The Influence of Growing Season Conditions on the End-Use Quality of Wheat

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Abstract
Environmental conditions during the growing season and harvesting are responsible for differences in milling and baking quality between the various grades of Canada Western Red Spring (CWRS) wheat. This presentation provides a review of the 2002 growing season, as well as observed degrading factors and their effects on end-use quality.

The 2002 growing season was particularly challenging due to drought, frost damage, and poor harvest weather. Extremely poor moisture conditions across most of the Prairies delayed planting, caused poor germination, and resulted in uneven stands in northern and central areas. Frost in early August caused damage across the same area, while frequent showers and cooler than normal temperatures during the remainder of the month extended development and promoted secondary growth. Grain filling and harvesting was characterized by wet, cloudy, and cool weather, resulting in very slow harvest progress and causing significant crop weathering. Frost in mid-September also prevented late-planted crops from fully maturing.

This year’s CWRS grade profile was poorer than normal due to a number of degrading factors, most notably sprouting, frost damage, green kernels, mildew, and Fusarium damage (FD). Pre-harvest sprouting results in an overabundance of the enzyme alpha-amylase, causing excessive starch damage that in turn affects flour water absorption and dough handling properties. Frost damage and immaturity influence flour yield, flour color, water absorption, and loaf properties, and may also affect protein quality. Frost-damaged kernels also require more energy during milling due to increased grain hardness. Mildew was a much more prominent degrading factor this year due to conditions during grain filling and harvesting. Mildew may affect flour color and is considered aesthetically unappealing. FD was generally less severe than in previous years due to unfavorable conditions for disease development during anthesis. Besides being responsible for the production of the toxin deoxynivalenol (DON), which is a food safety concern, the main effect of FD is to affect water absorption, dough handling, and protein quality, or composition.

Introduction
The Canadian grain grading system is primarily a visual system based on a combination of subjective and objective measurements (Dexter and Tipples 1987). Environmental conditions during the growing season and harvesting are responsible for differences in milling and baking quality between the various grades of Canada Western Red Spring (CWRS) wheat (Dexter 1993). This paper provides a review of the 2002 growing season, as well as observed degrading factors and their potential effects on end-use quality.

Growing Season in Review
The 2002 growing season was particularly challenging due to drought, frost damage, and poor harvest weather. A dry fall and winter in late 2001 and early 2002 led to extremely poor moisture conditions for the planting of the 2002 crop. Dryness stretched from western Manitoba to the Rocky Mountains and included about 80 per cent of the cropland in Western Canada. Heading into the spring of 2002, Western Canada was the driest since the beginning of settlement of the region. Soil moisture conditions were better in eastern and central Manitoba, but topsoil moisture was less than ideal even in these areas. The extremely dry conditions, combined with cooler-than-normal weather in April and May, delayed seeding
considerably. Planting in Western Canada was only 75 per cent complete by the end of May. However, planting progressed rapidly in eastern Saskatchewan and Manitoba and neared completion by the first week of June. Heavy rains (and in some instances snow) fell in the southern areas of Saskatchewan and Alberta during the first week of June, delaying planting in those regions into the third week of June. The heavy rains caused some flooding in all three provinces, resulting in re-planting, especially in southern Alberta.

Cool weather during May and early June slowed crop growth and development across the Prairies. Heavy rains in the southern Prairies did improve soil moisture conditions, especially in Alberta and Saskatchewan. Northern and central growing areas of Saskatchewan and Alberta remained dry throughout June, and many producers decided to plant into dust. Germination was spotty in these regions, with some crops not emerging until rains occurred in July.

Warmer than normal temperatures during the second half of June increased crop stress, especially in the parched regions of northern Alberta and Saskatchewan. The dry conditions caused uneven emergence in cereal and oilseed crops, with many fields having three to four stages of development. The rainfall pattern of the spring continued into July, with the heaviest rainfall reported in the southern Prairies. Northern regions reported only minimal rainfall accumulations during July, with only isolated areas reporting enough rainfall to improve crop prospects. Even in the regions that had received adequate moisture during the spring, severe heat stress began to take a toll on production prospects during July.

