.2	-	42.4 (35-47)	0	0	55.6 (34-74)

Table 5.3.
Changes in numbers of *O. surinamensis* and *S. granarius* (range in parentheses) on malting barley (initial n=25 adults, 5 reps) in laboratory tests simulating cooling phases from an initial temperature of 20°C

		O.surinamensis			*S.granarius.*	
		adult		stages	adult	
	m.c.	live	dead		live	dead
t 10-95	5.9	15.2 (11-19)	10.6 (9-14)	20.0 (8-26)	39.6 (37-43)	3.0 (0-5)
Cool to 15°C	16.9	10.2 (9-11)	10.0 (4-15)	19.2 (6-37)	271.2 (152-357)	7.2 (1-7)
Cool to 10°C	17.7	11.4 (7-15)	12.0 (11-16)	19.2 (2-29)	279.8 (129-403)	3.2 (2-6)
Cool to 5°C	18.8	6.4 (3-9)	12.4 (9-17)	0	352.8 (328-376)	5.8 (2-18)
6m @ 5°C		0	18.4 (17-20)	0	144.2 (107-168)	162.2 (107-237)

6. The effect of a sudden temperature drop on the emergence of malting barley from dormancy

J.L.Woods and D.J. McCallum

INTRODUCTION

The strategy being developed in the project is based on warm storage to break dormancy followed by rapid cooling, followed by cool storage, to control insects. In discussion of this with maltsters and grain merchants, a frequently recurring concern is the possibility of inducing dormancy by cooling, particularly if this involves a sudden and substantial temperature drop. The experiment described here examines temperature changes more severe than those likely to be encountered in the ambient cooling of grain.

In addition, the probit model of dormancy being used to develop the integrated storage strategy was developed from experimental data obtained in a constant temperature environment at temperatures of 8, 15, 27 and 38°C. In order to use the model in the variable temperature environment of an actual store, it is necessary to check that it is not influenced by temperature change. As a check on the model it is compared with the variable temperature data presented here.

METHOD

The two barley samples used were both Triumph from the south-east of Scotland from the harvest of 1990 and 1991 respectively. These were dried to 12% moisture content in a ventilated tray with air at 38°C and 10% immediately before storage prior to experimentation.

Experiment 1

Pen-Tr-90, storage at 33°C with transfer to 8°C and 15° at 4, 8 and 10 days.

Experiment 2

Pen-Tr-91, storage at 33°C with transfer to 8°C and 15°C at nominally 75% and 90% germination level.

In all experiments a sub-sample was maintained in storage at 33°C as a control. All germination levels were determined by the 4 ml Institute of Brewing (IoB) test at three days using 900 seeds (Anon., 1991).

RESULTS

Experiment 1

The first twenty five days of storage for the control and each transfer are illustrated in Figures 6.1 to 6.6. The germination levels achieved for times up to 50 days are presented in Table 6.1. It should be noted that all times in Tables 6.1 and 6.2 are relative to a time zero when the samples were placed into storage at 33°C. These results show that there is in no case a significant reduction in germination level due to the sudden temperature reduction. There is no evidence of a drop in germination due to the induction of secondary dormancy by a drop in temperature. In Table 6.1 the values after 50 days storage show that high germination levels are achieved providing the barley was not transferred from 33°C before a reasonable break of dormancy had occurred. In the control experiment, at 33°C continuously, the germination level reached 98.3% after 14 days and 99.4% after 24 days.

In Figures 6.7 and 6.8, the rate of emergence from dormancy at 8 and 15°C, subsequent to 33°C storage is plotted in probit form and compared with the predictions of Briggs and Woods (1993) based on continuous storage data at the same temperature. The slopes of the regressed data are clearly very similar for the continuous temperatures of 8 and 15°C and the temperature drop data. This gives confidence in the use of the data obtained at a steady state temperature (Briggs and Woods, 1993) under varying temperature conditions.

Experiment 2

In this experiment the transfer took place when the barley was well advanced in its break of dormancy. As can be seen in Table 6.2, again there was no induced dormancy due to cooling. There was no fall in germination level and therefore no evidence of a secondary induced dormancy. Break of dormancy proceeded more slowly at lower temperatures but high levels of germination were achieved, 97.6 - 98.4% in all cases. In the control experiment, at 33°C continuously, the barley achieved a maximum germination level of 98.3% after 21 days.

CONCLUSIONS

Cooling did not induce dormancy in any of the ten transfer experiments. There was no fall in germination level and the phenomenon of secondary dormancy was not observed. The ultimate germination levels achieved were high and were still rising, even at the lower temperature. The results suggest that a combination of warm/cool storage regime would not adversely affect germination.

The probit model predictions, based on single temperature data, were compatible with the data for the double temperature regime presented here. This gives confidence in the model under varying temperature conditions.

Table 6.1
Effect of transfer to a lower temperature on germination level (Experiment 1). Standard deviations in parentheses.

Initial G(%)	Transfer Temp.(°C)	Period to transfer (d)	G(%) at transfer	G(%) at 21 d	G(%) at 50 d
27.2 (5.6)	8	4	51.9 (3.8)	64.5 (2.6)	85.1 (4.1)
27.2 (5.6)	8	8	84.8 (2.5)	90.9 (1.9)	90.8 (3.1)
27.2 (5.6)	8	10	90.8 (2.1)	94.8 (1.6)	97.8 (1.0)
27.2 (5.6)	15	4	51.9 (3.8)	75.0 (2.7)	97.5 (1.1)
27.2 (5.6)	15	8	84.8 (2.5)	91.3 (3.3)	97.8 (1.2)
27.2 (5.6)	15	10	90.8 (2.1)	96.1 (3.7)	97.5 (1.3)

Table 6.2
Effect of transfer to a lower temperature on germination level (Experiment 2). Standard deviations in parentheses.

Initial G (%)	Transfer Temp (°C)	Period to transfer (d)	G (%) at 7 d	G (%) at 14 d	G (%) at 21 d	G (%) at 28 d	G (%) at 35 d	G (%) at 42d
60.3 (5.7)	8	3	79.4 (7.7)	79.7 (5.4)	93.9 (3.9)	96.8 (3.3)	98.1 (1.0)	98.4 (1.4)
60.3 (5.7)	8	7	91.4 (2.1)	-	96.9 (2.6)	97.1 (1.3)	97.9 (1.5)	97.9 (1.8)
60.3 (5.7)	15	3	79.4 (7.7)	84.0 (2.9)	97.7 (1.6)	97.3 (1.8)	98.5 (1.3)	97.6 (1.2)
60.3 (5.7)	15	7	91.4 (2.1)	-	96.1 (2.5)	97.0 (1.7)	97.8 (2.2)	98.1 (1.3)

Fig 6.1
Triumph stored at 33°C continuously (•) ; cooled after four days and kept at 8°C (o)

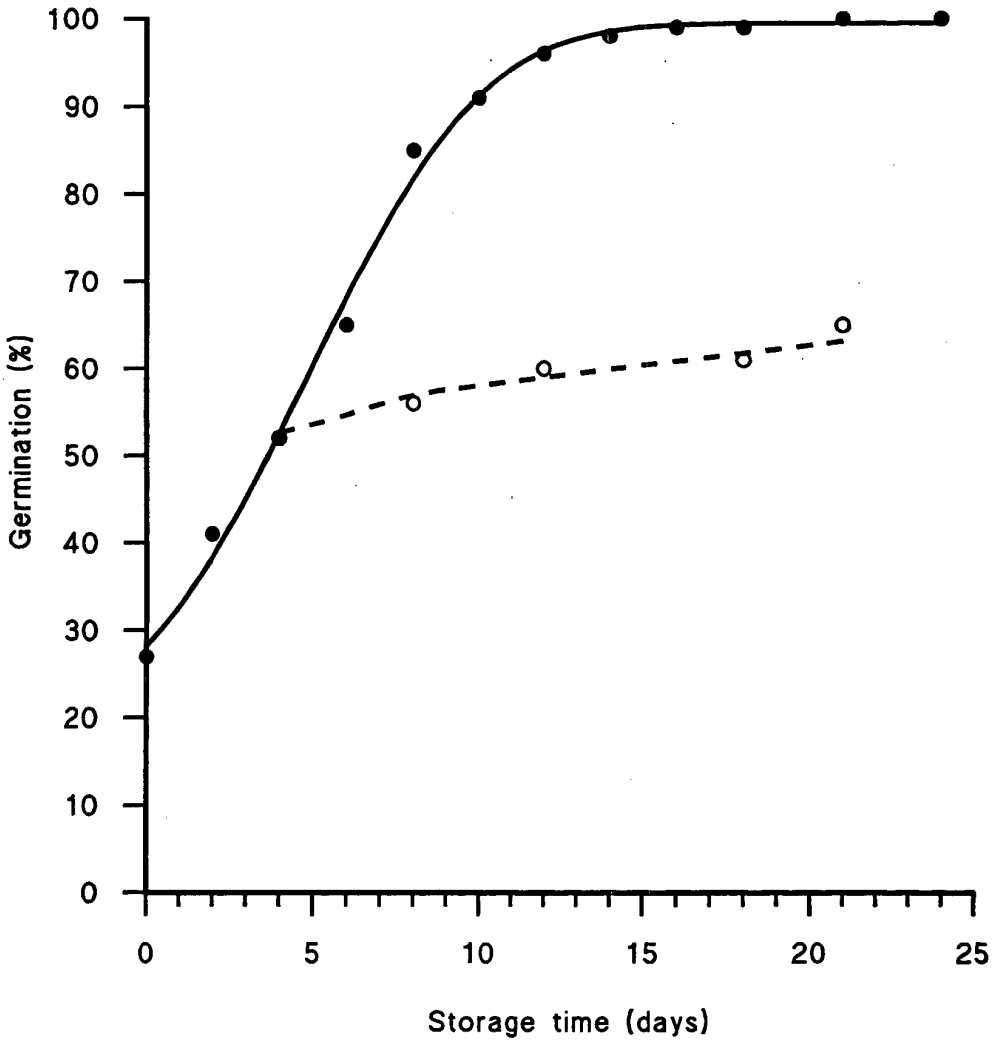


Fig 6.2
Triumph stored at 33°C continuously (•) ; cooled after eight days and kept at 8°C (o)

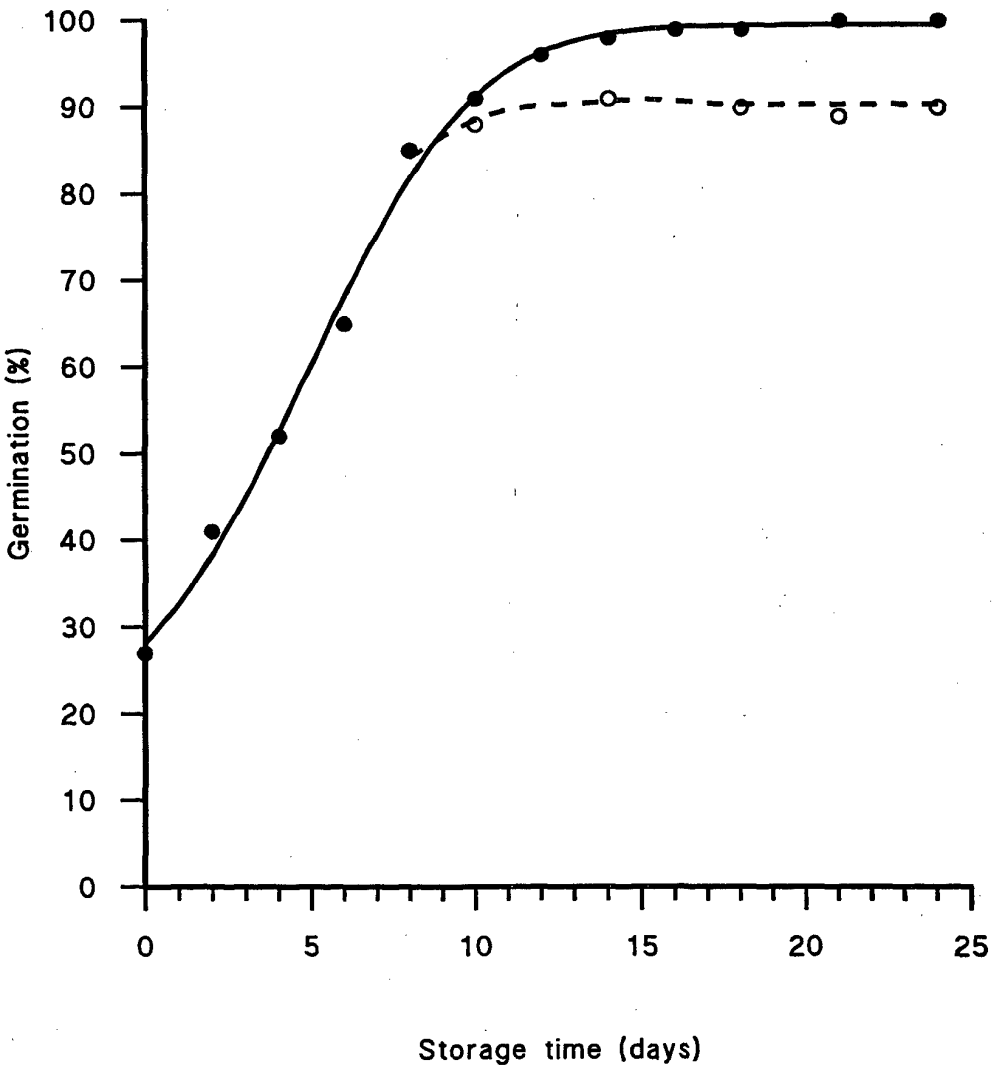


Fig 6.3
Triumph stored at 33°C continuously (•) ; cooled after ten days and kept at 8°C (o)

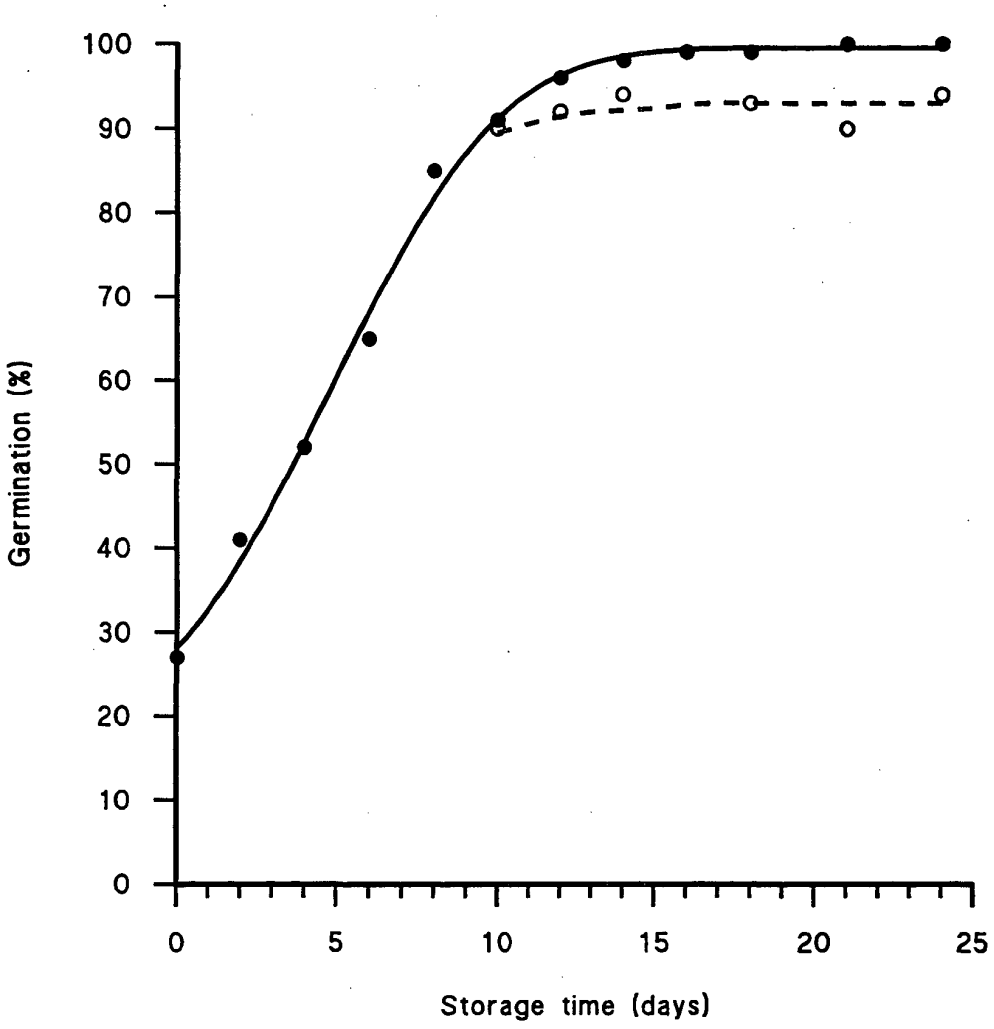


Fig 6.4
Triumph stored at 33°C continuously (•) ; cooled after four days and kept at 15°C (o).

