The influence of physical and chemical processes on dormancy breakdown in malting barley

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Abstract

Dormancy of barley that persists after harvest is undesirable because it prevents malting of newly received grain. This project aimed to assess the potential use of chemicals, dry heat and storage conditions to facilitate dormancy breakdown in Australian barley varieties. Ethyl formate was considered to be the most promising option from the twenty chemicals screened. However, very high doses of the liquid formulation applied under static conditions were phytotoxic to some samples. Use of the commercial ethyl formate formulation Vapormate™ in forced flow-fumigation, at doses similar to those intended for pest control, decreased dormancy and decreased water sensitivity in five batches of malting barley. There was no reduction in germination under these conditions. Exposing dormant barley samples to treatment temperatures below 50°C had little effect on germination of samples. Heat treatment of dormant and water sensitive barley at 60°C for up to 5 hours reduced dormancy and water sensitivity of samples in which these characteristics were strongly expressed. Treatment at 70°C had a similar effect when exposure time was less than 30 minutes. Use of heat in the form of fluidized beds increased germination in most batches of dormant and water sensitive malting barleys. Heat appears to be a useful tool for reducing dormancy and water sensitivity in barley, as long as care is taken to avoid exposing grain to excessive heat. Experiments using accelerated maturation investigated the exposure of samples to temperatures higher than those typically found in a store, but lower than what conventionally might be considered heat treatment. Storage of the most dormant sample at 35°C for two weeks successfully increased germination and decreased water sensitivity. However, further experiments at 35°C showed some varieties can be damaged by this treatment when stored at high moisture contents.

Key Words

Dormancy, water sensitivity, fumigation, heating, storage, malting

Introduction

Pre-harvest sprouting is a serious problem in cereals [1], and in malting barley results in downgrading of grain and heavy financial penalties to the grower. Low dormancy of barley is closely linked to pre-harvest sprouting of grain [2]. 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. However, dormancy that persists after harvest is highly undesirable because it prevents malting of newly received barley [2].

Our research has identified several options for managing barley dormancy to provide opportunities to malt and export barley earlier. The use of chemical treatments to break dormancy before or after storage is one possible option [3, 4, 5]. Alternatively, the use of dry heat is attractive, since it avoids difficulties such as chemical residues and market sensitivities to chemical use [6, 7]. Finally, by understanding and carefully manipulating the storage process, post-harvest dormancy breakdown can be accelerated without compromising barley quality [8, 9, 10]. This paper focuses on the tools available to decrease dormancy of malting barley before delivery into the central handling systems or after storage on-farm. Important new data on barley dormancy is presented with the aim of giving growers greater option in barley cultivation and storage and improving the quality and marketability of Australian malting barley and malt.

Methods

Sources and characteristics of barley varieties

After screening approximately 100 barley samples over three seasons, 13 barley samples were used in experiments (Table 1). Some samples were selected for their significant levels of dormancy and water sensitivity; those with high germination energy were used as controls. In the following sections particular batches of grain (samples) are referred to by their varietal name and sample number. To maintain dormancy and water sensitivity, samples were frozen on receival from the field until testing and assessed at the

received moisture content. This meant that the mc of most samples tested exceeded the 12.5% upper limit set by NACMA [11].

Germination tests

Germination testing was based on germination energy (GE) and water sensitivity (WS) tests recommended by the European Brewery Convention [12] and improved by Doran and Briggs [13], and methods described in the International Rules for Seed Testing [14]. The germination index (GI) of samples was calculated according to EBC methods (EBC 1998). 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). Seed moisture content (mc) was determined using the International Standards Organisation (ISO) standard oven-dried method No. 712 [15].

