

# Farm-Scale Experiments to Compare Infestation and Quality Changes in Malting Barley Stored at Three Moisture Contents

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## ABSTRACT

**J. Inst. Brew. 108(2), 178–186, 2002**

Comparison of changes in temperature, moisture content, infestation and germination were made in six aerated 20 t bins of malting barley. Two were at about 13.5% moisture content, three at about 15.5% moisture content, and one at about 16.5% moisture content. The grain started at between 20–25°C and, during aeration, fell at a rate dependent on the moisture content, damper grain being cooler, presumably due to evaporative cooling. The 'high' moisture content grain was often over 5°C cooler at 1 m and 2 m than the 'low' moisture content bins. Moisture uptake at the surface was related to bulk moisture content and trends in mite population changes were related to moisture content. Mite population achieved highest numbers at the grain surface but usually before the moisture content absorption was at its peak. They were commonest in the 'high' moisture content bin and least numerous in the 'low' moisture content bins. There were no apparent differences between bins in the numbers of insects trapped, for instance they were not less numerous in the coolest 'high' moisture content bin. However, the trends of numbers trapped followed a similar pattern in all bins; normally *O. surinamensis* and *S. granarius* only began to decline after nine weeks storage in December when temperatures fell below 10°C. Germination loss at the surface of the dampest bin was sufficient to cause rejection of the entire bulk for malting. Micromalting indicated that yield of extract and friability were particularly affected by the changes at the surface of the dampest barley.

**Key words:** Aeration, infestation, malting barley, micro-malting, moisture content, storage, viability.

## INTRODUCTION

The effects of individual components on the storability of malting barley have often been described, for instance effects of temperature and relative humidity on germination loss and dormancy break<sup>13,14</sup> or predictions of pest population changes<sup>3</sup> based on laboratory models. However, it is important to demonstrate how all these factors interact in practical circumstances and to validate how

closely laboratory-based knowledge matches what happens on a practical scale. For instance, Armitage and Woods<sup>5</sup> described a storage strategy for malting barley, intended to break dormancy, maintain viability and discourage germination, based on cooling by aeration which was tested over two years in maltings in the south and north of the UK. The moisture content of the grain is crucial to successful storage of malting barley, as well as affecting germination loss. It is also likely to affect infestation, temperatures achieved by aeration and moisture uptake at the grain surface<sup>4</sup>.

This experiment was therefore designed to compare mite, insect and fungal numbers, physical and quality changes in six cooled 3 m deep 20 t bins of a single malting barley variety (Chariot) at intended moisture contents of 13, 14.5 and 16%. The grain was freshly harvested and dried according to recommendations for malting barley (not exceeding 65°C), to preserve germination. All bins were intermittently cooled using 0.3kW fans controlled and monitored by prototype computer software using an ambient/grain temperature differential of 6°C with a lower set-point of 10°C, which is the minimum likely to be accepted by maltsters. Monitoring of insect numbers was carried out using traps. Mite numbers were estimated by examining sievings from 200 g spear samples, and temperatures were measured by thermistors attached to the aforementioned computer system giving hourly analysis. Quality changes were estimated by determining the germination of the barley at intervals throughout the experiment.

## MATERIALS AND METHODS

### Delivery and timing

Five 25 t lorry loads of malting barley were delivered between August 23 and 30. The first two, estimated by moisture meter at about 13% moisture content, were divided between two adjacent bins, as were the second which were estimated to be about 15% moisture content. The fifth load, at about 16% moisture content went into a fifth bin awaiting the final delivery which did not arrive until a month later.

The insects were inserted into the bins on September 25, the initial sampling carried out on October 2 and the first trapping exercise was carried out a week later when the fans were also switched on.

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## Aeration

All bins were cooled using 0.3 kW fans, switched on and off by prototype monitoring and control software on a PC (Robydome Electronic Ltd. - STORECHECK 2.56 monitoring & control software) The software was configured to switch fans on when the ambient temperature was 6°C lower than the slowest cooling layer of the bins which was determined from the mean 1m depth temperature of all six bins. A lower set-point setting of 10°C prevented over-cooling of the grain. The airflows were measured with a hot-wire anemometer and hours of operation recorded.

## Temperatures

Temperatures were measured in each bin by a central sensor array with single thermistor sensors at the surface, 1m and 2m depths. These were networked to the prototype software which logged data every hour into an 'Excel' compatible file for analysis.

## Introduced infestation

Initial populations of about 1/kg of *Sitophilus granarius* (L.) (granary weevil), *Oryzaephilus surinamensis* (L.) (saw-toothed grain beetle), *Acarus siro* (L.) (flour mite) and *Lepidoglyphus destructor* (Schrank) (cosmopolitan food mite) respectively, were achieved by introduction into each bin at three depths and nine columns via a narrow-bore plastic pipe, emptied of grain by vacuum.

## Insect populations

Each month, five pitfall cone (PC) traps were placed at the surface of each bin and five probe traps were inserted at each of 1m and 2m depth. These were left in place for a week before being withdrawn and the contents recorded.

