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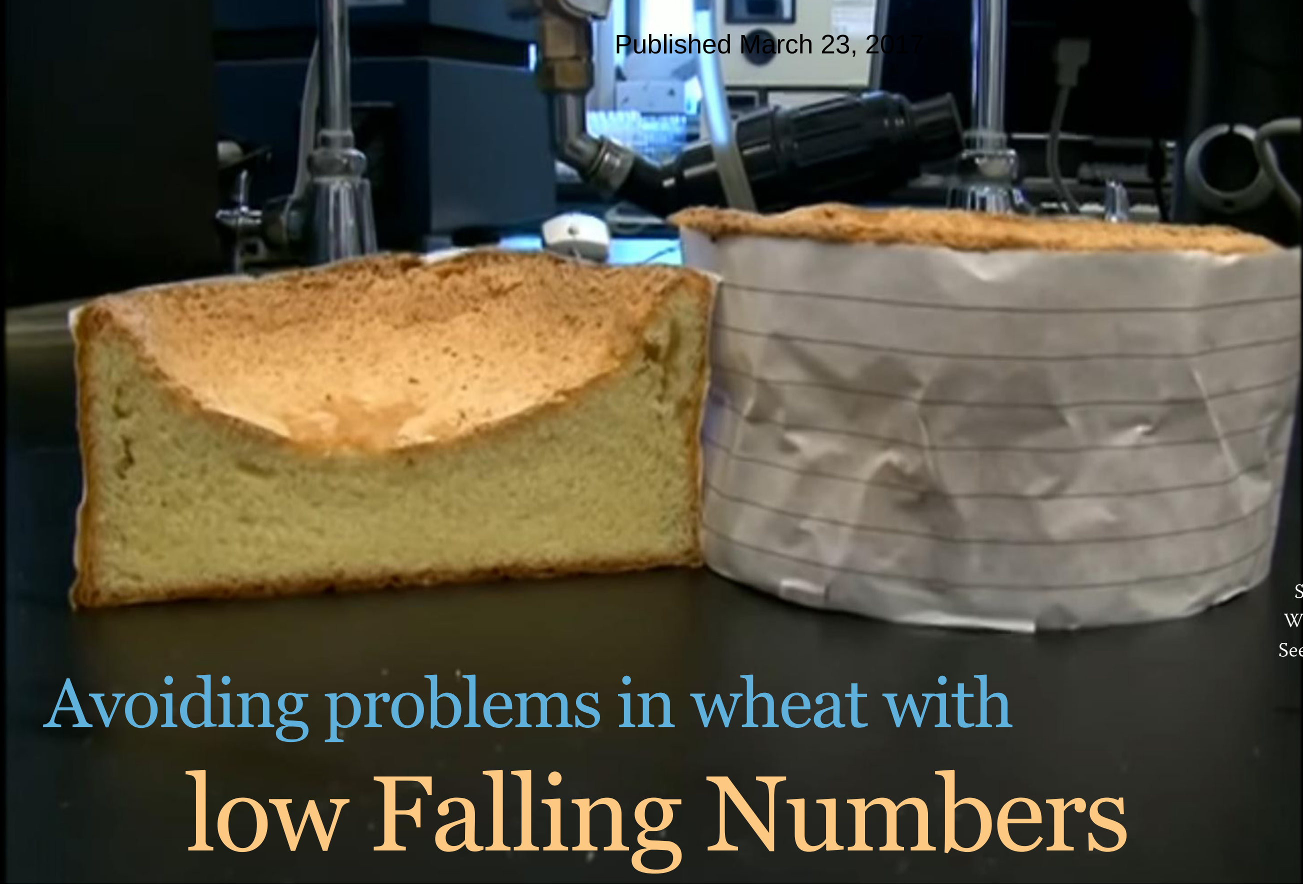

Fig. 1. Sponge cakes fall with the increasing alpha-amylase content that can come from preharvest sprouting (left). The sponge cake on the right was made from sound wheat flour. Source: Screenshot from an Idaho Wheat commission video. See http://bit.ly/1ISXYEz.

Avoiding problems in wheat with low Falling Numbers

The Northwest wheat-growing states suffered from widespread problems with low Falling Numbers (FN) in 2016. This article discusses the roles of preharvest sprouting and late-maturity alpha-amylase in triggering low FN as well as possible management strategies. Earn 0.5 CEUs in Crop Management by reading this article and taking the quiz at www.certifiedcropadviser.org/certifications/self-study/826.