A significant frost event in early August caused crop damage in northern and central areas of Saskatchewan and Alberta, as well as parts of northwestern Manitoba. More importantly, a cool, wet weather pattern settled over the Prairies during the first week in August, bringing significantly above normal rainfall accumulations to most of Saskatchewan and Manitoba (Table 1). The rains brought a flush of secondary growth in the drought regions and delayed maturity in southern areas. Portions of northwestern Saskatchewan, along with most of central Alberta, missed out on the precipitation for the most part.

**Table 1.** August precipitation for selected locations in Saskatchewan and Manitoba.

<table>
<thead>
<tr>
<th>Location</th>
<th>Normal (mm)</th>
<th>Actual (mm)</th>
<th>% of Normal</th>
<th>0.2 mm Normal</th>
<th>0.2 mm Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swift Current</td>
<td>40</td>
<td>123</td>
<td>308</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>Regina</td>
<td>38</td>
<td>115</td>
<td>300</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Moose Jaw</td>
<td>40</td>
<td>108</td>
<td>272</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Estevan</td>
<td>50</td>
<td>130</td>
<td>263</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Yorkton</td>
<td>62</td>
<td>109</td>
<td>176</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Brandon</td>
<td>69</td>
<td>79</td>
<td>114</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Pierson</td>
<td>52</td>
<td>206</td>
<td>397</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>75</td>
<td>91</td>
<td>122</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Morden</td>
<td>70</td>
<td>160</td>
<td>228</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>Pilot Mound</td>
<td>70</td>
<td>175</td>
<td>252</td>
<td>11</td>
<td>17</td>
</tr>
</tbody>
</table>

Source: Environment Canada.

The harvest started in southern Manitoba and southeastern Saskatchewan in the third week of August. Frequent rains during the last week of August and first two weeks of September resulted in downgrading of mature crops in the eastern Prairies. Severe frost was reported by the middle of the month in Saskatchewan and Alberta, bringing an end to the growing season in most areas. Harvest during the last half of September continued to be plagued by frequent light to heavy showers. In eastern growing areas,
significant progress was made during the last two weeks of September, while western areas continued to struggle with poor drying conditions. The uneven growth of crops in Alberta and Saskatchewan continued to delay harvest activity into October. Frequent precipitation events combined with cooler than normal temperatures delayed harvest progress further. Snow during the latter half of October brought harvesting to a standstill, although progress improved in November and early December as temperatures moderated. Precipitation accumulations were well below normal during this period as well.

Summary of Major Degrading Factors

The 2002 CWRS grade profile was poorer than normal due to a number of degrading factors. The proportion of CWRS samples affected by sprouting, mildew, frost damage and immaturity was much higher relative to 2001, attributable in large part to weather conditions encountered during the growing season and during harvesting. Although *Fusarium* damage (FD) was prominent again this year, its severity was reduced relative to 2000 and 2001 due to unfavorable conditions for development of the disease at anthesis.

Sprout Damage

The incidence of sprouting in swathed or standing grain is strongly dependent on weather conditions during both the filling period as well as harvesting. Due to their genetic background, wheat classes such as Canada Western Amber Durum (CWAD), Canada Western Soft White Spring (CWSWS), and Canada Prairie Spring White (CPSW) are predisposed to a higher risk of pre-harvest sprouting relative to CWRS. Conditions favorable for germination, namely prolonged dampness and warm temperatures, promote pre-harvest sprouting. Besides above-normal precipitation during August and September, precipitation was much more frequent compared to normal in August (Table 1). In many instances, notably between August 1-20 and September 1-10, precipitation occurred on consecutive days over a prolonged period (e.g. 15 of 18 days, 8 of 10 days, etc.), increasing the risk of sprouting, particularly in combination with warm temperatures.

