HGCA

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EVALUATION AND DEVELOPMENT OF SYSTEMS FOR STORING MALTING BARLEY

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EVALUATION AND DEVELOPMENT OF SYSTEMS FOR STORING MALTING BARLEY

by

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Final report of a four year project at the Brewing Research Foundation, Lyttel Hall, Nutfield, Redhill, Surrey, RH1 4HY. The work commenced in May, 1987 and was supported by a grant of £137,564 from the Home-Grown Cereals Authority (Project No. 0030/2/87).

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SUMMARY

1. Dormant barley samples showed poor germination performance and only slow recovery from dormancy when stored at low temperatures. Dried barleys (12% moisture) showed better rates of recovery from dormancy than undried samples (16% moisture) at all the storage temperatures investigated, but were still much slower to recover than were controls stored at 16°C.

2. Although water sensitivity was less affected by low temperature storage conditions than was Germinative Energy, virtually all the samples examined showed marked water sensitivity after 6 months storage at a range of temperatures between 2° and 10°C.

3. Barleys which had fully recovered from dormancy could be stored at low temperatures for as long as 5 months without any deleterious effects on germination.

4. Storage in atmospheres with relatively high nitrogen levels and low oxygen levels had no deleterious effects on germination or final malt quality. Grain stored in atmospheres with a high proportion of carbon dioxide recovered from dormancy somewhat slower than did grain stored in nitrogen or air, but final malt quality was unaffected.

5. Levels of N-dimethylamine (NDMA) in malt were unaffected by storing the barley in propane burner emission gases.

Low temperature storage is not likely to be suitable for UK barleys which show any signs of dormancy. It could, however, be useful for mature grain which has fully recovered from dormancy.

Malting barley can be stored in low oxygen atmospheres for the two months required to eliminate insect infestation without detrimental effects on germination performance or recovery from dormancy. Extension of the storage period under low oxygen to six months caused no deleterious effects.

Storage in low oxygen atmospheres can be used to reduce or eliminate the use of pesticides or fumigants in malting barley.

OBJECTIVES

To determine whether new methods of storage incorporating low temperatures and/or low oxygen atmospheres are suitable for storing malting barley.

To establish practical conditions suitable for storing British malting barley.

INTRODUCTION

It is necessary to maintain the viability and vigour of malting barley during storage and also to encourage and enhance its natural recovery from dormancy, a phenomenon associated with freshly-harvested seeds.

In order to keep infestation by mites, insects and fungi to a minimum, malting barley is normally dried to around 12% moisture, and chemicals may be added to the grain in silo. These may be applied as fumigants, which are very toxic chemicals, requiring specialist handling. Fumigants tend only to be added to grain in this country when an infestation has occurred. Alternatively, pesticides may be added to the grain as a prophylactic measure. Both these methods, however, may leave residues in the grain.

Alternative methods which have been proposed for preventing infestation during the long-term storage of malting barley include storage at low temperatures or in atmospheres low in oxygen.

Low temperature storage lowers the relative humidity of the interstitial spaces between the grains. This would imply, therefore, that the need for drying would be reduced. Cooling effectively prevents the spread of mites and insects, since low relative humidity limits proliferation of these organisms. The method is, though, less effective against fungi.

By storing grain in low oxygen atmospheres adult and larval stages of insects and mites can be destroyed by denying them sufficient oxygen for the maintenance of life. This storage strategy does not actively destroy insect and mite eggs, but destroys the larval and adult stages upon emergence. In the normal climatic conditions of the UK an exposure time of 8 weeks is sufficient to ensure that all eggs hatch into larvae, which are then destroyed by low oxygen atmospheres.

Such atmospheres also exert a fungistatic effect, although they do not destroy fungal spores.

MATERIALS AND METHODS

1. Selection of Barley

Details of the barley samples used in this work are given in Table 1.

2. Moisture Measurement and Germination Tests

At intake, all barley samples were cleaned and screened to ensure a grain size >2.2mm. Samples of grain (approximately 10g) were homogenised in a coffee mill and their moisture levels were determined using an infra-red top pan balance. When appropriate, barleys were dried to the desired moisture content at 35°C in the Brewing Research Foundation's pilot kiln. Germination performance, in terms of viability, dormancy and water sensitivity, of grain prior to and during storage was monitored by the methods recommended by the Institute of Brewing (IOB). Germinative Capacity (GC; the number of grains which are alive, i.e., viability) was determined from the percentage of grains which had germinated after immersion for three days in 0.75% (v/v) hydrogen peroxide, the peroxide solution being changed after the second day. Germinative Energy (GE; the number of grains which germinate given optimum water, temperature and oxygen, i.e., lack of dormancy) of grain was calculated from the percentage of grains which had germinated following a three day incubation at 16°C in a 9cm petri dish containing two Whatman No 1 filter papers moistened with 4ml water. Water sensitivity (the number of grains which will germinate if oxygen is limited) was monitored in the same way but using 8ml water to soak the filter paper.

In all the samples used in this study there was no decrease in viability during any of the trials.

3. Micromalting and Malt Analysis

Barley samples were malted by employing a standard malting regime, as outlined in Table 2 and the resultant malts were analysed by the methods recommended by the IOB. Measurement of NDMA was by a gas chromatograph linked to a thermal energy analyser. Barleys from the 1989 harvest stored in propane burner emissions were malted using two different regimes, the standard one as above, and a less aerobic regime of 8h wet, 16h air rest, 24h wet (see Table 3). This was to investigate the effect of more aerobic or less aerobic steeps on grain stored in atmospheres containing NO_x.

4. Storage Regimes

4.1 Cool Storage

Grain was stored at 12% moisture, the level recommended for storing malting barley, and at 16% moisture.Barleys delivered at >16% moisture were dried to the required moisture level as described in section 3.2.

1987 Harvest

Samples were stored at 2°C, 4°C, 10°C and 16°C. Storage at

4°C was selected for subsequent low temperature work because minimal differences were observed between barleys held at 2°C and 4°C. Other barley samples, English and Scottish Halcyon and Triumph, were stored at ambient temperatures from August to December 1987 at both moisture levels. The temperature range fell from 18-27°C to 0-5°C over this period and simulated approximately the practice of commercial maltsters, some of whom cool large grain bulks by using night-time air during the late autumn months.

1988 Harvest

English Halcyon, Scottish Magie and both English and Scottish Triumph were used. These were stored undried at 4°C and were withdrawn and conditioned at monthly intervals for germination assessments.

Magie and Natasha samples from the 1988 harvest were also stored at 4°C after they had recovered from dormancy.

1989 Harvest

Triumph and Doublet were used for cold storage trials. Triumph was stored at 4°C, either dried (12% moisture) or undried (16% moisture). Another sample was held at 35°C for three weeks in still air to condition after drying and prior to cold storage. A fourth sample of the same barley was dried at 35°C and then allowed to recover naturally from dormancy by storing at 16°C until such time as its GE was greater than 95%. The barley was then transferred and its germinative performance assessed each month.

A 10kg sample of Doublet, harvested at approximately 12% moisture, was stored at 4°C. A further 10kg of Doublet was conditioned as described above for the Triumph prior to cold storage.

