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Malting barley: storage, dormancy and processing quality

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Abstract. Preharvest sprouting of malting barley causes substantial commercial losses to the grain industry. The use of dormant barley varieties could reduce the risk of weather damage, but dormancy and water sensitivity are undesirable during malting. Storage conditions largely determine the rate of postharvest breakdown of dormancy and water sensitivity. This process may take months, to the disadvantage of handlers and maltsters. Our research has identified several options for managing barley dormancy to provide opportunities to malt and export barley earlier. This would open the door to the use of more dormant barley varieties to reduce preharvest sprouting. The use of agricultural chemicals to break dormancy before or after storage is one possible option. Alternatively, the use of dry heat is an attractive option avoiding market sensitivities to chemical use. Finally, by manipulating the storage process, postharvest dormancy breakdown can be accelerated without compromising barley quality. Here we present preliminary results of a three-year project that aims to understand the interaction between storage conditions, barley quality and dormancy.

Introduction

The effect of storage conditions on the quality of barley is of considerable importance to the barley industry. Storage can either reduce barley quality (Woods et al. 1994; White et al. 1999), or increase maltability (Woonton et al. 2002). To maximise quality of previously stored barley entering the malt house, the influence of storage environments on postharvest maturation and changes in malting quality of contemporary Australian barley varieties needs to be better understood.

Preharvest sprouting is a serious problem in cereals (Nagao 1995), and in malting barley results in downgrading of grain and heavy financial penalties to the grower. Low dormancy of barley is closely linked to preharvest sprouting of grain (Jacobson et al. 2002). The use of barley varieties with dormant genotypes reduces downgrading caused by rain and, in combination with improved harvesting practices, the risk of weather damage in rain-prone areas can be minimised (Moor 1987). However, dormancy that persists after harvest is highly undesirable because it prevents malting of newly received barley (Jacobsen et al. 2002). In contemporary Australian barley varieties, levels of dormancy are very low, and generally are only expressed when cool, wet weather conditions occur.

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Storage conditions largely determine the rate at which postharvest maturation occurs. Initial seed condition, seed temperature, seed moisture content and storage time are the major factors influencing changes in malting quality. Depending on storage conditions, Australian malting barley can take several months to reach optimum malting quality. Our research has identified three options for managing barley dormancy to provide opportunities to malt and export barley earlier. The use of agricultural chemicals to break dormancy before or after storage is one possible option. Alternatively, the use of dry heat is attractive, since it avoids difficulties such as chemical residues and market sensitivities to chemical use. Finally, by understanding and carefully manipulating the storage process, postharvest dormancy breakdown can be accelerated without compromising barley quality. Here we present preliminary results of a three-year project that aims to understand the interaction between storage conditions, barley quality and dormancy.

Materials and methods

Chemical treatments

After screening 65 barleys collected during the 2001–2002 harvest for dormancy, samples of Franklin from Tasmania and a breeding line from the Tasmanian Depart-

ment of Primary Industry were chosen for the experiments.

Nineteen chemicals were selected for assessment (Table 1). Duplicate 50 g samples were weighed into crystallising dishes and placed into sealed desiccators containing magnetic stirring paddles. Controls were exposed to the same handling procedures, except for the chemical treatment. Chemicals were injected into desiccators, which were placed on stirrer plates and the air mixed for 30 min and then kept at 25°C for 48 h. After exposure, samples were vented in a fume cabinet for 48 h. Samples were tested immediately or stored at –18°C until assessment.

Germination testing was based on the germination energy test developed by Doran and Briggs (1992) and methods described in the International Rules for Seed Testing (ISTA 1999). To define dormancy status, germination with water only was compared to germination in the presence of 0.05% gibberellic acid (GA_3) solution. Dormant (but not dead) grain will germinate in the presence of GA_3. For the purpose of rapid screening of chemicals, phytotoxicity was classified as high (>51% dead seeds), medium (21–50% dead seeds) and low (<20% dead seeds).