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The Hagberg–Perten Falling Number (FN) method is used to detect starch degradation due to alpha-amylase enzyme activity in wheat meal (Perten, 1964). The Falling Number test was introduced in the 1960s to measure alpha-amylase activity due to sprout damage in wheat. Sprout damage is caused by the enzyme alpha-amylase, which cleaves long starch chains in the wheat endosperm into shorter pieces, resulting in poor bread, cake, and noodle quality. A mixture of sound wheat flour in water will gelatinize upon boiling. Starch chains cleaved by alpha-amylase fail to gelatinize well. In the FN test, a flour/water slurry is stirred for 60 seconds, and then the FN instrument measures how long it takes the stirrer to fall to the bottom of the tube in seconds (see http://bit.ly/1ISXYEz). Alpha-amylase in the sample will decrease gelatinization of the slurry, causing the stirrer to fall faster, resulting in a lower FN. Wheat may be discounted by $0.25/bu for every 25 seconds below 300 seconds. Farm-

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ers get frustrated by this system because the variation in the FN test can be quite high. However, marketers are forced to use the FN test because foreign buyers request this information. Marketers must sell grain with an FN below 300 seconds at a discount because the reduced ability to "gel" is risky for baking, causing cakes to fall, noodles to be sticky, and bread that doesn't rise well (Farrand, 1964; Batey et al., 1997; Gooding and Davies, 1997). For example, sponge cakes show an increasing tendency to fall with increasing alpha-amylase levels (Fig. 1).

There are two main causes of low FN: preharvest sprouting and late-maturity alpha-amylase (LMA) (Lunn et al., 2001; Mares et al., 2014). Preharvest sprouting (PHS) is the initiation of grain germination on the mother plant in response to rain before harvest, and LMA is the induction of alpha-amylase in response to large temperature changes during late-grain maturation. It appears that both forms of weather-induced low FN occurred in 2016.

Preharvest sprouting

During PHS, alpha-amylase is produced as a natural part of seed germination (reviewed by Rodríguez et al., 2015). The enzyme degrades starch for use as fuel by the growing seedling. This alpha-amylase is important for seedling emergence and vigor. Hence, selection for rapid seedling emergence can inadvertently lead to PHS susceptibility.

Differences in seed dormancy explain 60 to 80% of the variation in PHS susceptibility (DePauw and McCaig, 1991). Some wheat varieties can germinate immediately after the grains mature while some cannot (Tuttle et al., 2015). Varieties that are unable to germinate immediately after maturity are considered dormant or "asleep." Several major loci providing increased grain dormancy and PHS resistance have been mapped or cloned in wheat, providing molecular markers for breeding (Forfana et al., 2008; Munkvold et al., 2009; Nakamura et al., 2011; Liu et al., 2013; Torada et al., 2016).

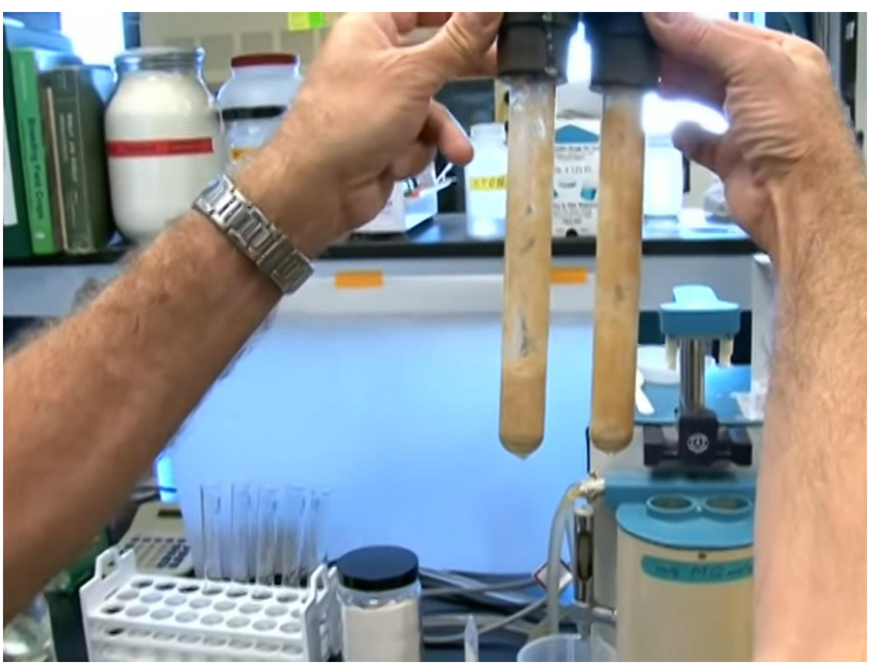
There are two ways to break the dormancy in wheat. The first is to store grain dry so that it "after-ripens." The period of dry storage needed to lose dormancy can range from two weeks to one year depending on the variety. The second way is to subject grain to cold and wet conditions (wetness alone is not enough) in a process called cold stratification.