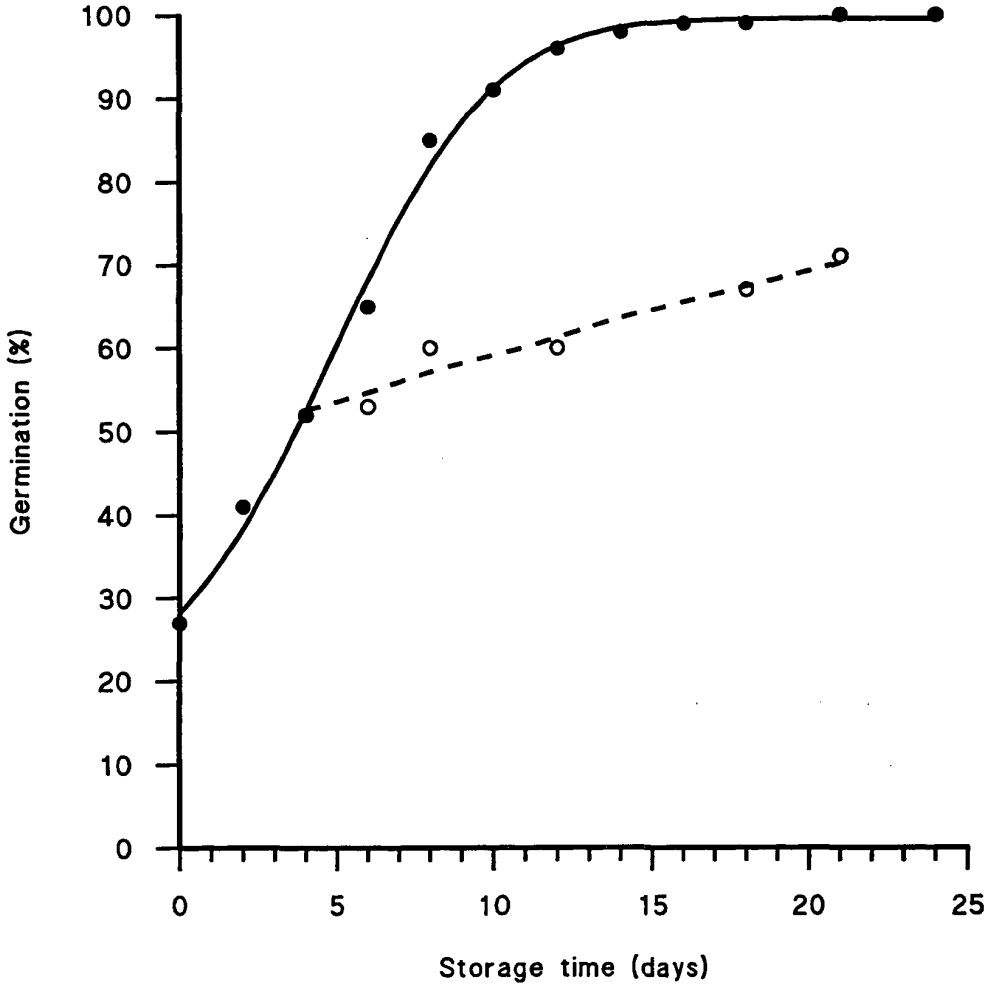


Fig 6.5
Triumph stored at 33°C continuously (•) ; cooled after eight days and kept at 15° C (o)

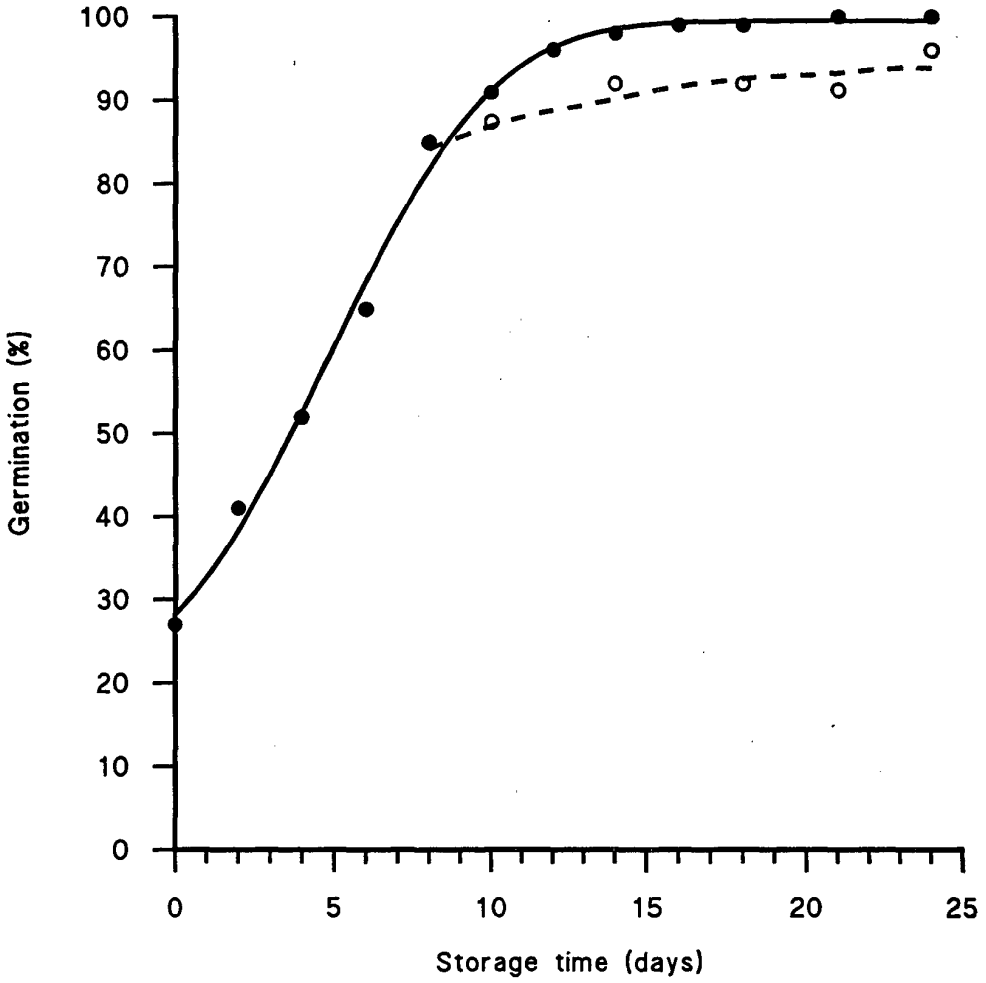


Fig 6.6
Triumph stored at 33°C continuously (•) ; cooled after ten days and kept at 15°C (o)

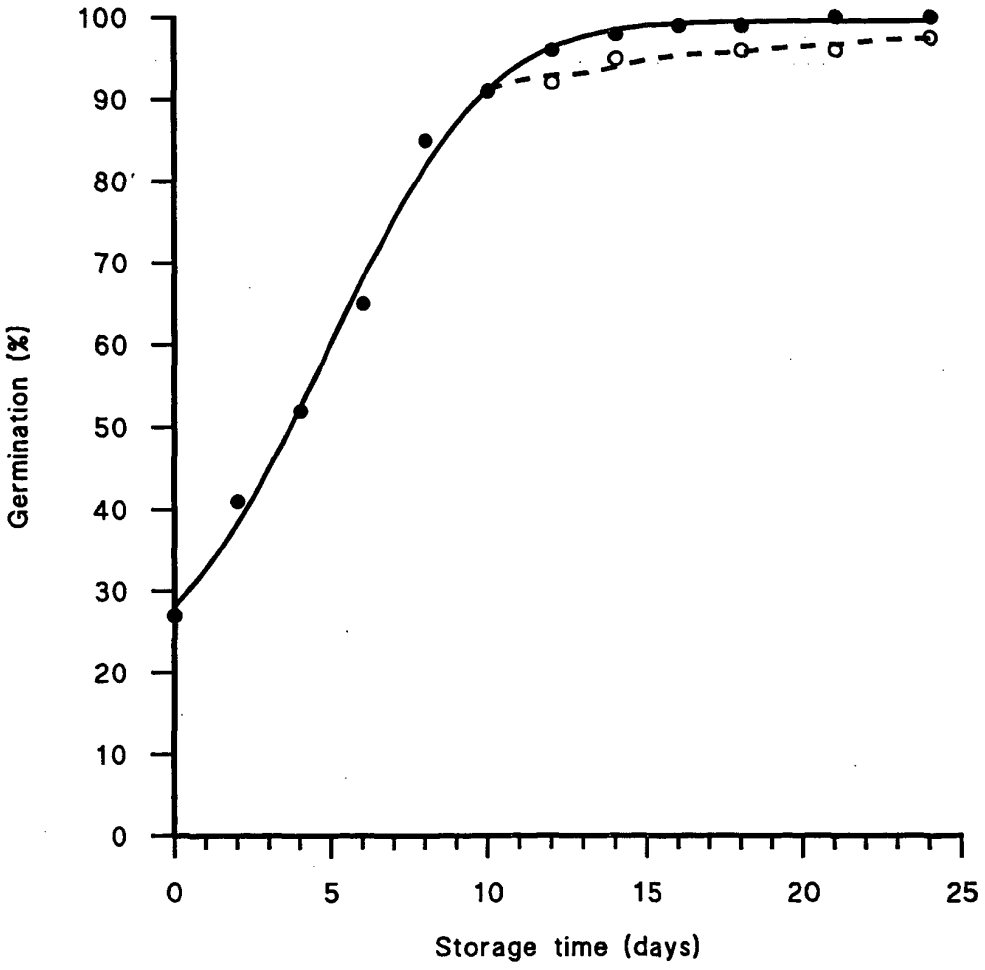


Fig 6.7
Recovery of germinative energy during storage at 8°C following transfer from 33°C initial storage. [----------, predicted curve at constant single temperature of 8°C and initial germination of 27 % (Briggs and Woods (1993)].

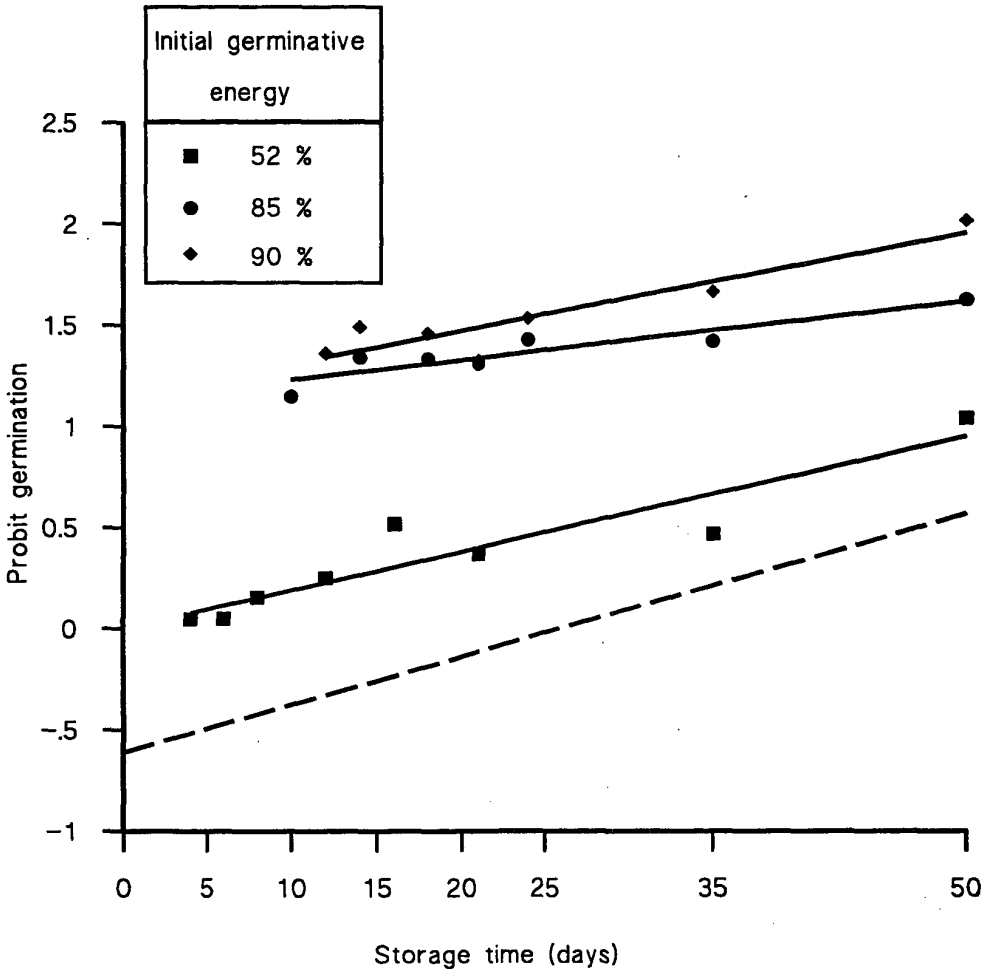
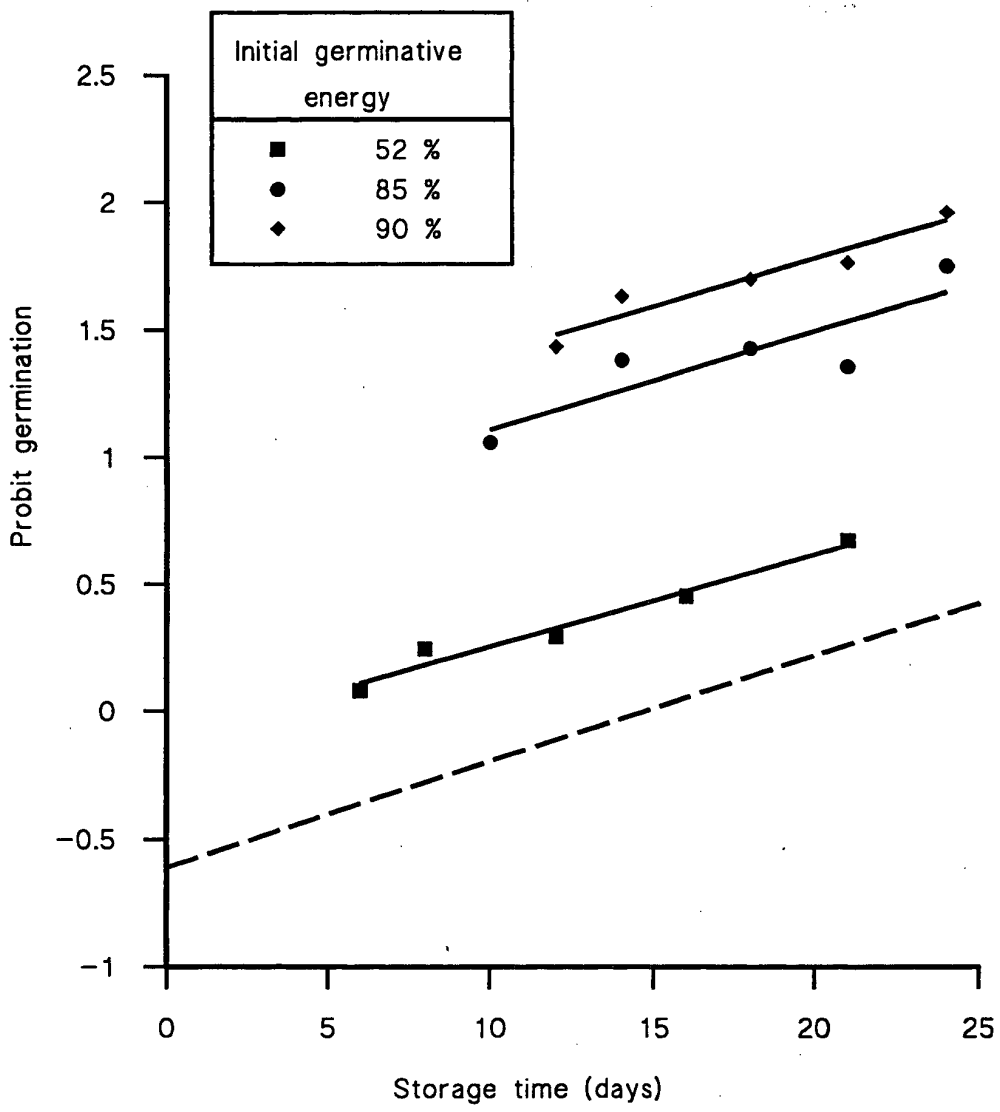


Fig 6.8 Recovery of germinative energy during storage at 15°C following transfer from 33°C initial storage.[----------, predicted curve at constant single temperature of 15° C and initial germination of 27 % (Briggs and Woods (1993)].



7. Varietal differences in dormancy recovery rate

J.L. Woods and D.J. McCallum

INTRODUCTION

The predictions of rate of break of dormancy in Chapter 3 were based on laboratory experiments on the variety Triumph (Briggs and Woods, 1993; Woods *et al.*, 1994). This variety had been identified by a consultative committee of maltsters as a barley notoriously susceptible to dormancy but popular with maltsters for its malting characteristics. In this project we wished to confirm that the data for Triumph were representative of a seriously dormant barley. It was therefore necessary to compare Triumph with other varieties.

Again, a consultative committee of maltsters identified currently popular but dormancy susceptible varieties. The spring barley, Blenheim (parentage: Triumph X Egmont) and the winter barley, Pipkin (parentage: Sergeant X Maris Otter) were chosen.

METHOD

Samples were obtained from maltings and tested for dormancy during the 1992 season. The most dormant two samples were Blenheim with a germinative energy of 6% (s.d. = 2.8%) and a M.C. of 15.5% from North East Scotland and Pipkin with a germinative energy of 53% (s.d. = 3.2%) and a M.C. of 13.8% from South Yorkshire. These were kept at -18°C until required for testing.

The experimental technique followed that of Briggs and Woods (1993). After drying to 12% M.C. at 38°C the barleys were stored in sealed glass containers at temperatures of 8, 18, 26 and 33°C. The stored barleys were sampled at appropriate intervals and stored at -18°C prior to germination testing. The 4 ml, 3 day count germination test specified by the Institute of Brewing Analysis Committee (Anon., 1991) was employed. For greater accuracy 9 x 100 seeds were counted for each sample.

RESULTS

The probit germination versus storage time graphs are presented in Figs. 7.1 and 7.2. The results for Blenheim show a more consistent rise in dormancy recovery rate with temperature than Pipkin. This is due to the greater range of germination change for

Blenheim (6%→100%) compared with Pipkin (53%→100%) enabling greater accuracy in the determination of slope. Following Briggs and Woods (1993), the data of each temperature were regressed and the slope determined.

The inverse of the slope gives σ_d, the standard deviation of the cumulative normal distribution curve as defined in Chapter 3. More simply, σ_d is in units of time (days) and its value is a direct measure of the rate of break of dormancy.

Figure 7.3 shows a log plot of σ_d versus time for Triumph, Blenheim and Pipkin. As would be expected Pipkin has the most scatter. The value of σ_d is smaller for Pipkin and Blenheim indicating a more rapid break of dormancy. Interestingly, the ln σ_d vs T plots are approximately linear with very similar slopes.

DISCUSSION

The "equal" slopes of the plots of ln σ_d vs T in Fig. 7.3 have an important implication. Although the rate of break of dormancy is different for each barley, for a given temperature rise the rate increases by the same factor for each barley. For a 10°C temperature rise, the rate of break of dormancy increases by a factor 2.25. This is often referred to as the temperature quotient, Q_{10}. This applies to Triumph, Blenheim and Pipkin, even though Pipkin is of very different parentage. It is interesting to speculate whether this is true for all varieties.

The most important observation with regard to the development of an integrated storage strategy is that, amongst three varieties chosen by maltsters for their tendency to dormancy, Triumph had the slowest rate of emergence. It is therefore a useful "worst case scenario" barley upon which to base an integrated storage strategy for malting barley.