The germination process is initiated once water is absorbed by the kernel. At that point, metabolic activities are elevated considerably (Kruger 1981), most notably the synthesis of the enzyme alpha (α)-amylase, particularly in the starchy layers of endosperm (CGC 2002b). Synthesis of α-amylase is generally in proportion to the extent of germination (H. D. Sapirstein, personal communication). In a normal kernel, the amount of α-amylase is approximately 3 to 20 units. Comparatively, a mildly sprouted kernel contains 100 to 200 units of α-amylase, while a single severely sprouted kernel contains between 20K to 30K units of α-amylase. Therefore, a wheat sample that contains a very low level of sprout damage may have a very high level of α-amylase (CGC 2002b; Kruger and Tipples 1980).

Sprout damage tolerances were tightened in 2001 for #2 and #3 CWRS (Table 2) after quality problems were experienced by end-users of both grades in 2000. Severely-sprouted grain being blended off with sound grain) adhered to grade specifications, (i.e. free of sprout damage) but resulted in undesirable end-use quality characteristics due to the very high amylase levels present in the severely sprouted kernels.

Table 2. CWRS sprout damage tolerances prior to and after August 1, 2001.

<table>
<thead>
<tr>
<th>Sprout Damage (%)</th>
<th>Severe (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 CWRS</td>
<td>0.1</td>
<td>no change</td>
</tr>
<tr>
<td>#2 CWRS</td>
<td>----</td>
<td>0.2</td>
</tr>
<tr>
<td>#3 CWRS</td>
<td>----</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The main effect of \(\alpha\)-amylase on end-use quality has to do with its effect on damaged starch (Tipples 1969). During the milling process, starch granules are subjected to physical damage. Damaged starch is much more susceptible to attack by \(\alpha\)–amylase compared to undamaged starch. When flour is mixed with water, \(\alpha\)–amylase breaks down damaged starch into starch molecules of smaller size. Furthermore, damaged starch acts as a sponge, absorbing far more water than undamaged starch (Tipples 1969). Intuitively, increasing water absorption is beneficial to the baker, the increased bread volume per unit of flour as a result of higher water absorption means the consumer is being sold a proportionately higher amount of water compared to flour that absorbs less water. However, whereas water absorption is increased as measured with a recording dough mixer such as a Farinograph, baking absorption is actually reduced, thereby reducing profitability. Baking absorption refers to the maximum amount of water that can be added to a fixed amount of flour without resulting in problems during dough handling and processing (Tipples 1969). During the dough mixing and fermentation processes, the damaged starch becomes liquefied, resulting in the release of water that was initially absorbed by the damaged starch. As a result, the dough becomes sticky and more difficult to handle (Dexter and Edwards 1997; Dexter and Tipples 1987).

Excessive levels of amylase are especially problematic in baking processes that utilize long fermentation times, since the enzyme has more time to act upon damaged starch (Dexter and Edwards 1997; Tipples 1969). Furthermore, loaves are generally more coarse and exhibit a gummier texture (Buchanan and Nicholas 1979; Dexter 1987). Due to the gumminess of the crumb, a gummy deposit tends to accumulate on the surfaces of slicing blades, resulting in poor loaf slicing properties.

Assessment of sprout damage is subjective and done visually (CGC 2002a). Mildly-sprouted kernels are characterized by swollen germs and visible evidence of root and shoot tips; kernels are considered to be severely sprouted if the roots and shoots grow past the edges of the germ area. However, kernels may not exhibit any visible signs of sprout damage, but levels of \(\alpha\)–amylase may still be elevated in the kernel, depending on weather conditions prior to harvesting. Sprout tolerances were tightened for the #2 and #3 CWRS grades in 2001 (Table 2) after problems experienced with the quality of these grades in 2000. Severely sprouted grain being blended off with sound grain resulted in a sample that was reasonably free of sprout damage, but end-use quality characteristics were undesirable due to the very high amylase levels present in the severely sprouted kernels.

