The development of a storage strategy for malting barley

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Abstract

Predictions indicate that dormancy can be broken so that germinative energy rises from 10% to 95% between 19 days at 35℃ and 116 days at 10℃. Higher final germinative energies are achievable at lower temperatures 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 *Oryzaephilus surinamensis* 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. *Cryptolestes ferrugineus* were the greatest threat at 35℃, *O. surinamensis* at 25 – 30℃ with few insects developing at 20℃ where *Sitophilus granarius* predominated Laboratory experiments at 20, 30 and 40℃ simulating times for dormancy break, cooling and subsequent storage showed that at 40℃, no insects tested were able to survive. At 30℃, moderate insect numbers developed during dormancy break and cooling but they failed to survive in subsequent storage. At 20℃, *O surinamensis* developed during dormancy break and cooling and none survived storage but large numbers of *S granarius* developed and half of them survived storage. A survey of maltings storage showed that most storage has aeration and that 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℃ in tall silos was as fast as expected and as fast as in flat stores but subsequent cooling to 10℃ was unexpectedly difficult Hot barley cooled by upward aeration late in the year required special measures to avoid roof condensation. At initial grain temperatures of just under 40℃, there was development of grain weevils after three to four months.

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Modelling Dormancy and Viability

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.

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 were predicted using probit analysis. This assumed 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 were calculated from the probability function and based on work by by Ellis and Roberts (1980), Briggs and Woods, (1993); Woods et al., (1994). 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. The value is based on five barleys tested at 38℃, one of which was replicated at four moisture contents. All values were above 98%. (iv) The mean moisture content in storage was 12% (wb). (v) All germination values refer to the 4 ml, 3 day, IoB test (Anon., 1991).

Based on these assumptions and the double probit analysis, the effect of temperature and moisture content on storage time is illustrated in Table 1. At 12% moisture

content the germinability can be raised from 10% to 95% in 19 days at 35℃ From these predictions, 24 days at 30℃ and 12% m. c would give a germinability rise from 10% to 95%. At lower temperatures and longer times it is possible to achieve higher germinabilities. This is due to the sensitivity of viability loss to temperature

Table 1. Time in days to break dormancy at a range of storage temperatures and moisture contents.

℃	10	15	20	25	30	35	40	45
t_{10-95}	116	78	52	35	24	19	-	-
g_{max}	97.4	97.2	97.0	96.7	96.1	95.0	92.8	88.3
t_{max}	168	110	72	46	30	19	12	7

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}

Changes during cooling

The data on the 15, 10 and 5℃ cooling front completion times (Wilkin et al , 1990, p. 36) were utilised to predict worse case viability loss during ambient cooling after warm storage (30℃, 24.2 days). Predictions for grain at 12% are presented in Table 2 for the case of 6.8 m^3/h/t (4 cfm/t) fan capacity and starting date 1st August

Table 2 shows that the predicted loss in viability is considerable and most of this occurs during the 24 day period at 30℃ from the time the fan is started to the arrival of the 15℃ front. In reality, the traverse time of the front is 8.7 days and therefore the grain will be at or near the mean ambient temperature within this time. Given that loss of viability increases by a factor of ~4 for a 10℃ temperature rise, this is very significant

Table 2. Dormancy and viability changes during cooling from 30℃ (6.8 m^3/h/t, start date 1.8).

Stage	Duration (days)	T (%)	g (%)	g_v (%)	g_d (%)
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

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℃ would be the quickest 'safe' treatment. From the previous dormancy project (Briggs and Woods, 1993), a number of barleys stored at 38℃ and 12% m. c. suffered vigour loss after 10 – 15 days. This would support a storage regime of around 30℃ 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

Calculations for the Development of Insects during Dormancy Break and Cooling

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.

Methods

These calculations are based on the methods outlined by Wilkin et al (1990) 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 = umber of eggs laid per day. For successive cooling fronts, the actual time taken by the cooling front to travel through the bulk (d_2) is converted to 'biological units', equivalent to days of the first cooling period – $d_2 \times t/t_2$, where t_2 = time for insects to complete development at the lower temperature. The biological data on *Oryzaephilus surinamensis* L was derived from the

work of Becket and Evans (1995), Howe (1956) and Jacob and Fleming (1994), that for *S. granarius* L from Eastham and Segrove (1947) and Eastham and McCully, (1943) and that for *C. ferrugineus* Steph. from Smith (1963, 1965). The moisture content/equilibrium relative humidity figures were taken from unpublished work by S. Henderson (CSL, Slough) based on the ISO standard for moisture determination.

Insects developing after dormancy break and during cooling from 20 – 35℃

O. surinamensis is the quickest developing species and the greatest margin of safety, between the insect development period and the time to break dormancy was at 20℃ while at 25℃ and 30℃ there was virtually no margin of safety. 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℃ but each species peaked at a different initial temperature so that *S. granarius* did best at 25℃, *O. surinamensis* did best at 30℃ and *C ferrugineus* did best at 35℃ (Table 3).

Table 3. Estimates of insects developing during cooling ($6.8m^3/h/t$, start date 1.8).