Treatments

Chemical treatment experiments were carried out in three stages. In stage 1, 20 chemicals were selected for assessment (Table 2). Doses were selected based on existing treatment schedules or on the doses used for related compounds and in most cases were deliberately set high to accelerate the screening process (Table 2). 50 g of duplicate samples were placed into separate sealed desiccators. Desiccators were mixed for 30 min, and stored at 25ºC for 48 h. After exposure, samples were aired for 2 days. Samples were then stored at -18ºC until assessment. In Stage 2, liquid ethyl formate was applied at 25-300 gm^{-3}. In Stage 3, fumigation using Vapormate™ (a mixture of 16% ethyl formate and carbon dioxide manufactured by BOC) was carried out as described by Damcevski et al [16]. The treatment vessel was filled with 50 kg of *Franklin* malting quality barley. Four other smaller samples (*Franklin 1 & 2*, *Triumph 1* and *PIT 1*) were contained in cloth bags and placed at three levels in the grain column. These samples were assessed separately and their GE and WS were averaged. Controls were kept under the same ambient conditions as the treated samples.

Heat treatments were also conducted in two stages. In Stage 1, 40 g samples of grain were rapidly heated to different temperatures according to Beckett et al. [17]. In Stage 2, Samples of 4 kg were heated to 60°C in a spouted-bed rig [18]. In the accelerated maturation experiments, Franklin and Stirling were stored at 30 or 35ºC for a period of up to 4 weeks, or 25ºC for up to 3 months. The samples were then stored at 20ºC for a total of 6 months. In a second experiment, samples were stored for 2 weeks at 35°C and assessed immediately after storage. To maintain the levels of dormancy and water sensitivity, the samples, were treated at the mc at which they were received after harvest. *Stirling 1*, a sample that showed little dormancy, was conditioned to 12% mc and used as a control.

Results

Chemical Treatments

The effect of exposure to chemicals on barley dormancy and its ability to germinate was highly variable with the type of barley treated. Phytotoxic effects were common, and this restricted the number of potentially useful chemicals and the concentrations at which they could be applied. Of the twenty chemicals screened hydrogen cyanide, methanol and sulphur dioxide were particularly toxic (Table 3). Ten of the chemicals tested had low levels of toxicity but did not break dormancy. Ethyl formate, methyl formate and dichlorvos showed some dormancy breaking capacity without damaging the grain. Of these three, ethyl formate was considered to provide the most promising option for on-farm use. Liquid ethyl formate appeared to break down dormancy and water sensitivity in some samples. However, high doses were phytotoxic to most samples, and lower doses of ethyl formate may be toxic to some samples. Use of the commercial ethyl formate formulation Vapormate™ at doses similar to those intended for pest control decreased dormancy and water sensitivity in five batches of malting barley without any deleterious effects to GE (Figure 1).

Heat treatments

Barley samples were treated by exposing them to elevated temperatures ranging from 40° to 70°C for periods of 15 minutes to 18 hours. Treatment of samples at 50°C for 1 hour slightly increased the ability of the sample to germinate. Heat treatment of dormant and water sensitive barley at 60°C for up to 5 hours reduced dormancy and water sensitivity of samples in which these characteristics were strongly expressed. Exposure to 60°C for longer periods decreased the ability of the grain to germinate. Higher temperatures (70°C) reduced dormancy and water sensitivity if exposure was less than 30 minutes. Longer exposure reduced the grain's ability to germinate (Figures 2 and 3). However, exposure to 70°C for longer periods caused pronounced reduction in germination. Exposure at 60°C for 1 hour was considered the best option to improve the germination of dormant and water sensitive barley due to the lower risk of damaging the grain. However, subsequent tests showed that some barley samples were more susceptible to the deleterious effects of heat treatments. Of six samples tested at 60°C for 1 hour, one sample showed improved germination, two samples

were not affected, and three samples were damaged by the treatment. In summary, treatment temperatures at or below 50°C had a marginal effect on germination of samples, but exposure to higher temperatures could increase or decrease germination depending on the exposure period.