4.2 Low Oxygen Atmosphere Storage

Samples (10-20kg) of English and dormant Scottish Triumph from the 1987 harvest, both at 16% moisture, were stored by MAFF Central Science Laboratories (CSL) at 21-24°C. They were sealed in containers atmospheres simulating propane burner emissions: 86% nitrogen, 13% carbon dioxide and 1% oxygen. Controls for the experiment were stored at the same temperatures but in air. All were stored for eight weeks.

Samples of English Halcyon, Scottish and English Magie, Scottish Triumph and English Natasha and Finesse were selected from the 1988 harvest for storage in simulated burner emissions, again for eight weeks. All samples had moisture contents of 15 - 16%.

Both Doublet (harvested at 12% moisture) and Triumph (dried, 12%, and undried, 16% moisture) from the 1989 harvest were stored at CSL in burner emissions to monitor for any effect on germinative performance or on levels of NDMA.

A one tonne batch of Triumph barley from the 1990 harvest, dried to approximately 11% moisture (Table 1), was also stored at CSL in propane burner emissions for eight weeks at ambient temperatures. The control one tonne batch of grain was stored under a normal atmosphere. Samples were taken from the top, middle and bottom of both containers every four weeks and germinative performance and quality of small scale malts was recorded. Following six months storage, 150kg of control and trial grain were bagged and taken to the Brewing Research Foundation (BRF) for pilot scale malting and brewing. Fifty kilogrammes of each were processed to produce a lager malt (Appendix 1) of which 18kg were used to prepare duplicate samples of lager (Appendix 2).

The Triumph barleys from 1987 and English Magie and Triumph from 1988 harvests were also stored in pure nitrogen and pure carbon dioxide for two months. Additionally, English Halcyon and Scottish Magie were stored for six months in similar pure gas atmospheres. In each case, sample sizes were smaller than in simulated or burner emission storage, with only about 2kg of each barley being used. These were stored at the BRF in closed glass jars. Gas concentrations were checked regularly with Drager tubes and 'topped up' where necessary. Control samples were maintained in similar conditions in air. All samples were held at 10°C.

RESULTS

1 Cool Storage

There was no decrease in grain viability for any of the samples used in cool storage trials. Table 4 shows the GE of four barley samples stored, dried and undried, at 4°C. Very similar results were obtained with barley samples stored at 2°C. The germination patterns of the four barley samples showed significant differences. The Scottish barley samples showed low initial GE values and, whilst these increased over the six months of the trial, they remained below those of the controls, particularly Triumph. The English samples showed higher initial germination but there was no significant change in GE during the four months storage. After four months, all samples, except for the Scottish Triumph, showed a GE of >78%. All these barleys were then transferred to storage at 16°C. The GE of the Scottish Triumph rapidly improved but improvements in other samples were inconsistent.

Dried barley (12% moisture) showed better germinative performance than did undried samples. After four months, three out of the four barleys had GE values of over 88%. Differences between the germination performance of dried and undried samples continued after transfer to 16°C. After five weeks at 16°C, the GE of dried grains was approximately 10% greater than for undried samples. None of the undried grain samples attained a sufficiently high germination to be considered for malting in normal commercial circumstances, even after transferring to 16°C for seven weeks.

The malting quality of these stored samples also reflected their germination performance. Only after conditioning at 35°C did most samples give analyses which would make them acceptable for brewing (Table 5). Halcyon stored undried was still unsuitable for brewing, even after conditioning. Controls stored at 16°C for six months (Table 6) recovered from dormancy but only samples stored dried were acceptable for malting after this period.

Samples from the 1988 harvest were used to determine whether malting barley could be stored undried at low temperature, but still have acceptable GE values after conditioning. English Halcyon and Triumph and Scottish Magie and Triumph, all at 16% moisture, were stored at 4°C for periods of up to six months. Sub-samples were withdrawn from the bulk periodically and conditioned at 35°C (Figures 1 and 2). Dormancy remained high in all the samples but an acceptable GE value was obtained for English Halcyon and Scottish Magie, even after six months storage at 4°C (Figure 1). With both Triumph samples, however, conditioning could not restore full germination at any stage during storage and there was a tendency towards higher residual dormancy after longer periods of storage
(Figure 2).

As the data in Table 7 shows, control samples of these barley samples dried after harvest and stored at 16°C for six months showed full recovery from dormancy. There was no need for conditioning and no loss of vigour even in the Triumph samples.

When samples of the varieties Natasha and Magie from the 1988 harvest were first conditioned (20°C for two months, to break dormancy) and subsequently stored at 4°C, there was no observable decrease in their GE values, even after five months under these conditions (Table 8).

These trials were also extended to cover samples from the 1989 harvest. Figure 3 shows results from storing different samples of Triumph at 4°C for up to ten months. The undried (16% moisture) barley slowly recovered from dormancy but was still unsuitable for malting at the end of the trial. A dried sample recovered from dormancy more quickly and had a GE value of 94% after ten months' storage. As found from the previous harvest (Table 8), if the barley was allowed to recover from dormancy naturally, it could be stored at 4°C for an extended period without any deleterious effects on germination. Similarly, if the undried barley was removed from storage, dried and conditioned or the dried sample removed and conditioned, there were no adverse effects on GE values (which were >95%) during 10 months storage at 4°C. Due to the unusually dry pre-harvest weather in 1989 the undried sample of Doublet arrived at

12% moisture. As may be seen from Figure 4, storage of this barley, or a conditioned sample of this barley, at 4°C had no deleterious effects on GE values, over a nine month period.

2. Low Oxygen Atmosphere Storage

2.1 Pure Gas Storage

Grain viability was unaffected for all samples used in these trials. Table 9 shows the GE values for two samples of 1987 Triumph barley which were both very dormant initially. Both were stored under nitrogen, carbon dioxide or air at ambient temperatures. All samples recovered from dormancy at similar rates but not sufficiently for them to be considered for malting. Even following their transfer into air for up to eight weeks at 16°C the GE values were still too low for malting. There were, however, no significant differences between the rates of recovery from dormancy for each of the three treatments. When each sample was conditioned, malted and the malt analysed there were no observable differences in quality between the three treatments. Results presented in Table 10 are for the sample of Scottish Triumph and very similar data were obtained for the English sample (results not shown). Even though the GE values after conditioning were still slightly lower than may have been commercially acceptable (>95%) the resultant malts would have been suitable for brewing.

A subsequent trial, using English Halcyon and Scottish Magie from the 1988 harvest, showed that undried grain of these varieties recovered from dormancy to virtually acceptable GE values in six months (Table 11). Storage in carbon dioxide, however, delayed the recovery from dormancy in the first 3 months but GE values were comparable in all three atmospheres at the termination of the trial. The low germination recorded for the Halcyon stored in air was due to a severe mite infection, highlighting the problems that may arise under normal storage conditions. Apart from this infested sample, the malting quality of these barley samples was unaffected by storage in pure nitrogen or carbon dioxide, and all the malts were acceptable for brewing as found for the previous year's crop (Table 10).

2.2 Modified Atmosphere Storage

2.2.1 Small Scale Storage

a) Simulated atmosphere

No loss in viability was observed for any of the barley samples used in this part of the project. Samples of Triumph barley from the 1987 harvest were stored in simulated propane burner gas emissions at 24°C on the CSL site, with control samples of the same barleys stored in air at the same temperature. There was a rapid recovery from dormancy for both treated and control samples, probably due to the relatively high temperature (Table 12). Although germination was not sufficiently high for malting after the two months storage no deleterious effects of the low oxygen atmosphere were discernible.