## Spear samples

Five 200 g spear samples were withdrawn from each bin at the surface and depths of 1m and 2m. Mite numbers were estimated by sieving through a 2mm mesh and examining the dust under a binocular microscope. Where mite numbers were very high, a disc divided into areas was used<sup>12</sup>. The moisture content of the samples was determined by the ISO oven method, drying in a ventilated oven at 130°C for 2 h.

## Germinations

After determination of mites and moistures, the spear samples were bulked by row and germination determined by germinative capacity (GC), viability and germinative energy (GE) tests<sup>2</sup>.

*Germinative capacity (GC) – hydrogen peroxide test.* This test determined grain viability – that is the percentage of living corns in a sample of grain, using a hydrogen peroxide-assisted growth test. Corns (100 kernels) were steeped in 50 mL of freshly prepared hydrogen peroxide solution (5 mL of 100 volume hydrogen peroxide diluted to 200 mL with deionised water) in a 60 g wide necked glass jar. The jars were incubated at 16°C. After 48 h the hydrogen peroxide was poured off and replaced with a fresh solution, then the jar incubated for a further 24 h. After a total of 72 h incubation the corns which had ger-

minated were separated and counted. If necessary the husk around the embryo was peeled back to check for the emergence of the chit. The results are expressed as the percentage of corns which have germinated. The average of triplicate tests gives the germinative capacity.

*Germinative energy (GE) – the IOB 4 mL plate test.* This test measured the percentage of grains which will germinate when provided with adequate, but not excessive, supplies of water. Thus they would be expected to germinate fully if the sample were to be malted normally at the time of the test. The test was performed in triplicate and the final results expressed as an average of the three values. Grains (100) were transferred to a 90 mm petri dish lined with two filter papers (white Whatman No. 1, 90 mm diameter). Deionised water (4 mL) was added to the petri dish and the lid replaced. The petri dishes were placed on a tray and inserted into a plastic sleeve secured with cellotape and placed in a dark germination cabinet or incubator set at 16°C. It is important that the trays sit flat on any shelving. The number of germinated corns on each plate was counted after 24, 48 and 72 h.

## Micromalting

Provided that there were no significant differences by depth, samples from each bin were bulked to form six samples for micro-malting. Barley samples (350 g) were weighed into large glass jars (capacity 3.5 L) and covered with approximately 750 mL of deionised water. The jars were covered with muslin and held at 16°C for 8 h (steeping). The water was then poured off and the jars allowed to drain for 16 h (air rest), again at 16°C. The jars were re-filled with water and the grain re-steeped for 24 h at 16°C. The water was poured off and the jars maintained in a horizontal position at 16°C for 4 days (germination). Each jar was shaken daily to prevent root matting. At the end of the germination period, the green malt was spread onto a

TABLE I. Changes in mean moisture content (%) in six 20-t bins of malting barley during aerated storage.

Week	Date	Bin 7 low	Bin 8 low	Bin 9 medium	Bin 10 medium	Bin 11 medium	Bin 12 high
Surface							
0	2/10	14.7	14.9	16.1	16.1	16.1	17.0
4	7/11	16.1	16.8	18.0	18.2	18.8	19.1
8	4/12	16.6	17.3	18.3	18.5	18.3	18.9
13	8/1	17.0	17.9	18.6	18.7	18.4	19.4
18	12/2	17.5	18.2	18.5	18.4	18.3	19.0
22	12/3	16.9	17.1	18.0	17.8	17.6	18.4
26	9/4	16.0	16.4	17.2	17.2	16.9	17.6
1 m							
0	2/10	13.7	13.8	15.8	15.8	15.8	16.7
4	7/11	13.1	13.2	15.6	15.7	15.8	16.4
8	4/12	13.4	13.4	15.8	15.7	15.7	16.4
13	8/1	13.3	13.5	15.8	15.7	15.7	16.5
18	12/2	13.5	13.4	15.8	15.8	15.8	16.6
22	12/3	13.3	13.2	15.7	15.7	15.6	16.4
26	9/4	13.2	13.3	15.6	15.6	15.9	16.3
2 m							
0	2/10	12.7	13.3	15.5	15.7	15.8	16.3
4	7/11	12.4	12.9	15.4	15.0	15.6	16.1
8	4/12	12.4	13.0	15.4	14.9	15.4	16.2
13	8/1	12.5	13.0	15.5	15.0	15.5	16.1
18	12/2	13.1	13.0	14.9	15.5	15.5	16.1
22	12/3	12.4	12.9	15.4	15.0	15.5	16.1
26	9/4	12.5	12.9	15.4	15.0	15.5	16.0