Given the inconsistent relationship between visual sprout damage assessment and \(\alpha\)–amylase activity, the grain industry uses objective measurements to assess \(\alpha\)–amylase activity. Currently, the primary objective means of assessing sprout damage in western Canada is the Hagberg Falling Number (FN) test, which is currently the international standard for assessing \(\alpha\)-amylase activity (CGC 2002b). The Hagberg test is based on the time it takes for a plunger to fall through a test tube containing a slurry of ground grain and heated water. The longer it takes for the plunger to fall through the slurry, the lower the \(\alpha\)–amylase activity. A FN less than 250 seconds is generally considered undesirable for CWRS (CGC 2002b).

The Canadian Grain Commission (CGC), along with the Canadian Wheat Board, initiated a pilot program in 2002 to use the Rapid Visco Analyzer (RVA) to evaluate sprout damage in wheat and durum. The RVA evaluates sprout damage in a similar manner as the Hagberg test. However, RVA equipment is easier to clean and set up compared to Hagberg equipment. The long-term goal is to replace visual assessment of sprout damage as a degrading factor with the RVA.
Mildew

Mildew, which is caused by *Cladosporium* spp. (Dexter and Edwards 1997), was by far the most prevalent degrading factor this year across the Prairies, occurring as a result of persistent, showery weather and poor drying conditions during August and September. Since prolonged periods of damp, cool weather promote the development of mildew, particularly in swathed grain (Dexter and Matsuo 1982), mildew is typically associated with weathering and sprout damage (Dexter and Edwards 1997). Mildew damage is characterized by tufts of grey spores at the distal ends of the kernel (Dexter and Tipples 1987).

Assessment of mildew damage is subjective and depends on the appearance of the grain to the grader (Dexter 1993). The effect of mildew on milling quality depends on the severity of the damage (G. Worden, personal communication). If damage is light (i.e. solely present at the tip of the kernel), mildew can usually be removed prior to milling by scouring during the cleaning process. However, if mildew is embedded in the crease, it cannot be removed by scouring. Severely mildewed kernels are rotten, appear bin-burnt and blackened due to the presence of spores inside the kernel, and are spongy (CGC 2002a). Furthermore, severely mildewed kernels are tolerated at very low levels in CWRS wheat. In order to grade #1 CWRS, a 1000g sample of wheat (usually about 30K kernels) can contain no more than one severely mildewed kernel. Comparatively, #2 CWRS can contain no more than a maximum of 4 severely mildewed kernels per 1000 g, and # CWRS can contain no more than 6 severely mildewed kernels per 1000 g.

Mildew has been demonstrated to reduce test weight and FN in Ontario wheat samples (Dexter and Edwards 1997), although flour yield is reduced and flour ash content is increased only in severe cases (Dexter and Tipples 1987). Although mildew does not pose a toxicological hazard, the main effect of mildew on end-use quality is to darken flour, resulting in darker end products that are aesthetically unappealing such as breakfast cereals (Dexter and Edwards 1997). In durum wheat, mildew damage causes dark specks in semolina (Dexter and Matsuo 1982).

Frost Damage and Immaturity

Frost damage and immaturity are often closely related, since kernel immaturity may occur as a result of a freeze event. Immaturity is characterized by green or grass green kernels due to incomplete kernel maturation. In 2002, as previously described, many fields exhibited multiple stages of crop development due to spotty germination as a result of poor moisture conditions. As a result, a much higher than normal proportion of fields exhibited very uneven development, making the decision as to when to swath or straight-cut harvest much more difficult.