Stage	Duration (days)	T (℃)	*O surinamensis*	*S. granarius*	*C ferrugineus*
20℃					
Warm storage	54	20	0	0	0
15℃ front	24	20	1 – 4	8	0
10℃ front	40	15		10	
25℃					
Warm storage	37	25	2 – 7	0	0
15℃ front	24	25	20 – 50	17	8
10℃ front	40	15		24	
30℃					
Warm storage	24	30	1 – 4	0	0
15℃ front	24	30	21 – 89	15	31
10℃ front	40	15		20	
35℃					
Warm storage	19	35	0	-	0
15℃ front	24	35	12 – 42	-	80
10℃ front	40	15		-	

From the point of view of pest control, the best strategy appears to be to store the grain at 20℃ 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℃ or more would also prevent insect development but the threat to germination would be proportionately greater.

Laboratory Tests of Insect Increase during Dormancy Break and Cooling

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 previous calculations were often based on studies using media other than grain, such as flour or oatmeal, in these experiments the insects had only barley to feed upon.

Method

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℃, 5℃ and after six months storage These

temperatures were achieved by turning down the incubator in sharp stepwise drops.

Three Strategies were tested : −40℃/11% m.c. (t_{10-95} = 12 days) 30℃/12% m.c. (t_{10-95} = 24 days) 20℃/13% m.c (t_{10-95} = 54 days). Sampling was carried out initially (to test for dormancy only), after t_{10-95} c After time to cool to 15℃ (24 days), after the time to cool to 10℃ (40 days), after the time to cool to 5℃ (104 days) and after storage at 5℃ for up to 6 months.

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

No insects survived at 40℃. 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℃ and after six months' storage at 5℃ were 10.3, 8.7, 8.7, 8 8 and 9.1% m.c.

At 30℃, 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 4). After the time estimated for cooling to 15℃, 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℃. The trends were similar with *S. granarius* The moisture contents during the experiment were in the range 11 − 12% m.c.

Table 4. 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℃.

		O. surinamensis			*S. granarius*	
		adult		stages	adult	
	m.c.	live	dead		live	dead
a. 20℃						
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℃	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℃	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℃	11.6	8.0(3−12)	32.4(29−40)	0	3.0(1−4)	41.4(35−58)
6m @ 5℃	11.2	-	42.4(35−47)	0	0	55.6(34−74)
b 30°C						
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℃	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℃	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℃	18.8	6.4(3−9)	12.4(9−17)	0	352.8(328−376)	5.8(2−18)
6m @ 5℃		0	18.4(17−20)	0	144.2(107−168)	162.2(107−237)

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

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

Table 5. Results of maltings storage survey.

Control measures		Length of storage (months)		Initial temperatures(℃)	
	%		%		%
Pesticide	10.9	2	0	15	1.1
Manual aeration	72.4	4	1.2	20	5.6
Auto. aeration	3.1	6	14.2	25	31.0
		8	21.3	30	41.2
		10	2.7	35	0
		12	30.9	40	21.1
		14	30.8		
Total (t)	927,704		675,813		749,260

Discussion

The high risk strategy of keeping the grain at 40℃, 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 (Armitage and Cook, 1997)

There was some development of both *S. granarius* and *O surinamensis* at 30℃ 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℃ 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 calculations reported earlier where it was suggested that *O. surinamensis* would be favoured at 30℃. 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℃ was also unexpected. This may be partly accounted for by the swifter development times and greater productivity of the laboratory strain of *S. granarius* so the difference may also be due to accumulation of metabolic water in the laboratory experiment which increased the rate of development

Analysis of Maltings' Storage Survey

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 to 14 maltsters. This was intended to determine normal length of storage and whether aeration or pesticide application facilities were available and/or used.

The majority of stores appear equipped to cool their grain (Table 6) 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. 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. Most of the grain is stored initially at 25 – 30℃ which is very favourable to insects but a significant proportion goes into store at 40°C at which temperature, germination decline is very rapid.

Commercial Scale Tests on Malting Barley Storage Strategies

The experiments described here 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.

Method

A southern malting barley store was cooled by upward aeration 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.

Table 6. 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

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 0.5m, 1.5m and 2.5m 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 × 2.5cm and holding 15g of barley) for each sampling period, each containing 25 *O. surinamensis* and another five containing 25 *S granarius*, were inserted to 0.5m. These cages were withdrawn at intervals, coinciding approximately to t_{10-95}, the time taken to cool to 15℃, 10℃, and 5℃ and at the end of storage, to determine the numbers developing during cooling. Controls were first maintained at 35℃, until the time for dormancy break and the first cooling front had passed and then they were dropped to 15℃.

Twelve samples, each of 0.2kg 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; 0.5m, 1m and 2m. The sample was sub-divided and half was examined for mites and half was deep frozen before determination of germination.