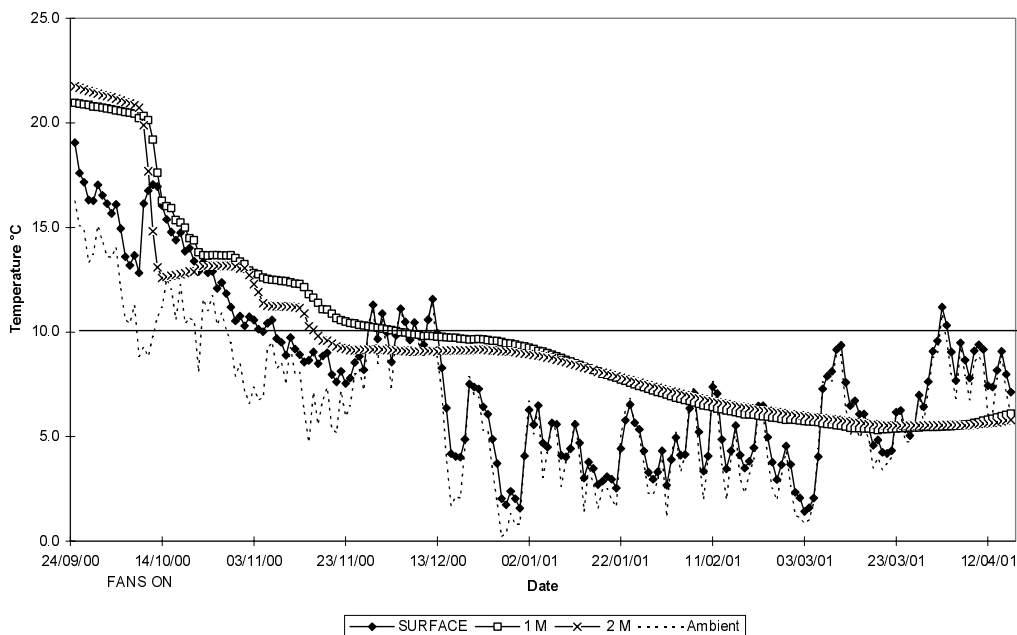


FIG. 1. Mean temperatures during cooling and storage of six bins of malting barley throughout the experiment.

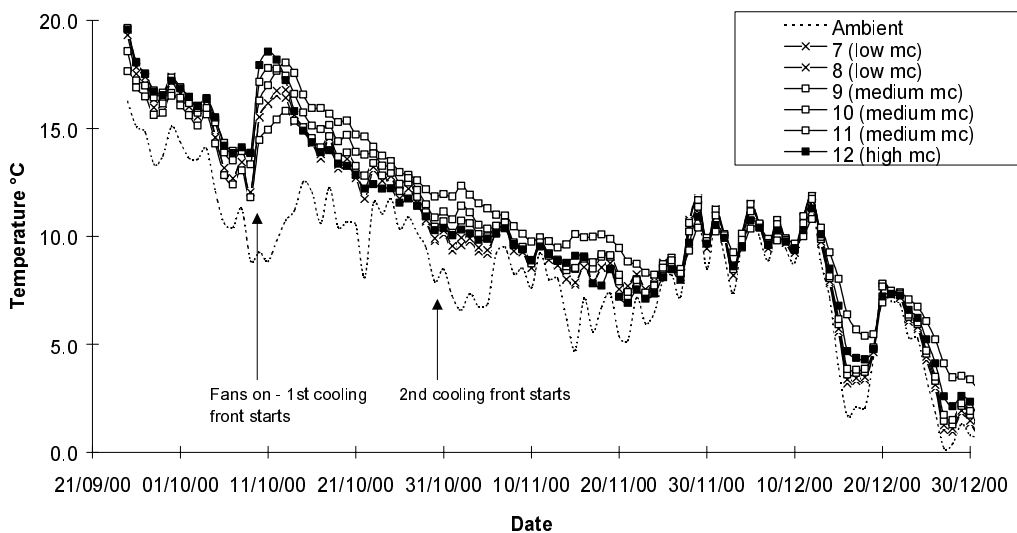


FIG. 2. Mean temperatures during cooling at the surface of six bins of malting barley during the first and second cooling fronts.

tray in a thin layer and dried in a forced draught oven for 8 h at 45°C followed by 16 h at 65°C. The dried malt was derooted before being analysed for key quality parameters. Malts were analysed for malt quality parameters using standard methods of the EBC<sup>1</sup>.

Samples of 200 g from the final assessment were taken from the top, 1 m and 2 m depths and combined to provide an aggregate. In Bin 12, where there were significant differences the surface sample was malted separately. Micro-malting was not carried out for Bin 11 as the germinations therein were too low.

## RESULTS AND DISCUSSION

### Moisture contents

Although the intention was to provide two batches of 20 t at each of three moisture contents, in the event, two batches were around 13.5% moisture content, three were about 15.5% and one was about 16.5% (Table I). (These moisture contents are in equilibrium with relative humidities (rh) of about 58, 69 and 74%<sup>8,11</sup>). For the purposes of this report, they will be referred to as 'low', 'medium' and 'high' moisture content barley. The moisture content of