In the spouted bed, the grain was heated in a stream of air at a temperature of 80-84°C for 2 minutes and 15 seconds; which resulted in a grain temperature of 60°C. The small scale treatments conducted in the heat sinks resulted in the grain losing up to 0.5% mc over the treatment time. The spout bed system had a greater drying effect on the grain with mc dropping by 1.0%. Under these conditions, heat treatment generally resulted in increased GE and a decrease in water sensitivity. Shorter treatment times were more effective than longer exposures, which in some samples decreased germination by damaging grain. The fluidized bed system was more effective in increasing germination than the static system in all samples except *Triumph 1*.

Accelerated maturation

Storage at 30° to 35°C for 1 week increased the GE and WS of two batches of dormant barley, and after 4 weeks there was no noticeable damage to the grain. Storage of the most dormant sample at 35°C for 2 weeks successfully increased GE and decreased water sensitivity of the grain. Short-term storage of *Franklin 2* at 30° to 35ºC slightly increased GE and reduced water sensitivity. The rate of germination (GI) increased from 8.5 (GE test) and 7.2 (WS test) to greater than 9.0 for both the GE and WS tests within two weeks after storage at 35°C, or three weeks at 30°C (Figure 4). Storage at 25°C for one month had a similar effect. *Stirling 1*, which had a GE of 96% and a WS of 93%, also showed an increased ability to germinate after short-term storage at high temperatures (Figure 5). However, further experiments at 35°C showed that some varieties were damaged by this treatment, in particular at high moisture contents. Treatment at 30°C may be a better option at higher moisture contents, although longer treatment times may be required.

Table 1. Initial quality of samples used for dormancy breaking treatments. **GE: Germination Energy; WS: Water Sensitivity. C: Chemical Treatments; H: Heat Treatments; A: Accelerated Maturation**

	Source			**Germination**		**Treatments**		
Sample	*Origin*	*Harvest*	*MC (%)*	*GE%*	*WS%*	*C*	*H*	*A*
Baudin 1	Vic	2003/04	13.2	90.0	75.7		✓	✓
Baudin 2	Vic	2003/04	13.0	87.0	72.6			✓
Dhow 1	Vic	2003/04	12.6	85.1	70.4		✓	✓
Franklin 1	Tas	2001/02	12.9	40.0	16.8	✓		
Franklin 2	Tas	2002/03	12.3	94.3	88.0	✓	✓	✓
Franklin 3	Tas	2002/03	12.1	95.0	69.6	✓		
Franklin 4	Vic	2003/04	13.2	96.2	86.6			✓
Gairdner 1	Vic	2003/04	12.4	93.4	85.6		✓	✓
PIT 1	Tas	2001/02	13.3	32.0	12.5	✓		
Schooner 1	Vic	2003/04	13.2	90.5	81.5			✓
Schooner 2	Vic	2003/04	13.1	92.1	83.0			✓
Stirling 1	WA	2002/03	11.1	93.8	89.7		✓	✓
Triumph 1	Tas	2002/03	12.6	88.7	46.8	✓	✓	✓

Table 2 Chemical treatments. Fumigants are shown in italics.

Gaseous treatments	**Dose**	**Vapour treatments**	**Dose**
Phosphine (PH_3)	3 gm^{-3}	*Ethyl formate* ($C_3H_6O_2$)	174 mLm^{-3}
Carbonyl sulphide (COS)	120 gm^{-3}	*Methyl formate* ($C_2H_4O_2$)	162 mLm^{-3}
Sulphuryl fluoride (F_2O_2S)	120 gm^{-3}	Propyl formate ($C_4H_8O_2$)	179 mLm^{-3}
Hydrogen sulphide (H_2S)	120 gm^{-3}	*Carbon disulphide* (CS_2)	120 mLm^{-3}
Sulphur dioxide (SO_2)	120 gm^{-3}	*Dichlorvos* ($C_4H_7Cl_2O_4P$)	26 mLm^{-3}
Carbon dioxide (CO_2)	95%	*Ethylene dichloride* ($C_2H_4Cl_2$)	160 mLm^{-3}
Carbon monoxide (CO)	95%	Methanol (CH_4O)	Saturated
Ethylene (C_2H_4)	95%	Ethanol (C_2H_6O)	Saturated
Hydrogen cyanide (HCN)	50 gm^{-3}	Propanol (C_3H_8O)	Saturated
Ethanedinitrile (C_2N_2)	50 gm^{-3}	Sodium hypochlorite (NaClO)	Saturated