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

One thousand tonnes of malting barley were stored 11m deep in an external silo. This was ventilated from the base up. 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 As the initial temperature was about 40℃, 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℃. At this time, in early August, the threat of air at 40℃ condensing on the roof of the tall bins at night was considerable so it was decided to aerate only between 8.00 – 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

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

Temperatures and hours of aeration – The grain temperature at the top of the bins fell from 35 – 40℃ to 25 – 30℃ after two weeks' aeration (Fig. 1) and 155h blowing (Fig. 2) and to 20 – 25℃ after a further week and a total of 190h blowing. During this period, when the mean ambient was 15 – 20℃, and aeration was during the day only, to prevent condensation, the temperature dropped at a rate of 5℃/week or 13h aeration for each 1℃.

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℃ at a rate of less than 0.5℃/week or about 30h aeration for each 1℃ drop. At this time, the ambient was mainly between 10 and 12℃ and aeration was between 24.00 and 07.00, using cheap, off-peak electricity.

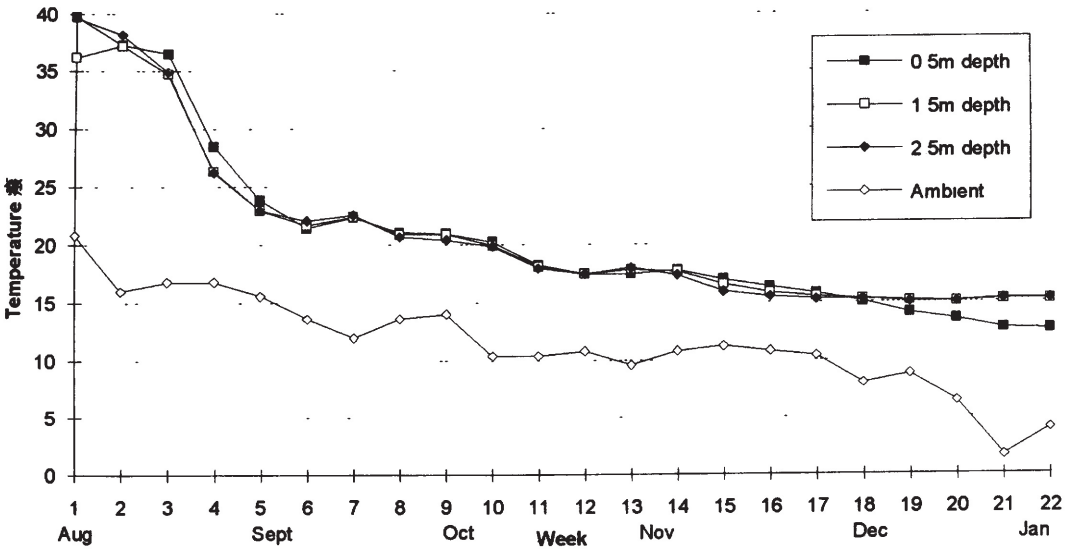

Fig. 1. Temperatures at the top of a 1,000 t bin of malting barley in Southern England during cooling

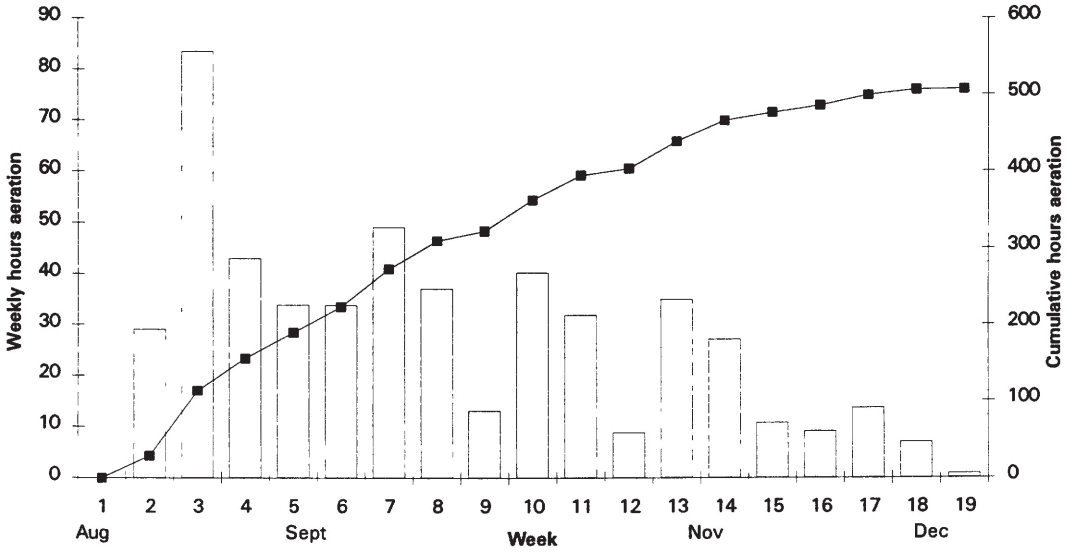

Fig. 2. Weekly hours of aeration (bar chart) and cumulative hours aeration (line) during cooling of a 10m deep, 1,000t bin of malting barley

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, based on the manufacturer sperformance data which revealed the power at the duty point to be 7.3 kW and assuming the fans were 2/3 efficient, 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 – 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 – The caged *S. granarius* died out in the bin at the high initial temperatures and low moisture contents (table 7) 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 – 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.

Discussion

It was 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℃ 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℃, 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.

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