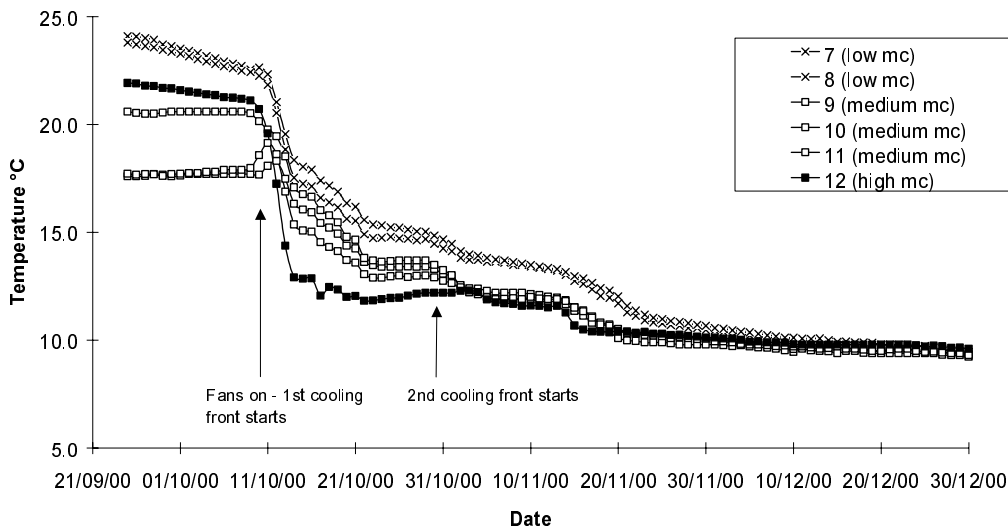


FIG. 3. Mean temperatures during cooling at 1m in six bins of malting barley during the first and second cooling fronts.

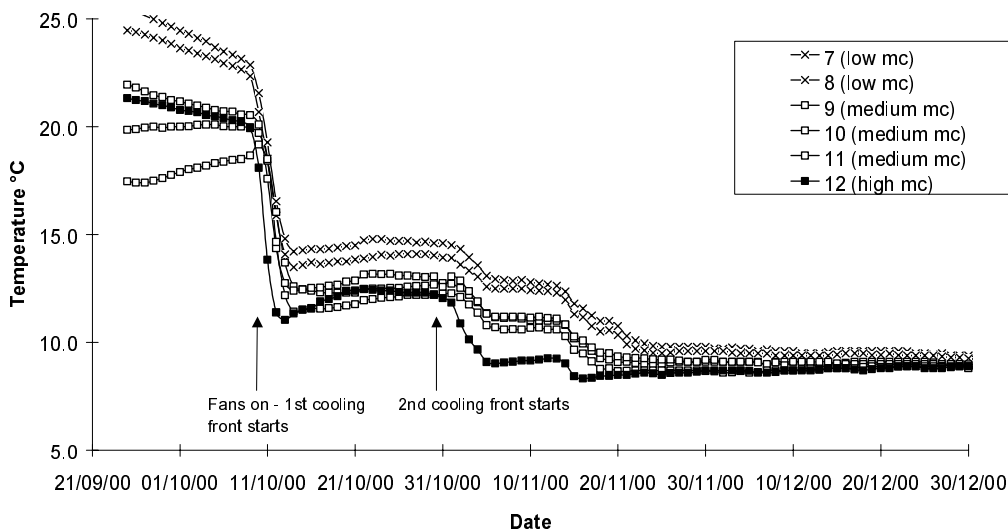


FIG. 4. Mean temperatures during cooling at 2m in six bins of malting barley during the first and second cooling fronts.

individual samples within any one layer usually ranged by no more than +/- 0.15%.

The surface of the barley gained moisture in relation to the initial moisture content and peaked at 13-18 weeks when the low moisture content barley attained 17.5-18.2% moisture content (77-80% rh), the medium moisture content barley was 18.4-18.7% (81-82% rh) and the single high moisture content bin reached 19.4% moisture content (84% rh). By the end of the experiment after 26 weeks, the moisture contents at the surface had declined to 16-16.4% (67-69% rh), 16.9-17.2% (73-73% rh) and 17.6% respectively (75% rh).

At 1m and 2m, the moisture content varied little throughout the experiment. The moisture content of the two 'low' bins varied between 12.4 and 13.5% (43-58% rh) the 'medium' bins were between 14.9 and 15.8% (59-71% rh) and the 'high' bin was between 16.0 and 16.6% moisture content (65-74% rh).

### Aeration and temperatures

The grain started at between 20 and 25°C (Fig. 1) and during aeration fell at a rate dependent on the moisture content, damper grain being cooler, presumably due to evaporative cooling. The grain surface fluctuated in temperature and was close to ambient (Fig. 2) but the 'high' moisture content grain was often over 5°C cooler at 1m (Fig. 3) and 2m (Fig. 4) than the 'low' moisture content bins until cooling was discontinued.

The airflows into the six bins were between 7.2 and 9.6 m<sup>3</sup>/h/t (mean 8.6 m<sup>3</sup>/h/t). The 'high' moisture content grain attained 10°C after 244 h of aeration, the 'medium' moisture content grain achieved this after 279 h and the 'low' moisture content bins did so after 314 h (Fig. 5).

Despite the fans being switched off, the temperatures of all bins continued to fall below 10°C, presumably because of convection facilitated by the uncapped fans, and

reached a minimum of about 6°C in March after about 23 weeks (Fig. 1).