Heating experiments

To assess the effect of dry heat on dormancy, 40 g samples of grain were rapidly heated to 60°C following the procedure developed by Beckett et al. (1998). Exposure times were 15, 30 and 60 minutes. The varieties Stirling (Western Australia, 2002–2003 harvest, 11.1% moisture content; MC) and Triumph (Tasmania, 2002–2003 harvest, 12.3% MC) were selected for treatment.

Storage experiments

Stirling (from Western Australia), Sloop and Gairdner (both from South Australia) from the 2001–2002 harvest were stored at 10, 12 and 14% MC and 15, 20, 25 and 30°C. All samples had been graded as malting barley, obtained immediately after harvest, and were conditioned to the required MC before storage under controlled laboratory conditions. Germinative energy (GE) and water sensitivity (WS) were determined as described by Doran and Briggs (1992).

Results and discussion

The use of agricultural chemicals to break dormancy

Nineteen chemicals were selected for assessment (Table 1). The compounds tested fell into two basic categories: gases and condensable vapours. The selection included past, current and potential fumigants (shown in italics in Table 1). Other chemicals were selected based on published data and likely low phyto- and mammalian toxicity. Doses were selected based on existing treatment schedules or, where this was not possible, on the doses used for related compounds. Doses were deliberately set high to speed up the screening process and to ensure that the compounds had low phytotoxicity—the most essential characteristic of any chemical compound applied to malting barley. Very high doses were applied for compounds which were considered to be of very low toxicity. Details of doses and application techniques will be published at the conclusion of the project.

Barley samples had to display persistent dormancy to be useful for chemical treatment trials. A clear distinction needed to be drawn between dormant kernels and kernels which were non-viable, i.e. dead. The percentage of grain that failed to germinate in the presence of gibberellic acid (GA_3) was considered to be a measure of non-viable (dead) grain. The difference between non-germinated grain in the standard test and non-viable grain was taken to be an indication of dormancy. Based on germination tests, treatments were assigned a phytotoxicity classification (high, medium, low) and a classification based on their effectiveness in breaking dormancy (the effects ranged from a high, medium or low ability to break dormancy through to actually increasing dormancy). We would like to emphasise that phytotoxicity classifications were only for comparison between compounds tested in this experiment; they do not measure the safety of any of the treatments when applied to malting barley.

Table 1. Chemical treatments (past, current and potential fumigants are shown in italics).

Gaseous treatments		Vapour treatments	
Phosphine	PH_3	*Ethyl formate*	$C_3H_6O_2$
Carbonyl sulfide	COS	*Methyl formate*	$C_2H_4O_2$
Sulfuryl fluoride	F_2O_2S	Propyl formate	$C_4H_8O_2$
Hydrogen sulfide	H_2S	*Carbon disulfide*	CS_2
Sulfur dioxide	SO_2	*Dichlorvos*	$C_4H_7Cl_2O_4P$
Carbon dioxide	CO_2	Methanol	CH_4O
Carbon monoxide	CO	Ethanol	C_2H_6O
Ethylene	C_2H_4	Propanol	C_3H_8O
Hydrogen cyanide	HCN	Sodium hypochloride solution	NaClO
Ethanedinitrile	C_2N_2		

The phytotoxic and barley dormancy-breaking effects of the chemicals tested are shown in Table 2. Where the effect of chemicals on dormancy breakdown was variable, the range of responses has been listed in the table. Three of the compounds screened displayed considerable phytotoxicity and no assessment of dormancy-breaking capability was possible (Table 2). Ethanedinitrile and two of the alcohols tested also showed unacceptable levels of phytotoxicity. The alcohols appeared to increase dormancy when applied at high concentrations. Ethanedinitrile decreased dormancy, but it was more phytotoxic than current fumigants, but less toxic than hydrogen cyanide or sulfur dioxide. The rest of the chemicals tested had low phytotoxicity. Of these compounds, ethyl and methyl formate stand out as the chemicals most likely to reduce dormancy. Dichlorvos could also be considered as a dormancy-breaking chemical. The other compounds were less promising.