The fact that seed dormancy is broken by cold and wet conditions is one reason that some rainstorms are more likely to induce PHS than others. Cool weather combined with rain increases the likelihood of PHS. When temperatures are greater than 80°F (over 27°C), rain is less likely to induce sprout than when temperatures are 50 to 60°F (10–16°C). Low Falling Numbers are also more likely when there are multiple rainy days in a row, as it is more likely that dormancy will be broken and germination started if the wheat stays wet longer. Even highly PHS-resistant cultivars will sprout when conditions are cool and wet for an extended period of time.

Low FN is not necessarily associated with visible sprouting. With PHS, the germination program can induce alpha-amylase production before the seedling begins to emerge from the grain. This is sometimes called "incipient sprout." It is possible to see early signs of germination. If you use a magnifying glass, you can sometimes see that the embryo is expanding or that a small root tip is poking out of the grain (Fig. 2). If the mildly sprouted grain dries, then the root can shrink back into the seed, leaving behind a crack at the germ end. This crack may expand, leaving a crater or a germ-less grain.

Late-maturity alpha-amylase

There will be no sign of visible sprout if low FN is due to LMA (also sometimes called prematurity alpha-amylase, or PMA; Mares and



With the Falling Numbers test, a flour/water slurry is stirred for 60 seconds, and then the FN instrument measures how long it takes the stirrer to fall to the bottom of the tube in seconds. On the right is a solid wheat sample and on the left is a sample that has been degraded with too much alpha-amylase, resulting in a low Falling Number. Source: Screenshot from an Idaho Wheat commission video. See http://bit.ly/1ISXYEz.

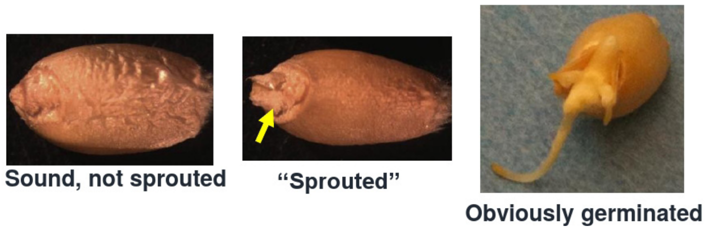


Fig. 2. A sound grain and a sprouted grain where the embryo has expanded, but has not yet obviously emerged from the grain. In such cases of “incipient sprout,” the embryo can shrink upon drying, resulting in lower FN/ higher amylase grain that is not obviously germinated. A germinated grain is included for comparison. Photos by S. Martinez and C. Steber.

Mrva, 2008; Farrell and Kettlewell, 2008). In LMA, cold shock or heat shock between 25 and 32 days after pollen shedding leads to expression of alpha-amylase. Late-maturity alpha-amylase is considered a genetic defect because it leads to accumulation of alpha-amylase during a period of development when starch should be accumulating rather than mobilized. Late-maturity alpha-amylase was defined as a cause of alpha-amylase without rain in Australian and UK wheat during the 1990s. It appears that LMA is quite common in synthetic hexaploid wheat stocks used to introduce new sources of disease resistance into domesticated wheat from wild relatives. Thus, it is important to select against LMA following such crosses.

