Study of the Effects of Pre-harvest Sprouting on the Storability and Malting Quality of Three Canadian Malting Barley Varieties

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ABSTRACT

Variations in the germination and malting performance during storage of three Canadian malting barley varieties AC Metcalfe, CDC Kendall and CDC Copeland, which had suffered from different degrees of pre-harvest sprouting damage (PHSD) at harvest, were examined. These barley samples were collected in Saskatchewan, Canada during two successive crop years (2007-2008). During storage significant changes in germination energy and water sensitivity for all PHSD barley samples were recorded; the higher the degree of PHSD the more variations in germination energy and water sensitivity were observed. Barley samples stored at higher temperatures showed more variations than those samples stored at lower temperatures. Difference between varieties in germination energy and water sensitivity and their interactions with storage conditions were also recorded. In malting trials, at steep the barley samples with higher degrees of PHSD showed faster water uptake and obtained lower chitting rates than samples with lower PHSD or samples devoid of PHSD. Barley samples with a high degree of PHSD stored at higher temperatures exhibited lower chitting rates than samples with the same degree of PHSD stored at lower temperatures. Some varietal differences in water uptake and chitting rate were also recorded. The trial results suggested that germination energy, water sensitivity and malting performance were all sensitive to PHSD and storage conditions.

Key words: pre-harvest sprouting, storage, malting.

INTRODUCTION

Pre-harvest sprouting (PHS) is defined as germination of seeds on the plant before the grain is gathered in and threshed\(^3\). It typically occurs when rainy or wet weather conditions delay harvest in the field. PHS is a serious and worldwide problem\(^2,15\) for barley growers, traders and end-users, particularly for the malting industry when unfavourable harvest weather occurs. PHS can cause potential germination loss in barley during storage\(^4,14\), which leads to the loss of suitability for malting. Because of problems in the malting process such as uneven germination and acrospire growth finished malts exhibit poor modification and/or unacceptable quality.
In general, plants with lack of seed dormancy are more susceptible to PHS\textsuperscript{12,13}. Unfortunately, most of the current malting barley varieties grown in Canada and USA have no or very limited dormancy\textsuperscript{11}. Thus, low dormancy combined with wet weather conditions at harvest on the Canadian prairies and in the upper Midwest of USA in recent years (since 2002) has led to very high PHS percentages in newly harvested barley. This resulted in serious problems in terms of barley's overall quality and selection rate for malting use. Although, in Canada and USA, the tolerance for sprouted kernels is 2% to 3% at selection (in the UK the tolerance limit is less than 5%)\textsuperscript{4}, and barley would be rejected for malting use to avoid potential problems. However, in some crop years, maltsters have to raise the tolerance limit for barley suffering from PHS due to the shortage of quality barley. Therefore, PHS imposes serious technological and economic impacts on both maltsters and growers.

Although, there are extensive works carried out on the relationships between PHS and dormancy, as well as on methods for PHS testing\textsuperscript{12,10}, there is limited information on how to avoid the potential losses in germination during storage for barley that had suffered from PHS, and how to process the PHS damaged barley at commercial malthouses.

The present study examined the effect of PHSD on barley's storability and malting performance of 2007 and 2008 crop year barley samples of AC Metcalfe, CDC Copeland and CDC Kendall, which had suffered from different degrees of PHSD at harvest. We probed the factors which may accelerate the changes in barley's germination energy and water sensitivity during storage, which could lead to cause processing problems and undesirable malt quality.

**MATERIALS AND METHODS**

**Barley samples**

Malting barley (*Hordeum vulgare* L.) varieties used in this study were Canadian AC Metcalfe, CDC Copeland and CDC Kendall. The samples of commercially grown AC Metcalfe, CDC Copeland and CDC Kendall barley were harvested in 2007 and 2008 from representative growing areas in Saskatchewan, Canada. These barley samples had experienced different degrees of pre-harvest sprouting damaged (PHSD) due to the undesirable wet weather in the grain filling stage and at harvest. In this study, the degree of PHSD was defined by commercial barley selectors based on the results of a pearling test (CGC Official Grain Grading Guide, 2011). Quality parameters for the barley samples included this study all met the quality specifications required for selecting malting grade barley, except for the degrees of PHSD (Table 1).

**Storage conditions**
Barley samples were cleaned using a Dockage Tester (Carter Day, USA) with a 2.38 mm screen. The cleaned samples were sealed in plastic containers and the sealed samples were stored up to 210 days (from January to August) at room temperature (@20 ~ 25°C), at a constant low temperature (in a cold storage facility, @0 ~ -10°C), and at a typical outdoor grain bin temperature (@-20 ~ +25°C) duplicating storage conditions on a farm. During this study, barley samples were taken from the storage sites at defined intervals for examining the changes in germination (germination energy and water sensitivity) and malting performance.

**Germination testing and malt quality analysis**

The germination energy (4ml) and water sensitivity (8ml GE) were determined in duplicate using ASBC methods (Barley 3). Malt friability, Kolbach Index, α-amylase, diastatic power and FAN were analyzed according to ASBC methods (Malt 5, 6, 7, 8 and 12).