Table 3 Effect of chemicals on barley dormancy and viability

Treatment	Phytotoxicity	Dormancy breakage capability
Hydrogen cyanide, methanol, sulphur dioxide	High	n/a
Ethanedinitrile	Medium	Medium
Ethanol, propanol	Medium	Dormancy increase
Ethyl formate, methyl formate	Low	medium-high
Dichlorvos	Low	Medium
Phosphine, hydrochloride solution	Low	Medium-low
Hydrogen sulphide, propyl formate	Low	Low-high
Carbon monoxide, ethylene	Low	Medium-Dormancy increase
Carbon disulphide, carbonyl sulphide	Low	Low
Carbon dioxide, sulphuryl fluoride	Low	Low-Dormancy increase

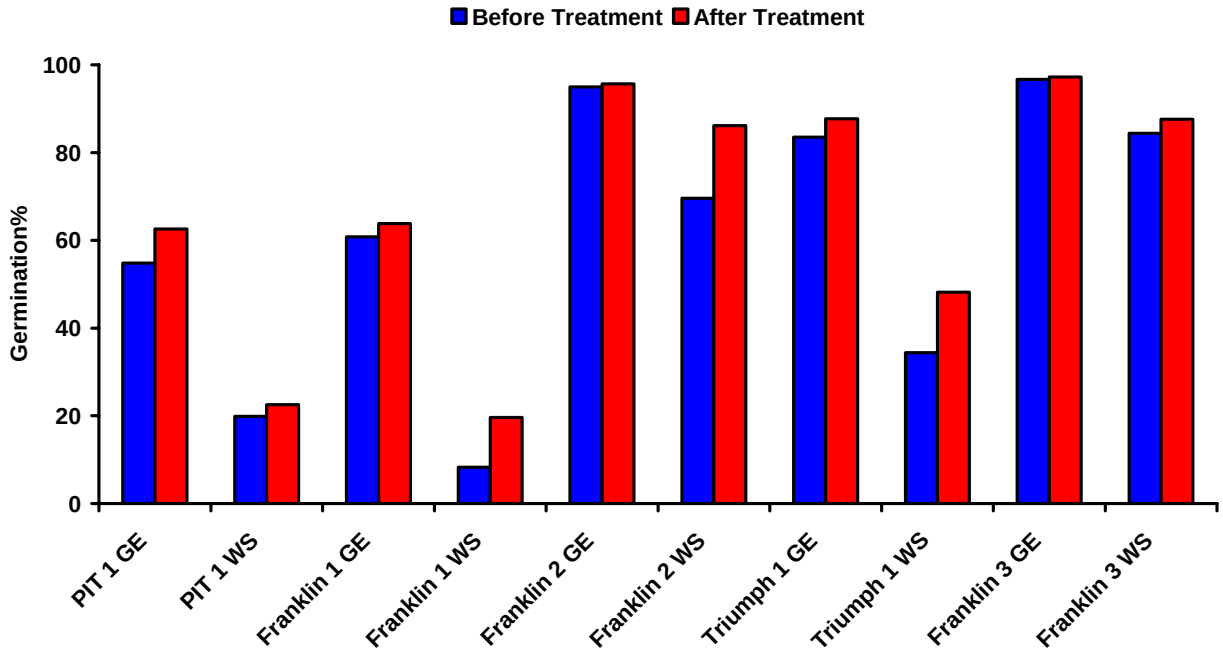

Figure 1. Germination Energy and Water Sensitivity of five dormant or water sensitive barley samples before and after treatment with Vapormate™.