The effect of frost damage on end use quality is dependent on the stage of crop maturity as well as the duration and severity of the freeze event (Dexter and Edwards 1997, Preston et al. 1991). Frost during early filling affects physiological processes substantially such as protein synthesis (see protein quality discussion below), resulting in immature kernels and a considerable reduction in end-use quality. At later stages near kernel maturity, frost has less of an effect on physiological development, but can cause wrinkling of the bran.

Frost damage and immaturity affect milling performance by increasing ash content and reducing flour colour (Tipples 1980). Frost damage increases kernel hardness, increasing milling energy costs and starch damage levels (Dexter et al. 1985). The flour yield of the first set of break rolls in the mill is reduced, in turn increasing the flow of milling stock to the tail-end of the mill, thereby increasing energy requirements. Preston et al. (1991) also found that frost-damaged wheat had a higher proportion of shorts (branny material) compared to sound wheat due to increased difficulty in separating endosperm from the bran. The authors postulated that the heavy yield of milling shorts attributed to frost-damaged grain is due to the disruption of cell structure as a result of ice formation. Tipples (1980) showed immaturity
resulted in poorer loaf crumb color and reduced dough strength. Similar results were observed by Preston et al. (1991), although the effect of frost damage and immaturity on dough strength was more pronounced compared to the effect on baking quality parameters.

**Fusarium Damage**

Fusarium head blight (FHB) is a fungal invasion of small grain kernels that causes significant structural damage to the kernel (Nightingale et al. 1999). Development of FHB is associated with moist, warm conditions during the flowering period. The severity of FD in Manitoba in 2002 was considerably lower compared to 2001 and 2002, since rainfall accumulations in southern areas of the province were well below normal. The most prevalent form of *Fusarium* in the black soil zone of western Canada is *F. graminearum* (Clear and Patrick 2002).

As a grading factor, FD is based on objective measurement (CGC 2002a). A grain sample is hand picked to remove kernels that display any evidence of FD and is assigned a grade based on the percentage of FD in the sample (by weight). The maximum FD of #1, #2, and #3 CWRS are 0.25, 1.0, and 2.0 per cent, respectively, while Canada Western Feed may contain no more than 5 per cent FD. The FD tolerance for #2 CWRS was revised from 2 per cent to 1 per cent in 1999 in order to protect the quality of the grade.

The primary concern for reduction in wheat quality due to FD relates to food safety and the accumulation of mycotoxins in the grain, namely deoxynivalenol (DON). However studies have shown that FD can also have a pronounced impact end use quality (Dexter and Nowicki 2001; Dexter et al. 1996; Dexter et al. 1999). As a result, FD is an important consideration for setting grade tolerances as well as blending and handling of FD grain. Studies conducted by the CGC (Dexter et al. 1996; Dexter et al. 1999) have shown that FD affects test weight due to the increased presence of shrunken and thin kernels. Furthermore, flour yield may be reduced by FD. More importantly, however, FD results in poorer flour colour and increased ash content.

Although the effect of FD on protein synthesis during kernel development (see protein quality discussion below) influences protein composition during kernel development, proteolytic activity during processing is likely playing a more pronounced role in influencing end-use quality (Dexter and Nowicki 2001), as demonstrated by Nightingale et al. (1999). While proteases actively degrade endosperm proteins during kernel development, proteases are very active during dough mixing and fermentation. The effect of protein degradation serves to result in dough that is weaker and more sticky and extensible. In turn loaf volume is reduced due to reduced dough strength (Dexter et al. 1999). The ability of the protein matrix to retain gas during fermentation is reduced, meaning the effects of FD on loaf volume tend to be more pronounced in breadmaking processes that utilize longer fermentation times (Dexter et al. 1999). Increased stickiness results in problems during processing, particularly dough panning (Dexter et al. 1996; Dexter et al. 1999; Nightingale et al. 1999).