All samples were stored for a futher period in air. Although the final germination achieved from these initially very dormant samples was still lower than would be required in commercial practice, there were no differences between treated and control samples.

Malts were prepared from samples of barley A (final germination 95% for both treated and control samples). Malt analyses are given in Table 13, and show no significant differences between the treated or control samples.

It was noted that these barley samples stored for an extended period (up to six months) showed some loss of germination performance, for both control and treated samples. This is thought to be due to the storage at 24°C, since warm temperatures will accelerate deterioration of embryo vigour as well as initial recovery from dormancy.

The trials were extended to include six samples of barley from the 1988 harvest (Table 14). Again there was little difference in GE values for grain stored under low oxygen atmospheres compared to controls held in air. Recovery from dormancy within two months was also enhanced by a storage temperature of 22°C. Acceptable GE values, either at the end of the two month storage or following conditioning, indicated that modified, low oxygen atmosphere storage did not reduce the germination performance for this range of barley varieties. Malting quality was also unaffected by storage conditions as may be seen from the results in Table 15. Only data for Magie (1) and Natasha are shown but the other varieties showed similar lack of difference between treated and control samples for most analytical parameters.

b) Burner atmosphere

In year three of the initial project two barley varieties, Doublet and Triumph, were stored for two months under an actual, rather than simulated, propane burner emission gas atmosphere. The Triumph sample was stored dried and undried but, because of the unusually hot summer in 1989, the Doublet was stored 'dried' at its intake moisture of 12.4% (Table 1). As was observed in previous years, there were no adverse effects on trial samples, either in terms of recovery from dormancy or GE (Table 16). Malt analyses for control samples were not significantly different from those found for treated samples (Table 17).

The detection of low levels of NO_x gases in the propane burner emissions prompted the measurement of NDMA in final malts prepared from these samples. The formation of NDMA during kilning is dependent upon the concentration of free amines in the grain, and these in turn can be influenced by the amount of aeration during steeping and germination. Malts were therefore prepared using two different steeping schedules, one of which (Table 2) was more aerobic than the other (Table 3).

The results given in Table 18 demonstrate that although levels of NDMA were generally higher in those malts prepared by the more aerobic regime, there were no consistent differences between malts from treated and control barleys. The highest level of NDMA found was in a control malt and was below the recommended guideline for malt (5ppb).

2.2.2 Large Scale Storage

In 1990 the project was extended to investigate if storage under propane burner emission gas had any effect on larger batches of grain. Triumph barley, which had been dried to 10-11% moisture and had fully recovered from dormancy, was stored at CSL in one tonne lots in plastic bins. Over the six month trial no significant differences were observed between control and trial barleys in terms of germinative performance or malt quality. At the end of the trial the two batches were pilot malted and brewed, data for malt analysis being presented in Table 19 and for beer analysis in Table 20. The only observable difference between control and trial results was the slight increase in grainy flavour on the beer brewed from trial malt. This was probably due to the increased root growth during the malting of the trial barley and was not an effect of storing under a low oxygen atmosphere.

DISCUSSION

1 Cool Storage

Storage of freshly-harvested barley at low temperatures (2-10°C) prolongs the period necessary for grain to recover from dormancy and may lead to germination being permanently impaired. When barleys were dried down to 12% moisture prior to storage at low temperatures they recovered from dormancy more quickly than did undried samples, but, in some cases, still showed GE values which made them unsuitable for commercial malting. If stored for long enough they may show sufficient recovery from dormancy but this may be accelerated by transferring grain to ambient temperatures or by conditioning. Barley samples which had fully recovered from dormancy (either by warm conditioning or by storage at ambient temperatures) appeared to exhibit no deleterious effects on germination or malting quality when subsequently stored at low temperature.

2 Low Oxygen Atmosphere Storage

2.1 Pure Gas Storage

Atmospheres high in nitrogen have shown no detectable effects on recovery from dormancy, germination performance or subsequent malt quality. Barley grains stored in pure carbon dioxide did tend to recover more slowly from dormancy, compared with controls stored in air or trials stored in nitrogen, but the effect was small and no permanent effects on germination or malt quality could be detected. Recovery from dormancy was enhanced by storing at higher temperatures, for example 22°C.

2.2 Modified Atmosphere Storage

Storage of barleys in atmospheres which simulated the emission gas of a propane burner (86% nitrogen; 13% carbon dioxide; <1% oxygen) had no adverse effect on their recovery from dormancy, germination performance or malt quality. Similarly, storing barley samples in an atmosphere generated by an actual propane burner for two months also had no deleterious effect on these parameters.

For the small scale modified atmosphere trials, all barley samples were stored undried (15-17% moisture) and no deterioration due to this high moisture content was observed, in either controls or grain stored under inert atmospheres. This is probably due to the relatively small scale of the trials and the absence of fungal pathogens. It is not therefore possible, on the basis of these trials, to assume that high moisture barleys could be satisfactorily stored in inert atmospheres under commercial conditions.

The use of specially modified propane burners to provide low oxygen atmospheres for barley storage has also been examined on a larger scale, using one tonne batch sizes. No differences between treated and control were noted suggesting that there are no adverse effects from low oxygen atmospheres when malting barley is stored in bulk. For uptake by the industry, further investigations on larger, commercial scale silos will be necessary.

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Table 1: Barley varieties used to monitor storage conditions, their area of harvest and intake moistures

Moisture levels were determined as described in Material and Methods

Harvest Year	Harvest Area	Variety	Moisture at intake (%)
1987	England	Halcyon (2) Triumph (2)	15.4 15.0; 14.5
	Scotland	Halcyon Triumph (2)	15.2 14.5; 15.3
1988	England	Halcyon Triumph (2) Natasha Finesse Magie	18.0 15.0; 16.0 16.4 15.9 14.6
	Scotland	Triumph Magie	19.3 17.3
1989	England Scotland	Doublet Triumph	12.4 18.2
1990	England	Triumph	11.2

Table 2: Standard micro-malting regime used at the Brewing Research Foundation

Resultant malts were analysed by the methods recommended by the Institute of Brewing.

Sample Size	-	350g
Barley germinative energy	-	>95%
Steeping	-	16°C
	-	7 hours wet
	-	17 hours air rest
	-	7 hours wet
	-	17 hours air rest
	-	1 hour wet
Typical moisture at casting	-	46% (w/w)
Germination	-	4 days at 16°C
Drying	-	8 hours at 45°C
	-	16 hours at 65°C
Typical moisture of final malt	-	5%

Table 3: Alternative, less aerobic micro-malting regime used at the Brewing Research Foundation

Malts were analysed as outlined in Table 2.

Sample Size	-	350g
Barley Germinative Energy	-	>95%
Steeping	-	16°C
	-	8 hours wet
	-	16 hours air rest
	-	24 hours wet
Typical Moisture at Casting	-	45% (w/w)
Germination	-	4 days at 16°C
Drying	-	8 hours at 45°C
	-	16 hours at 65°C
Typical moisture of final malt	-	5% w/w

Table 4: Germination performance of barleys stored at 4°C. 1987 harvest

Germinative energy was determined from 4ml plates as described in Materials and Methods.