Fig 7.1
Probit germination with time for Blenheim at a range of storage temperatures

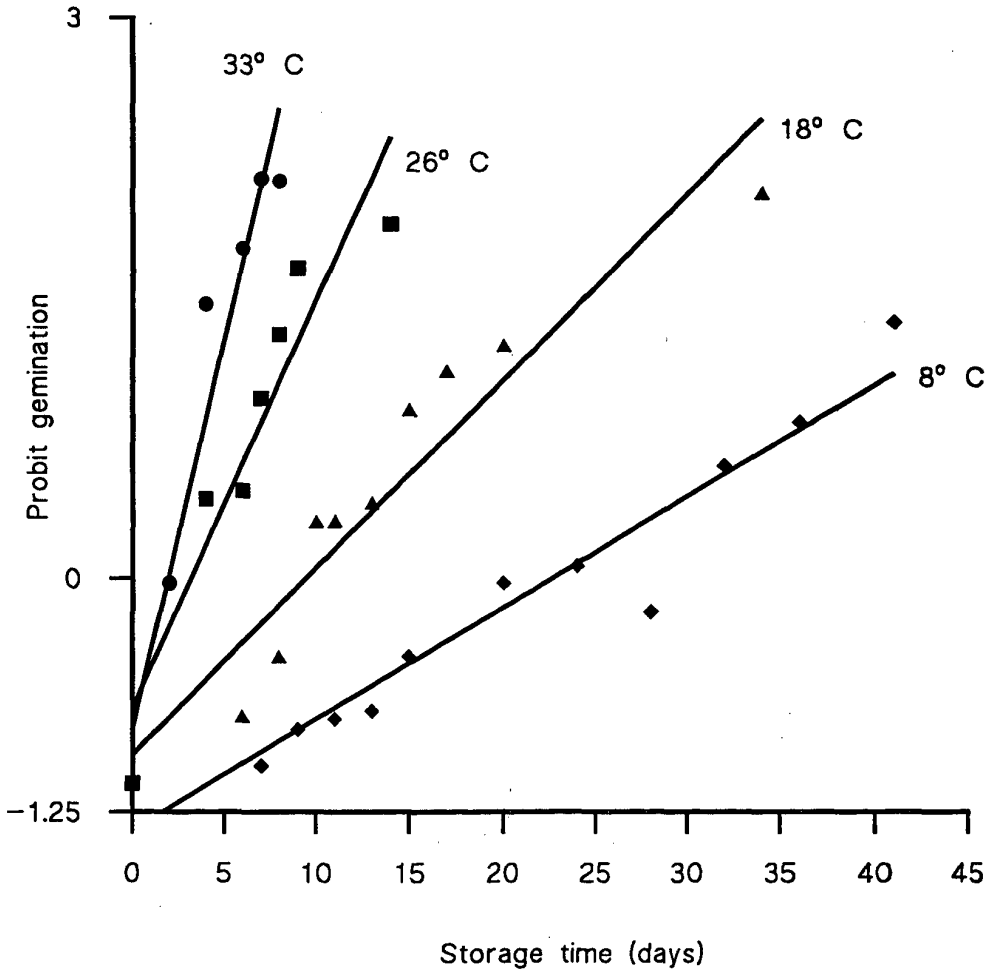


Fig 7.2
Probit germination with time for Pipkin at a range of storage temperatures

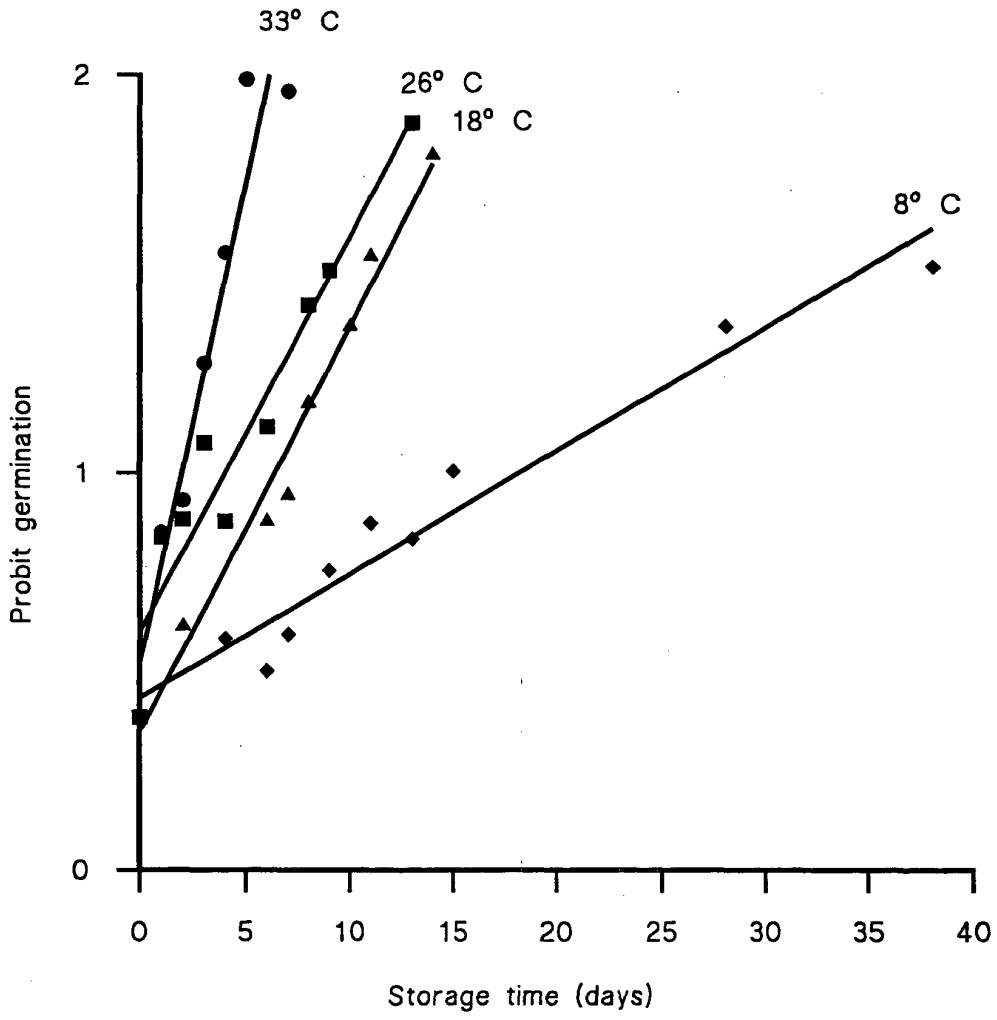
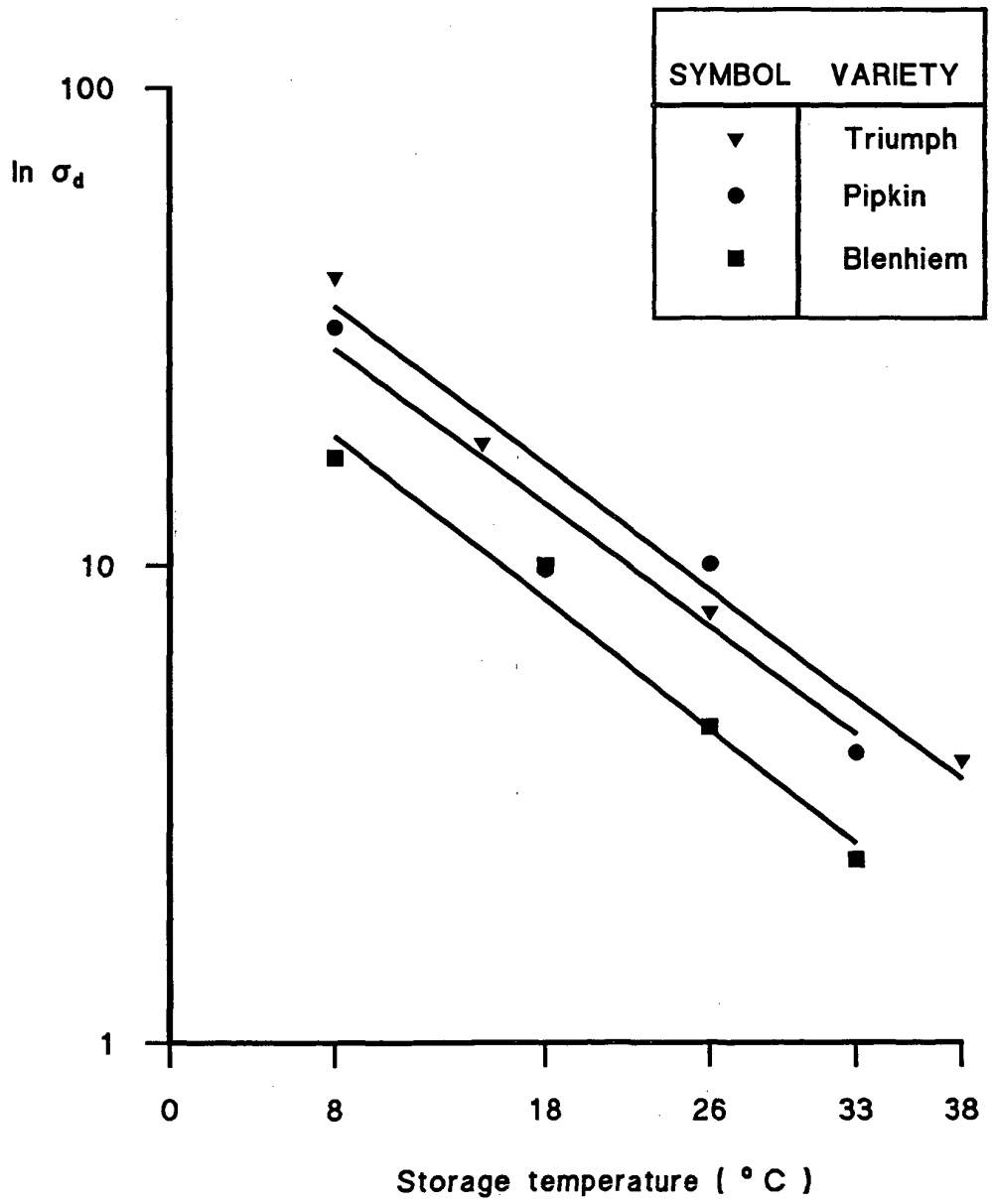


Fig 7.3
The logarithm of the slope of σ_d, a measure of the time to break dormancy, versus temperature.



8. Analysis of maltings' storage survey

M.P.Kelly and D.M.Armitage

INTRODUCTION

To ensure that existing maltings are in a position to put into practice any integrated strategy proposed by this project, a simple questionnaire was circulated (Appendix 8.1). This was intended to determine normal length of storage and whether aeration or pesticide application facilities were available and/or used.

Data from 14 returns, as they relate to the proposed storage strategy are set out below.

Table 8.1.
Insect control measures.

	Tonnes	%
Pesticide used	100,950	10.9
Manual aeration	671,896	72.4
Automatic aeration	29,132	3.1
Total	927,704	

The majority of stores appear equipped to cool their grain so it is practical for aeration to be used as part of a storage strategy for the malting industry. Very little automatic fan control was recorded, so investment in this aspect will be required as time clocks and thermostats are required for quick and cheap cooling. Only a small proportion of the barley is treated with pesticide, so the industry is already well on the way to reducing residues and the immediate cost of storage.

Although aeration is apparently used, it is not clear whether airflows are sufficient. This could be remedied by asking for additional details:-

1. Estimated airflow or

1a. Fanpower per tonne (e.g. W/t; Hp/t) or just give total fan power

2. Depth of grain

Table 8.2.
Length of storage.

Months storage	Tonnes	%
2	0	0
4	7,800	1.2
6	96,000	14.2
8	143,766	21.3
10	18,083	2.7
12	208,990	30.9
14	208,194	30.8
Total	675,813	

* Return 6 = 3-13 months for 210,000 t

The above shows that there is a considerable proportion of the barley stored for a year or more and none for less than two months, which is an important factor for the strategy to consider.

Table 8.3.
Maximum initial temperatures of storage.

Max. Temp.(°C)	Tonnes	%
15	8394*	1.1
20	42,000	5.6
25	232,366	31.0
30	308,500	41.2
35	0	0
40	158,000	21.1
Total	749,260	

*return 7; 'maybe in winter'- probably misunderstood the question.

Most of the grain is stored initially at 25-30 °C which is very favourable to insects but a significant proportion goes into store at 40°C at which temperature, germination decline is very rapid. The responses did not make it clear if the high-temperature, continuous dryers had adequate cooling facilities, to enable manipulation of the initial temperature of storage for dormancy break.

Table 8.4.
The type of storage

Type of storage	Tonnage	%
Flat	366,532	45.9
Internal bin/silo	72,766	9.1
External bin/silo	227,460	28.5
'Jumbo' bins	131,000	16.5
Total	797,758	

About half the barley is stored in silos and half in flat stores.

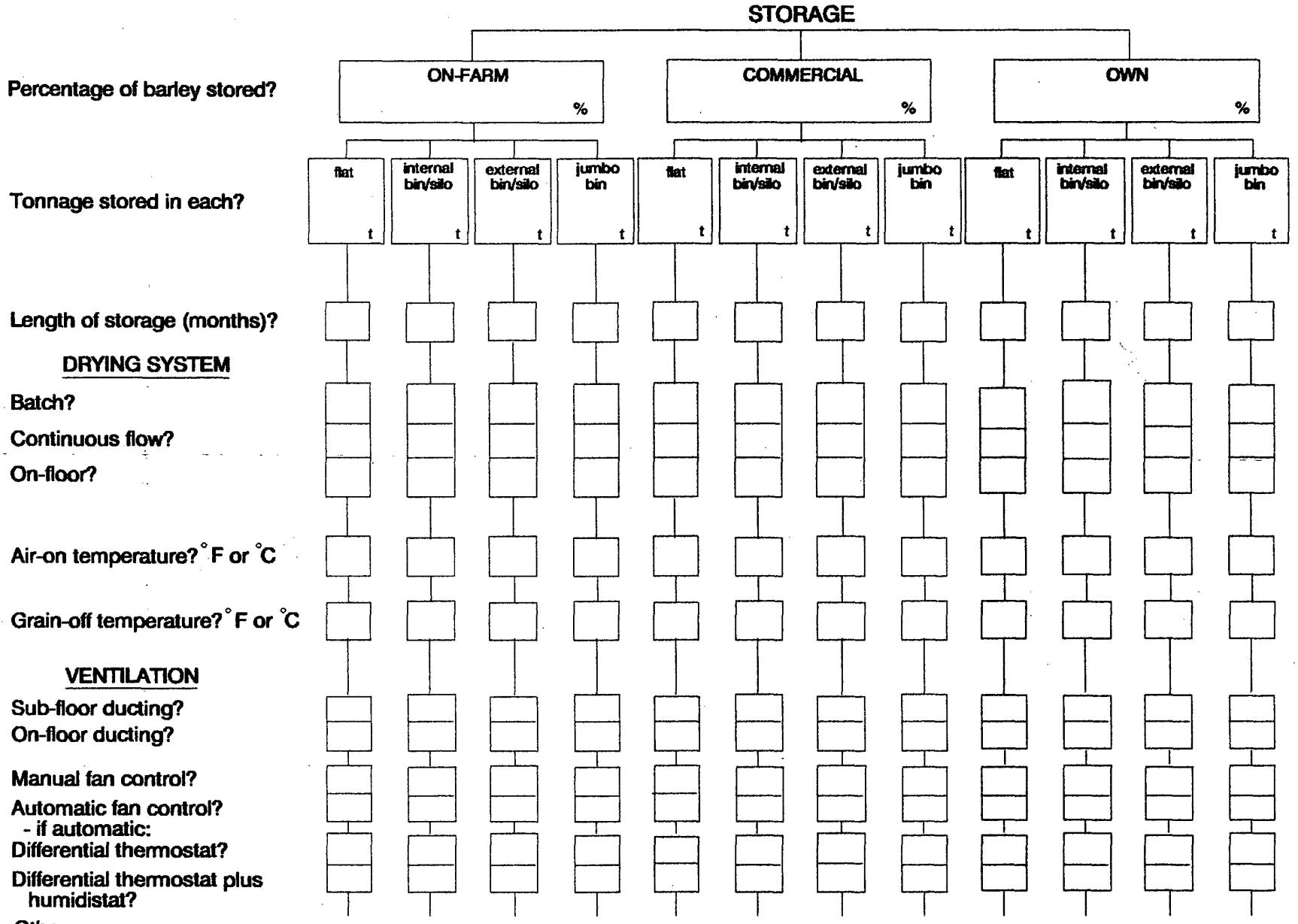
Table 8.5.
The site of storage

Site	Tonnage	%
Maltings	570,760	59.1
Commercial	255,150	26.5
On-farm	139,193	14.4
Total	965,103	

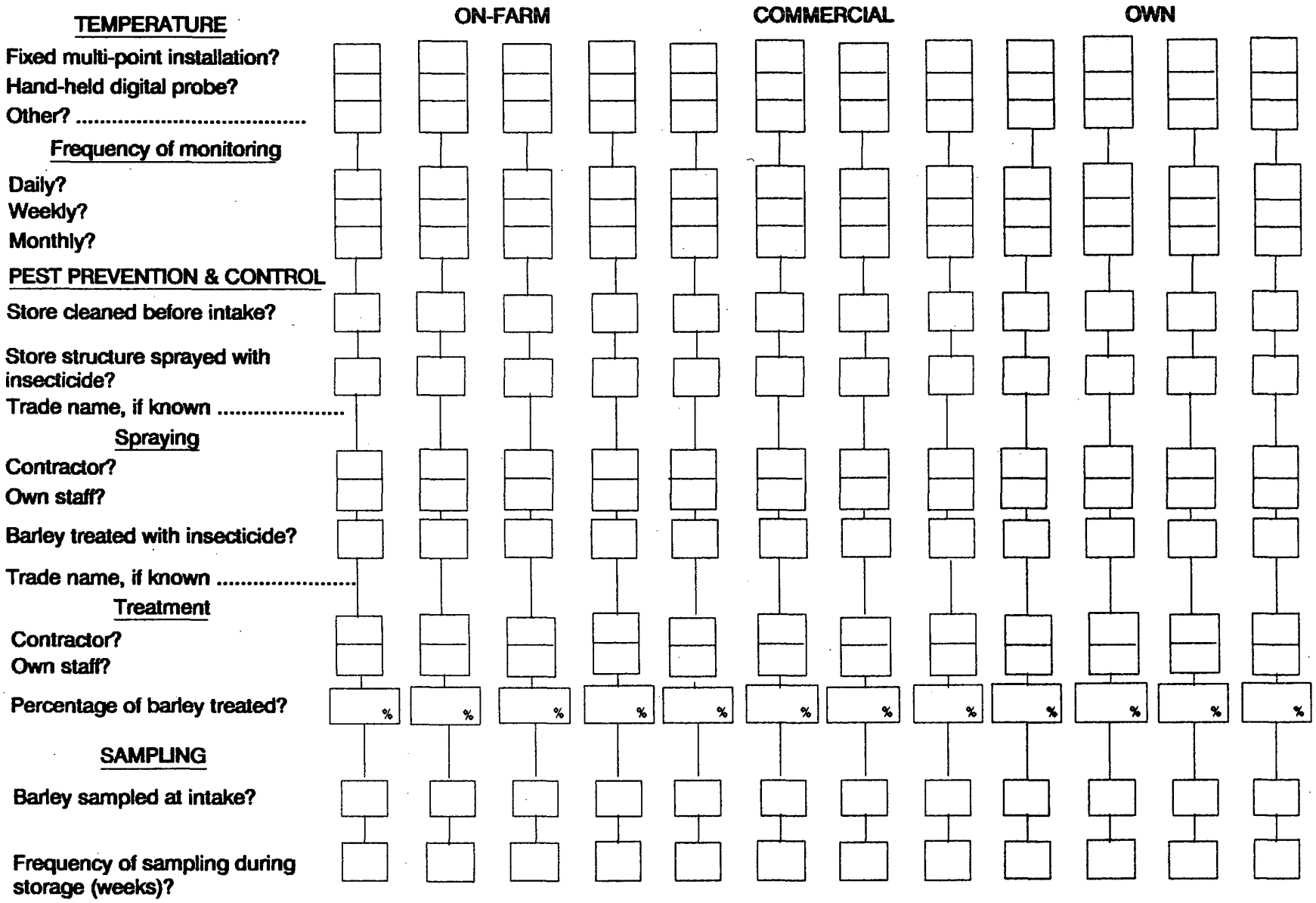
The majority of the malting barley is under the direct supervision of the malsters but over 40% is held at remote sites including a sizeable proportion, 14%, on farm-sites.

Another important piece of information that is missing from the questionnaire, is the usual or intended moisture content of storage.

HGCA funded project: The development of an integrated storage strategy for malting barley.
Collaborators: BRFI, CSL, University of Newcastle upon Tyne.



Appendix 8.1



Appendix 8.1 Cont'd

9. Commercial scale tests on malting barley storage strategies in the south of england using upward aeration.

D.M.Armitage and D.A.Cook

INTRODUCTION

The experiments described in this chapter were intended to put into practice the principles explored in the previous chapters. Specifically, it was necessary to see how the germination of the barley would be affected by the strategy, whether infestations would develop as expected and whether cooling would occur as rapidly predicted. Only by carrying out realistic commercial-scale experiments can the practical difficulties of a proposed storage strategy for malting barley be fully understood. Because of local climate variations, experiments were carried out both in the south and the north of the country. An additional interesting variable was that the southern site used upward air movement while in the north, it was downward.

METHOD

Two southern malting barley stores were cooled by upward aeration, in successive years, using fans controlled by differential thermostats and time clocks, after being allowed to stand for the maximum time predicted for dormancy to be broken (t_{10-95}). The hours run by the fans were recorded together with the temperatures achieved by cooling. Initially, for four weeks, bi-weekly sampling visits measured germination changes, naturally occurring mite numbers, and insects developing in cages buried in the bulk. Sampling thereafter was monthly. In this way the calculated strategy, established in laboratory tests, could be validated.

The cooling systems were wired up to a differential thermostat so that the fans switched on when ambient was cooler than the grain in the warmest part of the bin (furthest away from the fan). No humidity control was employed. An hours meter in circuit registered the fan hours run which were recorded daily by site staff.

The temperature of the grain was monitored by five columns of duplicate thermocouples in three rows 0.5 m, 1.5 m and 2.5 m from the top in the upward (blowing) system. These were attached to two 'Squirrel' data loggers which recorded temperatures at hourly intervals.