### Mites

Trends in mite population changes were related to moisture content and they thus achieved highest numbers at the grain surface but usually before the moisture content absorption was at its peak. They were commonest in the 'high' moisture content bin and least numerous in the 'low' moisture content bins. *Lepidoglyphus* spp. (Table II) peaked at nearly 8,500/kg after eight weeks in the 'high' moisture content bins and fell to below 600/kg after 26 weeks. In contrast, the peak attained in the 'low' moisture content bins was below 350/kg and numbers fell below 70/kg by the end of the test. At 1m and 2m, numbers in the 'high' moisture content bins declined from over 1,000/kg after four weeks to below 250/kg by the end of the test. By contrast, there were few fluctuations in population at 1m and 2m in the 'low' moisture content bins where there were always fewer than 50/kg. The *Acarus* spp. (Table III)

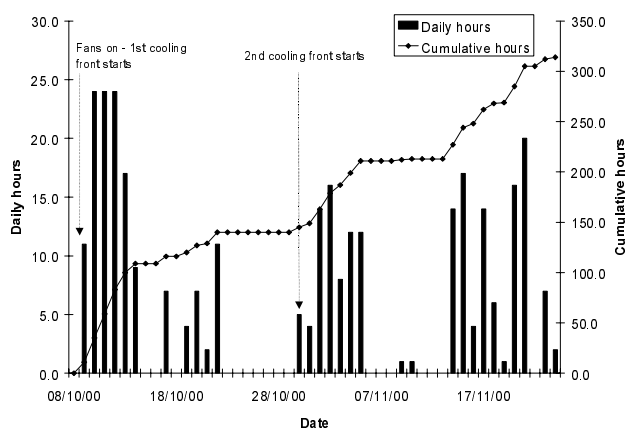


FIG. 5. Daily and cumulative hours of aeration.

TABLE II. Changes in mean numbers/kg of *Lepidoglyphus* in six 20-t bins of malting barley.

Week	Date	Bin 7 Low	Bin 8 Low	Bin 9 Medium	Bin 10 Medium	Bin 11 Medium	Bin 12 High
Surface							
4	7/11	74	245	1743	2738	3269	7935
8	4/12	124	337	3762	3330	7187	8488
13	8/1	91	217	1871	4299	4993	8261
18	12/2	117	235	2384	3652	1985	4105
22	12/3	23	69	1279	1358	1104	2130
26	9/4	27	65	833	674	208	552
1 m							
4	7/11	6	16	443	300	853	1845
8	4/12	10	19	757	220	471	1581
13	8/1	11	36	1597	764	213	1497
18	12/2	25	30	247	240	164	1614
22	12/3	1	7	165	159	133	533
26	9/4	1	3	67	64	82	212
2 m							
4	7/11	6	10	185	47	326	1335
8	4/12	3	5	268	54	222	1275
13	8/1	1	2	181	129	200	1311
18	12/2	14	16	130	35	239	720
22	12/3	1	8	96	38	150	103
26	9/4	0	1	50	8	32	105

generally achieved lower populations than *Lepidoglyphus* in all bins. At the surface of the 'high' moisture content bin, they peaked at over 3,000/kg before falling to below 500/kg at the end of the test. In contrast, their numbers were below 5/kg at all times and at all depths in the 'low' moisture content bins. At 1m and 2m, in the 'high' moisture content bins, numbers of *Acarus* fluctuated between 100 and 1400/kg. The predacious *Cheyletus eruditus* (Table IV) rarely occurred other than in the 'high' moisture content bin, when its numbers were always below 50/kg.

### Insects

There were no apparent differences between bins in the numbers of insects trapped, for instance they were not less numerous in the coolest 'high' moisture content bin. How-

TABLE III. Changes in mean numbers/kg of *Acarus* sp. in six 20-t bins of malting barley.

Week	Date	Bin 7 Low	Bin 8 Low	Bin 9 Medium	Bin 10 Medium	Bin 11 Medium	Bin 12 High
Surface							
4	7/11	1	0	30	15	96	1648
8	4/12	1	0	296	97	673	3108
13	8/1	3	0	941	223	777	1711
18	12/2	2	1	361	501	732	1455
22	12/3	2	0	256	1234	362	1295
26	9/4	0	0	148	336	175	488
1 m							
4	7/11	0	0	23	6	12	277
8	4/12	0	0	55	4	111	557
13	8/1	0	0	76	42	19	265
18	12/2	1	0	68	6	60	1405
22	12/3	0	0	11	10	18	320
26	9/4	0	0	22	17	41	308
2 m							
4	7/11	0	0	0	1	2	443
8	4/12	0	0	48	3	19	767
13	8/1	0	0	47	3	18	402
18	12/2	0	0	90	3	39	617
22	12/3	0	0	8	9	93	100
26	9/4	0	0	7	2	34	734

TABLE IV. Changes in mean numbers/kg of *Cheyletus* sp in six 20-t bins of malting barley.

Week	Date	Bin 7 Low	Bin 8 Low	Bin 9 Medium	Bin 10 Medium	Bin 11 Medium	Bin 12 High
Surface							
4	7/11	0	0	0	0	3	2
8	4/12	0	0	1	0	0	1
13	8/1	0	0	0	0	0	33
18	12/2	0	0	0	0	0	0
22	12/3	0	0	2	3	0	16
26	9/4	0	0	0	0	0	40
1 m							
4	7/11	0	0	0	0	1	7
8	4/12	0	0	0	0	2	19
13	8/1	0	0	0	0	0	8
18	12/2	0	0	8	0	3	9
22	12/3	0	0	0	0	2	5
26	9/4	0	0	0	1	0	27
2 m							
4	7/11	0	0	0	0	9	24
8	4/12	0	0	1	0	0	9
13	8/1	0	0	0	0	0	25
18	12/2	0	0	0	0	0	1
22	12/3	0	0	0	0	2	5
26	9/4	0	0	0	0	0	3

ever, the trends of numbers trapped followed a similar pattern in all bins.