**Malting test**

Prior to micro-malting, samples of each variety at the defined storage dates were taken from the storage sites, and kept at the lab overnight. Barley samples (500g d.b. each) were randomly placed within a Phoenix micro-mating unit. Malting was carried out with the following regime: steeped @13ºC for 41 hrs (9hr Wet-18hr Dry-8hr Wet-12hr Dry); germinated @15ºC for four days, then kilned with a 24hr-regime (55ºC/12 hr; 65ºC/6hr; 75ºC/2hr; 85ºC/4hr).

**RESULTS AND DISCUSSION**

**Effect on germination energy (GE)**

Under the trial storage conditions, when stored up to 210 days (from January to August), CDC Kendall, CDC Copeland and AC Metcalfe samples harvested in 2007 and 2008 crop years all showed significant changes in GE value with increased storage time (Figs. 1, 2 and 3).

For 2007 CDC Kendall barley samples with 0%, 3% and 10% PHSD (Fig. 1), when stored at room temperature, all trial samples were able to maintain stable GE values within the first 30 days, and after this period, drastic decreases in GE values were recorded for samples with 3% and 10% PHSD. A limited decrease in GE value for the samples with 0% PHSD was recorded. In contrast, when stored at a constant low temperature and at grain bin temperature, all CDC Kendall samples were able to maintain their GE values throughout the entire storage period. However, the samples
with PHSD showed reduction in GE value with increased storage time regardless of the storage conditions.

The changes in GE value for 2008 CDC Kendall samples (Fig. 1) generally agreed well with the variations in GE value recorded in the 2007 CDC Kendall samples. 2008 CDC Kendall samples with 0% PHSD stored at all three storage temperatures maintained good GE values over the entire storage period. Similarly, CDC Kendall samples with 4.8% PHSD stored at a constant low temperature maintained good GE values, but showed decreased GE values after 150 days of storage when stored at room temperature and at grain bin temperature. The samples with 13% PHSD were able to maintain their GE values when stored at a constant low temperature but did show reductions at the end of storage. When stored at room temperature and grain bin temperature the samples with 13% PHSD showed a continuous decrease in GE values.

The variations in GE value for CDC Kendall suggested that during storage CDC Kendall samples with PHSD tend to lose GE values more rapidly, particularly when the samples were stored at higher temperatures. Low storage temperatures tend to slow down the decrease in GE value over time.

For 2007 CDC Copeland barley (Fig 2), the sample with 0% PHSD stored at room temperature showed no obvious changes in GE value during the first 90 days of storage, after this point a continuous decrease in GE value occurred. When stored at a constant low temperature and at grain bin temperature, 0% PHSD samples maintained GE values well throughout the entire storage duration. CDC Copeland barley samples with 3% and 6% PHSD stored at room temperature showed a continuous decrease in GE value during storage, in contrast, when stored at a constant low temperature and at grain bin temperature, the GE values remained stable during storage, although some decreases in GE value were recorded for 6%PHSD sample at the end of the storage period.

Under the trial storage conditions, in general, the changes in GE value for 2008 CDC Copeland barley samples with 0%, 3% and 16% PHSD were comparable to 2007 CDC Copeland samples. Lower storage temperatures negated changes in GE value, and the samples with PHSD tended to lose GE more rapidly than the samples with 0% PHSD, particular, when the samples were stored at higher temperatures.

For 2007 AC Metcalfe barley samples with 0%, 3% and 10% PHSD (Fig. 3), when stored at room temperature, all the samples showed continuous decrease in GE values with increased storage time. In contrast, when stored at a constant low temperature, all the samples were able to maintain their GE values up to the end of storage. When stored at grain bin temperature they showed a gradual decline in GE value. During storage the samples with PHSD showed more variations in GE values than the samples with 0%PHSD.
For 2008 AC Metcalfe barley samples with 0%, 5.3% and 10% PHSD (Fig. 3), the samples with 0% PHSD maintained GE values during storage regardless of the storage temperature. In contrast, samples with 5.3% and 10% PHSD stored at constant low temperature and at grain bin temperatures showed some changes in GE value comparable to the 2007 AC Metcalfe samples. When stored at room temperature, the 2008 samples at 5.3% and 10% PHSD showed more reduction in GE value than 2007 AC Metcalfe samples.

In summary, CDC Kendall, CDC Copeland and AC Metcalfe samples showed more decline in GE values when stored at room temperature than when stored at lower temperatures. Greater variations in GE values were recorded for barley samples with a higher degrees of PHSD. Lower storage temperatures either significantly delayed or reduced the decline in GE value, although there were some varietal differences in the response to storage temperature over time. The effect of room temperature storage on GE values recorded in this study contradicted the results reported by Woonton and his coworkers. They found that GE values for barley samples of three Australian varieties improved with storage time when stored at room temperature (22-27°C) for up to one year.