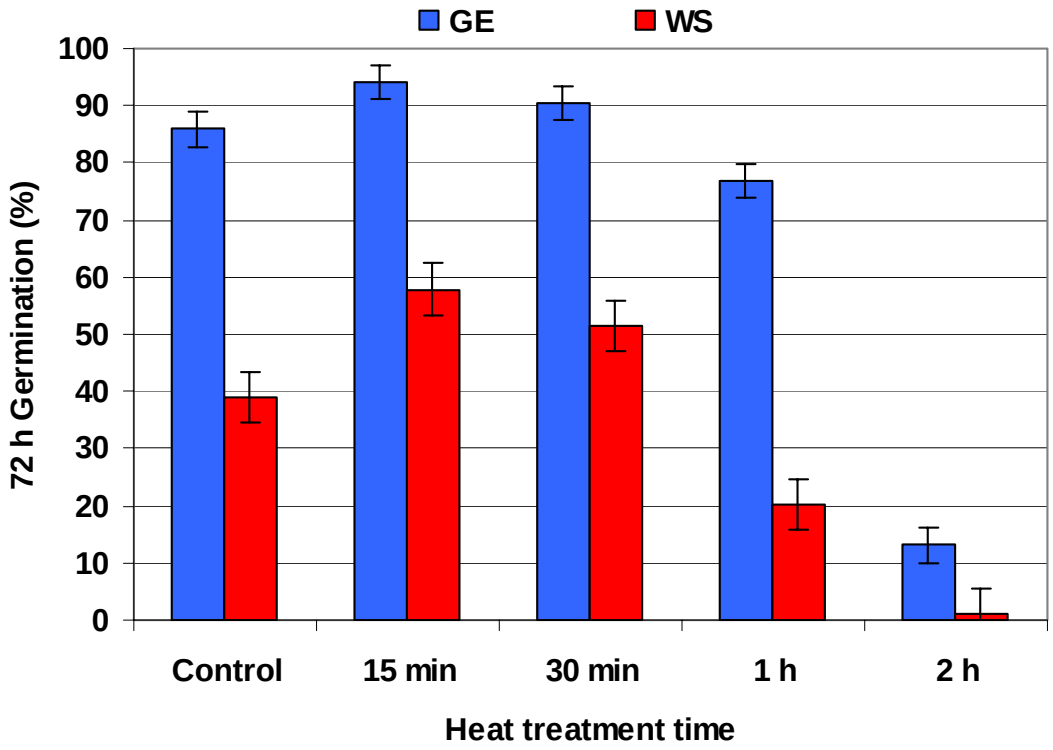

Figure 2. Germination of barley var. *Triumph 1* heat treated at 70°C for different lengths.