There are few published data on the use of vapour and gases to break seed dormancy. Many types of chemicals can influence seed dormancy (Taylorson and Hendricks 1981). Cohn and Hillhorst (2000) summarise the literature on the effect of small organic molecules, including alcohols and some esters, on the dormancy of a range of seeds, including cereals. Results vary between species and with application methods and range from breaking to inducing dormancy. To the best of our knowledge, no wide-ranging studies have been published on the use of chemicals for breaking seed dormancy with large-scale industrial applications in mind. We have concentrated on chemicals that may be applied as in-bin treatments and which are likely to be available to industry in the near future. In this respect, ethyl formate seems to show the most promise.

The use of dry heat to break barley dormancy

Germination testing of barley samples before treatment showed that germinative energy (GE) was 94% and 96%, and water sensitivity (WS) was 91% and 72% for Stirling and Triumph, respectively. After heat treatment at 60°C for 15–60 minutes, GE was found to increase slightly and there was a trend for a breakdown of WS. Much more work is required in this area, including treatment of a variety of samples at range of temperatures and exposure times.

Breaking dormancy by manipulating the storage process

Viable grain may not germinate under conditions that are considered suitable for germination, i.e. the grain is dormant. Non-germination of viable grain can also be caused by an excessive amount of water used during germination testing, i.e. the grain is water-sensitive. In this case, low levels of germination signify a high level of water-sensitive grains, and an increase in germination

Table 2. Effect of chemicals on barley dormancy and viability.

Treatment	Phytotoxicity	Dormancy breakage capability[a]
Hydrogen cyanide	High	n/a
Methanol	High	n/a
Sulfur dioxide	High	n/a
Ethanedinitrile	Medium	Medium
Ethanol	Medium	Dormancy increase
Propanol	Medium	Dormancy increase
Ethyl formate	Low	Medium to high
Methyl formate	Low	Medium to high
Dichlorvos	Low	Medium
Phosphine	Low	Medium to low
Hypochloride solution	Low	Medium to low
Hydrogen sulfide	Low	Low to high
Propyl formate	Low	Low to high
Carbon monoxide	Low	Medium to dormancy increase
Ethylene	Low	Medium to dormancy increase
Carbon disulfide	Low	Low
Carbonyl sulfide	Low	Low
Carbon dioxide	Low	Low to dormancy increase
Sulfuryl fluoride	Low	Low to dormancy increase

[a] Range of responses is shown where necessary.

means a breakdown of water sensitivity. Before storage, all three barley varieties displayed some level of WS and low GE (Table 3). These characteristics were most pronounced in Gairdner. Storage at 30°C for 1.5 months at 14% MC led to a significant increase in GE and loss of WS in Gairdner and Stirling. In contrast, Sloop lost its ability to germinate over the same period. Further storage at 30°C had the same negative effect on Sloop, Stirling and Gairdner.

Table 3. Germinative energy and water sensitivity of three commercial barley varieties stored at 14% moisture content for 9 months at three temperatures.

Variety	Storage temperature (°C)	Storage period (months)	Germinative energy (%)	Water sensitivity (%)
Gairdner		0	87	49
	20	3	93	79
		9	92	82
	25	3	96	90
		6	90	84
		9	57	40
	30	1.5	96	92
Sloop		0	94	81
	20	3	97	93
		9	98	94
	25	3	98	95
		6	99	95
		9	81	72
	30	1.5	1	0
Stirling		0	95	70
	20	3	100	95
		9	100	98
	25	3	99	99
		6	100	99
		9	99	100
	30	1.5	100	98

Stirling continued to improve in quality during storage at 20°C and 25°C. Sloop was similar to Stirling, but some deterioration could be seen after storage for 9 months at 25°C. Gairdner also improved in quality when stored for up to three months. However, longer storage periods were detrimental.

In summary, the germination of three barely varieties can be improved by storage through the loss of dormancy and water sensitivity. At the same time, germination may be lost, especially with extended storage periods at elevated temperatures. The effect of storage temperatures on barley dormancy have been previously reported (e.g. Briggs et al. 1994; Woods and McCallum 2000). To allow Australian grain handlers to safely store grain at temperatures high enough to rapidly break dormancy, it is necessary to carry out systematic studies on a range of current Australian varieties stored at different moisture contents. An integrated strategy for managing barley dormancy in the United Kingdom has been presented by Armitage and Woods (1997). This project will contribute towards building models that will allow the development of a thermally based integrated storage strategy for Australian malting barley.