At the surface, *O. surinamensis* (Table V) peaked after five or nine weeks, before declining but numbers trapped there were rarely above ten in five PC traps on each sampling occasion. Numbers of this species trapped in the five

TABLE V. Changes in mean numbers of *O. surinamensis* trapped in six 20-t bins of malting barley during aerated storage.

Week	Date	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
		Low	Low	Medium	Medium	Medium	High
Surface							
0	9/10	1	4	5	7	1	0
1	16/10	5	2	5	4	1	5
5	15/11	16	8	9	23	5	5
9	11/12	9	14	6	3	5	1
14	15/1	1	1	0	2	1	0
19	20/2	0	0	0	1	1	3
23	21/3	1	0	0	1	1	1
27	17/4	0	0	1	2	0	0
1 m							
0	9/10	345	188	265	93	408	689
1	16/10	62	510	96	31	217	568
5	15/11	439	188	147	220	207	153
9	11/12	23	4	2	36	61	11
14	15/1	21	29	15	19	11	8
19	20/2	0	1	1	1	1	7
23	21/3	1	0	0	0	1	0
27	17/4	0	0	1	0	2	0
2 m							
0	9/10	713	1064	34	52	83	439
1	16/10	20	39	51	41	32	185
5	15/11	78	179	100	111	221	132
9	11/12	20	37	22	8	30	14
14	15/1	8	15	3	4	8	8
19	20/2	0	0	1	0	1	2
23	21/3	0	0	2	1	0	1
27	17/4	0	0	0	0	0	1

TABLE VI. Changes in mean numbers of *S. granarius* trapped in six 20-t bins of malting barley during aerated storage.

Week	Date	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
		Low	Low	Medium	Medium	Medium	High
Surface							
0	9/10	23	35	27	39	22	26
1	16/10	9	7	9	12	13	20
5	15/11	12	8	17	11	18	28
9	11/12	11	38	5	19	14	29
14	15/1	3	8	1	0	7	6
19	20/2	8	7	5	6	6	6
23	21/3	1	4	5	3	5	2
27	17/4	0	2	7	3	1	5
1 m							
0	9/10	20	66	32	46	95	80
1	16/10	4	109	46	58	67	64
5	15/11	5	5	15	11	29	15
9	11/12	2	5	3	3	19	7
14	15/1	1	1	0	27	13	6
19	20/2	0	0	1	0	6	8
23	21/3	1	0	0	0	0	1
27	17/4	0	0	0	0	0	0
2 m							
0	9/10	9	39	12	26	29	14
1	16/10	20	18	31	28	13	39
5	15/11	7	11	5	3	5	18
9	11/12	8	5	2	1	17	3
14	15/1	2	1	2	4	5	0
19	20/2	0	0	1	0	2	1
23	21/3	0	0	2	0	1	5
27	17/4	0	0	3	0	0	0

probe traps at 1m and 2m usually exceeded 100 for the first five weeks but after nine weeks, usually only one or two were caught on each sampling occasion. At the end of the test, it occurred in half of the bins at 1m and 2 and two bins at the surface. There were only two bins (7 and 8) where none of these beetles were trapped.

At the surface, numbers of *S. granarius* (Table VI) trapped did not fall noticeably until after the ninth week, when usually less than ten were trapped in each bin. In contrast, the greatest decline at 1 and 2m was between the first and fifth weeks. At the end of the test, it was only detected in one out of six bins beneath the surface but in five out of six at the surface. Only one of these, Bin 7, was free of this beetle at all depths.

Psocid populations (Table VII) behaved similarly to those of mites, in that they were commonest at the surface, peaked when moisture absorption there was also at its highest and declined when the moisture content at the surface also declined. However, their numbers were not so apparently correlated to the moisture content of the barley in the bins. Thus, the highest numbers in excess of 1,000/kg were recorded at the surface of Bin 10, one of the 'medium' moisture content bins. However, peak numbers in Bin 11, another of the 'medium' moisture content bins were below 100/kg and lower than those in the 'low' moisture content bins. At 1m and 2m, psocids declined noticeably between weeks nine and fourteen and usually fewer than 20/kg were present in all bins at the end of the test.

### Germinations

*Viability.* At the start of the trial each of the batches were fully viable, with the exception of the batch in bin 11. This had an initial germinative capacity of 71%, which

TABLE VII. Changes in mean numbers of psocids trapped in six 20-t bins of malting barley during aerated storage.

