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Black Point and Smudge in Wheat

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Summary

There are various types of discolouration that can affect common (*Triticum aestivum* L.) and durum [*T. turgidum* L. ssp. *durum* (Desf.) Husn.] wheat kernels grown on the Canadian Prairies. Black point and dark smudge, mostly associated with *Alternaria alternata* (Fr.) Keissl., and *Cochliobolus sativus* (Ito & Kurib.) Drechs. ex Dast. [anamorph *Bipolaris sorokiniana* (Sacc.) Shoemaker] are common discolourations of cereal seed, which occur in most regions where these crop species are grown. Red smudge, caused by *Pyrenophora tritici-repentis* (Died.) Drechs. [anamorph *Drechslera tritici-repentis* (Died.) Shoemaker], is also ubiquitous, especially in durum wheat. These types of kernel discolouration vary significantly in incidence and severity depending on environmental conditions during kernel maturation. Kernel discolourations are downgrading factors in wheat and thus can cause significant economic losses in years conducive to the development of these diseases. In most cases, kernel discolouration has been associated with the presence of fungal pathogens. Some studies have shown that black point in wheat might not be initiated by fungal infection. However, a recent study showed that although abiotic factors, such as high humidity levels, can promote the occasional development of black point or dark smudge on durum wheat kernels under controlled-environment conditions, fungal infection by *C. sativus* or *A. alternata* was the main factor associated with their development. Further research to determine the main causes of black point under field conditions and different soil types is needed to identify resistance to the various types of discolouration, and determine the most effective screening techniques. Unpredictability of weather will continue to be a risk factor in grain downgrading and the resulting economic losses to cereal producers. Thus, it is necessary to continue research on these important wheat diseases.

Fig. 1. Black point symptoms in wheat kernels, discolouration located mainly on the germ end. Courtesy of the Canadian Grain Commission.

Kernel Discolouration in Common and Durum Wheat

There are various types of kernel discolouration in common and durum wheat, which range from brown to black, or are reddish. These vary not only in colour but in the location of the symptoms on the kernel, and the extent of the discolouration.

Black point (Fig. 1) is a common discolouration of cereal seed, which occurs in most regions where common and durum wheat are grown. It is characterized by a dark brown to black discolouration of the pericarp and testa, primarily at the embryo end of the seed[1]. The discolouration can also occur along the crease or on the seed coat (Fig. 2). If the discolouration occurs in parts of the kernel other than the germ end, it is referred to as dark smudge[2]. For grading purposes, if the discolouration penetrates and extends throughout the endosperm, it is referred to as penetrated smudge[3].

Fig. 2. Black point and dark smudge symptoms in wheat kernels. Courtesy of the Canadian Grain Commission.

Red smudge is manifested as a reddish discolouration most often located over the seed coat, and can also be accompanied by black point (Fig. 3)[4,5,6]. This discolouration occurs mostly in durum wheat, and its incidence and severity vary considerably with environmental conditions during kernel development.

Fig. 3. Red smudge and black point symptoms in durum wheat kernels. Courtesy of the Canadian Grain Commission.

Kernel discolouration in wheat has been associated with various micro-organisms, and although it is not believed to be generally associated with mycotoxins, it affects the visual quality of the end product. When durum wheat is milled into semolina, black pointed kernels results in the formation of black specks in an otherwise bright, yellow product, producing pasta which is undesirable[7]. The negative impact of kernel discolouration on grain quality and its economic value depends on the grade tolerance levels for each type of discolouration.

Downgrading is based on the incidence of affected kernels and the severity of infection, and it varies with market class[3] (Table 1).

Table 1. Percentage smudge and black point kernels allowed in various grades of the Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD) wheat classes, compiled from Canadian Grain Commission (2010).

	CWRS		CWAD			
Grade	**Smudge**	**Total smudge and black point**	**Penetrated smudge**	**Red smudge**	**Total smudge**	**Total smudge and black point**
			%			
No. 1	0.3	10	0.03	0.3	0.3	5
No. 2	1	20	0.25	1	1	10
No. 3	5	35	0.5	1	3	20

Kernels with black point have a distinct dark brown or black discolouration of the whole germ and surrounding area. When the discolouration affects more than one-half of the kernel or extends into the crease, it is considered smudge. In kernels with penetrated smudge, the discolouration penetrates and extends throughout the endosperm, usually as a result of a more severe infection. Kernels with red smudge have a dark reddish discolouration usually associated with amber durum wheat, which usually affects the entire bran portion of the kernel.

For red smudge, there is a low tolerance in the top grades of durum wheat[3] (Table 1). Because the discolouration penetrates the bran and endosperm, and because the bran is not removed when making semolina, the discolouration can show up in the semolina as red specks.