Five cages of insects (measuring 8 x 2.5 cm and holding 15 g of barley) for each sampling period, each containing 25 *O. surinamensis* and another five containing 25 *S. granarius,* were inserted to 0.5 m. These cages were withdrawn at intervals, coinciding approximately to $t_{10\text{-}95}$, the time taken to cool to 15°C, 10°C, and 5°C and at the end of storage, to determine the numbers developing during cooling. During the first test, in 1993-4, the equivalent numbers of controls were set up at 12°C but these were not particularly instructive as they did not show that the insects could breed, given acceptable conditions. Therefore in the second year, 1994-5, they were first maintained at 35°C, until the time for dormancy break and the first cooling front had passed and then they were dropped to 15°C.

Twelve samples, each of 0.2 kg were taken for determination of m.c., mite population and germination at the normal sampling intervals. These were from four columns and at three depths; 0.5 m, 1 m and 2 m. The sample was sub-divided and half was examined for mites and half was deep frozen before determination of germination. Samples of 100g each of dormant 'Blenheim' barley were also inserted into the grain to be removed at the regular sampling visits.

The store(s) were visited for sampling bi-weekly initially and then at monthly intervals when the temperature data were downloaded to disc and sampling carried out.

Experiment 1993-4

One thousand tonnes of malting barley were stored 11m deep in an external silo (Fig 9.1). This was ventilated from the base up by a 10 kW fan. Loading began in August and took about a month. The bin was finally filled on 6 September when the test started, the thermocouples inserted and the initial samples taken. As the initial temperature was 25°C, the grain was left for 37 days, the time estimated to break dormancy at this temperature (had it existed), before aeration started using a differential of 6°C. By this time, in mid-October, the threat of air at 25°C condensing on the roof of the tall bins was considerable. It was decided to aerate only from 0800-20.00, until the first cooling front had passed through the grain, the temperature was 10-15°C and the risk of condensation had fallen. This was judged to have happened on 29 October, after 9 weeks, when instructions were left to change the hours of blowing to 24.00-06.00. Unfortunately, these were misunderstood and the hours were set instead to 20.00-0800. This was corrected on 7 December, when the hours were adjusted to use wholly off-peak tariffs.

Unfortunately, in February the site was closed and the grain sold ending the experiment prematurely. To check that aeration had not altered the moisture content of the grain significantly, 4 samples each of about 200g were taken during outloading of the third, 25 tonne load, from the bin.

Experiment 1994-5

One thousand tonnes of malting barley were stored 11m deep in an external silo (Fig 9.2). This was ventilated from the base up (Fig 9.3). Loading took place on 25 July and the bin was filled by the first visit on 1 August when the test started, the thermocouples inserted and the initial samples taken. In addition to the temperatures measured by these thermocouples, readings at 4 equidistant vertical intervals and from 4 columns were also recorded by the on-site 'Credshire' system. As the initial temperature was about 40°C, the grain was left for 8 days, the time estimated to break dormancy (had it existed) at this temperature, before aeration started using a differential of 10°C. At this time, in early August, the threat of air at 40°C condensing on the roof of the tall bins at night was considerable. Once again, it was decided to aerate only between 0800-20.00, until the first cooling front had passed through the grain and the risk of condensation had fallen. This was judged to have happened on 29 August, after 5 weeks, when instructions were left to change the hours of blowing to 24.00-07.00. to use wholly off-peak tariffs.

Unfortunately, in January the grain was malted, ending the experiment prematurely. To check that aeration had not altered the moisture content of the grain significantly, 16 samples each of about 200g, were taken during outloading of the first and last 12 tonnes from the bin.

RESULTS

Experiment 1993-4

Temperatures (Fig 9.4) and hours of aeration (Fig. 9.5)

Before aeration was started, temperatures remained at about 22°C for 6 weeks, the time estimated to break dormancy. Once cooling was started, temperatures fell to about 12°C in week 9 at a rate of 5°C/week, after 280 h aeration or 28h aeration /°C drop. This temperature was maintained for a further 3 weeks until the grain began to cool again, to about 7°C, which was attained in week 16 at 2°C/week, after an

additional 208h of blowing or 104h aeration/°C drop. This temperature was maintained until the end of the test by which time, 672h of aeration had occurred.

In week 9, and then again in week 13, grain temperatures were close to ambient but they did not continue to fall in weeks 11 and 12, when ambient temperatures were below 5°C.

Costs

The manufacturer's performance data of these fans revealed the power at the duty point to be 7.3 kW. The precise tariffs applying to this site were not obtained but the kWh/tonne used, assuming the fans were 2/3 efficient, were 2.2 to week 9, 3.7 to weeks 12 and 4.9 to week 22. At domestic tariffs of 7.5p/kWh, the maximum costs would be 16.5, 28 and 37 p/t and at off-peak tariffs of 2.5p/kWh the costs would have been 5.5, 9.3 and 12.3 p/t.

Moisture contents (Table 9.1)

At 2m, the mean moisture content varied between 12.6 % and 13.6% and at 1m, the variation was 12.8-13.3%. At the surface the maximum moisture content recorded was 15.7%, in November but otherwise was usually within the range 13-14%. The samples taken from the base of the bin, during outloading, were 12.7-13% m.c.

Infestation (Table 9.2)

No insects or mites were detected in samples taken from the bin and all the caged insects had died by January.

Germinations (Table 9.3)

The bulk stored barley gave acceptable germinative capacity immediately after harvest (6/9/93) and this was maintained at each sample point and over the five months of the storage period. A small degree of dormancy was seen for the first samples (6/9/93) but this rapidly declined, giving acceptable values within one week of storage. Germinative energy remained constantly acceptable at each sample point and over the period of storage. Water sensitivity also recovered relatively quickly, values of >80% being recorded within one month after harvest.

The dormant grain inserted into the silo had, probably, just acceptable viability but even though it was small, the grain did retain a degree of dormancy that would make it unsuitable for malting, even after five months' storage.

Experiment 1994-5

Temperatures (Figs 9.6& 9.7) and hours of aeration (Fig 9.8)

The grain temperature at the top of the bins fell from 35-40°C to 25-30°C after two weeks' aeration (Figs 9.6, 9.7.) and 155h blowing (Fig. 9.8) and to 20-25°C after a further week and a total of 190h blowing. During this period, when the mean ambient was 15-20°C, and aeration was during the day only, to prevent condensation, the temperature dropped at a rate of 5°C/week or 13h aeration for each 1°C.

Between the following week, the 6th of storage and the 5th of aeration and the end of the test after 22 weeks, in January, the temperature dropped only by a further 7°C at a rate of less than 0.5°C/week or about 30h aeration for each 1°C drop. At this time, the ambient was mainly between 10 and 12°C and aeration was between 2400 and 0700, using cheap, off-peak electricity.

Costs

No details of the on-site fans were available and there was insufficient space between fan inlet and the nearest obstruction, to measure the airflow. However, on the basis of the details from the previous year, the kWh used until the 6th and 22nd week respectively were about 1.43 kWh/t and 3.26 kWh/t. At domestic tariffs this would have been 10.7 and 28.2 p/t and for off-peak tariffs, 3.6 and 9.4 p/t.

Moisture contents (Table 9.4)

These were originally in the range 11-12% in the top 2m of the bin. At the surface they rose to above 13 % in November and December but beneath, fractional reductions to below 11% occurred.

The samples taken during unloading of the bin were about 11.2% (11.17-11.33) indicating that no significant dampening had occurred due to aeration.

Infestation (Table 9.5)

The caged *S. granarius* died out in the bin at the high initial temperatures and low moisture contents but survived in the controls where the moisture content was higher and the temperature slightly lower. In November and December, however, new adults had emerged from the controls and, more surprisingly, the cages in the bins.

In contrast, *O. surinamensis* showed some increase during August, when temperatures were still relatively high but the adults and larvae died out during the subsequent months, as temperatures fell in both controls and in the bin.

Germinations (Table 9.6)

As with the previous year's harvest, there were no problems with the viability of the stored barley and the early small degree of dormancy rapidly disappeared; germinative energy being >95% after two weeks' storage. Similarly, water sensitivity decreased in the same period, >80% germination being measured at each depth of the silo after two weeks' storage.

The dormant grain inserted into the silo gave some inexplicable germination test results. Germinative energy started off high and acceptable but appeared to drop and become unacceptable within one week. Further results were extremely low and, although the samples were retested, no changes were found. It is not possible to explain why the germinative capacity appeared lower than the germinative energy, in theory this cannot occur. If the samples of dormant grain had been insufficiently dried, then they may have been subject to overheating and/or microbial damage. Throughout the storage period however, the grain did not appear to lose any degree of dormancy and water sensitivity also seemed to deepen. None of these samples would have been acceptable for commercial malting.

DISCUSSION

Experiment 1993-4

The aeration regime cooled the malting barley without causing a rise in moisture content, or infestation or permitting a fall in germination (The dormant samples inserted into the grain gave some anomalous results, particularly in the second year and should therefore be disregarded). However the automatic system used (a differential of 6°C) permitted an excessive amount of aeration which resulted in higher than usual costs. Nevertheless, at night tariffs, these were still below those of insecticide admixture which would have been at least 35 p/t for material costs alone.

In particular, the fans ran for many hours between weeks 10 and 12, without achieving a reduction in temperature at the top 2.5m, despite ambient temperatures being below 5°C at this time. It was not possible to check the airflow into the bin, because of the orientation of the fan but the power and specification suggest the airflow should have

been 10 cu.m/h/t. It may be that age and wear of the machinery had caused a drop in the airflow or that the sound dampers had reduced the airflow. A solution may be to ensure that the differential setting of the thermostat is greater for tall bins.

Experiment 1994-5

Although the rate of aeration could not be measured and there were no site records for the fan details, it is clear from the satisfactory initial fall in temperature during aeration that the recommended rate of around 10 cu m/h/t was being delivered However, it proved difficult to lower the temperatures thereafter, as shown by the trebling of the hours of aeration required to produce the same degree of cooling. Nevertheless, despite the excessive hours of aeration, there was no evidence of dampening of the malting barley during cooling.

The initial cooling was not swift enough to prevent some late summer increase of *O.surinamensis* which was nevertheless unable to survive during storage due to a combination of the low temperature, the difficulty of invading whole grain and to a lesser extent, the low moisture content. The difficulty in reducing temperatures below 10°C meant that *S.granarius* within the grain were able to survive, develop and emerge in the winter.

This experiment was as severe a test of a cooling strategy as could be devised, using high initial barley temperatures, aeration in early August, the warmest part of the year, and cooling in one of the mildest winters on record. It highlighted the threats to malting barley, namely that cooling was not swift enough to prevent increase of *O.surinamensis* and did not achieve low enough temperatures to prevent the increase of *S.granarius* by winter. Although the industry may not want to steep barley much below 20°C, because of the energy cost of warming it up, the ability of the weevils to increase indicates the risk in this strategy. However, just as the risk of the early increase in saw-toothed beetles was moderated by its inability to survive for long in storage, it should be noted that weevils only increased because eggs were able to survive within the grain. Normally, it may be assumed that grain would be taken into store before becoming infested and only adults, which could not survive the high temperatures, would be available to establish the infestation.

The difficulties in cooling malting barley in tall silos contrasts with previous experiences with feed wheat in floor stores (e.g. Cook *et al.*, 1995). The reasons are not yet clear but may be due to release of latent heat of condensation or to the

automatic fan control chosen. It is clear that further work is required to resolve the issue as it has important consequences, perhaps not only for the malting barley industry. So far, we have examined blowing strategies in the south which involve initial grain temperatures of 22°C and 40°C. However, our earlier survey showed most grain to be put into store at 30-35°C, so it would be desirable to repeat the experiment at this range of temperatures, if only to evaluate the practical risks.

Table 9.1
1993-4. Southern site. Moisture contents at 3 depths (n=4) during cooling of a 10m deep, 1000 t bin of malting barley.

Date	Surface mean	(se)	1m mean	(se)	2m mean	(se)
6.9.93	13.2	(0.07)	13.3	(0.06)	13.1	(0.03)
17.9.93	13.3	(0.07)	13.1	(0.07)	13.0	(0.06)
1.10.93	14.3	(0.04)	13.3	(0.04)	13.0	(0.01)
13.10.93	13.7	(0.06)	13.3	(0.09)	13.0	(0.08)
25.10.93	14.4	(0.14)	13.3	(0.04)	13.6	(0.43)
8.11.93	15.7	(0.46)	12.9	(0.02)	12.7	(0.04)
6.12.93	13.6	(0.15)	12.8	(0.03)	13.2	(0.42)
10.1.94	14.0	(0.16)	12.8	(0.04)	13.4	(0.74)
7.2.94	14.0	(0.20)	12.9	(0.09)	12.6	(0.05)

Table 9.2
1993-4. Southern site. Changes in insect populations (live free-roaming adults and larvae per 15g) in malting barley bins and in laboratory controls held under sub-breeding conditions (n=5).

Date	*S.granarius*				*O.surinamensis*			
	Control Mean	(se)	Bin Mean	(se)	Control Mean	(se)	Bin Mean	se
6.9.93	25.0	(0)	25.0	(0)	25.0	(0)	25.0	(0)
1.10.93	no count	*	12.2	(0.37)	no count	*	5.2	(1.32)
13.10.93	14.2	(0.92)	11.0	(0.89)	4.2	(1.39)	4.0	(1.82)
1.11.93	12.0	(1.7)	7.4	(0.68)	4.6	(2.32)	3.0	(2.00)
10.1.94	4.6	(0.81)	0	(0)	0	(0.2)	0	(0)
7.2.94	6.6	(1.81)	0	(0)	0	(0)	0	(0)

Table 9.3
1993-4. Southern site. Germination of barley from 3 depths in a 1000 t, 11m deep malting barley store.

Date	Depth	H2O2 Mean capacity (range)		4ml Mean energy (range)		8ml Mean w.sensitivity (range)	
6.9.93	Surface	99.3	(98-100)	94.0	(91-97)	58.5	(51-70)
	1m	99.8	(99-100)	97.5	(92-100)	77.8	(58-91)
	2m	98.8	(98-100)	98.3	(97-100)	73.0	(65-82)
10.9.93	Surface	99.3	(98-100)	97.3	(96-99)	62.0	(55-78)
	1m	98.0	(97-99)	99.5	(98-100)	83.3	(67-90)
	2m	98.3	(98-99)	99.5	(99-100)	87.5	(76-94)
13.9.93	Surface	100	(100-100)	98.5	(98-99)	64.0	(60-72)
	1m	98.8	(99-100)	99.0	(97-100)	80.8	(66-92)
	2m	99.8	(99-100)	99.0	(98-100)	82.0	(73-86)
17.9.93	Surface	100	(100-100)	99.0	(99-99)	84.3	(80-88)
	1m	99.3	(99-100)	99.3	(99-100)	92.0	(88-99)
	2m	99.0	(99-99)	98.5	(98-99)	87.3	(80-90)
20.9.93	Surface	100	(100-100)	99.5	(99-100)	85.5	(82-87)
	1m	99.3	(99-100)	99.0	(98-100)	89.8	(88-92)
	2m	99.0	(99-99)	98.5	(98-100)	90.8	(90-92)
13.10.93	Surface	99.5	(99-100)	99.3	(99-100)	85.3	(80-88)
	1m	99.0	(98-100)	99.5	(99-100)	92.8	(89-96)
	2m	99.8	(99-100)	99.5	(99-100)	93.3	(90-96)
8.11.93	Surface	99.0	(98-100)	98.5	(98-99)	88.8	(81-92)
	1m	100	(100-100)	99.0	(99-99)	93.8	(92-96)
	2m	99.0	(98-100)	99.3	(99-100)	93.8	(92-96)
6.12.93	Surface	99.5	(99-100)	99.3	(99-100)	85.8	(82-91)
	1m	99.5	(99-100)	100	(100-100)	92.8	(91-94)
	2m	99.3	(98-100)	98.8	(98-99)	82.5	(63-94)
10.1.94	Surface	99.5	(99-100)	100	(100-100)	89.0	(87-91)
	1m	99.8	(99-100)	100	(100-100)	93.3	(89-94)
	2m	99.5	(99-100)	99.8	(99-100)	96.8	(95-99)
Dormant grain samples inserted 1m down at beginning of trial (n=1).							
1.10.93	1m	99		92		21	
1.11.93	1m	97		96		71	
10.1.94	1m	97		90		68	

Table 9.4
1994-5. Southern site.The moisture content of grain at the top of a 10m deep, 1,000 t bin of malting barley. (n=4).

Date	Surface		1m		2m	
	Mean	(se)	Mean	(se)	Mean	(se)
1.8.94	11.5	(0.08)	11.2	(0.05)	11.7	(0.11)
8.8.94	11.9	(0.09)	11.2	(0.08)	11.9	(0.05)
15.8.94	12.4	(0.08)	11.3	(0.05)	12.0	(0.05)
22.8.94	13.2	(0.19)	11.3	(0.05)	11.5	(0.04)
30.8.94	11.4	(0.06)	11.2	(0.1)	11.1	(0.07)
12.9.94	12.1	(0.08)	11.0	(0.05)	11.0	(0.03)
26.9.94	12.4	(0.07)	10.9	(0.04)	10.9	(0.02)
24.10.94	13.3	(0.10)	10.9	(0.03)	10.9	(0.01)
21.11.94	13.6	(0.18)	10.7	(0.02)	10.8	(0.03)
19.12.94	12.7	(0.31)	10.9	(0.07)	11.1	(0.12)

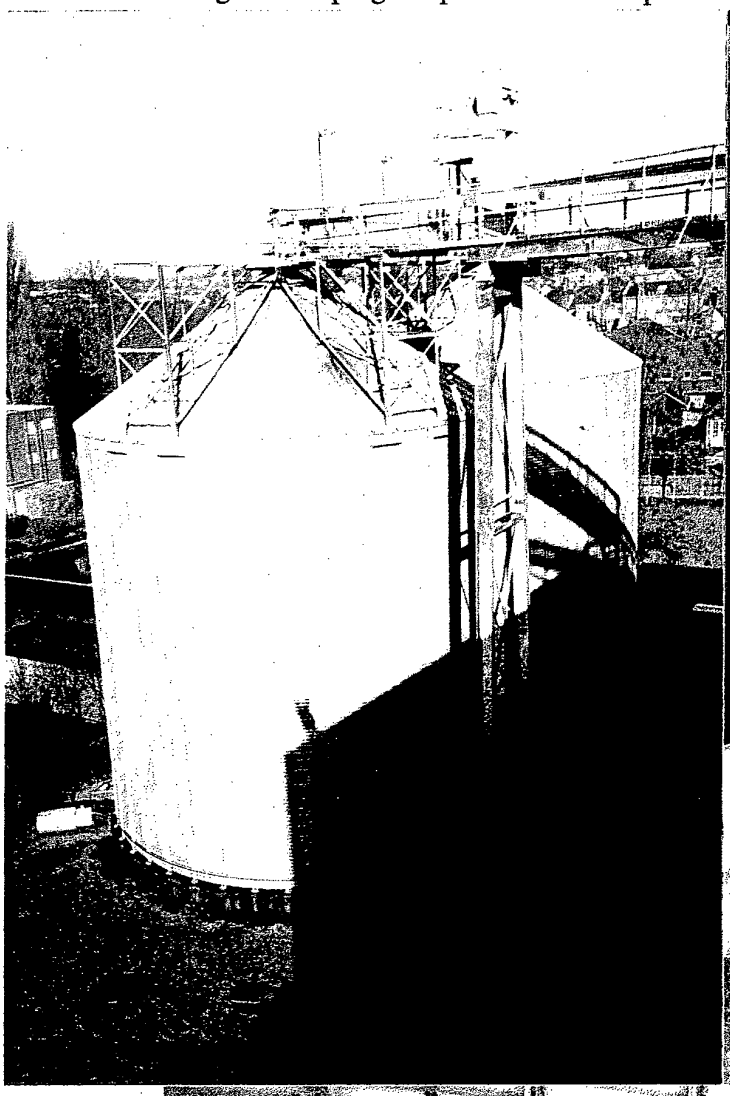
Table 9.5.
1994-5. Southern site. Changes in insect populations (live free-roaming adults and larvae per 15g) in malting barley bins and in laboratory controls held under comparable conditions (n=5).