Time from Harvest	Germinative Energy (%)							
	Scottish Halcyon		Scottish Triumph		English Halcyon		English Triumph	
	A	B	A	B	A	B	A	B
0	53	6	24	35	85	95	82	81
1 month	56	74	18	30	79	87	80	90
3 months	77	91	54	52	77	92	82	82
4 months	78	93	44	52	78	90	87	88
Transferred to 16°C								
+ 2 weeks	75	93	45	58	91	96	89	95
+ 4 weeks	84	92	55	76	91	98	90	94
+ 5 weeks	78	91	73	81	84	96	85	91
+ 7 weeks	84	93	69	89	91	97	89	97
Control (dried and stored at 16° for 3 months)		97		91		96		97
6 months at 4°C	83	95	53	68	72	94	84	92

A = 15-16% moisture

B = 11-12% moisture

Table 5: Malt analyses from barley stored at 4°C. 1987 harvest

Barleys were stored as outlined in Table 4, conditioned at 35°C to give 95% Germinative Energy when necessary and malted as described in Table 2. Subsequent malts were mashed and analysed by methods recommended by the Institute of Brewing.

Parameter	Scottish Halcyon		Scottish Triumph		English Halcyon		English Triumph	
	A	B	A	B	A	B	A	B
HWE_2 (L°/kg)	301	310	313	313	295	310	309	307
HWE_7 (L°/kg)	278	309	307	312	267	306	301	304
TSN (%)	0.46	0.69	0.61	0.67	0.38	0.72	0.62	0.66
FAN (mg/L)	110	220	180	180	80	180	180	180
Fermentability (%)	-	79	76	78	-	76	74	76
Viscosity (cP)	2.1	1.53	1.54	1.63	2.21	1.48	1.6	1.45
Friability (%)	40	88	86	85	31	89	71	81

A = 15-16% moisture

B = 11-12% moisture

Table 6: Germination performance of barleys stored at 16°C. 1987 harvest

Percentage germinative energy was calculated as described for Table 4.

	Germinative Energy (%)							
Time from Harvest	Scottish Halcyon		Scottish Triumph		English Halcyon		English Triumph	
	A	B	A	B	A	B	A	B
0	53	67	24	35	85	95	82	81
1 month	66	92	31	40	90	96	88	91
3 months	93	97	79	92	96	96	97	97
4 months	91	91	82	91	95	95	94	91
6 months	91	98	85	98	88	95	95	97

A = 15-16% moisture

B = 11-12% moisture

Table 7: Germination performance of control barleys. 1988 harvest

Samples were dried at intake and stored at 16°C for six months. GE values were determined as described for Table 4.

	Germinative Energy (%)	
Barley Variety	After drying	After 6 months at 16°C
English Halcyon	57	100
Scottish Magie	64	98
English Triumph	16	99
Scottish Triumph	18	98

Table 8: Germination performance of barleys stored at 4°C after recovering from dormancy. 1988 harvest

Samples were conditioned at 20°C for two months prior to storage and GE values calculated as for Table 4.

Barley Variety	Germinative Energy (%) Storage Time (months) 0	2.5	5
English Natasha	100	100	100
English Magie	97	97	97
Scottish Magie	95	97	97

Table 9: Germination performance of barleys stored in pure gas. 1987 harvest

Samples were stored at ambient temperature, under the specified atmosphere, for two months and then transferred into air at 16°C for up to eight weeks.

	Germinative Energy (%)					
Storage Conditions	N_2		CO_2		Air (Control)	
Time from Harvest	A	B	A	B	A	B
0	6	10	6	10	6	10
2 months	43	28	34	33	41	41
4 months	59	38	44	35	63	42
Transferred to normal atmosphere at 16°C						
+ 4 weeks	64	54	50	47	67	44
+ 8 weeks	85	69	53	71	74	57

A = Scottish Triumph, 16% H_2O

B = English Triumph, 16% H_2O

Table 10: Malt analyses from barley stored in pure gas. 1987 harvest

Barleys from each atmosphere were malted as described in Table 2 and mashed and analysed by methods recommended by the Institute of Brewing.

	Storage Conditions		
Parameter	N_2	CO_2	Air (Control)
HWE_2 (L°/kg)	312	311	313
HWE_7 (L°/kg)	308	308	309
TSN (%)	0.59	0.58	0.61
FAN (mg/L)	160	160	161
Fermentability (%)	75	75	76
Viscosity (cP)	1.65	1.56	1.54
Friability (%)	74	77	77
Germination (4 months, specific atmosphere)	59	44	63
Germination (prior to malting)	94	92	91

Table 11: Germination performance of barleys stored in pure gas. 1988 harvest

Samples were stored under the specified atmospheres for six months and GE values calculated as outlined for Table 4.

	Germinative Energy (%)					
Barley Variety	English Halcyon			Scottish Magie		
	Storage Conditions					
Time from	N_2	CO_2	Air (Control)	N_2	CO_2	Air (Control)
0	24	24	24	22	22	22
2 months	48	44	45	58	51	51
3 months	65	48	59	70	56	70
4 months	79	77	80	88	71	87
5 months	91	84	91	89	85	96
6 months	97	94	87*	97	94	96

*mite infestation

Table 12: **Germination performance of barleys stored under a modified atmosphere. 1987 harvest**

Barleys were stored under a simulated burner gas atmosphere or under air at ADAS for 2 months. They were then transferred to ambient conditions for a further two and one half months followed by another four weeks, at 16°C. GE values were determined as described for Table 4.

	Germinative Energy (%)			
Time from Harvest	Low-oxygen Storage (24°C)		Control (24°C)	
	A	B	A	B
0	6	10	6	10
2 months	88	80	85	78
Transferred to normal atmosphere and ambient temperature for 2.5 months				
4.5 months	93	78	86	83
Transferred to 16°C for 1 month				
5.5 months	92	84	92	87

Table 13: Malt analyses from barley stored under a modified atmosphere. 1987 harvest

Treated and control samples were conditioned and malted, mashed and analysed as outlined for Table 10.

Parameter	Storage Conditions: Treated	Storage Conditions: Control
HWE_2 (L°/kg)	312	312
HWE_7 (L°/kg)	308	310
TSN (%)	0.63	0.64
FAN (mg/L)	160	160
Fermentability (%)	75	76
Viscosity (cP)	1.57	1.52
Friability (%)	77	82
Germination (2 months, specific atmosphere)	88	85
Germination (prior to malting)	95	95

Table 14: Germination performance of barleys stored under a modified atmosphere. 1988 harvest

Samples were stored and GE values calculated essentially as described for Table 12.

	Germinative Energy (%)				
Treatment	None (intake)	2 months storage		2 months storage + conditioning	
Barley Variety	-	Treated	Control	Treated	Control
Halcyon	24	93	94	95	97
Magie (1)	22	96	95	-	-
Magie (2)	83	97	97	-	-
Triumph	20	74	84	96	97
Natasha	81	99	100	-	-
Finesse	35	69	79	99	97

Table 15: Malt analyses from barley stored under a modified atmosphere. 1988 harvest

Procedure was as outlined for Table 13.