Downgrading in common and durum wheat caused by kernel discolouration may result in substantial economic losses to cereal producers in years when environmental conditions during grain filling, in particular abundant moisture in the form of precipitation, dew or irrigation, favour seed infection[8,9,10,11]. Wet conditions can also delay harvest further promoting the development of kernel discolouration.

Fungal Species Associated with Black Point and Dark Smudge

The most commonly isolated fungus from discolored kernels is *A. alternata*, followed by *C. sativus* [10] (Fernandez et al., 1994b). Other fungi have also been associated with black point symptoms, including *Fusarium proliferatum* (Matsush.) Nirenberg[12], and *P. tritici-repentis*, which typically causes red smudge in wheat[13] (Fernandez et al., 2001), among other fungal species[10,14].

In the irrigated areas of southern Alberta and Saskatchewan, Conner and Kuzyk[9] reported correlations between black point incidence and percentage of common wheat kernels infected by *Alternaria* spp. *C. sativus* infected a low percentage of kernels and thus was of minor importance as a cause of black point. Symptoms produced by these two fungi in common wheat could not be visually distinguished, and infection by both fungi resulted in discolouration that was not limited to the area around the embryo, but also extended to the ventral surface of the kernel. Fernandez et al.[10] also reported that *Alternaria* spp. were more frequently isolated than *C. sativus* from durum wheat kernels showing black point symptoms in irrigated fields in southern Saskatchewan. *Cochliobolus sativus* has been shown to be more damaging to wheat kernels than *A. alternata* [10,11]. Black point associated with *Alternaria* spp. had no detrimental effect on germination of the affected kernels, but *C. sativus* reduced germination[10,15,16]. Seed heavily infected with *C. sativus* may also result in seedling blight and root rot in plants grown from them.

Shriveled durum wheat seed caused by heavy black point infections under field conditions resulted in a decrease in kernel weight[17]. However, positive associations of kernel discolouration with kernel size have been found in common and durum wheat[18], and suggests that the larger kernels are more likely to force open the glumes, which facilitates fungal penetration and infection.

Some *Alternaria* spp. have also been associated with mycotoxins, although the extent of these toxins in black-pointed kernels needs to be more intensively evaluated. Ostry[19] demonstrated that *A. alternata* produced a number of mycotoxins in cereal crops, including alternariol, alternariol monomethyl ether, altenuene, and tenuazonic acid.

In western Canada, no currently registered hard red spring or durum wheat varieties are reported to be resistant to black point. Among market classes, durum wheat was reported to be more susceptible to black point than common wheat, especially under conditions favouring the development of kernel discolouration[17,13,18,2]. However, variations in the reactions of durum wheat genotypes and registered cultivars to black point have been reported[17,20]. Conner and Davidson[21] showed that resistance to *A. alternata* and *C. sativus* in common wheat are not necessarily related and may be under separate genetic control.

Black point has also been reported in the apparent absence of fungal infection. Ellis et al.[22] and Shipton and Chambers[23] reported that black point was not always associated with fungal infection in common wheat. In a controlled-environment study of durum wheat, non-inoculated controls had more black point at high (30°C) than low (10°C) temperature; but the occurrence of black point symptoms in non-inoculated durum wheat kernels exposed to high humidity was low[4]. Huguelet and Kiesling[15] also reported that incubation of non-inoculated plants at high humidity for various time lengths did not result in significant black point development.

Williamson[24] reported that kernel discolouration in common wheat was not associated with infection by *A. alternata*. He proposed that the formation of black point symptoms was due to an enzymatic browning reaction caused by phenolic compounds within the grain being oxidised by peroxidases to form discolored end products, and concluded that fungal presence was likely a result of secondary colonization rather than the cause of black point. Differences in isozymes were identified between resistant and susceptible lines. Mak et al.[25] concluded that abiotic factors were significant causative agents of black point in common wheat and that fungal infection was not a constant causal agent of this disease. They observed an absence of fungal proteins and decreased levels of stress-, disease- and defence-related proteins in black point-affected grain, which suggested that disease protection might be afforded by increased levels of ‘stress’ proteins.

Thus, although environmental conditions have been shown to affect kernel appearance and the development of black point in cereals, the discolouration might not be initiated by the fungal infection. The latter might be a consequence of abiotic stresses causing physiological changes in the grain. Alternatively, the fungal infection, favoured by environmental conditions, might be the trigger for the physiological changes causing kernel discolouration.

In a recent study, Fernandez et al.[26] showed that abiotic factors can promote the occasional development of black point or dark smudge on durum wheat kernels under controlled-environment conditions. However, fungal infection by *C. sativus* or *A. alternata* was the main factor associated with kernel discolouration of durum wheat, confirming that these organisms are the most important causes of wheat kernel discolouration.

Red Smudge and Associated Fungal Species

Red smudge is caused by the same pathogen (*P. tritici-repentis*) responsible for tan spot on wheat leaves.