Effect on water sensitivity (8mL GE)

For 2007 CDC Kendall samples with 0%, 3% and 10% PHSD (Fig. 4), 8mL GE values for all the samples decreased with storage time regardless of the degree of PHSD and storage temperature. In addition, significant differences in 8mL GE value at the beginning of storage were recorded among these barley samples, 10% PHSD sample had the highest 8mL GE value, and 0% PHSD sample had the lowest 8mL GE. Storage temperatures showed a significant impact on the changes in the 8mL GE values during storage. The samples stored at room temperature showed more decrease in 8mL GE than the samples stored at a constant low temperature and at grain bin temperature. Samples with PHSD showed more reduction in 8mL GE value during storage than the samples with 0% PHSD, particularly when the samples were stored at higher storage temperature.

For 2008 CDC Kendall samples with 0%, 4.8% and 13% PHSD (Fig. 4), 8mL GE values for all the samples stored at room temperature decreased with storage time regardless of the degree of PHSD, however, when stored at a constant low temperature, all the samples were able to maintain their 8mL GE values during storage. In addition, when stored at grain bin temperature, the samples with 0% and 4.8% PHSD maintained their 8mL GE values while 13% PHSD samples showed a trend of gradual decrease in 8mL value. This indicated that there were some significant interactions between the degree of PHSD and storage temperature.

For 2007 CDC Copeland samples with 0%, 3% and 6% PHSD (Fig. 5) all exhibited reducing 8mL GE values with longer storage time regardless of the degree of PHSD and storage temperature. However, it was observed that all samples stored at room
temperature showed more rapid and more significant decreases in the 8mL GE value than samples stored at a constant low temperature and at grain bin temperature. During storage, the samples stored at a constant low temperature showed the least decline in the 8mL GE value and all samples maintained their 8mL GE values well up to the end of the trial storage period.

For 2008 CDC Copeland barley samples with 0%, 5% and 16% PHSD (Fig. 5), when stored at room temperature, all of the samples showed a decrease in 8mL GE value with increased storage time. When stored at a constant low temperature, these samples were able to maintain their 8mL GE values throughout the entire storage period. When stored at grain bin temperature, a limited reduction in 8mL GE value was recorded for the sample with 0% PHSD, while significant reductions in the 8mL GE value were recorded with longer storage for the samples with 5% and 16% PHSD. In general, the results agreed well with those observations recorded with 2007 CDC Copeland samples.

For 2007 AC Metcalfe barley samples with 0%, 3% and 10% PHSD (Fig. 6), as observed with CDC Kendall and CDC Copeland, when stored at room temperature all the samples exhibited a reduced 8mL GE values with increased storage time regardless of the degree of PHSD. When stored at a constant low temperature, the samples with 0% and 3% PHSD showed a steady decrease in 8mL GE values, while the sample with 10% PHSD showed limited decrease in the 8mL GE value. When stored at grain bin temperature, all the samples showed reductions in 8ml GE values, but the reduction was less than in samples stored at room temperature.

For 2008 AC Metcalfe barley samples (Fig. 6), the samples with 0% PHSD showed gradual increases in 8mL GE values during storage, regardless of the storage temperature. In contrast, the samples with 5.3% and 11% PHSD stored at room temperature showed a continuous decrease in 8mL GE values. When stored at grain bin temperature, both samples maintained the 8mL GE value up to 150 days of storage then declined thereafter and when stored at a constant low temperature, significant reductions in 8mL GE values were recorded only after 180 days of storage.

It was observed that for the trial barley varieties, the samples with PHSD were more sensitive to storage temperature than the samples with 0% PHSD, and high storage temperature tended to promote decreasing values in 8mL GE for the samples with higher degrees of PHSD.

The recorded changes in water sensitivity for CDC Kendall, CDC Copeland and AC Metcalfe barley samples were inconstant when compared to the results reported in other studies with different barleys where the water sensitivity decreased with storage time. This suggested that the response of barley’s water sensitivity to storage condition is varietal dependent, and PHSD tended to complicate this response. This is significant to the malting process since barley with strong sensitivity usually requires
maltsters to employ different steeping regimes to improve the malting potential of barley bearing strong water sensitivity.

**Effect on barley water uptake at steep**

In the micro-malting trials, significant differences in water uptake were recorded between barley varieties and within each variety with different degrees of PHSD. In addition, interactions between PHSD and storage temperature were also recorded.

2007 CDC Kendall barley samples with 0%, 3% and 10% PHSD showed an increase trend in water uptake with increased storage time regardless of the degree of PHSD and storage temperature (Fig. 7). However, the samples with higher degrees of PHSD tended to show faster water-uptake, and the samples stored at a constant low temperature and grain bin temperature showed faster water uptake than the samples stored at room temperature regardless of the degree of PHSD.

For 2008 CDC Kendall samples with 0%, 4.8% and 13% PHSD (Fig. 7), the changes in water uptake during storage agreed well with the results recorded for 2007 CDC Kendall. 2008 CDC Kendall samples also showed an increase trend in water uptake with increased storage time regardless of the degree of PHSD and storage temperatures. However, the samples with higher degrees of PHSD showed faster water uptake. Regardless of the degree of PHSD, samples stored at the low temperatures tended to result in faster water uptake than those stored at room temperature.

As observed in CDC Kendall barley samples, 2007 CDC Copeland samples with 0%, 3% and 10% PHSD also showed an increase trend in water uptake with increased storage time regardless of the storage temperature (Fig. 8). On average, the samples stored at the lower storage temperatures showed faster water uptake than the samples stored at room temperature regardless of the degree of PHSD. At the late storage stage, when stored at room temperature and at the constant low temperature, the samples with 0% PHSD showed faster water uptake than the samples with 3% and 6% PHSD.