In the Northwest wheat-growing region, PHS events are infrequent and widely scattered due to usually warm, dry summer conditions. Some years, however, bring more widespread rain during July and August, as happened in 2013 when 9 of 10 soft white winter Washington State University (WSU) cereal variety testing locations statewide had low FNs (http://steberlab.org/project7599data.php). The 2016 problem was far more widespread in Washington, with 16 of 20 WSU soft white winter locations showing low FN. The low FN in 2016 was due to sprouting, LMA, or a combination of both LMA and sprouting in a single environment. While the low FN problems in 2013 were mainly due to sprouting, LMA events were detected in 2011, 2012, 2013, 2014, and 2016. There appears to be a trend towards LMA problems in Northwest wheat, suggesting that LMA resistance needs to become a serious breeding objective.

Causes of Falling Number variability

Farmers can become very frustrated by the FN test because it can be highly variable. The variability in FN is partly due to the test itself. Falling Number varies in response to small differences in sample handling, altitude, and atmospheric pressure (Delwiche et al., 2015). Operators do their best to minimize sources of variation by following standard protocols (AACC, 1999), but some technical variation is inevitable. Much of the variation in FN is also due to the biology of the wheat itself. Differences in moisture, temperature, and crop maturity dates on different parts of a farm can result in differences in degree of sprouting and LMA on the same farm (Risius et al., 2015). Thus, sampling from a different part of the field may give different FNs. Because LMA susceptibility occurs during a very short developmental window, it causes a great deal of variability in FN. Late-maturity alpha-amylase may be induced in some spikes but not others on the same plant. Some farmers hope to get a higher FN by having the test repeated. It is important to keep in mind that a second test may give either a higher or a lower FN.

Management advice

We cannot hold an umbrella over the wheat when it rains, nor tuck it in with a blanket when it’s cold. But there are some pieces of practical advice that can help farmers manage the problem of low FN.

Harvest wheat quickly after maturity

Harvesting wheat quickly after maturity reduces the chances of rain damage. Wheat loses more dormancy the longer it is left to mature in the field, increasing the chances that it will sprout if it rains. Thus, the severity of the sprouting problem depends on the timing of the rain event relative to when the wheat reached maturity. Don’t harvest too early, however. Green kernels have high alpha-amylase activity (and can cause lower FN) because the enzyme helps provide fuel for grain development. Never combine wheat that is yellow with green wheat. Wait for rained-on wheat to dry before harvesting to avoid germination during storage.