Barley Variety	Magie(1)		Natasha	
	Storage Conditions			
Parameter	Treated	Control	Treated	Control
HWE_2 (L°/kg)	315	311	317	316
HWE_7 (L°/kg)	312	307	312	314
TSN (%)	0.57	0.55	0.57	0.58
FAN (mg/L)	126	121	131	130
Fermentability (%)	76	76	76	76
Viscosity (cP)	1.58	1.58	1.51	1.53
Friability (%)	68	69	79	79

Table 16: Germination performance of barleys stored in propane burner emissions. 1989 harvest

Samples were stored under actual burner gas and analysed as described for Table 4.

	Germinative Energy (%)		
Treatment	None (intake)	2 months storage	
Barley Variety	-	Treated	Control
Doublet	97	97	97
Triumph (undried)	47	90*	100
Triumph (dried)	52	99	100

* GE value = 98% after conditioning.

Table 17: Malt analyses from Doublet barley stored in propane burner emissions. 1989 harvest

Procedure was as outlined for Table 13.

	Storage Conditions	
Parameter	Treated	Control
HWE_2 (L°/kg)	302	300
HWE_7 (L°/kg)	295	292
TSN (%)	0.54	0.66
FAN (mg/L)	121	129
Fermentability(%)	70	69
Viscosity (cP)	1.6	1.55
Friability (%)	75	67

Table 18: Levels of NDMA in malts prepared from barleys stored in propane burner emissions. 1989 harvest

Malts were prepared using a standard (Table 2) and an alternative (Table 3) malting regime and NDMA analysed as described in Materials and Methods.

		NDMA (ppb)	
Barley Variety	Malting Regime	Treatment	Control
Doublet	A	1.7	0.9
	B	<0.5	<0.5
Triumph (dried)	A	<0.5	2.1
	B	<0.5	<0.5
Triumph (undried)	A	1.7	1.7
	B	<0.5	<0.5

Table 19: **Malt analyses from Triumph barley stored in propane burner emissions. 1990 harvest**

Barley was malted as outlined in Appendix 1 and analysed as for Table 5.

	Storage Conditions	
Parameter	Treated	Control
HWE_2 (L°/kg)	313	314
HWE_7 (L°/kg)	312	311
TSN (%)	0.78	0.79
FAN (mg/L)	170	173
Fermentability (%)	75	74
Viscosity (cP)	1.52	1.53
Friability (%)	89	86

Table 20: **Analysis of Lyttel Hall Premium Lager made from barley stored in propane burner emissions. 1990 harvest**

Malt was prepared as described in Appendix 1 and brewing parameters were as outlined in Appendix 2. Analysis was by the recommended methods of the Institute of Brewing.

	Storage Conditions	
Parameter	Treated	Control
pH	4.27	4.27
Colour (°EBC)	3.7	3.8
Head retention (s)	91	90
Bitterness (BU)	25.8	25.2
TSN (mg/L)	544	534
FAN (mg/L)	69.5	67.9
Ethanol (mg/L)	5.4	5.4

Figure Legends

Figure 1: Germination performance of barley stored at 4°C, 1988 harvest.
English Halcyon (□——□) and Scottish Magie (△—△) were stored undried. Subsamples of each were taken and conditioned at 35°C (○——○, Halcyon; ▽—▽, Magie). GE values were measured as described in Materials and Methods. Acceptability for malting (.....) is 95% GE.

Figure 2: Germination performance of barley stored at 4°C. 1988 harvest.
Triumph barley from England (□——□) and Scotland (△——△) was stored undried. Subsamples of each were taken and conditioned at 35°C (○—○, English; ▽——▽, Scottish). GE values were measured as outlined in Figure 1.

Figure 3: Germination performance of barley stored at 4°C. 1989 harvest.
Triumph barley was stored undried (□——□) and dried (△——△) and GE values measured as described for Figure 1. Samples were also conditioned (▽——▽) or allowed to recover naturally from dormancy (○——○) and GE values monitored.

Figure 4: Germination performance of barley stored at 4°C. 1989 harvest.
Doublet barley (12.4% H_2O) was stored undried (□——□) or after conditioning (○——○) and GE values monitored as outlined for Figure 1.

Figure 1: Germination performance of barley stored at 4°C. Halcyon & Magie, 1988 harvest. Effect of conditioning.

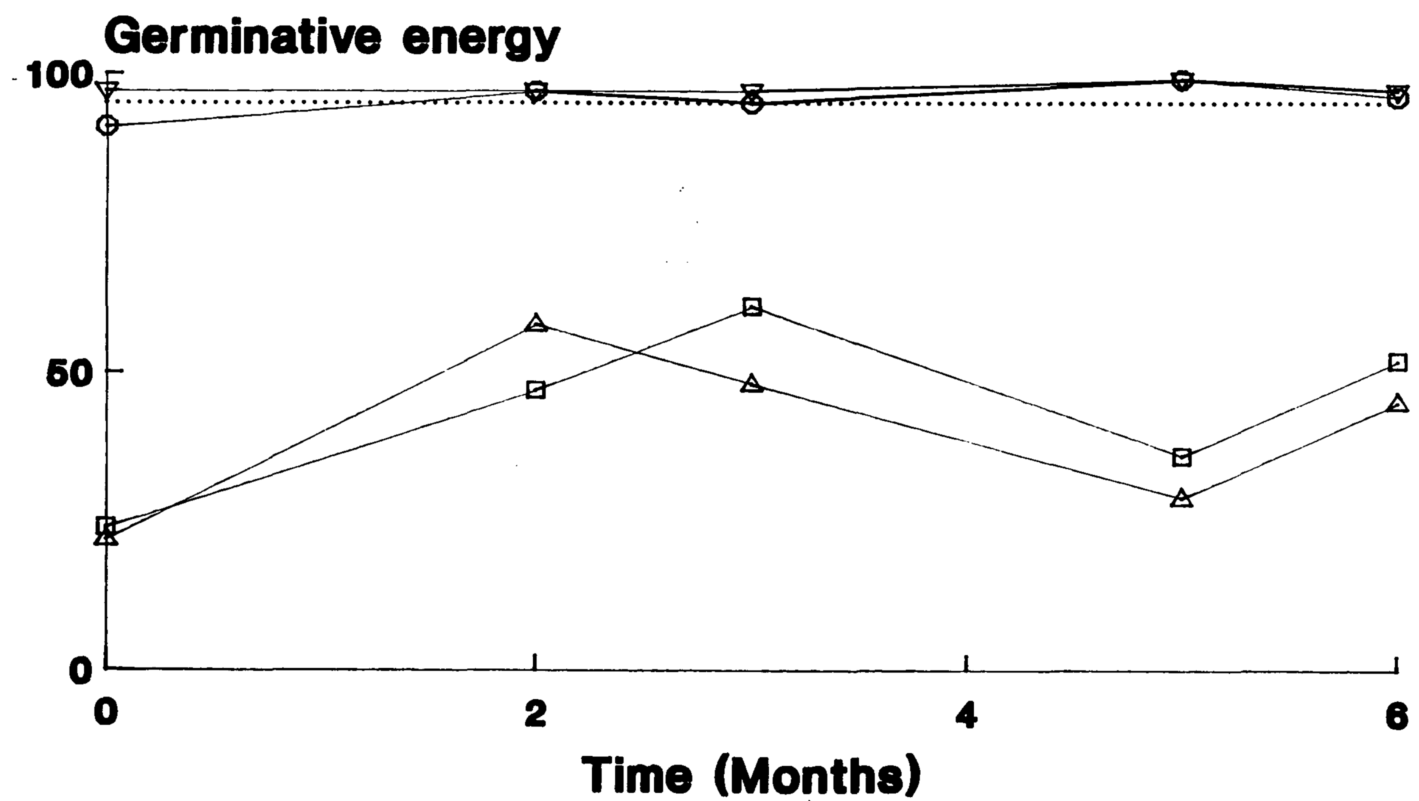


Figure 2: Germination performance of barley stored at 4°C. Triumph, 1988 harvest. Effect of conditioning.