For 2008 Copeland, the samples with 0%, 5% and 16% PHSD also showed significant changes in water uptake during storage. All the samples showed an increased water uptake with increased storage time, except for the samples with 5% and 16% PHSD, which showed a reduction in water uptake when stored at room temperature. On average the samples stored at the low temperatures tended to take up water faster than the samples stored at room temperature. Also, the samples with higher degrees of PHSD took up water faster than the ones with lower PHSD.

As recorded with CDC Kendall and CDC Copeland, significant changes in water uptake during storage were recorded for 2007 AC Metcalfe samples with 0%, 3% and 10% PHSD (Fig. 9). For the samples stored at a constant low temperature and grain bin temperature, their water uptake increased with increased storage time. For samples
stored at room temperature, the sample at 3% PHSD showed a increase in water uptake, and the samples with 0% and 6 PHSD showed a slight decrease in water uptake.

The general trend in water uptake for 2008 AC Metcalfe with 0%, 5.3% and 11% PHSD was comparable to 2007 AC Metcalfe. The water uptake increased with storage time regardless of the storage temperature. The barley samples with PHSD showed faster water uptake than the samples with 0% PHSD regardless of the storage temperatures.

Although there were varietal differences and crop year variations in water uptake, all the three varieties tested here showed an increased water uptake with storage time. This agreed well with the results reported by other researchers with other Canadian and UK varieties\textsuperscript{7,8}. In addition, it was recorded in this study that PHSD significantly enhanced water uptake of all the three varieties. This suggested that PHSD might have damaged the husk and seed coat, which leads to faster water uptake.

**Effect on chitting at steep**

In the micro-malting trials, it was recorded that there were remarkable differences in chitting rate between the varieties, between the same variety with different degrees of PHSD, and between the samples that were stored at different temperatures.

With increased storage time, 2007 CDC Kendall samples with 0%, 3% and 10% PHSD all showed a decrease in chitting rate across the storage temperatures (Fig. 10). Of these samples, the samples with 3% and 10% PHSD showed greater decreases in chitting rate than the samples with 0% PHSD. When stored at the lower temperatures, all the samples showed either slight decreases or no changes in chitting rate up to 120 days of storage but showed decreases upon longer storage time. During storage, the samples with PHSD showed more variations in chitting rate than the samples without PHSD. The samples stored at room temperature showed more reduction in chitting rate than those stored at a constant low temperature and grain bin temperature, particularly for the samples with PHSD.

For 2008 CDC Kendall barley, the samples with 0% and 4.8% PHSD stored at a constant low temperature maintained chitting rates well throughout the entire storage period, but when stored at room temperature and grain bin temperature they showed significant reductions in chitting rate toward the end of storage. In contrast, the sample with 13% PHSD stored at low temperature maintained its chitting rate well during storage, while when stored at room temperature it showed a rapid and continuous reduction in chitting rate from the beginning of the storage.

For 2007 Copeland barley samples with 0%, 3% and 6%, when stored at room temperature, they showed decreasing chitting rates with increased storage time, particularly for the samples with 3% and 6% PHSD. When stored at a constant low temperature, the samples with 0% and 3% PHSD maintained their chitting rate well.
during the storage; but the sample with 6%PHSD showed slight decrease after longer storage time. When stored at grain bin temperature, the samples with 0% and 3% PHSD showed decreased chitting rates when stored longer while the samples with 6%PHSD showed a continuous decrease in chitting rate, regardless of storage length.

For 2008 CDC Copeland barley samples with 0%, 5% and 16% PHSD, when stored at room temperature all the samples showed a rapid and continuous decrease in chitting rate, when stored at grain bin temperature they showed a similar declining trend but the degree of the reduction was lower. In contrast, when stored at a constant low temperature, 0% and 5% PHSD samples showed no reduction in chitting rate, while the sample with 16% PHSD showed a reduction in the chitting rate. The overall changes in chitting rate for 2008 CDC Copeland were comparable to 2007 CDC Copeland.

For 2008 AC Metcalfe barley samples with 0%, 5.3% and 11% PHSD, the changes in chitting rate generally agreed with that recorded for 2007 AC Metcalfe barley. The sample with 0% PHSD maintained chitting rate well throughout the entire storage time regardless of storage temperatures; while the samples with 5.3% and 11% PHSD maintained chitting rate well during storage when stored at a constant low temperature and grain bin temperature. In contrast, when stored at room temperature, their chitting rates decreased drastically with increased storage time.

Of the three barley varieties, the samples with PHSD when stored at room temperature showed the highest variations in chitting rate, while the sound barley (sample with 0% PHSD) showed fewer changes in chitting rate regardless of storage temperatures. This suggested that the chitting rate for the damaged barley is more sensitive to the storage conditions and storage time than the sound barley.

Effect on malt friability

As one of the major indicators of malt’s overall modification, the changes in malt friability value measured at different storage stages reflected the potential maltability of barley in storage.