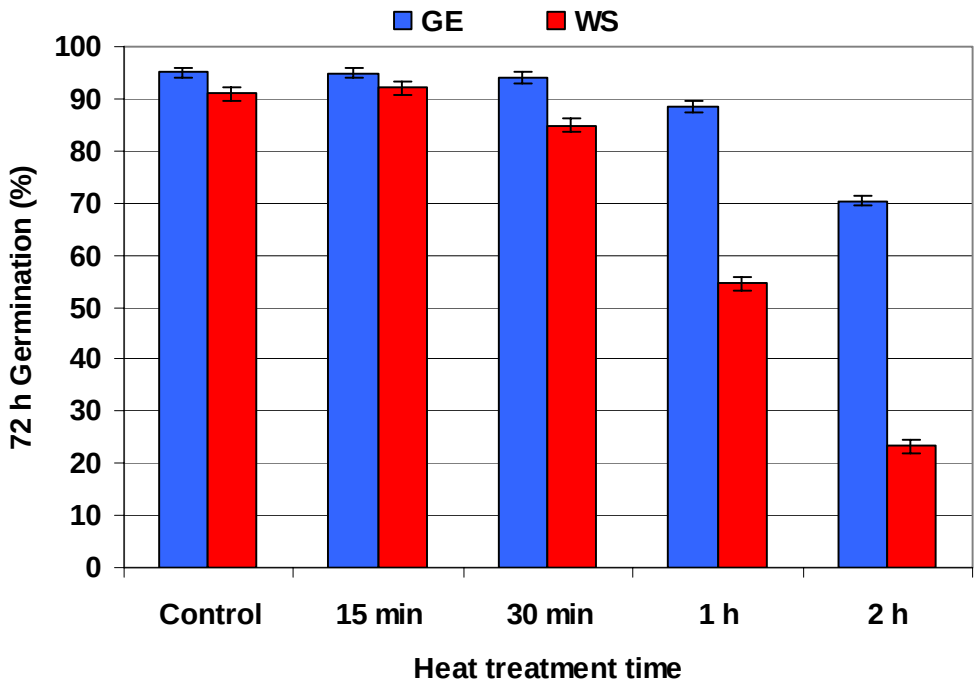

Figure 3. Germination of barley var. *Stirling 1* heat treated at 70°C for different lengths of time.

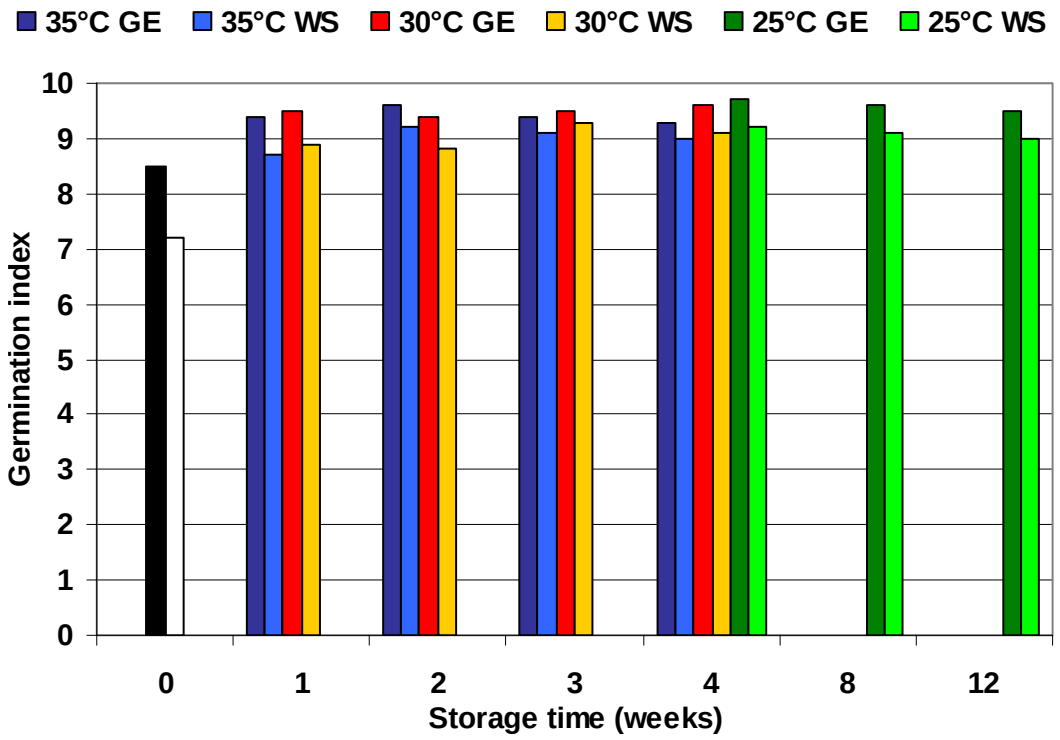

Figure 4. Change in germination index of barley var. *Franklin 2* with accelerated maturation. Black (GE) and white bars (WS) show germination indices before storage.