**Effect of Various Frost and Fusarium Damage on Protein Quality and End-Use Quality**

Although protein content is traditionally recognized as the most influential factor affecting wheat breadmaking quality (Bushuk et al. 1969; Finney and Barmore 1948; Shewry et al. 1986), protein quality is also an important consideration. The two protein fractions that constitute gluten protein, namely gliadin and glutenin, each have unique effects on end-use quality (Gupta et al. 1992; MacRitchie 1992; Schofield 1994; Stone and Savin 1999). Gliadin, which is a very heterogeneous protein fraction, is responsible for the viscous properties of dough during mixing (Fido et al. 1997; Wooding et al. 2000). Conversely, glutenin is polymeric protein that exhibits a high degree of inter-molecular bonding (Gianbielli et al. 2001), reduces dough extensibility (Wieser and Kieffer 2001) and is the protein fraction responsible for dough strength (Schofield 1986; Wall 1979).
Interestingly, the accumulation of various protein fractions in the developing grain is both highly ordered and asynchronous (Daniel and Triboi 2002; Jamieson et al. 2001; Stone and Nicolas 1996a; Stone and Savin 1999). The gliadin fraction is detectable within the first 7 to 10 days after anthesis (DAA), is the first storage protein fraction to accumulate in quantity, and is synthesized most rapidly during mid-development of the wheat kernel (Gupta et al. 1996; Panozzo et al. 2001; Stone and Nicolas 1996). The glutenin fraction is not present in the kernel in large quantities until the latter half of the filling period, and is readily detectable around 20 DAA (Gupta et al. 1996; Panozzo et al. 2001; Stone and Nicolas 1996a). Given these results, the ratio of gliadin to glutenin has been shown to increase during the first half of filling and then decrease considerably, particularly at the end of filling when the steep decline in kernel moisture content occurs (Triboi et al. 1990; Triboi and Leblevenec 1995). Clearly, conditions during the filling period are likely to have pronounced effects on protein quality. For example, a reduction in the duration of the filling period due to high temperature stress has been demonstrated to shorten the duration of glutenin synthesis, in turn reducing dough strength (Ciaffi et al. 1996; Corbellini et al. 1997; Stone et al. 1997; Stone and Nicolas 1996b).

Altered protein composition may help to partially explain the poor breadmaking quality of frost-damaged wheat observed by many researchers (Dexter et al. 1985; Preston et al. 1991; Tipples 1980). When frost damage occurs when the grain is physiologically immature, it can have pronounced effects on end-use quality as a result of altered protein composition, presumably as a result of termination of glutenin synthesis. Using scanning electron microscopy to evaluate CWRS and durum wheat kernel microstructure, Dexter et al. (1985) observed that compared to sound kernels, severely frozen kernels had less well-defined kernel structure and a more amorphous appearance (i.e. starch granules were more strongly held in the protein matrix). Using reversed-phase high-performance liquid chromatography (RP-HPLC), Dexter et al. (1994) observed quantitative differences in a number of gliadin bands as the severity of frost damage and immaturity increased in durum wheat. Furthermore, the ratio of gliadin to glutenin actually declined. The authors attributed this observation to premature termination of both gliadin and glutenin synthesis.

FD also has a pronounced effect on protein composition, resulting in reduced baking quality (Dexter and Nowicki (in press)). Dexter et al. (1996) observed an increase in the ratio of gliadin to glutenin in CWRS and durum wheat that displayed high levels of FD, while Nightingale et al. (1999) observed a lack of high molecular weight (HMW) glutenin (i.e. large polymer) in wheat with severe FD. Meyer et al. (1986) demonstrated that wheat with severe FD displayed a lower proportion of HMW glutenin and a higher proportion of low molecular weight glutenin.

Summary
Growing season conditions have a considerable impact on end-use quality of wheat. Under the adverse environmental conditions experienced in 2002, a number of downgrading factors affected this year’s CWRS grade pattern. Dryness early on during the growing season set the stage for reduced yields and delayed crop maturity, while harvesting conditions led to weathering, as well as its subsequent effects on end-use quality.

References