Week	Date	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
		Low	Low	Medium	Medium	Medium	High
Surface							
0	9/10	4	2	17	4	1	20
1	16/10	0	0	1	2	1	20
5	15/11	39	21	662	1332	29	449
9	11/12	139	196	623	986	64	314
14	15/1	6	8	28	35	13	125
19	20/2	0	2	2	1	0	3
23	21/3	3	6	3	0	3	9
27	17/4	21	7	11	12	9	8
1 m							
0	9/10	53	4	22	21	2	20
1	16/10	4	1	26	20	1	26
5	15/11	5	1	36	50	2	47
9	11/12	11	40	107	23	8	29
14	15/1	12	3	7	5	2	14
19	20/2	6	3	0	1	2	2
23	21/3	9	2	7	4	3	6
27	17/4	9	2	4	6	1	12
2 m							
0	9/10	34	31	31	11	39	31
1	16/10	5	2	14	1	1	22
5	15/11	0	0	31	24	17	23
9	11/12	17	6	11	26	5	18
14	15/1	2	3	3	1	3	5
19	20/2	5	0	1	3	1	5
23	21/3	9	2	7	4	3	6
27	17/4	18	4	5	12	2	5

did not change significantly during the course of the trial (Table VIII).

*Dormancy.* Since the trial did not commence until 2-3 months after harvest, some of the initial dormancy in the crop would have diminished. The germinative energy of both the low and the medium moisture batches (bins 7 & 8 and bins 9 & 10 respectively) was quite high at the start of the trial (Table VIII). However, the drier samples, at 99% germination after three days, would have been acceptable for commercial malting whereas the medium moisture content samples, at 94%, would have been rejected. The rate of germination, however, was slow for both, but especially for the medium moisture content batches in bins 9 and 10. The high moisture content sample in bin 12 still displayed substantial dormancy. These results support commercial experience, which shows that drying of grain generally enhances the recovery from dormancy. The medium moisture content sample in bin 11 also displayed little dormancy, in spite of the poor viability.

*Four weeks storage.* After four weeks storage, when all the grain had been delivered and the experiment started, little change was observed in the low (13.0 – 13.2% moisture content) and medium (15.5 – 15.7% moisture content) batches in bins 7 & 8 and bins 9 & 10. The higher moisture sample (16.4%) in bin 12 showed a high overall germinative energy (95 – 97% after 3 days) but the rate of germination was still slow. There was no evidence of any variation in germination with depth for any of the batches.

*Twenty-four weeks storage.* After 24 weeks storage, the low moisture content samples in bins 7 and 8 showed no trace of residual dormancy (Table VIII). Germination was rapid and even, with more than 96% of the corns chitting after 48 h incubation. There were no significant differences between the two bins, nor between the samples taken at different depths. The medium moisture content samples in bins 9 and 10 also germinated fully after 3 days but were significantly slower than the low moisture content batches, with less than a quarter chitting after 24 h, compared with almost a half in bins 7 and 8. There was some variation between the two bins, with 2m samples from bin 9 being markedly slower to germinate than the other samples, while no such trend was observed with bin 10. This may simply have been due to sample-to-sample variation, or there may have been some differ-

ences in physical conditions between bins 9 and 10. However, if the results are averaged, the overall sample would just come within the germination threshold for commercial malting.

The high moisture content samples from bin 12, although they showed a significant improvement in vigour from December, showed signs of deterioration in the surface layers. Total germination after 3 days had declined to 88%, from 96% in December. The deeper samples would just have come within the germination threshold for commercial malting, but the average of all three samples was lower than the threshold, so the overall sample would have been rejected. The reason why the surface layers, rather than the lower layers, suffered may be due to moisture migration and uptake during the winter.

*Twelve weeks storage.* After seeing the results from 24 weeks storage, it was decided to also test samples taken after 12 weeks (January 2001) and held cold, in order to try and identify when the deterioration of the undried samples had commenced. The low moisture content samples (Bins 7 and 8) had essentially fully recovered from dormancy by 12 weeks of storage (Table VIII), and showed no further change during the remaining 12 weeks of the trial. The medium moisture content samples (Bins 9 and 10) generally germinated faster than in October but slower than after 24 weeks. The surface samples showed poor overall viability, not evident in the 24 week samples, which could not be explained. It was concluded that they had been damaged subsequent to the bins being sampled, and while they had been held at 5°C. The barley in Bin 11 displayed the same poor viability as it did when sampled at four weeks. The high moisture content sample in Bin 12 germinated faster overall than in October but deterioration at the surface layers and loss of viability was already apparent.

### Micro-malting

After 24 weeks storage the barleys had completely recovered from dormancy. With Bins 7, 8, 9 and 10 there were no significant differences between surface, 1 metre, and 2 metre samples in germination characteristics. Samples from each level were therefore mixed together for micromalting. Barley from Bin 11, which had a poor viability from the beginning, was not malted.

TABLE VIII. Effects of moisture content during storage on germination performance (as %).