Date	*S.granarius*				*O.surinamensis*			
	control		bin		control		bin	
	mean	se	mean	se	mean	se	mean	se
01/08/94	25.0	0	25	0	25.0	0	25	0
08/08/94	25.0	0	0.2	0.20	22.6	1.08	22.2	0.49
15/08/94	23.0	0.84	0	0	22.0	0.95	24.4	0.40
30/08/94	24.0	0.32	0	0	65.8	1.28	53.2	1.83
22/11/94	93.8	3.97	86.8	4.82	4.8	0.80	5.6	1.47
03/01/95	125.6	3.70	50.8	3.75	2.6	0.51	0	0

Table 9.6
1994-5. Southern site. Germination of malting barley in cooled 1,000t, 10m high bins (n=4).

Date	Depth	H2O2 mean capacity (range)	4ml mean energy (range)	8ml mean w.sensitivity (range)
1.8.94	Surface	98.3 (97-99)	83.3 (81-88)	47.8 (39-56)
	1m	98.5 (97-100)	80.3 (78-83)	34.5 (27-43)
	2m	98.8 (98-99)	79.3 (77-81)	39.3 (35-42)
8.8.94	Surface	97.5 (95-99)	94.8 (90-97)	66.3 (61-70)
	1m	97.5 (96-99)	96.5 (93-99)	73.5 (72-75)
	2m	97.3 (97-98)	94.5 (91-97)	71.0 (65-78)
12.9.94	Surface	97.5 (96-99)	96.0 (94-98)	83.3 (81-85)
	1m	97.0 (96-98)	96.8 (94-99)	93.5 (94-96)
	2m	97.5 (95-99)	97.3 (96-99)	95.3 (94-96)
24.10.94	Surface	98.8 (98-100)	98.8 (98-100)	94.0 (92-95)
	1m	97.5 (97-98)	98.8 (98-100)	94.5 (88-99)
	2m	98.3 (97-99)	98.3 (98-99)	95.3 (93-97)
19.12.94	Surface	98.3 (98-99)	97.5 (97-98)	94.3 (93-95)
	1m	98.0 (97-99)	96.5 (96-97)	95.3 (95-96)
	2m	98.3 (97-99)	97.5 (96-98)	95.3 (95-96)
Dormant grain samples inserted 1m down at beginning of trial (n=1).				
Pre-trial	0.5m	98	76	28
8.8.94	0.5m	99	82	52
15.8.94	0.5m	94	77	57
30.8.94	0.5m	29	71	27
21.11.95	0.5m	30	54	15
3.1.95	0.5m	39	60	24

Fig 9.1.
1993-4. Southern site. Above left: 1000t bins used to store malting barley. Above right. Dumping temperatures to computer. Below: 10 kW fans used for ventilation.



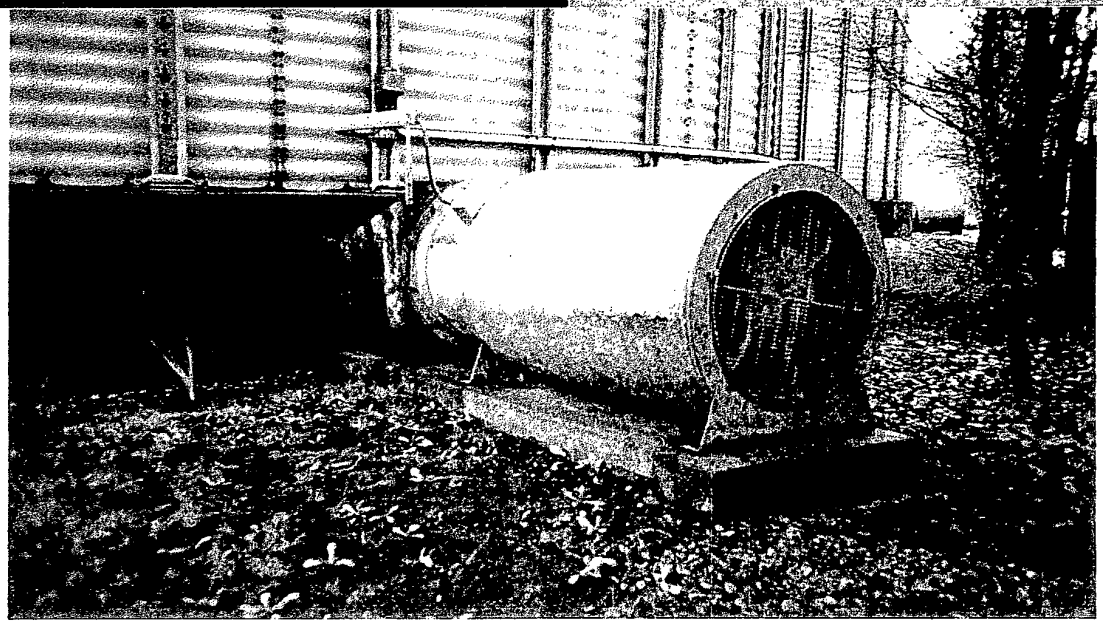


Fig 9.2.
1994-5. Southern site Top: General view of bins, Bottom left: Roof access to bin, Bottom right: making measurements inside the bin.

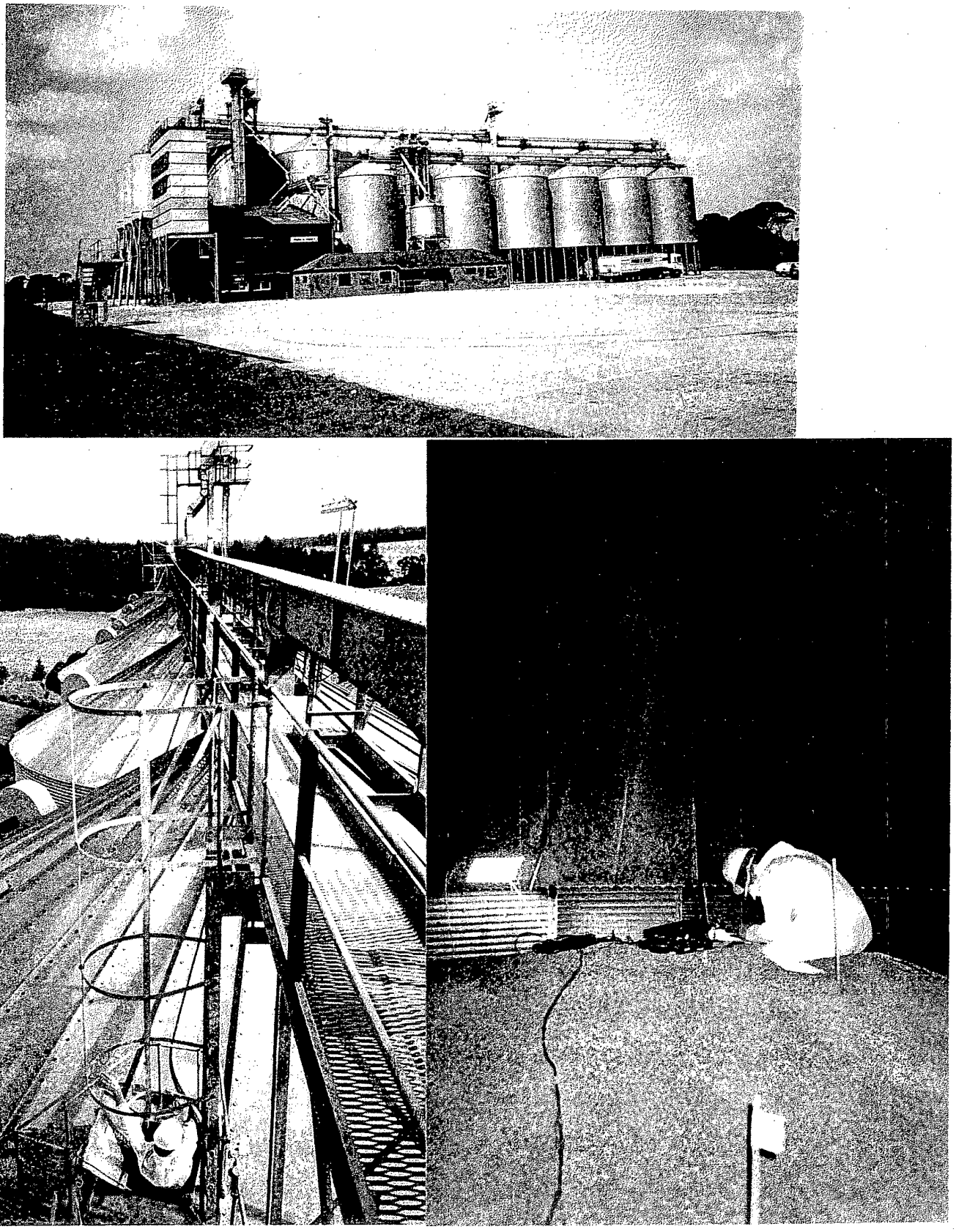


Fig. 9.3
1994-5. Southern site. Top: Aeration fans at base of bins, Bottom: Control room showing electric panel and siting of thermostat and time-clock (arrowed).

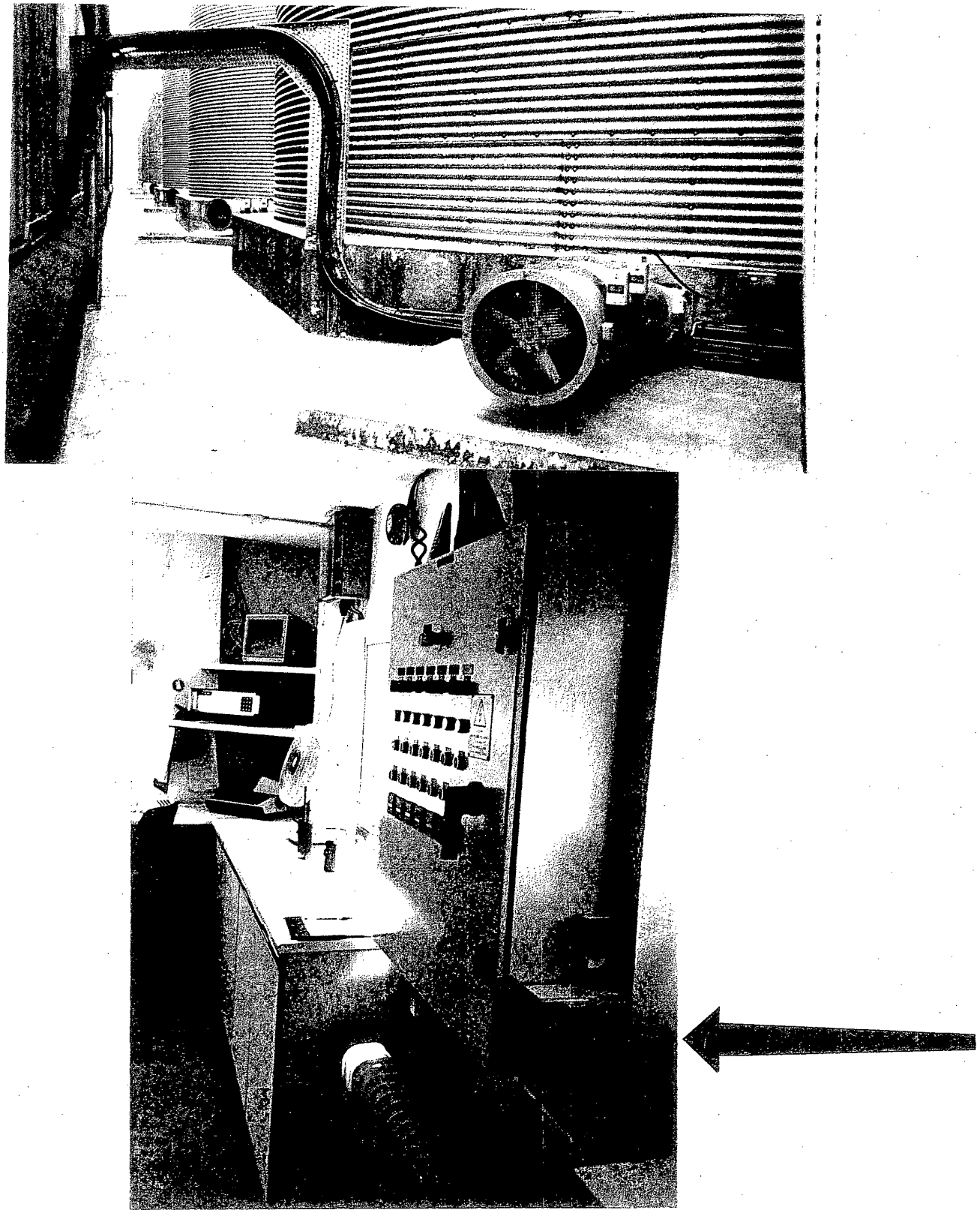


Fig.9.4
1993-4. Southern site. Ambient temperatures and temperatures at three depths (n=5) during cooling in a 10 m deep, 1000 t bin of malting barley.

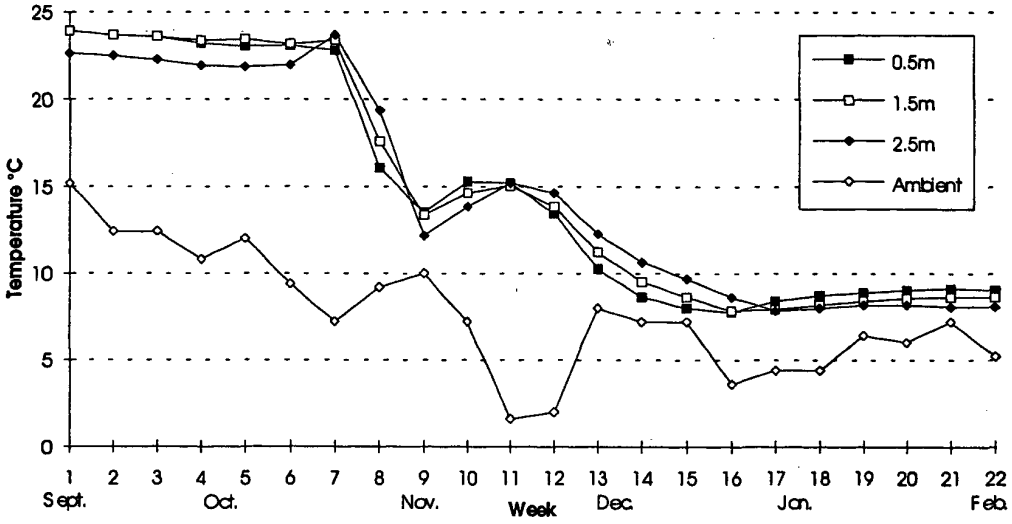


Fig 9.5.
1993-4. Southern site. Weekly hours aeration (bar chart) and cumulative hours aeration (line) during cooling of a 10m deep, 1000 t bin of malting barley.

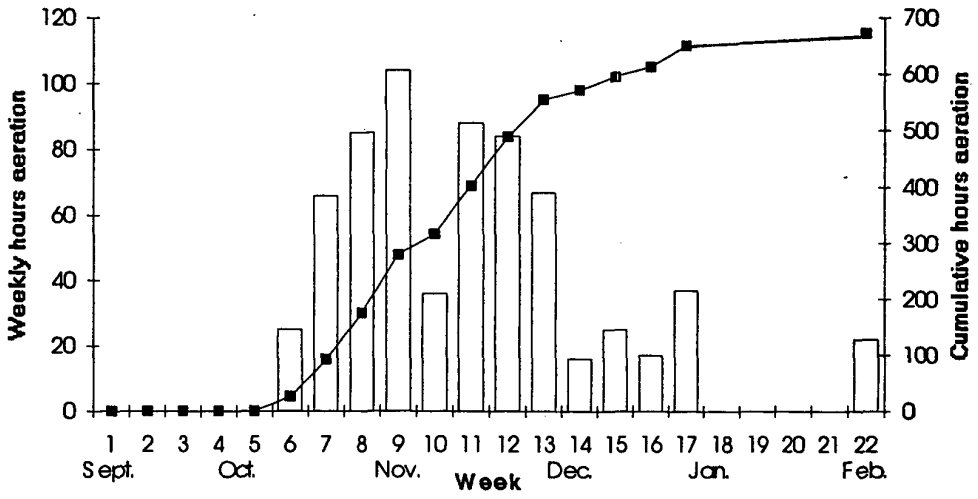


Fig 9.6.
1994-5. Southern site. Temperatures at the top of a 1,000 t bin of malting barley in southern England during cooling.

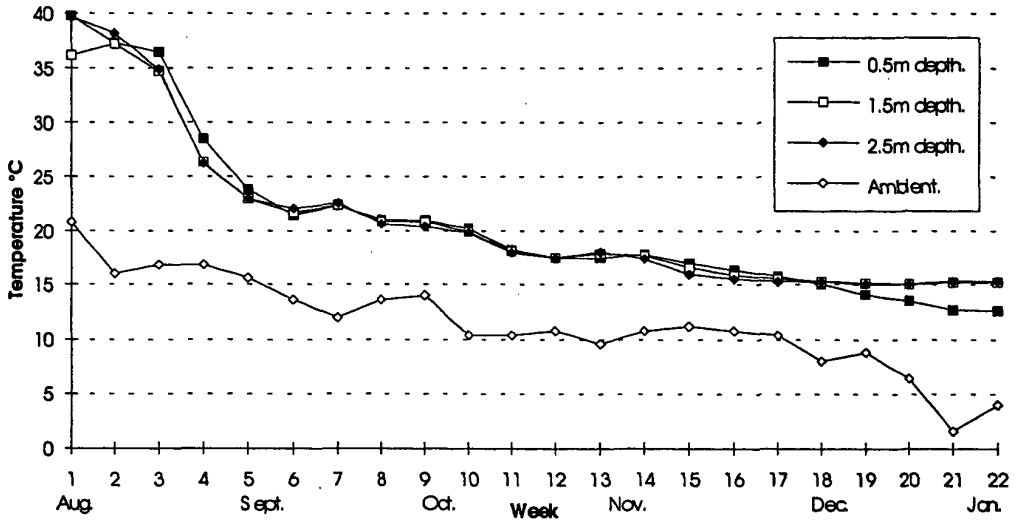


Fig. 9.7.
1994-5. Southern site. Temperatures measured by on-site equipment at four equidistant depths in a 1,000t bin of malting barley during cooling in southern England.