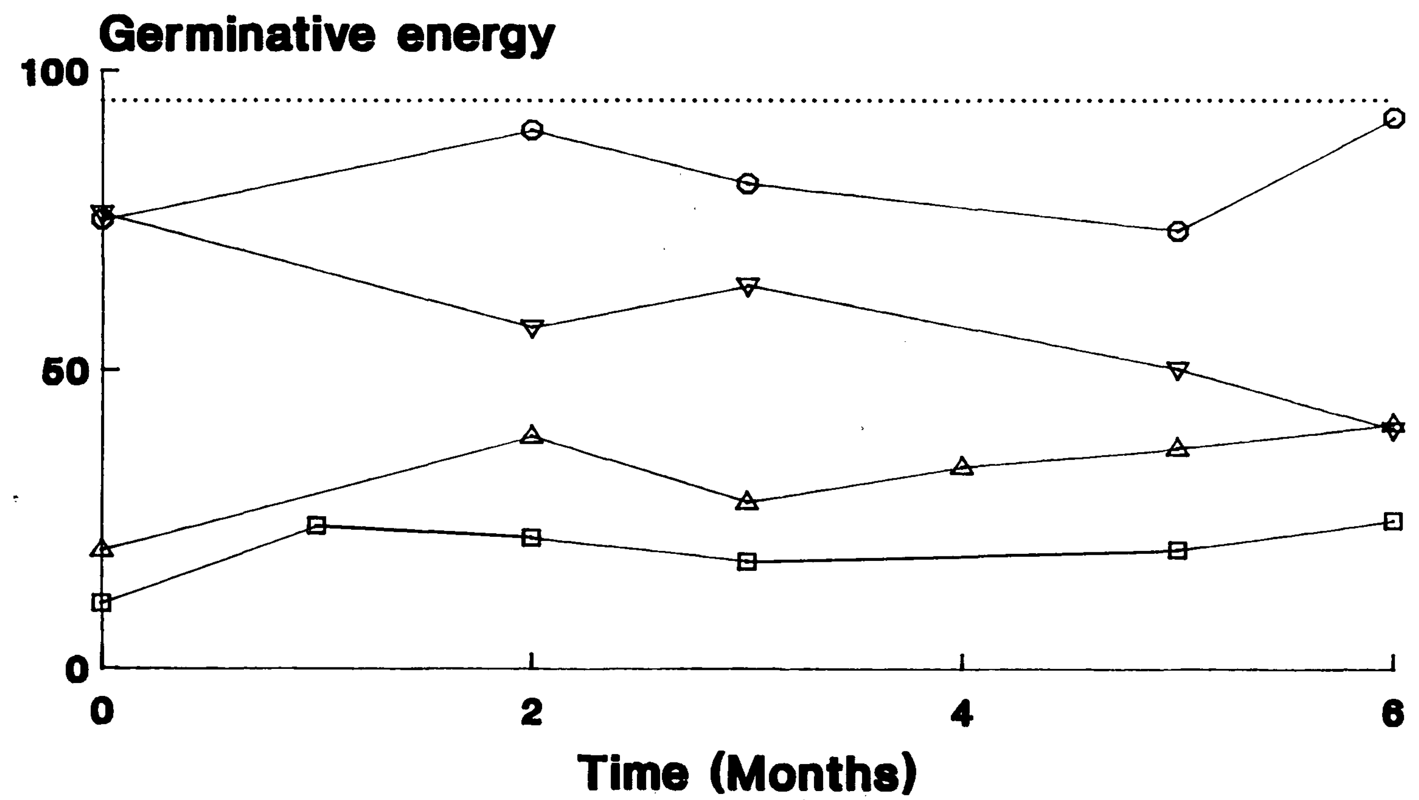


Figure 3: Germination performance of barley stored at 4°C. Triumph, 1989 harvest. Effect of drying and conditioning.