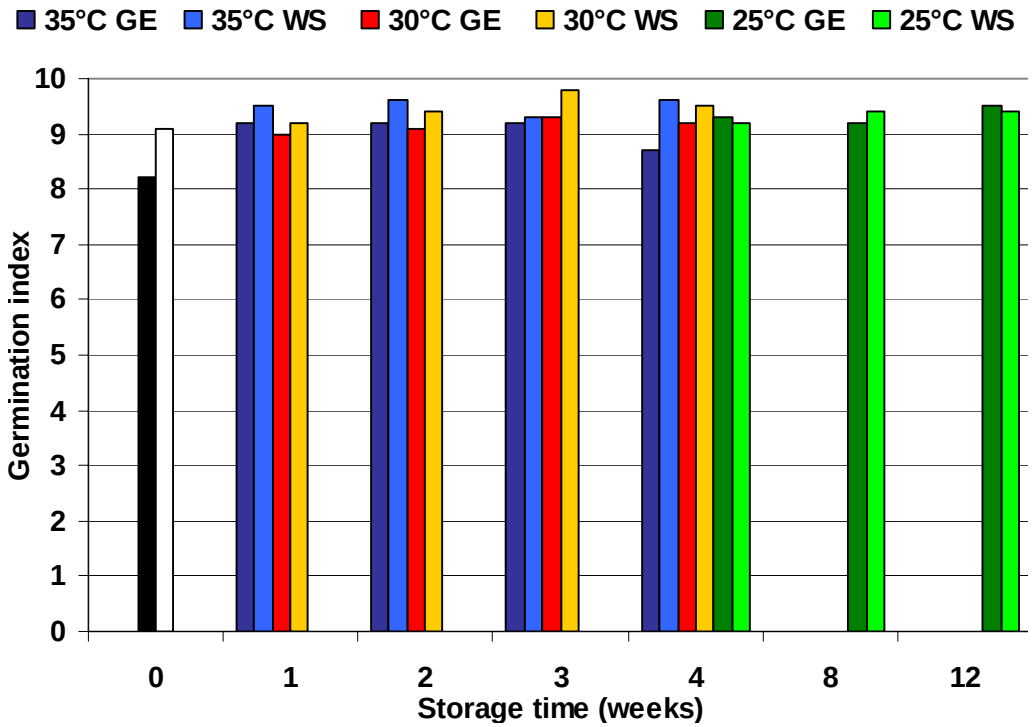

Figure 5. Change in germination index of barley var. *Stirling 1* with accelerated maturation. Black (GE) and white (WS) bars show germination indices before storage.

Summary and Conclusions

The treatment of grain with ethyl formate to break dormancy appeared to be a promising option as long as the risk of damage to the grain can be controlled. Existing preparations should be used to avoid additional registration requirements. Treatment at high concentrations must be restricted to grain with pronounced levels of water sensitivity. Silo scale trials, which currently focus on pest control and residues, should be used to gather further information of phytotoxic effects. Treatment with heat also showed promise as an option to reduce dormancy, but the risk of damage to the grain needs to be carefully controlled. In practice, this means treatment at low moisture, and an awareness of the of the heat sensitivity of cultivars to be treated. A reliable comparative measurement of heat sensitivity of barley needs to be developed. Fluidization should be given preference over static heat exposure.

Perhaps the safest and most effective method for improving the germination of barley was storage at higher than conventionally recommended storage temperatures. This should only be applied to grain with appropriate mc and storage potential. This method could be included in an on-farm storage plan by delaying aeration cooling for a short period, or by raising the temperature of grain bulk by aeration with warm ambient air, followed by cooling after dormancy is broken. The success of such an approach would rely heavily on the availability of models of the storage potential of different types of malting barley, which can be used to maximise germination at precisely the right time and without a loss of malting quality.

We compared three options for breaking dormancy and decreasing water sensitivity. The common factor in all these treatments was the variable response of samples to the same treatments. This can be explained by cultivar (genetic variation), by growing and harvest conditions (environmental variation), post-harvest conditions prior to the experiments, and by the interaction between these factors. The type of material that is to be treated needs to be well understood if any of the proposed post-harvest treatments are to be applied. Consequently, the development of sophisticated and reliable diagnostics procedures that have the capacity to precisely define and monitor grain characteristics are critical to successful treatments. Furthermore, an understanding of the biochemical and molecular processes that define post-harvest changes in barley is necessary to make informed decisions on the type of grain suitable for treatment.

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