Kernel infection by *P. tritici-repentis* was also reported to cause a reduction in thousand kernel weight[5]. In durum wheat, red smudge did not affect seed germination, but reduced seedling emergence, plant vigour, stand establishment, and plant growth[27,28]. Fernandez et al.[28] concluded that the reduction of grain yield caused by planting *P. tritici-repentis*-infected durum wheat seed in a commercial field would depend to a great extent on the ability of the crop to compensate for reduced stands caused by lower plant vigour. Red smudge infection was reported to contribute to sprouting of common wheat[29].

There are no durum wheat cultivars with good resistance to tan spot or red smudge registered in western Canada[4,30]. Among all market classes of spring wheat, durum wheat is the most susceptible to both tan spot and red smudge, although there is variation among cultivars in the expression of symptoms[31,13]. A lack of correspondence between reaction of leaves and kernels to *P. tritici-repentis* in durum wheat was reported[31].

Management of Kernel Discolouration

Because the fungi most commonly associated with black point and dark smudge, *Alternaria* spp., are common saprophytes, there are few cultural practices that will reduce these types of kernel discolouration. Conner[8] showed that disease incidence increased with heavy irrigation and precipitation during early stages of kernel development. The effect of precipitation on disease development appeared to be due to a stimulation of sporulation by *Alternaria* on crop debris and the creation of a suitable environment for infection. Therefore, if wheat is grown under irrigation, the frequency and amount of irrigation should be reduced after flowering.

Practices that help to control spot blotch on leaves and common root rot caused by *C. sativus*, such as crop rotation with non-hosts, might help to reduce inoculum levels and the possibility of kernel infection by this pathogen.

High fertilizer nitrogen inputs can also favour the development of black point. Conner et al.[32] suggested that higher levels of black point in the presence of high nitrogen levels might result from the production of a denser canopy, which provides a more conducive microclimate for the development of black point, an increase in kernel weight, or delayed maturity extending the period when infection is most likely to occur.

Fungicides registered for foliar disease control can be applied only up to 30 to 45 days before harvest[33], and thus applications during susceptible kernel development stages would infringe on the pre-harvest application interval. When applied at the end of flowering, Conner and Kuzyk[34] showed that fungicides were not consistently effective in reducing black point incidence.

Inoculum levels of the causal agent of red smudge, *P. tritici-repentis*, should also be kept low during the growing season. This might reduce the chances of red smudge developing later on if environmental conditions are favourable for infection.

Tan spot is the most widespread leaf spotting disease of wheat in western Canada[35], and crop residues are the main source of inoculum of *P. tritici-repentis*[36]. Crop rotation away from wheat for at least two years with a non-cereal crop to reduce local inoculum sources, is one of the best ways of reducing inoculum levels of *P. tritici-repentis*. However, depending on environmental conditions, crop rotation may have little effect on infections late in the season because of the spread of wind-borne spores from neighbouring fields. The abundance of inoculum of this pathogen in the field, and the limited impact of crop rotation on leaf spotting development in wheat[35] make it a challenge to reduce the potential for red smudge infection, and avoid further economic losses as a result of durum wheat downgrading.

Similarly, foliar fungicide applications to reduce tan spot severity, and thus decrease the inoculum load of the pathogen, might have little impact on kernel infection and the development of red smudge in years favourable to kernel infection given other significant sources of inoculum. Early fungicide application, which could lead to increased kernel infection resulting from an increase in grain size[18], should also be avoided. Genetic resistance to tan spot would be the best way of reducing *P. tritici-repentis* inoculum in wheat crops.

Concluding Remarks

Under dryland conditions on the western Prairies, it is difficult to conduct effective research on kernel discolouration because in most years environmental conditions during kernel maturation are not conducive to the development of significant levels of discolouration. In the eastern Prairies, wet conditions in the latter part of the growing season would primarily lead to Fusarium head blight/*Fusarium*-damaged kernels, which in general would interfere with identification of kernel discolouration caused by other pathogens.

Unpredictability of weather in the later stages of crop growth will continue to be a significant factor in the downgrading and economic losses to cereal producers, and thus it is of importance to continue research on kernel discolouration.

As is the case with most other wheat diseases, genetic resistance would be the best way to control kernel discolouration, and minimize its negative impact in wet years. Further work to determine the main causes of black point under field conditions and different soil types is important to develop and identify resistance to the various types of discolouration, and determine the most effective screening techniques. Because red smudge usually occurs at lower levels than black point and dark smudge, and can also be manifested as black point, testing for resistance of wheat genotypes to *P. tritici-repentis* is best achieved under controlled-environment conditions.

Despite the limited impact of agronomic practices, integrated management methods for minimizing the development of kernel discolouration, should be a future research objective for these diseases.

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