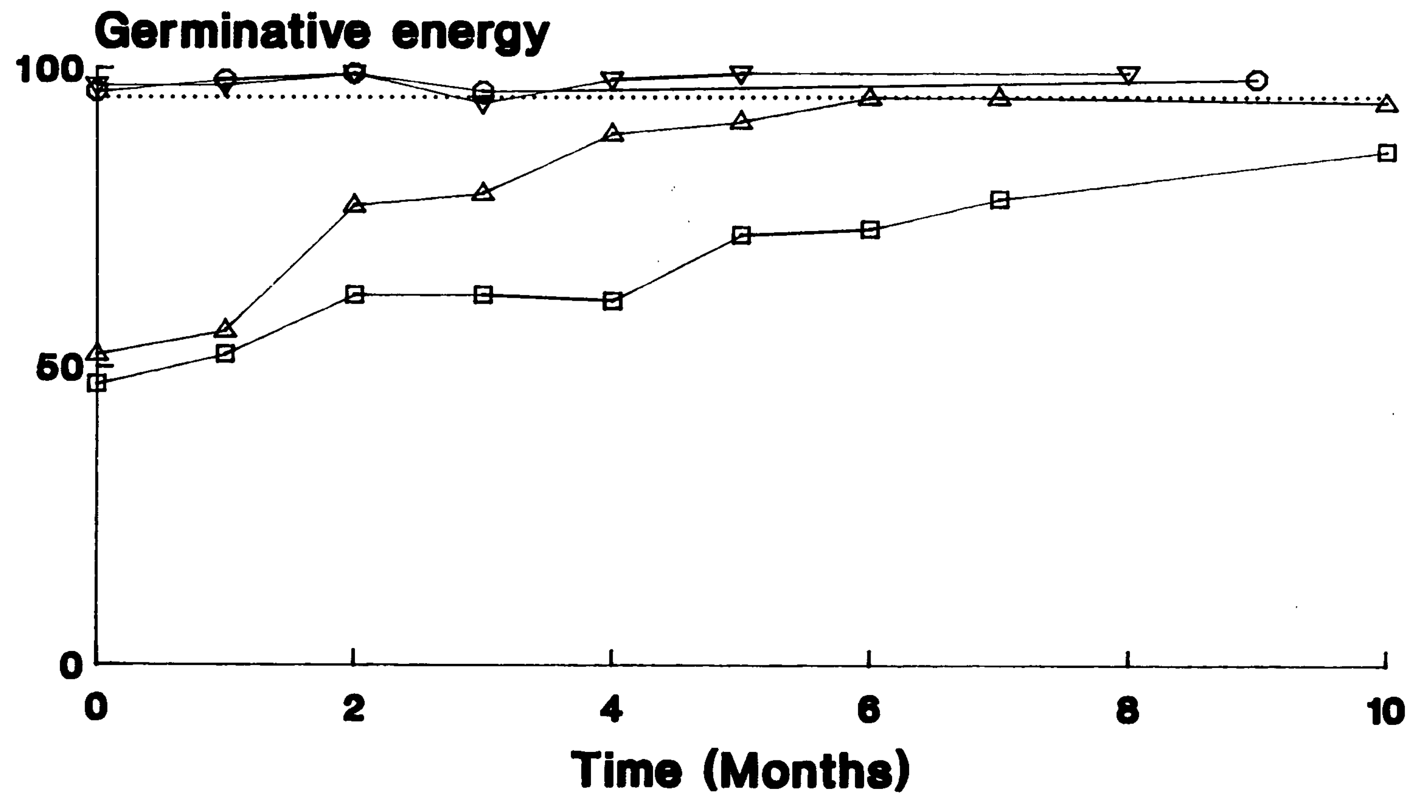
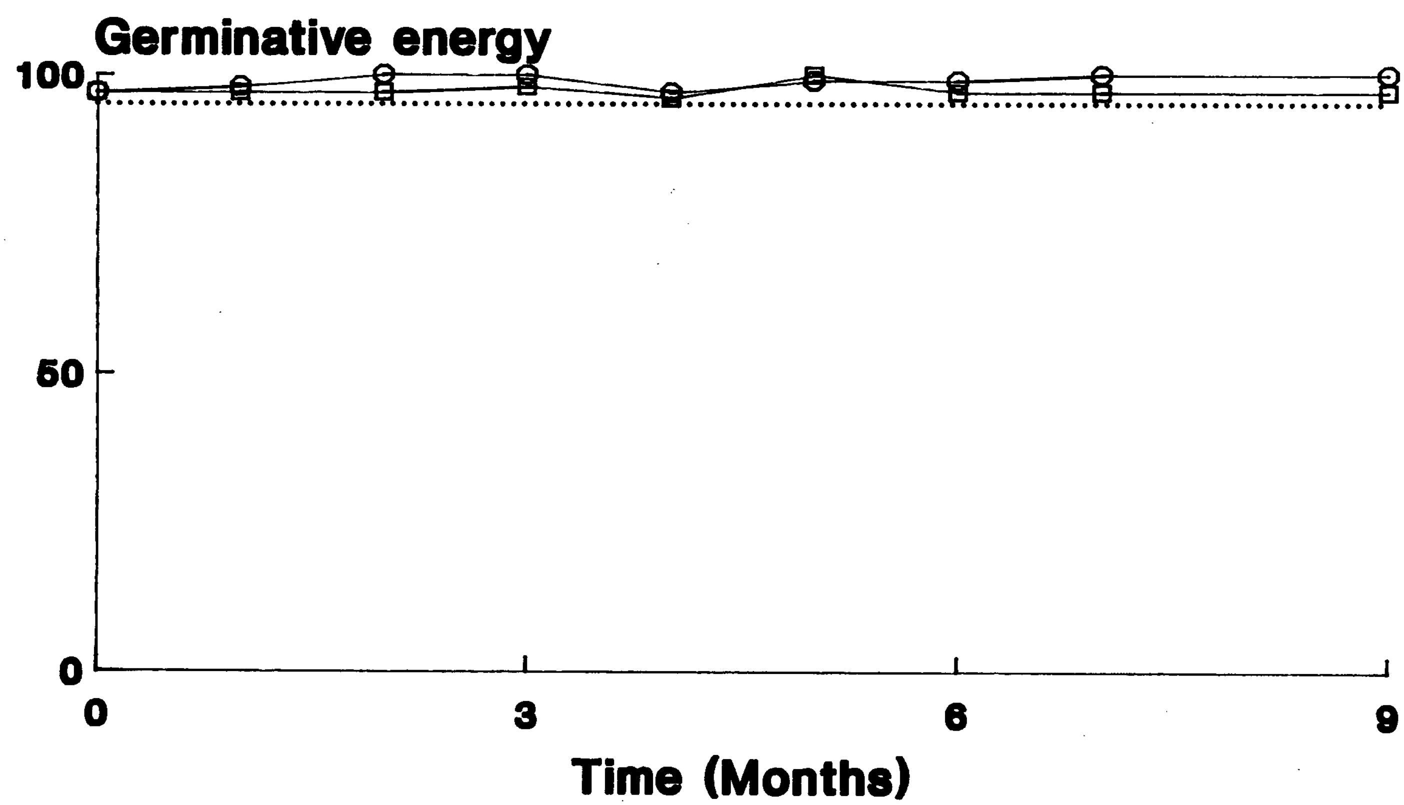


Figure 4: Germination performance of barley stored at 4°C. Doublet, 1989 harvest. Effect of conditioning.



APPENDIX 1 - PILOT MALTING REPORTS

APPENDIX 1

BREWING RESEARCH FOUNDATION

PILOT MALTING REPORT (50kg SCALE)

STEEP NO:	315P	DATE STARTED:	3.4.91
BARLEY VARIETY:	TRIUMPH 90/123	REQUESTED BY:	MOP
MOISTURE %:	10.4	PROJECT NO:	87/MPD
T.N.%:	1.74	COST CENTRE:	MP006

OBJECTIVES — Storing Malting Barley
ADAS - TEST.

BARLEY TREATMENT

Cleaned and screened >2.25mm.

1. STEEPING

	WET	DRY	WET	DRY	WET	DRY	WET	DRY
TIME (h)	10	16	8	10	1	2		
TEMP (°C)	13.5 15.5	15.5 19	16.5 17	17	16	16.5		
STEEP AERATION	NO		NO		NO			

TOTAL STEEPING TIME (h): 51

	H_2O%
1st STEEP	32.3
2nd STEEP	nm
3rd STEEP	46.0
4th STEEP	

ADDITIVES

NONE

2. GERMINATION Batch No. 315P

CONTROL: HC DRUM 3

DAYS

	1	2	3	4	5	6	7
GRAIN SET POINT TEMP °C	12.5	13.5	14.5	14.5	14.5		
STAGE	1	2	3	4	5		

MEASURED VALUES

Grain temperature

Grain moisture

TOTAL GERMINATION TIME: 5 days.

KILNING

Batch No:315P

LAGER

Time (h)	AIR ON (°C)	% RECIRC	% FAN	AIR OFF (°C)
8	50	0	85	24
6.5	55	20	75	24-33
3	60	60	50	33-38
1.5	65	70	45	38-44
1.5	70	80	40	44-53
1.5	75	90	35	53-62
1.5	80	90	35	62-67
4.0	85	90	35	67-76

Break Point Temp (°C) : 32

Time to Break (h) : 13.5

Total Kilning Time (h) : 27.5h

PROCESS DATA

Wt of Barley Steeped (kg) 50

Wt of Derooted Malt (kg) 42.9

"As is" Malt Yield (%) 85.9

Dry Malting Loss (%) 8.4

Total Process Time (Days): 8

Signed:

Date :

APPENDIX 1

BREWING RESEARCH FOUNDATION

PILOT MALTING REPORT (50kg SCALE)

STEEP NO:	314P	DATE STARTED:	3.4.91
BARLEY VARIETY:	TRIUMPH 90/122	REQUESTED BY:	MOP
MOISTURE %:	10.2	PROJECT NO:	87/MPD
T.N.%:	1.77	COST CENTRE:	MP006

OBJECTIVES

Storing Malting Barley
ADAS - CONTROL.