Plant cultivars with genetic resistance to low Falling Number

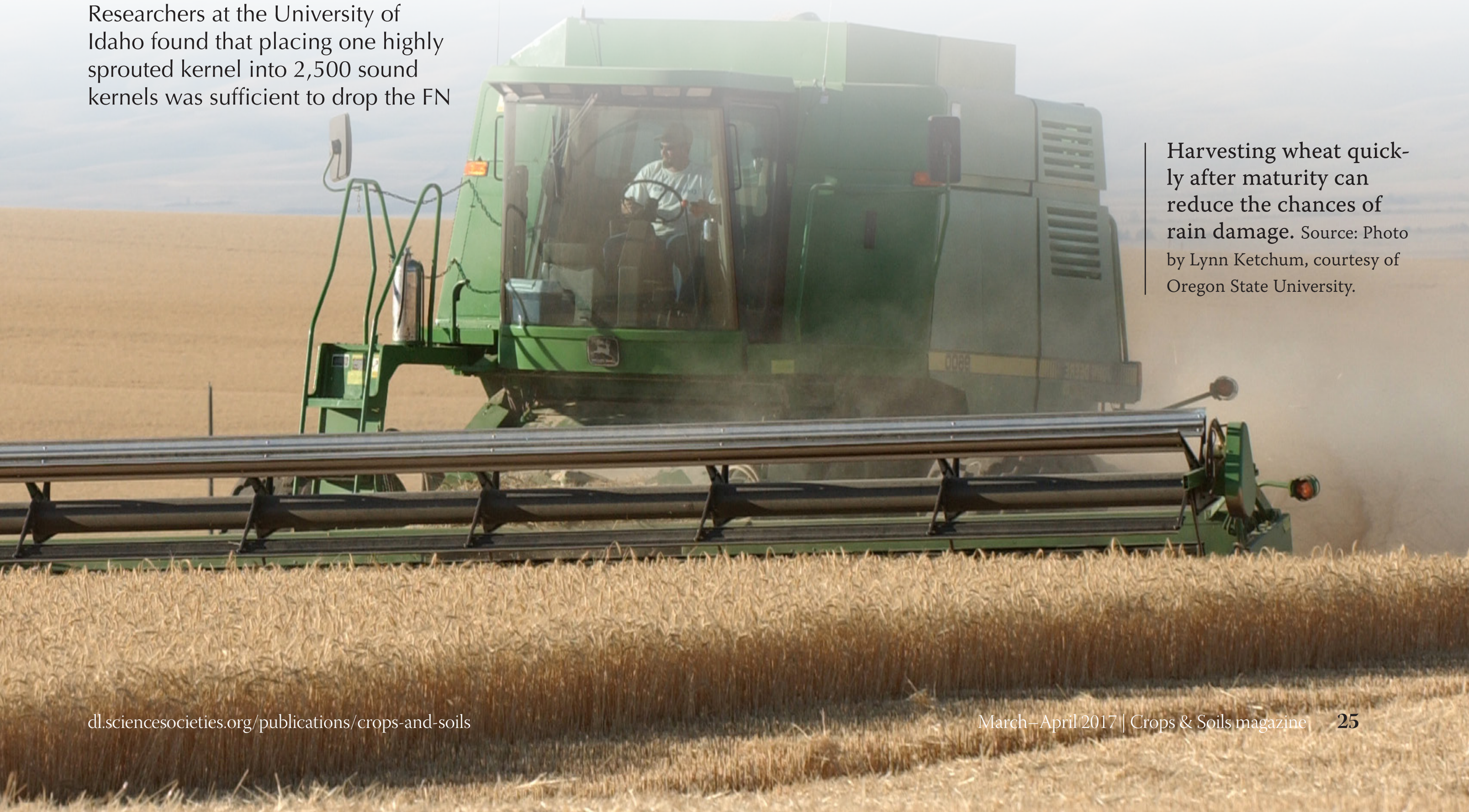
Plant wheat cultivars with genetic resistance to PHS and LMA. Past PHS events can be used as an indicator as to which cultivars have more genetic resistance to low FN due to sprouting. For example, there were major sprouting events in Fairfield, Lamont, Pullman, and other locations in 2013. The Falling Numbers of cultivars grown in the Washington State University Cereal Variety Testing Trials during 2013 and subsequent years can be found on the Falling Numbers website (http://steberlab.org/project7599.php). The FN versus yield tool on the Falling Numbers website can help growers take both yield and FN into account when choosing a cultivar. It is clear, however, that more wheat cultivars with improved resistance to PHS and LMA are needed. It should be noted that the higher seed dormancy that provides PHS tolerance can cause problems with poor emergence, especially in dry, deep-planting conditions if sufficient after-ripening has not occurred.

Avoid mixing sprouted grain with unsprouted grain

Because alpha-amylase is an enzyme catalyst, a little bit of enzyme can cause serious FN problems (Kruger and Lineback, 1987). For example, mixing equal amounts of 200-second grain with 400-second grain will not give you a load with a FN of 300 seconds. Instead, you will end up with an FN well below 300. Researchers at the University of Idaho found that placing one highly sprouted kernel into 2,500 sound kernels was sufficient to drop the FN by 100 seconds. Thus, "blending" grain with different FNs is risky.

Store grain with mildly low Falling Number

Research suggests that FN increases during storage, apparently because the alpha-amylase enzyme becomes less active over time (Gras et al..1994; Karaoglu et al., 2010; Ji and Baik, 2015). If the FN is moderately low (220–300 seconds), it can help to store grain for a few months to see if the FN rises. However, it is important to have realistic expectations. Storage is more effective for increasing FN at higher temperatures and when the starting FN is not too low. With five months storage, Ji and Baik (2016) saw approximately a 25-second increase at 73°F/23°C and a 35-second increase at 95°F/35°C. Another study showed about a 50-second increase with three months storage at 104°F/40°C but no significant increase after three months storage at 68°F/20°C (Adams, 2015; A. Ross, personal communication). The FN of badly sprouted grain does not improve with storage. For example, the Steber lab had a sample with an FN of 145 seconds that showed no significant change over three years of storage at room temperature. Farmers need to decide whether the possible increase in FN is worth the cost of storage.



Harvesting wheat quickly after maturity can reduce the chances of rain damage. Source: Photo by Lynn Ketchum, courtesy of Oregon State University.