2007 CDC Kendall barley samples with 0%, 3% and 10% PHSD, stored under the given storage conditions, all showed a downward trend in malt friability with increased storage time (Fig. 13). The samples with 3% and 10% PHSD showed faster reduction in malt
friability than the samples with 0% PHSD. The samples stored at room temperature showed more reduction in malt friability than those stored at a constant low temperature and grain bin temperature, particularly for the samples with PHSD.

For 2008 CDC Kendall barley samples, the sample with 0% PHSD (Fig. 13) showed increased malt friability when stored at room temperature and the constant low temperature, but showed a downward trend when stored at grain bin temperature. In contrast, the samples with 4.8% and 13% PHSD showed a downward trend in malt friability regardless of the storage temperature, however, the sample with 13% PHSD showed more severe reduction in friability than the 4.8% PHSD sample, particularly when stored at room temperature.

2007 CDC Copeland barley samples with 0%, 3% and 6% of PHSD (Fig. 14), regardless of the storage temperature, showed a decrease in malt friability with increased storage time as observed with CDC Kendall samples. Of these barley samples, samples with higher degrees of PHSD showed lower malt friability and showed more reduction in malt friability during storage. In addition, it was recorded that the barley samples stored at a constant low temperature and grain bin temperature showed less reductions in malt friability than those stored at room temperature.

In 2008 CDC Copeland barley samples with 0%, 5% and 16% PHSD (Fig. 14), during storage they exhibited a trend of friability variations similar to that recorded with 2007 CDC Copeland. All samples showed decreases in malt friability with increased storage time; the samples stored at room temperature and grain bin temperature showed more reductions in malt friability than those stored at a constant low temperature. Also, the samples with PHSD showed more rapid reductions in malt friability than the sample with 0% PHSD, particularly when the samples were stored at room temperature.

In 2008 CDC Copeland barley samples with 0%, 5% and 16% PHSD (Fig. 14), during storage they exhibited a trend of friability variations similar to that recorded with 2007 CDC Copeland. All samples showed decreases in malt friability with increased storage time; the samples stored at room temperature and grain bin temperature showed more reductions in malt friability than those stored at a constant low temperature. Also, the samples with PHSD showed more rapid reductions in malt friability than the sample with 0% PHSD, particularly when the samples were stored at room temperature.

In 2007 AC Metcalfe barley samples with 0%, 3% and 10% PHSD, as observed in CDC Kendall and CDC Copeland, AC Metcalfe recorded decreased malt friability with increased storage time (Fig. 15). Most importantly, storage temperature did exert a significant effect on malt friability, and the samples with PHSD stored at room temperature showed sharper declines in friability than those stored at a constant low temperature or grain bin temperature.

Variations in friability values also were observed in 2008 AC Metcalfe barley samples with 0%, 5.3% and 11% PHSD (Fig. 15). Similar to 2007 AC Metcalfe barley samples, the 2008 samples showed a decrease in malt friability with increased storage time regardless of storage temperature. However, the samples with 5.3% and 11% PHSD showed higher reductions in malt friability than the sample with 0% PHSD; and the sample stored at constant low temperature exhibited less reduction in malt friability than the samples stored at room temperature, particularly those samples with PHSD.

PHSD and storage temperature had significant effects on malt friability for all the three barley varieties included in this study, and significant interactions between the degree of
PHSD and storage temperature were recorded. High storage temperatures tended to promote decreases of malt friability for all the samples, particularly for the samples with PHSD.

**Effect on Kolbach Index (KI)**

2007 CDC Kendall barley samples with 0% and 3% of PHSD stored at the three different temperatures all showed increased Kolbach Index (KI) with increased storage time (Fig. 16). In contrast, the sample with 10% PHSD first showed a trend of increase in KI then a decrease after peaking at 120 days of storage. The effect of storage temperature on KI was less evident although the samples stored at room temperature tended to give slightly higher KI than the samples stored at lower temperatures. Regardless of the storage temperature, the samples with a higher degree of PHSD tended to give higher KI than the samples with lower degree of PHSD.

In general, the recorded changes in KI during storage for 2008 CDC Kendall barley samples with 0%, 4.8% and 13% PHSD were similar to that recorded for 2007 CDC Kendall samples (Fig. 16). All the samples showed an increase in KI with increased storage time regardless of storage temperature and degree of PHSD. The samples stored at a constant low temperature and grain bin temperature recorded lower KI than the samples stored at room temperature. Regardless of the storage temperature, the samples with higher degrees of PHSD tended to give higher KI than the samples with lower degrees of PHSD.

2007 CDC Copeland samples with 0%, 3% and 6% of PHSD stored at three temperatures all showed noticeable changes in KI (Fig. 17) and the recorded changes were comparable to the CDC Kendall samples. Samples stored at room temperature tended to give higher KI than the samples stored at lower temperatures. And samples with higher degrees of PHSD showed more variations in KI than the samples with lower degrees of PHSD.

2008 CDC Copeland samples with 0%, 5% and 16% PHSD also (Fig. 17) showed a gradual increase in KI with increased storage time. The general pattern was comparable to that of 2007 CDC Copeland but with more variation.