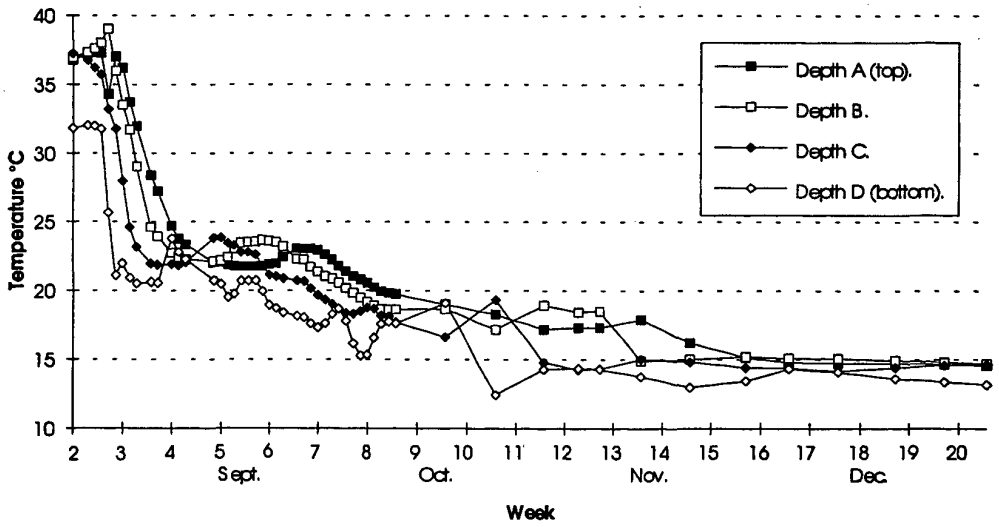
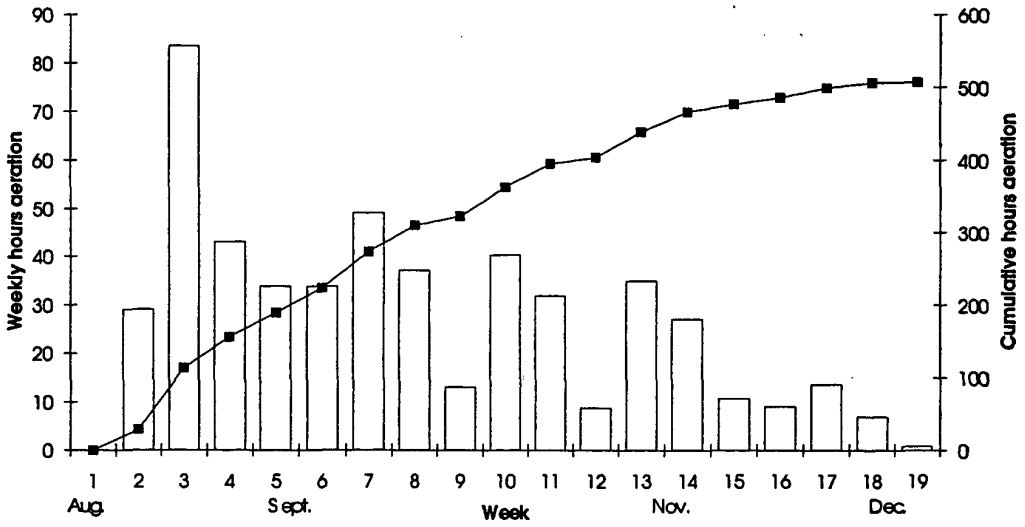


Fig 9.8.
1994-5. Southern site.Weekly hours of aeration (bar chart) and cumulative hours aeration (line) during cooling of a 10m deep, 1,000 t bin of malting barley.



10. Commercial - scale tests on malting barley storage in the north of England using downward aeration.

J.L. Woods and D.J. McCallum

INTRODUCTION

In order to validate the storage strategy for malting barley, two cooling experiments were conducted on 1000 t malting barley stores in successive years. The stores were identical and adjacent on the same site. The contents of the stores were allowed to remain warm after filling to break dormancy for a period based on the predictions from laboratory data described in Chapter 3. The fans were controlled by differential thermostats and time clocks and the running time was recorded. Temperatures were monitored during cooling. The bed was sampled for moisture and germination, first at weekly then monthly intervals. Insect cages were buried in the surface region and similarly sampled.

The major difference between the north and south sites was the downward air flow employed on the north site, as compared with upward at the south. This made sampling at the bed exit, about 10 m from the surface, more difficult. However, the comparability of the two sites is still retained in the experimental design by the use of 10 m vacuum probes through the bed for sampling and drawing in the thermocouple probes. This also facilitated moisture profiling and so the northern site work includes this aspect, whilst the southern site undertook more detailed insect monitoring work.

METHODS

These are in general the same as for the South. However, the depth of the bed exit required some modifications to technique. To sample the bottom of the bed 10-12 m vacuum sampling tubes were vacuum drawn and pushed into the bed at three locations, one at the centre and two at half radius. These were placed by taking them to the bottom of the bed and withdrawing them 1 m for sampling. These sampling tubes were adjacent to three thermocouple probes again running to the bottom of the bed, with a fourth thermocouple probe standing separately again at half radius. The thermo-couple heights from the silo floor were 0.5, 1.25, 2.5 and 4 m on all four probes, with additional thermocouples at 6, 8 and 10 m on two of the probes.

As a result of the increased complexity introduced by working 10 m below the grain surface, the number of sampling locations were reduced. In the north we used four thermoc-ouple probes as opposed to five in the south and bottom grain samples for testing were taken at three probe locations as opposed to four in the south. A set of grain samples therefore consisted of three from the bottom and four from the top.

In order to get the probes in place, it was necessary to traverse the bed depth vacuuming up barley as the probes were pushed into the bulk. It was therefore decided that we would raise and lower the probes a number of times during the experiment to investigate moisture content.

Dormant samples of Triumph barley were buried at a depth of 0.5m at the 4 sampling locations over the grain surface.

Insect work was very basic and involved the removal of cages at intervals from the four sampling points, 0.5m below the surface and counting the remaining live adults, which were then compared with controls at sub-breeding temperatures.

Moisture contents and germination were conducted according to the Institute of Brewing (Anon., 1991) as outlined in Chapter 2.

The store and monitoring processes are illustrated in Figs. 10.1 to 10.2.

Experiment 1993-4

An estimated 900 tonnes of malting barley, variety Alexis, was stored in an outside cylindrical silo to a mean depth of about 11 m. These are usually termed 'Jumbo' silos in the trade. The silo was ventilated from the top downwards by a 9 kW fan located at the base. The bin was filled on the 1st September over a period of 12 hours. The thermocouple probes were inserted and indicated a mean grain temperature of 49°C. This was above the temperature range considered in Chapter 3 for breaking dormancy. On the 2nd September the insect cages and dormant barley were buried to a depth of 0.5 m below the surface. On the 6th September the fan was switched on under manual control for the initial cooling phase. This was a rainy period and in accord with policy on the site, all fans were switched off manually during rainfall, due to concern over re-wetting.

On the 17th September, when all grain was around 20°C, the fan was set to operate on a 2°C differential. Due to concern over the initial high temperature, a low differential was employed and the fan was not restricted to off-peak running. At the end of January the grain was required for malting and the last set of samples and readings were taken on the 21/1/94. During the unloading of the silo, samples were taken at intervals for commercial germination and micro-malting analysis.

Experiment 1994-5

Again, an estimated 900 tonnes of malting barley was stored to a depth of 11 m and ventilated downwards by a 9 kW fan. The bin was filled with barley, variety Camargue, over the three day period prior to the 6th September. The thermocouple probes indicated an initial mean temperature of 46°C. Temperature control was improved by a sensor in the grain flow, downstream of the drier. This was again on the upper limit of the temperatures considered in Chapter 3 for breaking dormancy. On the 7th September the insects and dormant barley were buried to a depth of 0.5 m below the surface. On the 12th September the fan was switched on to run continuously apart from manual interruptions during rainy periods. On the 26th September the fan was set on a 6° differential control with the timer restricting the on time to the off-peak period from 24.00 - 07.00 hours. In the middle of January the grain was required for malting and the last set of samples and readings were taken on the 5/1/95.

RESULTS

Experiment 1993-4

Temperature and hours of aeration (Figs. 10.3, 10.4 and 10.5)

Before aeration commenced, temperatures were around 49°C for about 5-6 days. Once aeration was started, temperatures fell to around 18°C by week 3 at a rate of about 16°C/week, after 300 h of aeration or 28 h aeration/°C drop. Thereafter, the temperature fell to around 8°C by week 8 and was held at this until the end of the experiment, requiring about 630 h of aeration in total.

Costs

Based on the duty point performance, calculated from the air flow resistance data for barley in the ASAE Standards (1995), the kWh/tonne required in total were 2.1

kWh/tonne. At domestic tariffs of 7.5 p/kWh, the total cost would have been 15.8 p/tonne and for off-peak tariffs of 2.5 p/kWh the total cost would have been 5.3 p/tonne.

Moisture Contents (Table 10.1 and Fig. 10.6)
The mean moisture content at the bottom of the bed did not vary greatly after the major cooling phase. During long term storage they fell from around 11.4 to 11.0%. It should be noted that these values were below the input target moisture content of 12%.

The distribution of moisture content is shown in Fig. 10.6. Although the initial moisture content was not measured, assuming the grain to be originally about 12% m.c., there was an apparent increase in moisture content of 1-4% between 9m and 12m (the top one-third of the bin).

Infestation
S. granarius and *O. surinamensis* adults were all killed in samples taken after 1 day and 4 days exposure to the storage temperature of around 49°C. There was less than a 1% mortality in the controls.

Germination (Table 10.2)
These results suggest some decline in germination performance particularly at the bottom of the bed. In the downward flow system, the most vulnerable area is the bottom of the bed, which is last to cool. The ventilation ducting consisted of a below ground square of ducts covered by perforated metal. The 'dead' flow area in the centre of the bed was therefore particularly vulnerable due to slow cooling. Closer inspection of the results showed that germination results at the centre bottom accounted for much of the average deterioration in germination performance.

Commercial tests on samples from the bin at the time of malting indicated perfectly acceptable results for germination and micro-malting.

The dormant Triumph samples took some 14 days to break dormancy, which was longer than expected at these temperatures but could be due to surface cooling.

Experiment 1994-95

Temperature and hours of aeration (Figs. 10.7 - 10.9)

Before aeration commenced, temperatures were around 45°C. Once aeration was started, temperatures fell to around 18°C by week 3 at a rate of about 13°C/week, after 350 h of aeration or 13 h aeration/°C drop. Thereafter, the temperature fell to around 15°C by week 17, requiring about 500 h of aeration in total. Although the ambient conditions and fan running hours were similar, the long-term cooling effect was less in 1994-5.

Costs

In this case, using the same fan for a reduced number of hours - 520 h - resulted in a reduced total requirement of 1.7 kW/t. At 7.5 p/kWh this gives a cost of 13 p/t or at the off-peak rate of 2.5 p/kWh a cost of 4.3 p/t.

Moisture Contents (Table 10.3 and Figs. 10.11, 10.12)

In the second year of experiments moisture content was carefully monitored into store. Table 10.3 shows an initial mean moisture content at the bottom of the bed of 11.8%, falling to 10.3% after the cooling phase and holding steady. Distributions of moisture at the centre and one of the half radius probes (East) were very similar. These clearly showed a considerable decrease in moisture content of around 1.5% during the initial cooling phase. This was followed by a stable period without any re-wetting during cooling.

Infestation

As in the 1993-4 experiment, all adult insects were dead in samples taken after 6 and 10 days of storage, whilst the controls showed less than 1% mortality.

Germination (Table 10.4)

There was no loss of germination capacity or energy during storage and the dormant Triumph samples broke dormancy rapidly.

DISCUSSION

The cooling curve at the bed exit followed a gradual and not a steep change. Cooling took place in the second and third weeks and to achieve cooling to ~20°C, took 200 h of fan time in 1993-4 and 290 h in 1994-5.

The fan electricity costs ranged from 4 - 16 p/t depending on season and assumptions. It is interesting to compare these costs with the costs of reheating barley at 5°C to a steep temperature of 15°C. Based on the specific heat as determined by Disney (1954) and a domestic gas tariff of 1.5 p/kWh the cost is 6.7 p/t. It is difficult to compare industrial tariffs as these are individually negotiated and not readily communicated. This is quite appreciable relative to fan running costs and shows the need for caution in overcooling barley.

In the 1993-4 experiment the 2°C differential control gave rise to limited rewetting at the inlet surface. This was avoided in 1994-5 by a 6°C differential control. Higher differentials of 6 and 10°C were used on the southern site and no rewetting was observed. This reduction in rewetting at an increased temperature differential is confirmed by the computer simulation of the process by Sun and Woods (In Press).

During the initial grain cooling, considerable moisture reduction was observed in 1994-5. The cooling process is identical with a process termed 'dryeration', first used in America (Thompson and Foster, 1967) and often used for tempering of maize (Lasseran, 1977). As the air is heated, the RH falls and drying takes place. The reduction in moisture content will reduce the loss of seed viability due to high temperatures (Chapter 3). This may account for the ability of the barley, particularly in 1993-4, to survive the higher storage temperatures. In dryaeration, drying is greatest at the exit of the bed and is therefore particularly beneficial in protecting the last of the barley to be cooled.

The results for insects are largely illustrative. However, a high initial storage temperature followed by rapid cooling and avoiding the optimum for storage insects of around 30°C is a very effective strategy. The germination results confirm that temperatures approaching 50°C are risky and as shown in Chapter 3 temperatures of 40°C or lower are to be preferred. However, the dryeration process during cooling gives added protection due to the lower moisture content. Therefore the predictions in Chapter 3 are a little pessimistic.

The downward air flow ventilation system has the advantage of avoiding the condensation problems experienced in the upward flow system in the south. Its disadvantage is that the grain in the 'dead' areas between vents at the bottom is in double jeopardy. Firstly it is the last to be cooled and secondly it is slow to cool due to poor ventilation in the 'dead' areas.

Table 10.1

1993-4. Northern site. The moisture content at the bottom of a 1,000 t bin of malting barley (n = 3).

Date	Depth		
	1.25 m	2.5 m	4 m
23.9.93	11.3	11.5	11.2
13.10.93	11.6	11.5	11.3
23.11.93	11.0	11.0	11.1
21.01.94	11.0	11.0	11.1

Table 10.2
1993-4. Northern site. Germination (%) of barley at the surface (n = 4) and bottom (n = 3) from a 1000 t store (variety Alexis).

Date	Depth	H202 Mean capacity (range)	4 ml Mean energy (range)	8 ml Mean W.Sensitivity (range)
06.09.93	surface	95.8 (94-98)	94.3 (93-97)	66.0 (60-70)
	bottom	97.7 (96-99)	97.0 (94-99)	86.0 (78-96)
14.09.93	surface	96.0 (93-98)	94.0 (92-96)	68.8 (65-76)
	bottom	94.5 (94-95)	85.5 (85-86)	31.0 (25-37)
23.09.93	surface	95.8 (95-98)	93.0 (90-96)	68.8 (62.76)
	bottom	90.3 (81-96)	78.0 (56-96)	46.7 (25-70)
01.10.93	surface	95.3 (90-99)	90.8 (87-92)	59.0 (30-78)
	bottom	86.3 (75-97)	80.0 (63-94)	34 7 (20-58)
13.10.93	surface	95.5 (94-97)	87.8 (85-94)	39.8 (27-52)
	bottom	86.3 (78-94)	76.3 (52-89)	23.7 (10-37)
28.10.93	surface	93.8 (92-96)	88.3 (85-94)	37.0 (27-54)
	bottom	82.7 (61-94)	77.3 (55-91)	33.3 (16-48)
23.11.93	surface	92.3 (88-99)	87.3 (81-92)	47.0 (24-70)
	bottom	86.0 (73-90)	75.0 (55-86)	31.0 (20-42)
20.12.93	surface	96.0 (96-96)	91.5 (91-92)	37.5 (34-41)
	bottom	97.5 (97-98)	98.5 (97-100)	72.5 (50-95)
21.01.94	surface	95.0 (94-96)	87.5 (86-88)	36.5 (35-38)
	bottom	98.0 (97-99)	99.0 (98-100)	71.5 (62-81)
Dormant samples of Triumph inserted at 1 m depth (n=3)				
06.09.93	1m	98.7 (98-99)	28.0 (28-28)	10 .0 (10-10)
10.09.93	1m	98.0 (98-98)	89.0 (87-91)	34.7 (27-48)
14.09.93	1m	97.0 (95-98)	94.7 (94-96)	57.7 (46-64)
21.09.93	1m	97.3 (97-98)	94.7 (93-96)	52.7 (46-62)
27.09.93	1m	95.5 (95-96)	93.5 (92-95)	56.5 (50-63)
21.01.94	1m	97.3 (95-100)	94.7 (91-98)	56.0 (51-62)

Table 10.3

1994-5. Northern site. The moisture content of grain at the bottom of a 1,000t bin of malting barley (n = 3).

Date	1.25m	Range	2.5 m	Range	4 m	Range
06.09.94	12.1	(11.9-12.2)	11.9	(11.8-12)	11.3	(11.0-11.5)
26.09.94	10.7	(10.4-10.9)	10.0	(9.6-10.4)	10.3	(9.8-10.7)
15.12.94	10.6	(10.5-10.6)	10.1	(10-10.2)	10.3	(10.2-10.3)
05.01.95	10.6	(10.3-10.8)	10.3	(10.2-10.4)	10.0	(9.9-10.0)

Table 10.4

1994-5. Northern site. Germination (%) of barley from the surface (mean of 4 locations) and bottom (n = 3) of a 1000 t store (variety Camargue).

Date	Depth	H_2O_2 Mean Capacity (range)	4 ml Mean energy (range)	8 ml Mean w.sensitivity (range)
07.09.94	Surface	97.5 (97-98)	96.3 (93-98)	69.3 (63-75)
	Bottom	98.3 (98-99)	96.0 (94-98)	82.3 (79-85)
12.09.94	Surface	97.8 (97-99)	97.3 (96-99)	85.3 (82-90)
	Bottom	98.7 (98-99)	97.7 (97-98)	88.7 (85-90)
05.01.95	Surface	98.0 (97-99)	97.3 (96-99)	89.3 (86-92)
	Bottom	98.3 (98-99)	98.0 (97-99)	92.3 (89-94)
Dormant samples of Triumph inserted at 1 m depth (n=3)				
12.09.94	1m	96.3 (95-98)	92.3 (89-94)	27.0 (24-30)
16.09.94	1m	96.7 (96-97)	94.3 (93-96)	24.3 (18-30)
20.09.94	1m	97.0 (97-97)	95.7 (94-98)	21.7 (20-25)
06.10.94	1m	97.7 (97-98)	94.7 (94-95)	21.0 (17-23)
14.12.94	1m	97.0 (96-98)	94.3 (94-95)	31.0 (22-37)
05.01.95	1m	97.0 (96-98)	93.0 (93-93)	29.3 (26-31)

Figure 10.1

Northern site. Top: 1000 t bins used to store malting barley. Bottom: Ventilation fan and control box.