BARLEY TREATMENT

Cleaned and screened >2.25mm.

1. STEEPING

	WET	DRY	WET	DRY	WET	DRY	WET	DRY
TIME (h)	10	16	8	10	1	2		
TEMP (°C)	14-15.5	15.5 18.5	16.5 17	17	14	16		
STEEP AERATION	NO		NO		NO			

TOTAL STEEPING TIME (h): 47

	$H_2O\%$
1st STEEP	32.6
2nd STEEP	nm
3rd STEEP	44.6
4th STEEP	

ADDITIVES

NONE

2. GERMINATION   Batch No. 314P

CONTROL: HC   DRUM 2

DAYS

	1	2	3	4	5	6	7
GRAIN SET POINT TEMP °C	12.5	13.5	14.5	14.5	14.5		
STAGE	1	2	3	4	5		

MEASURED VALUES

Grain temperature

Grain moisture

TOTAL GERMINATION TIME: 5 days.

KILNING

Batch No:314P

LAGER

Time (h)	AIR ON (°C)	% RECIRC	% FAN	AIR OFF (°C)
8	50	0	85	25
5.5	55	20	75	25-33
3	60	60	50	33-38
1.5	65	70	45	38-44
1.5	70	80	40	44-53
1.5	75	90	35	53-62
1.5	80	90	35	62-67
4.0	85	90	35	67-77

Break Point Temp (°C) : 32

Time to Break (h) : 12.5

Total Kilning Time (h) : 26.5h

PROCESS DATA

Wt of Barley Steeped (kg) 50

Wt of Derooted Malt (kg) 43.6

"As is" Malt Yield (%) 87.3

Dry Malting Loss (%) 7.2

Total Process Time (Days): 8

Signed:

Date :

APPENDIX 2 - PILOT BREWING REPORTS

ANALYTICAL DATA

	TRIALS		CONTROLS		TARGET VALUES (1)
CODE NO.	GPL3261	GPL3262	GPL3260	GPL3263	
BEER NO	63A/91	67A/91	62A/91	68A/91	
PROPERTY			WORT ANALYSIS		
WORT pH	5.66	5.63	5.66	5.64	5.40
WORT COLOUR °EBC	6	6	6	7	9
WORT GRAVITY °	44.2	43.0	43.6	43.7	44.0
WORT TSN mg/l	899	872	898	890	700
WORT FAN mg/l	183	166	186	172	140
WORT FERMENT %	74	75	75	72	70
WORT BITTERNESS BU	44	40	41	42	44
			BEER ANALYSIS		
P D OR C	BOTTLED	BOTTLED	BOTTLED	BOTTLED	
pH	4.28	4.26	4.30	4.24	4.10
COLOUR °EBC	3.7	3.7	4.0	3.6	7
HEAD RETENTION secs	95	87	89	90	>95
CARBON DIOXIDE g/l	4.8	4.6	5.0	4.1	4.9
PRESENT GRAVITY °	3.8	2.8	3.2	4.0	7.0
ATT. LIMIT °	3.4	2.5	2.8	3.5	6.0
PG-AL °					1.0
BITTERNESS BU	26.7	24.8	25.3	24.9	22
TSN mg/l	544		534		420
FAN mg/l	68.7	70.3	70.4	65.3	30
DIACETYL mg/l	0.02		0.02		<0.01
PENTANEDIONE mg/l	0.02		0.02		<0.01
DMS ug/l	92		63		40
ACETALDEHYDE mg/l	4.4		4.3		<1
i-AMYL ACETATE mg/l	1.4		1.7		1.50
ETHYL ACETATE mg/l	20.0		21.8		18
i-BUTYL ACETATE mg/l	0.0		0.0		0.1
ETHYL HEXANOATE mg/l	0.2		0.2		<0.2
n-PROPANOL mg/l	8.7		7.9		14
n-BUTANOL mg/l	0.04		0.04		<0.2
i-BUTYL ALCOHOL mg/l	18.9		17.1		22
i-AMYL ALCOHOL mg/l	84.20		82.10		70
ETHANOL %v/v	5.4		5.4		4.80
ISO-a-ACIDS mg/l					22.0
AV H/SPACE AIR ml					<0.8
AV H/SPACE ml					15
AV INIT HAZE					

TASTING DATA

	TRIALS		CONTROLS		TARGET SCORES (1)
CODE NO_	GPL3261	GPL3262	GPL3260	GPL3263	
BEER NO_	63A/91	67A/91	62A/91	68A/91	
T D OR C					
FLAVOUR TERMS		AVERAGE SCORES			
ESTERY (A)	3.8	<u>3.9</u>	3.3	3.4	3
ESTERY (T)	<u>4.1</u>	<u>4.1</u>	<u>4.3</u>	<u>4.4</u>	3
FRUITY (A)	3.8	<u>4.0</u>	3.8	3.5	3
FRUITY (T)	<u>4.1</u>	<u>4.3</u>	<u>4.0</u>	<u>4.1</u>	3
FLORAL (A)	<u>1.6</u>	<u>2.1</u>	<u>1.9</u>	<u>2.3</u>	3
FLORAL (T)	<u>1.8</u>	<u>1.6</u>	<u>2.1</u>	<u>2.1</u>	3
DMS (A)	2.3	1.6	<u>2.5</u>	1.5	2
DMS (T)	2.1	1.9	<u>2.5</u>	2.1	2
SWEET (A)	3.8	<u>4.1</u>	<u>3.9</u>	3.3	3
SWEET (T)	<u>4.4</u>	<u>4.8</u>	<u>4.4</u>	<u>4.4</u>	4
BITTER (T)	3.8	4.0	4.0	<u>4.4</u>	4
ASTRINGENT (T)	3.5	3.4	3.3	<u>3.6</u>	3
BODY (T)	4.4	4.3	4.0	3.8	4
		'S' VALUES (2)			
ALCOHOLIC-A	<u>4.4</u>	0.3	2.8	0.3	<4
ALCOHOLIC-T	<u>8.6</u>	2.8	<u>6.3</u>	<u>5.6</u>	<4
SPICY-A	<u>5.5</u>	0.9	<u>5.6</u>	1.3	<4
SPICY-T	3.8	1.3	<u>5.6</u>	3.3	<4
GRAINY-A	<u>18.0</u>	<u>23.4</u>	<u>6.3</u>	<u>7.8</u>	<4
GRAINY-T	<u>18.0</u>	<u>19.5</u>	<u>5.6</u>	<u>9.6</u>	<4
MALTY-A	0.2	<u>4.2</u>	1.6	0.0	<2
MALTY-T	0.9	1.6	0.3	0.2	<2
TOFFEE-A	0.0	0.2	<u>2.8</u>	0.3	<2
TOFFEE-T	0.0	1.3	0.9	1.3	<2
COOKED VEG-A	<u>9.4</u>	<u>9.4</u>	1.6	<u>9.4</u>	<2
COOKED VEG-T	<u>5.0</u>	<u>7.5</u>	0.9	<u>2.3</u>	<2
FATTY ACID-A	0.3	0.3	2.8	2.3	<4
FATTY ACID-T	<u>5.6</u>	<u>6.3</u>	<u>8.8</u>	<u>5.6</u>	<4