For 2007 AC Metcalfe barley, the samples with 3% and 10% of PHSD stored at three different temperatures recorded increases in KI with increased storage time, but no significant changes in KI for the sample with 0% PHSD were recorded (Fig. 18). As observed with CDC Kendall and Copeland samples, across the storage temperatures, the samples with higher degree of PHSD tended to give slightly higher KI, and showed more variations than the samples with lower degree of PHSD.

The changes in KI for the 2008 AC Metcalfe samples with 0%, 5.3% and 11% of PHSD were very similar to that recorded with 2008 CDC Kendall and CDC Copeland barley (Fig. 18). AC Metcalfe samples stored at the three temperatures all showed a gradual
increased KI with increased storage time and the samples with higher degree of PHSD tended to give higher KI and exhibited more variation.

Increases in KI with barley storage time for all the three tested barley varieties were evident, and this agreed well with what was reported by other researchers\textsuperscript{7,16}. This could be related to the improvement in activities of the proteolytic enzymes in barley kernels with storage time (No direct test on those enzymes were conducted in this study). The KI changes strongly suggested that PHSD did not show negative effect on protein solubilisation for all the barley samples included in this study, and the high storage temperature tended to enhance KI.

**Effect on Diastatic Power (DP)**

2007 CDC Kendall barley samples with 0%, 3%, and 10% PHSD stored at the three different temperatures showed very obvious changes in DP during storage (Fig. 19). In general, the effect of storage temperatures on DP was more obvious for the samples with PHSD than for the samples with 0% PHSD. All CDC Kendall barley samples stored at a constant low temperature and grain bin temperature either maintained their DP or increased their DP. In contrast, higher variations in DP were recorded for the samples stored at room temperature, where the samples with PHSD exhibited a trend of rapid decline in DP with increased storage time.

When stored at room temperature 2008 CDC Kendall barley samples with 0%, 4.8%, and 13 % PHSD (Fig. 19) showed decreasing DP during storage and the higher the degree of PHSD the more severe the decline in DP became. When stored at a constant low temperature and grain bin temperature the samples with 4.8%, and 13 % PHSD showed less decline in DP than when stored at room temperature. The sample with 0% PHSD showed slight decrease in DP when stored at a constant low temperature and it showed some increase in DP when stored at grain bin temperature.

In general, the effect of storage temperatures on DP was more obvious for the samples with PHSD than for the samples with 0% PHSD. All CDC Kendall barley samples stored at a constant low temperature and grain bin temperature either maintained or slightly increased in DP with storage time. In contrast, higher degrees of variations in DP were recorded for the samples stored at room temperature, where the samples with PHSD exhibited rapid decline in DP with increased storage time.

2007 CDC Copeland barley samples with 3% and 6% PHSD (Fig. 20), when stored at room temperature, showed a trend of gradual increase in DP with increased storage time regardless of storage temperatures. No obvious variations were noted in the samples with 0% PHSD.

2008 CDC Copeland barley (Fig. 20) with 0% PHSD showed an increase in DP with increased storage time regardless of storage temperature; in contrast, the samples with 5% and 16%PHSD showed a reduction in DP when stored at room temperature, but
showed an upward trend when stored at a constant low temperature and grain bin temperature. Under the trial storage conditions, for both crop years, Copeland samples with higher degrees of PHSD showed more changes in DP than the samples with lower degrees of PHSD.

2007 AC Metcalfe barley (Fig. 21), when stored at low temperatures all the samples showed a trend of gradual increase in DP during storage, while when stored at room temperature, 0% and 10% PHSD samples showed decrease in DP during storage, but 3% PHSD sample showed very limited variation in DP during the same storage period. Again, as observed with CDC Kendall and CDC Copeland, the samples with higher degree of PHSD showed more variations in DP than the samples with lower degree of PHSD.

During storage 2008 AC Metcalfe barley samples with 0%, 5.3% and 11% of PHSD (Fig. 21), showed an increase in DP when stored at a constant low temperature and grain bin temperature. When stored at room temperature, the samples with 0%, 5.3% and 11% PHSD showed slight decreases in DP as storage time increased, and the samples with higher degree of PHSD were more sensitive to storage temperature.

In general, for all the three barley varieties included in this study, the effect of storage temperatures on DP was more obvious for samples with PHSD than for the samples with 0% PHSD. DP was maintained or increased with storage time in the samples stored at a constant low temperature and grain bin temperature. In contrast, higher degree of variations in DP were recorded for the samples stored at room temperature, where samples with PHSD exhibited more rapid decline in DP with increased storage time.

**Effect on α-Amylase (AA)**

As observed with the changes in diastatic power, 2007 CDC Kendall barley samples with different degrees of PHSD (Fig. 22) stored at different temperatures all exhibited significant variations in α-Amylase during storage. The samples with 0% PHSD showed a slight increase in α-Amylase with increased storage time regardless of storage temperature. In contrast, the samples with 3% and 10% PHSD showed an obvious trend of increase in α-Amylase when stored at a constant low temperature and grain bin temperature, but a downward trend when stored at room temperature.