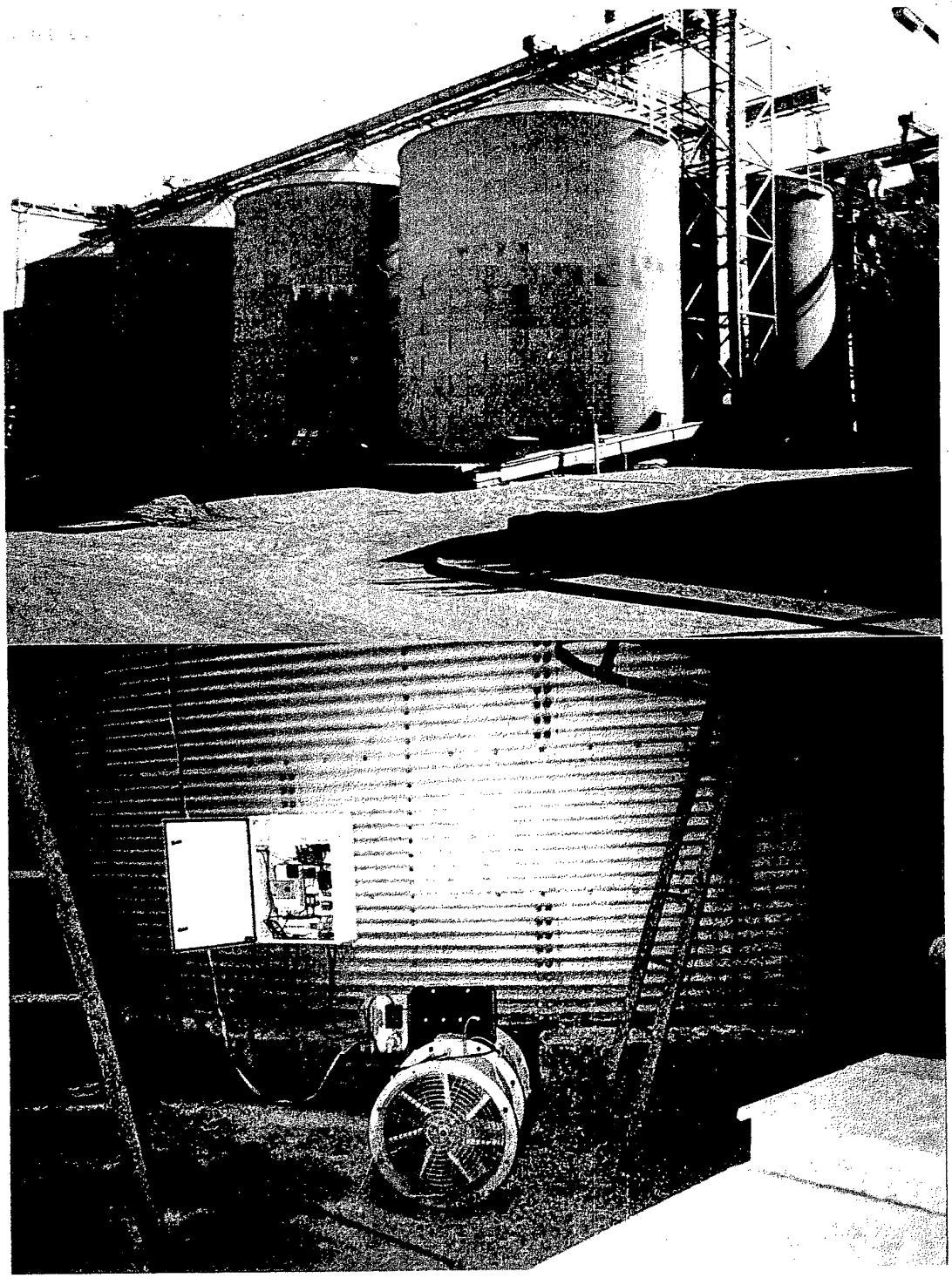


Fig. 10.2

Northern site. Top: The centre thermocouple cable and sampling probe. Bottom: Downloading the data-logger to a PC.

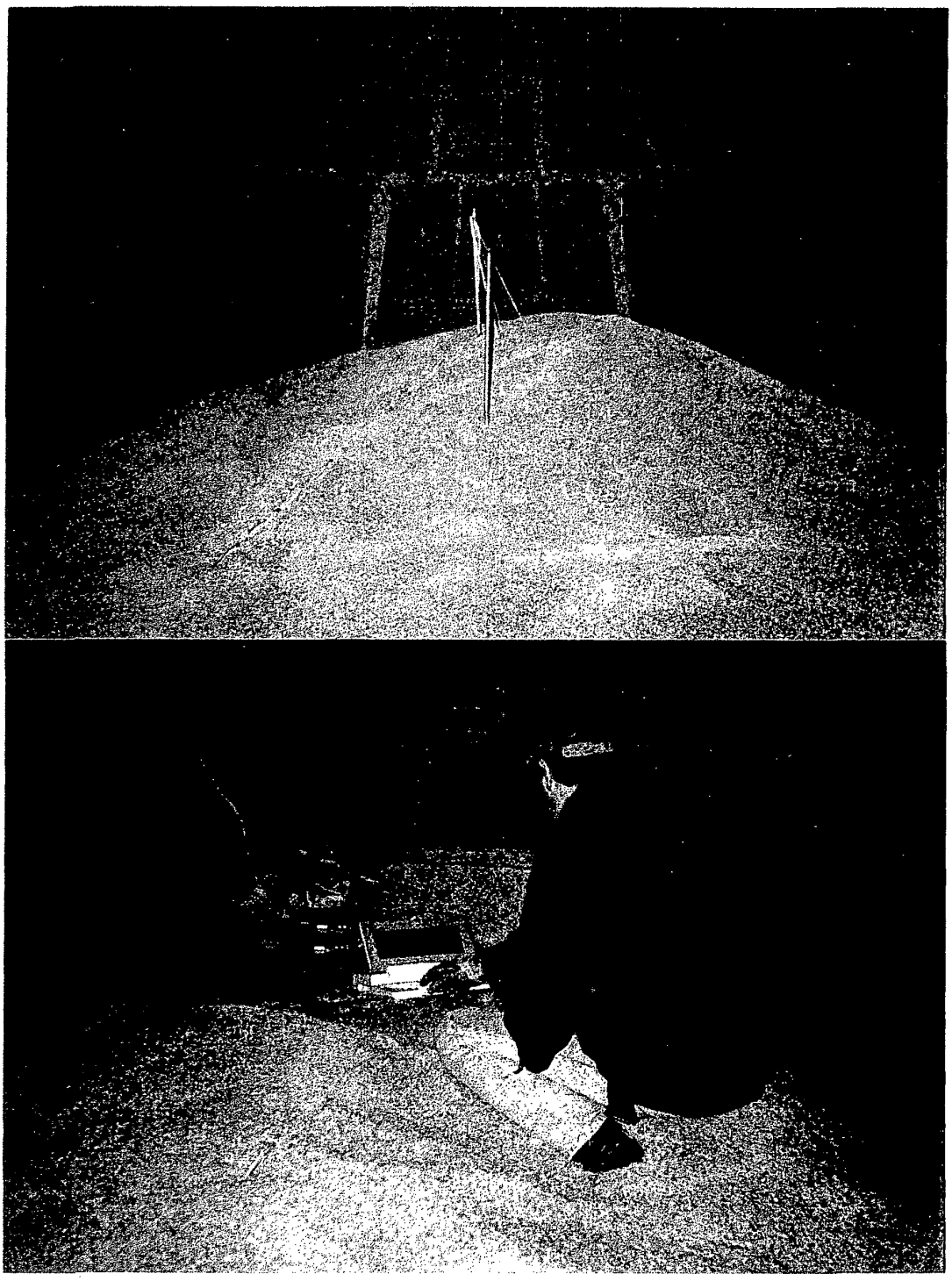


Fig. 10.3

1993-4 Northern site. Temperatures at three distances from the bottom of a 1,000 t bin of malting barley during cooling (n = 4) and ambient.

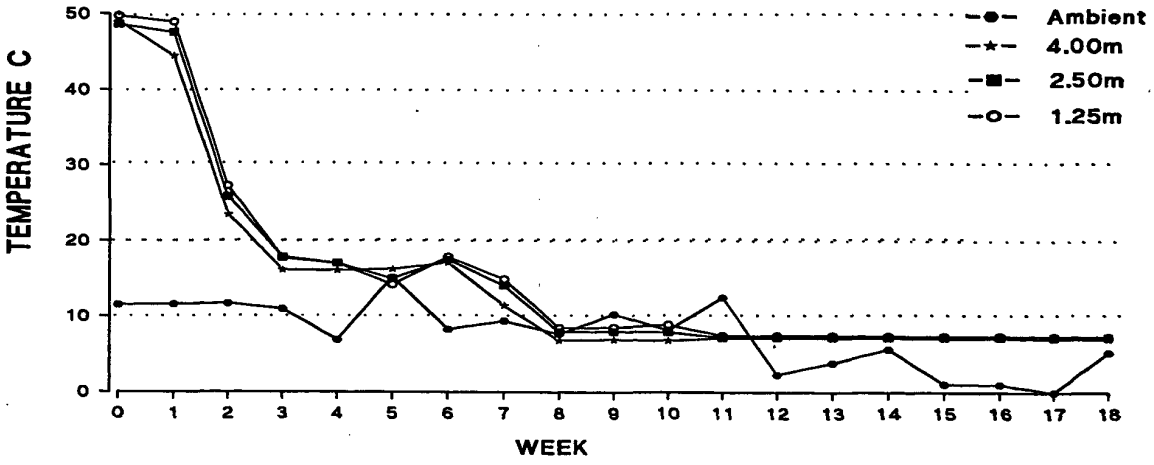


Fig. 10.4

1993-4. Northern site. Weekly hours of aeration (bar chart) and cumulative hours aeration (line) during cooling of a 1,000 t bin of malting barley.

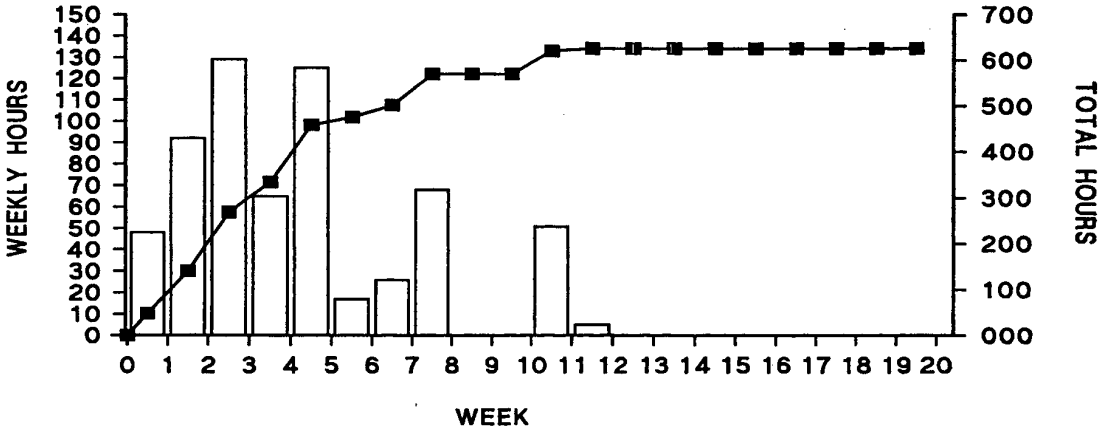


Fig. 10.5

1993-4. Northern site. Temperatures at 5 equidistant depths in a 1,000 t bin of malting barley, upper layers cooling most rapidly.

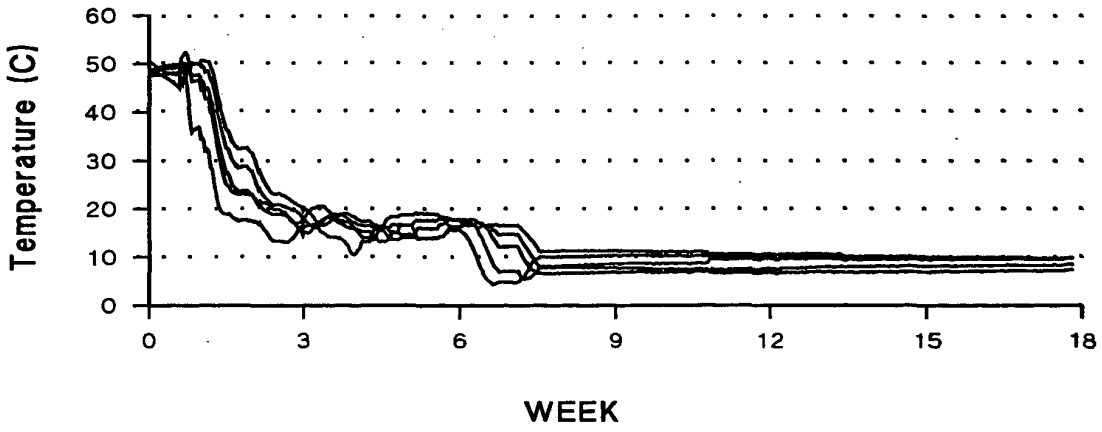


Fig 10.6
1993-94. Northern site. Grain moisture content with depth at the West probe (half radius)

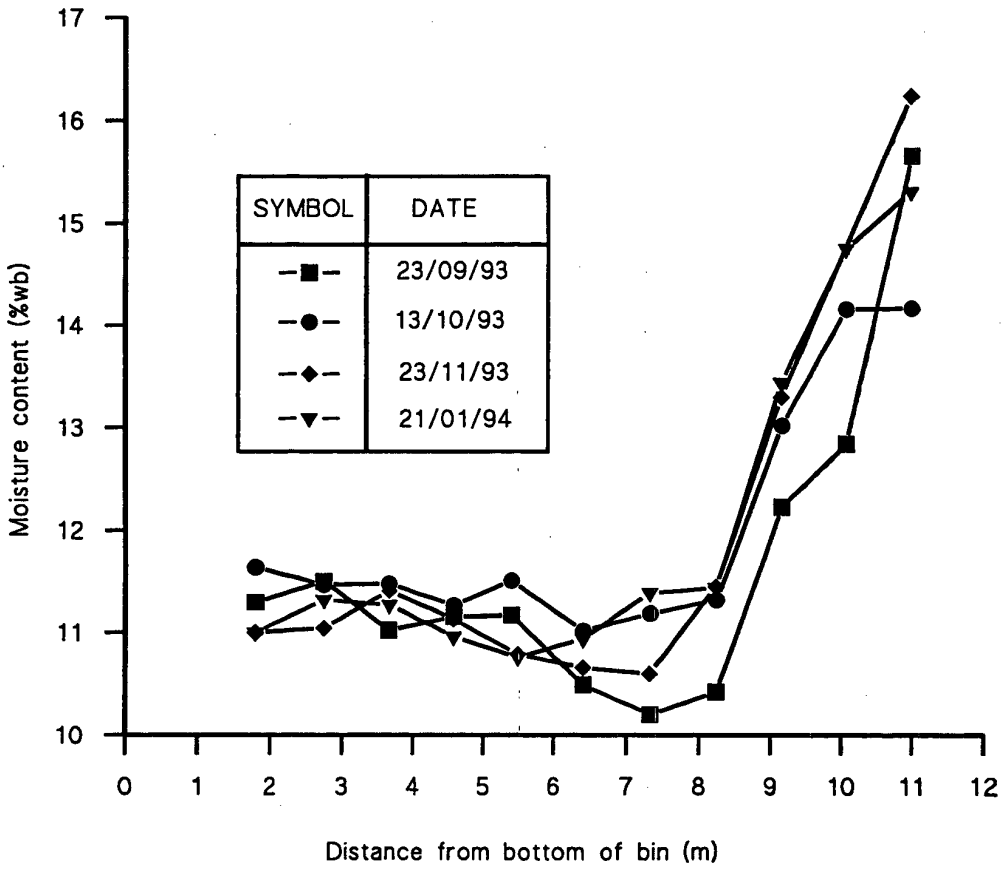


Fig. 10.7

1994-5. Northern site. Temperatures at three distances from the bottom of a 1,000 t bin of malting barley during cooling (n = 4) and ambient.

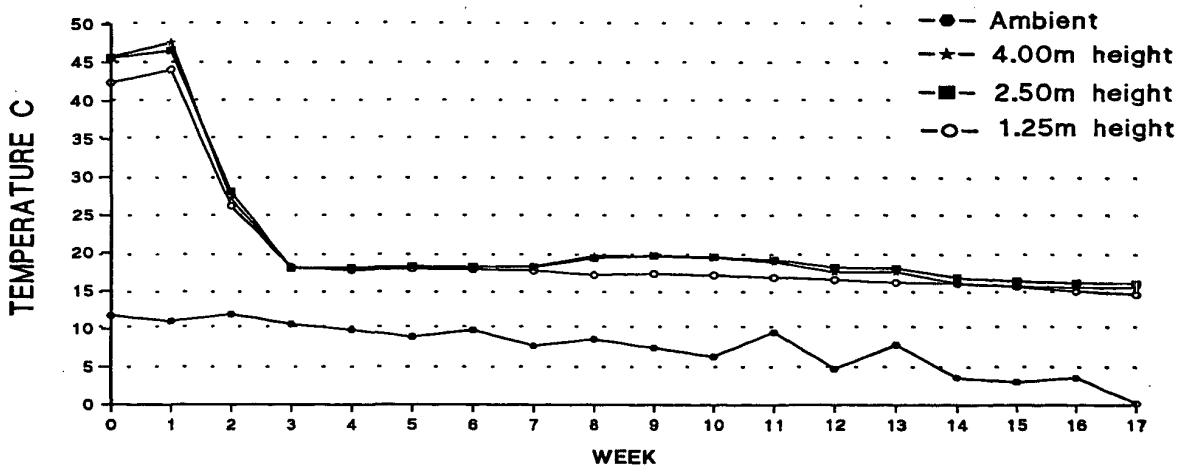


Fig. 10.8

1994-5. Northern site. Weekly hours of aeration (bar chart) and cumulative hours aeration (line) during cooling of a 1,000 t bin of malting barley.

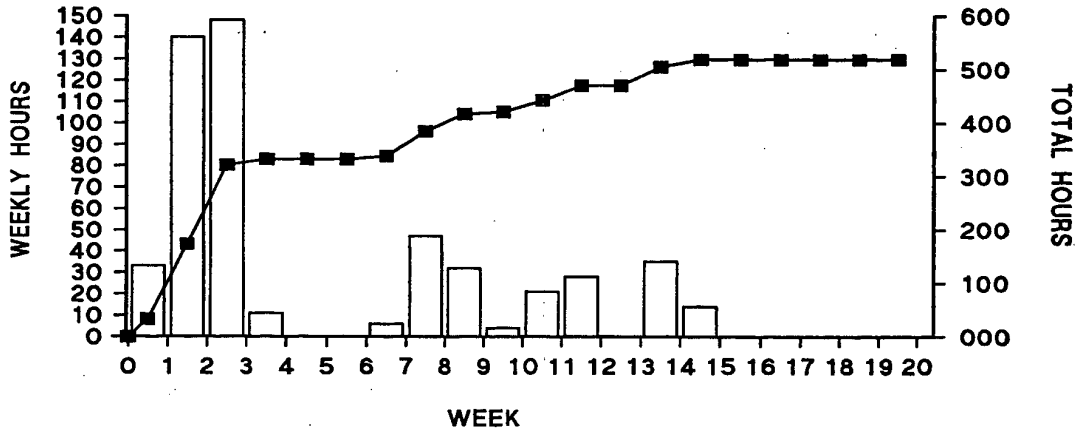


Fig. 10.9

1994-5 Northern site. Temperature at 5 equidistant depths in a 1,000 t bin of malting barley, upper layers cooling most rapidly.