Time	Location, and moisture content (%)					
	Bin 7 13.0(%)	Bin 8 13.2(%)	Bin 9 15.7(%)	Bin 10 15.5(%)	Bin 11 15.7(%)	Bin 12 16.4(%)
Initial GC	99 %		99 %		71 %	98 %
Initial GE (24, 48, 72 h)	25, 94, 99		14, 78, 94		77	7, 36, 46
<b>4 Weeks</b>						
GE surface	20, 93, 97	23, 98, 100	13, 75, 96	7, 75, 94	19, 71, 78	7, 83, 96
1 m	21, 97, 99	27, 98, 100	10, 72, 94	4, 79, 95	26, 74, 79	6, 82, 95
2 m	25, 95, 98	31, 95, 100	9, 78, 95	10, 82, 95	20, 73, 81	10, 89, 97
<b>12 Weeks</b>						
GE surface	46, 96, 99	43, 98, 99	16, 64, 88	13, 60, 88	10, 62, 70	20, 73, 90
1 m	45, 99, 100	41, 99, 100	21, 83, 95	20, 77, 94	20, 75, 82	23, 91, 96
2 m	44, 96, 98	49, 98, 99	18, 88, 96	17, 85, 97	19, 72, 78	26, 87, 97
<b>24 Weeks</b>						
GE surface	40, 96, 99	48, 97, 98	25, 80, 95	18, 77, 93	24, 73, 81	3, 79, 88
1 m	41, 97, 99	51, 97, 100	24, 87, 97	15, 83, 97	17, 62, 71	25, 90, 96
2 m	43, 96, 99	53, 97, 98	9, 78, 96	23, 90, 98	11, 56, 60	34, 90, 96

TABLE IX. Effects of moisture content during storage on malting quality.

Parameter	Bin 7	Bin 8	Bin 9	Bin 10	Bin 12 (surface)	Bin 12 (depth)
Barley moisture %	13.0	13.2	15.7	15.5	16.4	16.4
Malt moisture %	4.8	4.8	5.0	5.0	5.3	5.2
Hot water extract						
Fine (%)	83.0	82.8	80.9	81.0	81.8	82.0
Coarse (%)	82.2	82.1	80.0	79.8	80.3	81.3
Coarse/fine difference (%)	0.8	0.7	0.9	1.2	1.5	0.7
Colour (EBC)	2.9	2.9	3.1	3.1	3.1	3.1
Total soluble nitrogen (%)	0.48	0.46	0.56	0.55	0.50	0.52
Total nitrogen (%)	1.43	1.38	1.74	1.76	1.53	1.52
Kolbach (%)	34	33	32	31	33	34
Free amino N (%)	0.11	0.11	0.13	0.13	0.12	0.13
pH	6.18	6.19	6.10	6.13	6.13	6.12
Fermentability (%)	72	72	70	70	70	72
Viscosity (mPas)	1.49	1.47	1.48	1.50	1.49	1.48
Diastatic power (°WK)	363	375	405	416	354	378
Friability (%)	92	91	77	79	80	87
Homogeneity (%)	98.5	98.8	93.0	95.1	92.0	97.7

The low moisture content barleys in Bins 7 and 8 gave the best quality malt (Table IX), with the highest yield of extract, the highest friability and the best homogeneity. However, the barley in these bins also had the lowest protein content (approximately 1.4% total nitrogen, compared with 1.75% in bins 9 and 10 and 1.52% in Bin 12). The differences in malt quality between the fully dried barley in bins 7 and 8 and the medium moisture content barley in bins 9 and 10 can be explained almost entirely by this difference in protein content. The higher protein barley would be expected to give malt with a lower yield of extract, a lower Kolbach and a poorer friability, together with a higher soluble nitrogen (TSN) and a higher viscosity. The higher diastatic power of the partially dried barley can also be explained by its higher protein content. However, the difference in friability is probably larger than can be explained by nitrogen alone.

With the high moisture content barley in Bin 12, it is possible to make a direct comparison with malt produced from the surface layer of barley (germination 88% after 3 days) and malt produced from barley taken lower down in the bin (germination 96% after 3 days). It is apparent that malt from the fully viable barley gave a higher yield of extract with a lower coarse/fine difference. (This is the difference in extract obtained from finely ground malt and that from coarsely ground malt, and is a measure of the physical modification of the endosperm. The better modified the endosperm, the lower the coarse/fine difference). The coarse/fine difference from the fully viable barley malt was less than half that of the poor viability barley malt. The poor viability barley also gave malt which was less friable, although the homogeneity, perhaps surprisingly, was almost as high as that of the malts from the fully dried barley. However, bigger differences could well be apparent on the commercial scale.

Mite populations adversely affect the germination of seed<sup>10</sup> and are therefore particularly unwelcome in malting barley. This study indicates that surface populations are inevitable even in dry grain as the moisture content at the surface increases due to moisture translocation and equilibration with damp winter air. However, this effect can be minimised by reducing the bulk moisture content and populations beneath the surface become un-

important. To ensure that no mites occur, even at the surface of bins of dry grain would mean combining the cooling regime with a top-dressing of pesticide. Organophosphorus insecticidal dusts have been found effective<sup>6</sup> but are no longer available for this purpose. However, diatomaceous earths, which require no registration in the UK as they act by physical means<sup>9</sup>, would be an alternative proven to have efficacy under UK conditions<sup>7</sup>. This experiment also indicated that the changes caused by the moisture uptake at the surface of barley bulks stored at higher moisture contents, can be such as to affect the germination and malting qualities sufficiently to render the entire bulk unsuitable for malting. These are powerful arguments for storing the grain at lower moisture contents.

#### ACKNOWLEDGEMENTS

The study was carried out with financial support from DEFRA and the Commission of the European Communities, Agriculture and Fisheries (FAIR) programme.

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(Manuscript accepted for publication April 2002)