For 2008 CDC Kendall barley (Fig. 22), the samples with 0% PHSD stored at three different temperatures showed a gradual increase in α-Amylase with increased storage time up to 150 days then showed some declines thereafter. The sample with 4.8% PHSD exhibited variations in α-Amylase comparable to 0% PHSD samples. In contrast, the sample with 13% PHSD showed a trend similar to the samples with 0% and 4.8%
PHSD when stored at a constant low temperature and grain bin temperature but exhibited a trend of rapid decline in α-Amylase when stored at room temperature.

2007 CDC Copeland barley samples with 0%, 3% and 6% PHSD stored at the three temperatures recorded noticeable increases in α-Amylase with increased storage time (Fig. 23). The sample with 3% PHSD, when stored at room temperature exhibited a decrease after 60 days storage. In general, this agreed with that observed with CDC Kendall samples stored at a constant low temperature and grain bin temperature (Fig. 29).

When stored at room temperature 2008 CDC Copeland barley samples with 0%, 5% and 16% of PHSD (Fig. 23), reported decreasing α-Amylase with increased storage time. When stored at a constant low temperature, the samples were able to maintain their α-Amylase during storage. When stored at grain bin temperature, the samples were able to maintain their α-Amylase during storage, except for 0% PHSD sample, its α-Amylase decreased after being stored for 90 days.

For 2007 AC Metcalfe barley samples with 0%, 3% and 10% PHSD (Fig. 24), when stored at room temperature, all the samples showed a downward trend in α-Amylase with increased storage time. In contrast when stored at a constant low temperature and the grain bin temp, all the samples were able to maintain their α-Amylase or to increase α-Amylase slightly. Of these barley samples, the samples with PHSD showed more variations in α-Amylase during storage than the samples without PHSD.

For 2008 AC Metcalfe samples with 0%, 5.3% and 11% PHSD (Fig. 24), when stored at a constant low temperature and grain bin temperature for stored up to 150 days, no declines in α-Amylase were observed, and afterwards some slight decrease occurred for the samples with PHSD. When stored at room temperature, significantly decrease in α-Amylase level occurred after stored for 150 days, particularly for the sample with PHSD.

As observed with the changes in diastatic power, barley samples of CDC Kendall, CDC Copeland and AC Metcalfe with 0% PHSD showed a slight increase in α-Amylase level with increased storage time, although there were varietal difference and crop year differences. This was in agreement with the results reported by other researchers\(^9,16\); they observed increased activities of amylolytic enzymes during barley storage. In contrast, the barley samples with PHSD showed a downward trend in α-Amylase levels with increased storage time, particularly when stored at high temperatures. Regardless of the storage temperatures, in all of the varieties, the samples stored at room temperature showed more changes in α-amylase during storage, the least variations in α-amylase level were recorded for the samples stored at the lower temperatures. This suggested there were some significant interactions between the degree of PHSD and storage temperature. This indicated that high storage temperature had detrimental effect on barley’s potential enzyme development during the malting process.
Conclusions

Under the storage conditions defined in this study, all the barley samples exhibited significant changes in germination energy, water sensitivity, water-uptake, chitting rate and overall malt quality. It was observed that there were some varietal differences in storability and some interactions between varieties, degrees of PHSD, storage temperature and duration. PHSD had adverse effects on barley’s maltability and quality of resultant malts. Quality deterioration occurred after increased storage duration, particularly for the samples with PHSD stored at higher temperatures.

The key points derived from this study are:

Barley samples with higher degrees of PHSD exhibited greater declines in germination energy and increased water sensitivity as storage time increased.

Storage conditions significantly influenced the changes in germination energy and water sensitivity. Higher storage temperature resulted in lower germination energy and higher water sensitivity in barley samples with PHSD.

For the barley samples with PHSD, during storage CDC Kendall exhibited the greatest decreases in germination energy and increases in water sensitivity, followed by CDC Copeland and AC Metcalfe.

In malting, for all three varieties the water uptake rate increased with storage time, and the samples with PHSD showed faster water uptake than the samples without PHSD regardless of storage duration.

In malting, for all three varieties the higher the degree of PHSD the greater the decrease in chitting rate as storage time increased, particularly, for the samples stored at higher temperature.

With 0% PHSD, CDC Kendall, CDC Copeland and AC Metcalfe barleys produced quality malt when stored up to 210 days, regardless of storage temperatures.

With 3-13% of PHSD CDC Kendall barley produced quality malt when stored at higher storage temperatures for up to 60 days; when stored at a lower temperature this period was extended substantially.

With 3-16% of PHSD CDC Copeland barley produced quality malt when stored at higher storage temperatures for up to 60-90 days, when stored at a lower temperature this was extended substantially.

With 3-11% PHSD, AC Metcalfe produced quality malt when stored at higher storage temperature for up to 90 days, when stored at a lower temperature this period was extended substantially.
The above observations help to lay the foundations for maltsters to develop a strategy for utilizing malting potential of the barley which had suffered from PHSD at harvest.

ACKNOWLEDGMENTS

We are grateful to Mr. Leigh Lamontagne and Mr. Jeff Danielson of the Viterra for selecting and providing barley samples for this study and to CMBTC technical staff Deye Tian and Aleksander Eg for their technical assistances during the course of this study. We extended our sincere thanks to the CMBTC board for allowing us to publish this paper and providing financial assistance for conducting this study.