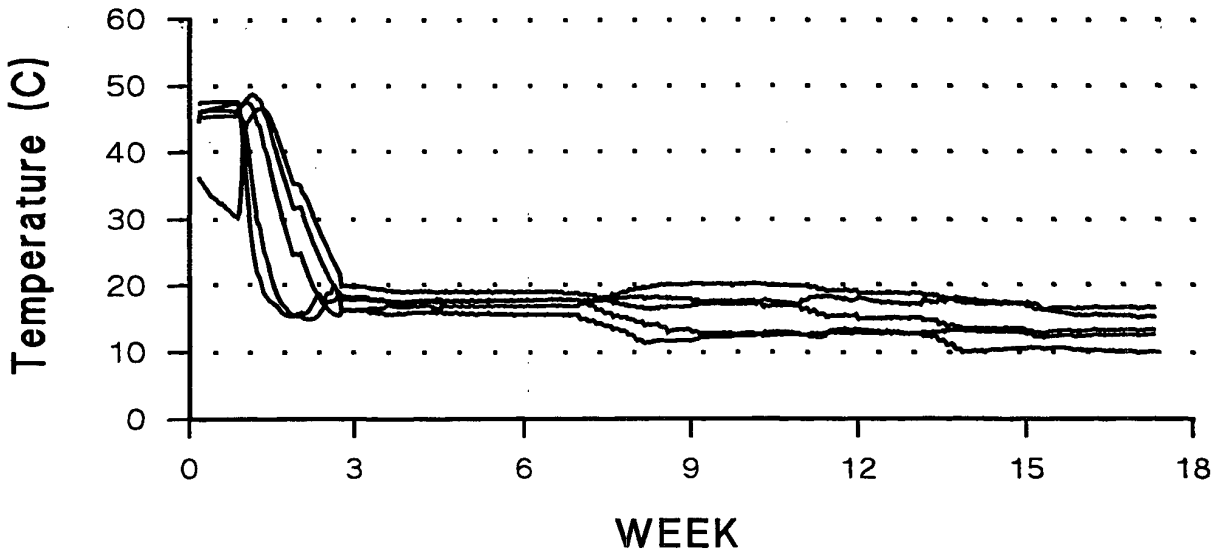


Fig 10.10
1994-95. Northern site. Grain moisture content with depth for the Centre probe (half radius)

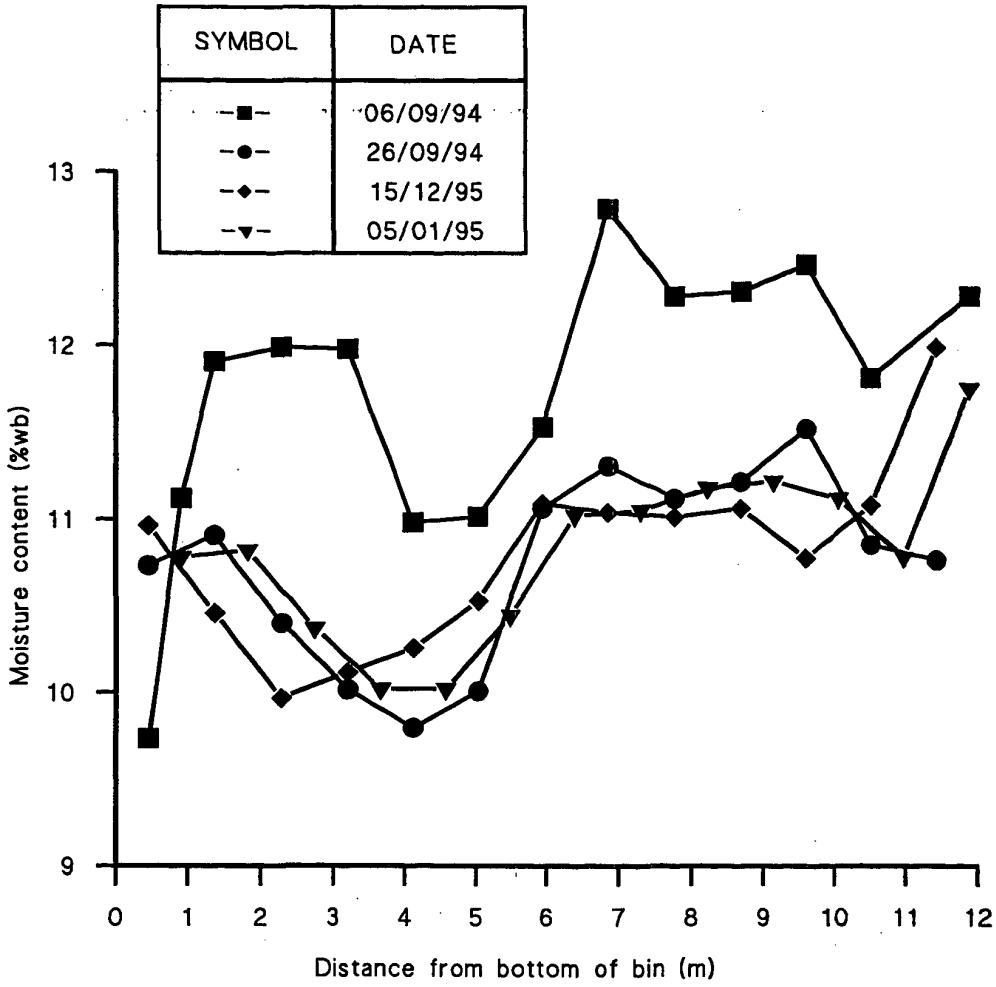
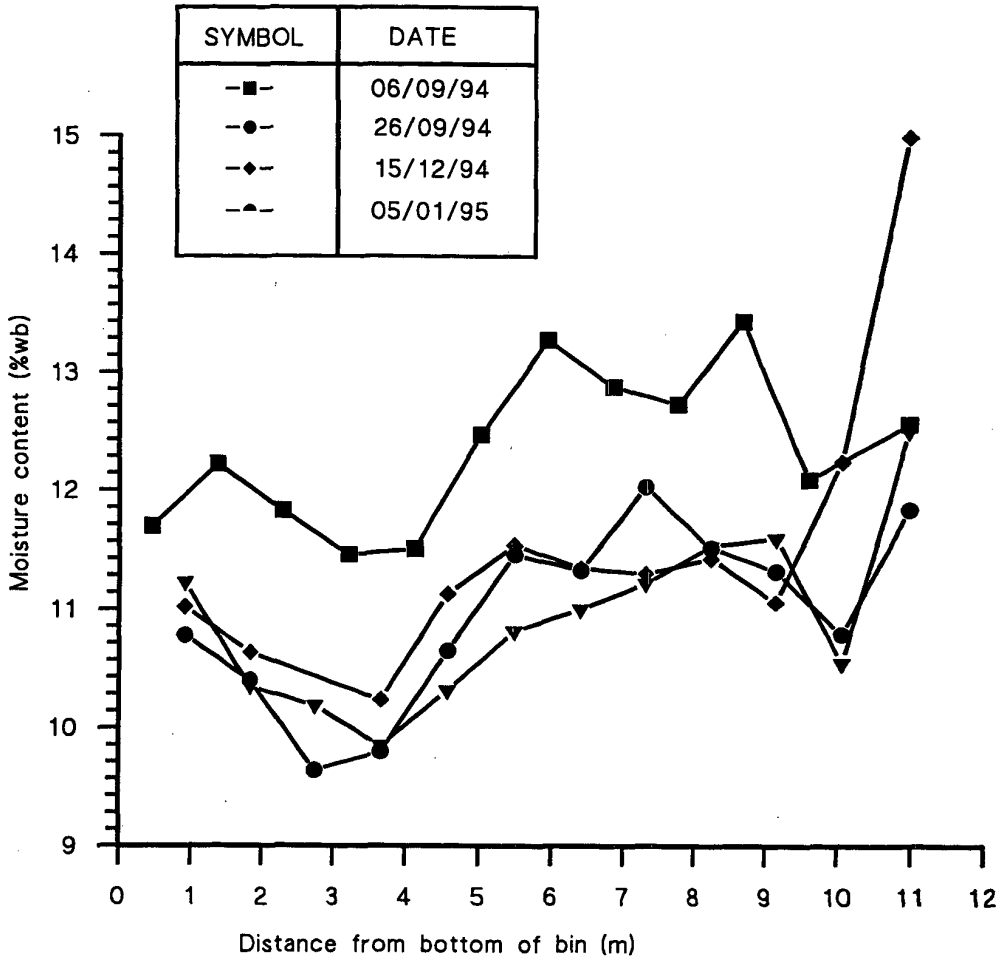


Fig 10.11
1994-95. Northern site. Grain moisture content with depth for the East probe (half radius)



11. Discussion

This report integrates knowledge and experiments on quality loss during malting barley storage, principally germination and infestation, to advise on storage strategies which will provide minimal risk from these two factors. However, a single strategy is unlikely to be appropriate for the industry as malt is required throughout the year and so the maltster might need to adopt different storage techniques, depending on how quickly the barley is likely to be needed for processing.

Dormancy break is quicker at higher temperatures, so there may be a temptation to break dormancy as quickly as possible at a relatively high temperature (30-35°C) before cooling so the barley is always available for processing. However, calculations in this report indicate the likely development of *O. surinamensis* above 25°C while the complementary laboratory experiments indicate that *S. granarius* could develop at 20°C. These results conflict rather with results from commercial trials in the south when insects failed to survive in grain, initially at 22°C. (The conflict between laboratory and practical studies is likely to be due to the small degree of grain damage in commercial malting barley which impedes *O.surinamensis* development and to moisture build-up in laboratory experiments which favours *S.granarius*.) In commercial tests at about 38°C, the development of *O. surinamensis* was confirmed although they failed to survive subsequently in low temperature storage. In contrast, *S. granarius* adults died almost immediately at 38°C but their eggs were apparently able to survive as considerable numbers of adults emerged after about 4 months.

However, the fate of insects in the fastest cooling areas at the top of the downward-cooled bins in the north may be even more revealing. No insects survived at initial temperatures of 45 - 50°C. At these higher temperatures, germination loss during cooling might be expected to be severe, based on the predictive model but our measurements showed the barley to be acceptable for malting. This may be related to the drying process that occured during the initial cooling phase ('dryeration') which gave the grain additional protection against viability loss. An additional threat at these high temperatures may come from different species of insect such *as Trogoderma granarium* but in extended laboratory tests, starting at 40°C (Cook, personal

communication) only a very few of this species were able to develop after nearly 250 days of cold storage and adults died almost immediately.

These observations suggest that, if the dormancy is to be broken at moderate temperature (up to 40°C), then processing should follow fairly swiftly, to minimise the threat of infestation. A temperature of 45°C, would probably guarantee freedom from insects but further experiments on germination loss are required before this could be confidently suggested. Temperatures above 40°C require very careful and accurate monitoring and need to be reduced swiftly by efficient aeration. Further training in and development of both these technologies is probably required by the trade. At the moment, the risk to germination at these temperatures is deemed higher than the risk of infestation avoided.

As with all strategies, immediate and rapid cooling to 10°C or lower should not be neglected, if the prophylactic use of admixture or fumigation chemicals is to be avoided. The results from the commercial trials indicate that at least 300 h of aeration at recommended rates is required to lower the temperature to below insect development thresholds. The field results for the cooling of the malting barley could be divided into 2 phases. In the first, after dormancy break, the temperature fell fairly steeply and easily but in the second, it proved quite difficult to further lower the temperature quickly (Table 11.1). The lower the temperature of the grain, the higher the volume of air that was required to cool it further.

Table 11.1
Comparison of rates of cooling at 2 malting barley sites in the north and south of England.

			Year 1 (93-4)		Year 2 (94-5)	
			South	North	South	North
1st phase	Temperature	Initial	22	50	38	47
	(°C)	Final	15	18	22	18
	°C / week		5	16	5	13
	h/°C		28	12	13	13
2nd phase	Temperature	Initial	15	18	22	18
	(°C)	Final	7	10	15	15
	°C / week		2	1.5	0.5	0.3
	h/°C		104	40	30	50

There were interesting differences between the cooling rates in the north and the south, where both aeration rates were the recommended 10 m3 h-1 t-1. These can be accounted for by different ambient conditions (in the second year, ambient in the north was 5°C cooler than in the south). Fan aeration control regimes also differed. In the south, the differential was 6°C in the first year and 10°C in the second but during the initial cooling phase was during the day only, to avoid condensation. In contrast, in the north the differential settings were 2°C and 6°C in the first and second years respectively but cooling was initially continuous with manual interruptions on rainy days. Moisture levels substantially above 12% only occurred for the 2°C differential setting and not for the other three settings all at 6°C or above. There is clearly scope for increased efficiency of automatic fan operation and for harmonisation throughout the industry.

The choice of upward or downward aeration is largely an individual choice, based on local conditions. Some of the advantages and disadvantages of each are set out below

Table 11.2

Comparison of the advantages of cooling by upward or downward aeration.

Upward

- Aeration can be started during loading without transferring heat from warm to cool grain.
- Fan heat lowers the r.h. of ventilating air, thus reducing the risk of wetting.
- Warmest grain is near the surface and more easily monitored.
- Solar gain from the roof, impeding daytime cooling, does not occur.

Downward

- Condensation of hot air on the cold roof is avoided.
- Avoids an excessive rise in air temperature in very deep (17m) grain beds.
- Solar heat from the roof can be utilised to reduce the r.h..
- The inlet region, which is most vulnerable to rewetting, is easily monitored.

Recommendations

Storing all malting barley at between 20°C and 35°C, for the period required to break dormancy in the most difficult variety, Triumph, before starting cooling is a high risk strategy, likely to encourage infestation. The survey shows that most malting barley is stored initially at around 30°C. If this strategy is to be followed, then processing should follow as soon as possible or temperatures for prolonged storage should be lower and attained more rapidly. This would require increased aeration Rapid dormancy break above 40°C is likely to kill invading adult insects and is therefore a more suitable treatment to produce dormancy broken barley that can be held in cold storage, at less risk from insects and ready for use at short notice. However, the risk to germinative capacity at these high temperatures needs to be further investigated.

Slow dormancy break, below 20°C is another low risk strategy. For example, Triumph at 15°C breaks dormancy in around 80 days (Chapter 3) and achieves a higher final germinative energy than warm stored barley. Barleys that can be identified for malting 2-3 months ahead could be more safely handled by cool storage. In this context, the effects of storage temperature and time combinations needs investigation.

It appears there is market pressure to have as much barley as possible, ready for malting as soon as possible after harvest. It would be more rational, to adopt a strategy that takes into account the initial variety and state of dormancy of the grain. The date at which the barley will be taken out of store for malting should then determine the temperature at which any dormancy is broken, with a preference for temperatures below 20°C or above 40°C, to discourage infestation. However this 'rational' approach would depend on predictions of requirements for malt throughout the year. This would require investigation in collaboration with the industry.

Decision support systems could be developed, which would predict dormancy break at different temperatures and germination loss in subsequent storage, for different varieties of malting barley. These would be essential for the choice of the most appropriate storage strategy. As an input to the decision support system, dormancy characteristics of new varieties need monitoring.

Following dormancy break, cooling should be as rapid as possible and immediate where there is no requirement to break dormancy. Hours of required aeration at the recommended rate of 10 m3 h-1 t-1 are likely to be around 300 h. Because of the threat of infestation where dormancy is to be broken at around 30°C before cooling, temperature for long-term storage should be below 10°C, despite the cost of re-heating during steeping. [To raise 1 tonne from 5 to 15°C would require 16 MJ of energy and would cost 6.7 p (/t) based on natural gas at 1.5p/kWh.] Rapid cooling would be facilitated by purpose-built automatic control including, for instance, differential thermostats, time-clocks to use cheap electricity, hours meters and facilities to deal with special problems such as roof condensation in upward ventilated bins. Reasons and remedies for the unexpectedly slow cooling of dry malting barley need to be sought. There is evidence that, using a higher differential temperature for aeration control reduces the risk of rewetting. A setting of 6°C was succesful in this work. Further work is needed on the significance of the rewetting problem to the industry and the simplest method of minimizing it. It is of sufficient concern to some maltings that all fans are switched off manually when rain sets in.

Secondary dormancy imposed by low temperature storage has often been described but never proven. The experiments in this report failed to induce secondary dormancy but as low temperature storage is such a vital component of a non-chemical storage strategy, longer term tests than those reported here are possibly justified.

Existing cooling models could be utilised to interact with the models of germination and infestation and integrated into decision support systems specific to the malting industry but which could be adapted to other end uses. Such a decision tool would enable individual store managers to predict and manage malting barley quality in a precise fashion appropriate to their individual end-use needs.

The success of any proposed strategy lies in its ability to prevent infestation, as well as to maintain germination properties. In this area, unanswered questions concern the development of insects at the margins of their development. Although we know adults will be killed at some of the high temperatures we investigated, we also have

evidence that a proportion of developing stages within the grain could survive. We need to know the proportion able to survive and subsequently develop during cooling and low temperature storage and the time needed to hold the grain at low temperature before they all die. A change in storage practice might lead to a change in relative importance of different species, for instance, high temperature storage may favour the Khapra beetle, *Trogoderma granarium.* Future studies should investigate a wider spectrum of species, therefore. The project showed discrepancies between calculations of insect development and actual observations in laboratory and field experiments which were ascribed to differences in food used in experiments. Safe storage temperatures are related to insect development times, for instance the historic recommendation to store at 17°C was related to the fact that the grain weevil, *S. granarius* took over 100 days to complete development at this temperature. New data should be generated showing times for complete development on malting barley rather than artificial media such as oats or flour.

Our tests examined strategies at temperatures below 25°C and above 40°C, yet the survey showed most barley was stored between 25 and 40°C and as much was stored in flat stores as in tall silos. Any new strategies need to be validated for these additional parameters.

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REFERENCES

Anon. 1991. Recommended methods of analysis. Institute of Brewing, London.

Anon. 1995. ASAE Standards handbook,. 30 th. Edn. D272.2: Resistance to airflow of grains, seeds, other agricultural products and metal sheets. American Society of Agricultural Engineers, St. Joseph, MI 49085 USA.

Armitage, D.M., Cogan, P.M. and Wilkin, D.R. 1994. Integrated pest management in stored grain: combining surface insecticide treatments with aeration. J. stored Prod. Res. 30, 303-319.

Beckett, S.J. and Evans, D.E. 1994. The demography of *Oryzaephilus surinamensis* (L.) (Coleoptera : Silvanidae) on kibbled wheat. J. stored Prod. Res. 30, 121-137.

Briggs, D.E. and Woods, J.L. 1993. Dormancy in malting barley : studies on drying, storage, biochemistry and physiology. Project Report No. 84, Home-Grown Cereals Authority, London.

Cook, D.A., Armitage, D.M. and Fleming, D.A. 1995. Integrated pest management for stored grain: Experiments in commercial stores - I A comparison of manual with automatic cooling a surface-insecticidally treated wheat. II A comparison of two methods of applying insecticide dust to the surface of cooled barley. CSL Report No. 63, 29pp MAFF, Slough.

Disney, R.W. 1954. The specific heat of some cereal grains. Cereal Chem. 31, 229-239.

Eastham, L.E.S. and McCully, S.B. 1943. The oviposition responses of *Calandra granaria* Linn. J. Exp. Biol. 20, 35-42.

Eastham, L.E.S. and Segrove, F. 1947. The influence of temperature and humidity on instar length in *Calandra granaria* Linn. J. Exp. Biol. 24, 79-94.

Ellis, R.H. and Roberts, E.H. 1980. The influence of temperature and moisture content on seed viability in barley (*Hordeum distichum* L.). Annals of Botany 45, 31-37.

Essery, R.E., Kirsop, B.H. and Pollock, J.R.A. 1995. Studies in barley and malt. II Tests for germination and water-sensitivity J. Inst. Brew. 61, 25-28.

Howe, R.W. 1956. The biology of the two common storage species of *Oryzaephilus* (Coleoptera, Cucujidae). Ann. Appl. Biol. 44, 341-355.

Jacob, T.A. and Fleming, D.A. 1989. The difference in developmental period and mortality of some field strains of *Oryzaephilus surinamensis* (L.) at constant temperatures (Coleoptera : Silvanidae). J. stored Prod. Res. 25, 73-76.

Lasseran, J. 1977. Dryaeration or delayed aeration cooling. Perspectives Agricoles, 6, 59-66.

McLeod, A.M. 1950. Determination of germinative capacity of barley by means of terazolium salts. J. Inst. Brew. 56, 125-134 .

Smith, L.B. 1963. The effect of temperature and humidity on the oviposition of the rusty grain beetle, *Cryptolestes ferrugineus* (Steph.). Proc. North central Branch ESA 18, 74-76.

Smith, L.B. 1965. The intrisic rate of natural increase of *Cryptolestes ferrugineus* (Stephens) (Coleoptera, Cucujidae). J. stored Prod. Res. 1, 35-49.

Solomon, M.E. 1951. Control of humidity with pottasium hydroxide, sulphuric acid or othr solutions. Bull. ent. Res. 42, 543-554.

Sun, D.W. and Woods, J.L. In Press. Deep bed simulation of the cooling of stored grain with ambient air: ventilation control strategies. J. stored Prod. Res.

Thompson, R.A. and Foster, G.H. 1967. Dryaeration - high speed drying with delayed aeration cooling. ASAE Paper No. 67843.

Wilkin, D.R., Armitage, D.M., Cogan, P.M. and Thomas, K.P. 1990. Integrated pest control strategy for stored grain. Project Report No. 24, 87pp Home-Grown Cereals Authority, London.

Woods, J.L., Favier, J.F. and Briggs, D.E. 1994. Predicting the germinative energy of dormant malting barley during storage. J. Inst. Brew. 100, 257-269.