Conclusions and future work

Ethyl formate has been shown to be the most promising candidate for reducing dormancy in stored barley. Research will be taken forward by a set of static exposures of several lots of dormant barley to different doses of ethyl formate. If these are successful, a second set of experiments will confirm the doses in a flow-through system. If dormancy can be removed through this process, then this will lead to the recommendation of application rates of ethyl formate for the purpose of reducing dormancy in barley. Any recommendations will be based on treatment schedules developed for pest control. Samples will be micromalted to confirm that the quality of the barley is not affected by the treatment. At the same time, and using a similar experimental plan, barley samples will be exposed to a variety of heat treatments for the purpose of breaking dormancy.

In a separate experiment, we will use data collected to date to run a storage trial on two samples of Stirling from the north and south of Western Australia. A storage schedule of alternating temperatures will be used to speed up postharvest maturation and reduce water sensitivity and dormancy in barley grain without an unacceptable reduction in malting quality.

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References

Armitage, D.M. and Woods, J.L. 1997. The development of an integrated storage strategy for malting barley. Project Report No. 138, London, Home Grown Cereals Authority.

Beckett, S.J., Morton, R. and Darby, J.A. 1998. The mortality of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) at moder-

ate temperatures. Journal of Stored Products Research, 34, 363–76.

Briggs, D.E., Woods, J.L. and Favier, J.F. 1994. Drying and storage treatment for overcoming dormancy in malting barley. Journal of the Institute of Brewing, 100, 271–278.

Cohn, M.A. and Hilhorst, H.W.M. 2000. Alcohols that break seed dormancy: the anaesthetic hypothesis, dead or alive? In: Viemont, J.D. and Crabbe, J., ed., Dormancy in plants. Wallingford, CAB International.

Doran, P.J. and Briggs, D.E. 1992. Studies on germination tests. Journal of the Institute of Brewing, 98, 193–201.

ISTA (International Seed Testing Association) 1999. Seed science and technology rules. Switzerland, International Rules for Seed Testing.

Jacobsen, J.V., Pearce, D.W., Poole, A.T., Pharis, R.P. and Mander, L.N. 2002. Abscisic acid, phaseic acid and gibberellin contents associated with dormancy and germination of barley. Physiologica Plantarum, 115, 428–441.

Moor, T. 1987. Problems encountered in storage of sprout damaged barley. In: Mares, D.J., ed., Proceedings of the fourth international symposium on pre-harvest sprouting in cereals. Boulder, CO, Westview Press.

Nagao, S. 1995. Detrimental effect of sprout damage on wheat flour products. In: Noda, K. and Mares, D.J., ed., Proceedings of the 7th international symposium on pre-harvest sprouting in cereals. Osaka, CASJO.

Taylorson, R.B. and Hendricks, S.B. 1981. Anaesthetic release of seed dormancy—an overview. Israel Journal of Botany, 29, 273–280.

White, N.G.G., Hulasare, R.B. and Jayas, D.S. 1999. Effect of storage conditions on quality loss of hull-less and hulled oats and barley. Canadian Journal of Plant Science, 79, 475–482.

Woods, J.L., Favier, J.F. and Briggs, D.E. 1994. Predicting the germinative energy of dormant malting barley during storage. Journal of the Institute of Brewing, 100, 257–269.

Woods, J.L. and McCallum, D.J. 2000. Dormancy in malting barley: quantifying the effect of storage temperature on different varieties and the response to sudden cooling. Journal of the Institute of Brewing, 106, 251–258.

Woonton, B., Jacobsen, J., Sherkat, F. and Stuart, M. 2002. Effect of post-harvest storage period on barley germination and malt quality. In: Proceedings of the 10th Australian Barley Technical Symposium, Canberra, ACT, 16–20 September 2001. Australian Barley Technical Symposium Incorporated.