REFERENCES:


Abbreviations used: AA (α-amylase), DP (Diastatic Power), GE (Germination Energy), KI (Kolbach Index), PHSD (Pre-harvest Sprouting Damage), WS (Water Sensitivity), RT (Room Temperature), CLT (Constant Low Temperature), GT (Grain Bin Temperature); PHS (Pre-harvest Sprouting), PHSD (Pre-harvest Sprouting Damage)
Table I. Analysis of AC Metcalfe, CDC Copeland and CDC Kendall barley samples from 2007 and 2008 crop years.

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<th>Protein, %</th>
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<th>Germination, % (8ml)</th>
<th>1000 Kernel, wt g</th>
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Legends to Figures

Fig. 1. Changes in germination energy (GE) during storage for 2007 and 2008 crop CDC Kendall barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 2. Changes in germination energy (GE) during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 3. Changes in germination energy (GE) for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 4. Changes in water sensitivity (8mL GE) during storage for 2007 and 2008 CDC Kendall barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 5. Changes in water sensitivity (8mL GE) for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), the constant low temperature (CLT) and grain bin temperature (GT).

Fig. 6. Changes in water sensitivity (8mL GE) for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 7. Changes in water uptake during storage for 2007 and 2008 CDC Kendall barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 8. Changes in water uptake during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 9. Changes in water uptake during storage for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 10. Changes in chitting rate during storage for 2007 and 2008 CDC Kendall barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 11. Changes in chitting rate during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).
Fig. 12. Changes in chitting rate during storage for 2007 and 2008 AC Metcalfe barley samples stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 13. Changes in malt friability during storage for 2007 and 2008 CDC Kendal barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 14. Changes in malt friability during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 15. Changes in friability during storage for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 16. Changes in Kolbach Index during storage for 2007 and 2008 CDC Kendal barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 17. Changes in Kolbach Index during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 18. Changes in Kolbach Index during storage for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 19. Changes in diastatic power during storage for 2007 and 2008 CDC Kendal barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 20. Changes in diastatic power during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 21. Changes in diastatic power during storage for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 22. Changes in α-Amylase during storage for 2007 and 2008 CDC Kendal barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).

Fig. 23. Changes in α-Amylase during storage for 2007 and 2008 CDC Copeland barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).
Fig. 24. Changes in α-Amylase during storage for 2007 and 2008 AC Metcalfe barley samples with different degrees of PHSD stored at room temperature (RT), constant low temperature (CLT) and grain bin temperature (GT).
Figure 1.

2007 Kendall

2008 Kendall
Figure 2.

2007 Copeland

2008 Copeland
Figure 3.

2007 Metcalfe

2008 Metcalfe
Figure 4.
Figure 5.

2007 Copeland

2008 Copeland
Figure 6.

**2007 Metcalfe**

![Graph showing 8ml GE% vs. Storage (day) for 2007 Metcalfe with different treatments marked by lines of different colors and styles.]

**2008 Metcalfe**

![Graph showing 8ml GE% vs. Storage (day) for 2008 Metcalfe with different treatments marked by lines of different colors and styles.]
Figure 7.

2007 Kendall

2008 Kendall
Figure 8.

2007 Copeland

2008 Copeland

PHSD & Temp

Moist, %

0% 3% 6%
RT

0% 3% 6%
CLT

0% 3% 6%
GT

0 day
60 days
120 days
210 days

PHSD & Temp

Moist, %

0% 5% 16%
RT

0% 5% 16%
CLT

0% 5% 16%
GT

0 day
60 days
90 days
150 days
210 days
Figure 9.

2007 Metcalfe

2008 Metcalfe
Figure 10.

2007 Kendall

2008 Kendall
Figure 11.

2007 Copeland

Chitting, %

0% 3% 6% 0% 3% 6% 0% 3% 6%
RT CLT GT
PHSD & Temp

2008 Copeland

Chitting, %

0% 5% 16% 0% 5% 16% 0% 5% 16%
RT CLT GT
PHSD & Temp
Figure 12.

2007 Metcalfe

2008 Metcalfe
Figure 13.

2007 Kendall

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2008 Kendall

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Figure 14.

2007 Copeland

2008 Copeland
Figure 15.

2007 Metcalfe

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0 day, 60 days, 120 days, 210 days

2008 Metcalfe

Friability, %

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0 day, 60 days, 90 days, 150 days, 210 days
Figure 16.

2007 Kendall

2008 Kendall

PHSD & Temp

KL, %

0% 3% 10%

RT

CLT

GT

0 day

60 days

120 days

210 days

0% 4.8% 13%

RT

CLT

GT

0 day

60 days

90 days

150 days

150 days

210 days
Figure 17.

2007 Copeland

2008 Copeland
Figure 18.
Figure 19.

2007 Kendall

2008 Kendall
Figure 20.

2007 Copeland

2008 Copeland
Figure 21.

**2007 Metcalfe**

**2008 Metcalfe**
Figure 22.

2007 Kendall

2008 Kendall
Figure 23.
Figure 24.

2007 Metcalfe

2008 Metcalfe