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Strategies for management of fusarium head blight (FHB) in cereals

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Summary
Individual management options are unlikely to fully protect crops from FHB, therefore multiple strategies (varietal resistance, rotation, and fungicide application) provide the best means of maintaining yield potential, reducing the risk of mycotoxin contamination, protecting quality, and enhancing producer returns.

Background
Fusarium head blight (FHB) continues to be one of the most serious diseases affecting cereal crops, especially in the eastern Canadian prairies. Losses to the Canadian grain industry during the 1990s totalled US$200 million for Ontario and Quebec and US$300 million for Manitoba[1] (Windels, 2000). Yields and grain quality are reduced and the potential contamination of grain by mycotoxins, predominantly the trichothecene, deoxynivalenol (DON), is a constant threat to domestic and export markets[2] (Gilbert and Tekauz, 2000). Symptoms of the disease are usually distinctive and can be easily recognised in the field (Fig. 1). Several *Fusarium* species cause FHB. The predominant species in North America is *Fusarium graminearum* Schwabe [teleomorph: *Gibberella zeae* (Schwein.) Petch], especially on wheat. More than 90% of the isolations from *Fusarium*-damaged kernels are *F. graminearum* in Manitoba[3] (Gilbert et al., 2008). *Fusarium avenaceum* (Fr.) Sacc., *F. poae* (Peck) Wollenw., and *F. sporotrichioides* Sherb. account for a greater proportion of the species reported on cereals in the provinces west of Manitoba and on oat and barley across the Prairies (Fig. 2)[4,5,6] (Tekauz et al., 2000; 2004; 2009).

The pathogen over-winters in residues at or below the soil surface and over-winters producing ascospores as the primary inoculum in the spring. It was once thought that inoculum dispersal distance was limited to a few metres from a point source[7] (Fernando et al., 1997), but it is now known that ascospore discharge from perithecia into the planetary boundary layer facilitates dispersal over many kilometres depending on wind speed and direction[8] (Maldonado-Ramirez et al., 2005). The random aerial deposition of ascospores increases the importance of local management of FHB *via* varietal selection (and continued efforts to breed resistant crop varieties), fungicide application, tillage and rotation. The provincial seed guides (e.g. Seed Manitoba, 2010) provide information on disease reactions of current varieties. The Canada western hard red spring wheat class (CWRS) has varieties with better resistance to FHB, while Canada prairie spring (CPS) and Canada amber durum wheat (CWAD) are more susceptible. Six-rowed barley varieties are generally more susceptible than two-rowed ones. In oat, while no definite resistance rankings have been developed, a few adapted Canadian varieties of both hulled (e.g. 'Leggett') and hulless oats have demonstrated improved resistance[4,9] (Tekauz et al., 2000; Tekauz and Mitchell Fetch, 2009). The most susceptible stage of crop growth for infection is heading to soft dough for barley and from flowering to soft dough for wheat[10] (McCallum and Tekauz, 2002).

The disease is strongly influenced by the environment; warm, moist weather when crops are at a susceptible stage, favours disease development[11] (Miller et al. 1998). The disease triangle predicates the requirement for a susceptible host, the presence of the pathogen and a suitable environment for an epidemic to occur. Little can be done to alter the pathogen or manipulate the environment, thus control strategies have relied on breaking the disease cycle by developing resistance in the host and reducing the severity of the disease through management strategies such as protective fungicides, tillage, and crop rotation to reduce levels of pathogen inoculum. The effects of control strategies traditionally have been examined singly, or at most in pairs, but recently, integrated management studies have demonstrated that incremental improvements may be gained by combining multiple strategies[12] (McMullen et al., 2008).

Varietal Resistance

Success in breeding for resistance to FHB has proven to be elusive. The resistance is multigenic and expression of resistance is dependent on the genetic background of the germplasm. The use of quantitative trait loci (QTL) analysis which identifies regions of the genome responsible for conferring resistance, has revealed that most QTLs explain a relatively small proportion of the variance associated with FHB disease traits[13,14] (Buerstmayr et al., 2009; Miedaner et al., 2009). However, some improvements are apparent in the levels of resistance in registered cereals, which are listed in the provincial seed guides, and the first line of defence for crop management is still varietal selection, which has been shown to be a significant factor for reducing disease incidence, severity, *Fusarium*-damaged kernels (FDK) and DON accumulation[15,16,17] (Schaafsma, 2001; Champeil, 2004; Fernandez et al., 2005). However, these studies also indicated that no varietal effect was seen in dry years when disease severity and DON accumulation were low.

Rotation

Fusarium graminearum is not host specific and can be isolated from many species[18,19] (Inch and Gilbert, 2003a; Pereyra and Dill-Macky 2008). Further, the fungus has wind-borne ascospores which may be transported for kilometres from a source of inoculum, thus rotation alone is not sufficient to prevent disease. Obst et al.[20] (1997) found no effect of rotation on disease in south Germany, and no consistent effects were seen in an eastern Saskatchewan study[17] (Fernandez et al., 2005). The latter, based on a four year study, concluded that higher levels of FHB occurred in wheat fields following oilseed crops (mostly canola) in two of the years of the study and higher FDK in wheat crops following cereals in just one year of the study. Results were not definitive from a study to identify the *Fusarium* species. naturally occurring on field stubble produced by rotations typically used in Manitoba[21] (Golkari et al., 2008). Wheat and oat residues were commonly colonized by *Fusarium* species, but levels in pea and canola stubble were reassuringly low. In Saskatchewan, prevalence of *F. graminearum* was lower on barley after a pulse crop[22] (Fernandez et al., 2007), a pattern which was also evident in the two-year (but not three-year) rotations in Manitoba[21] (Golkari et al., 2008). It is generally understood that a rotation involving maize, also a host of *F. graminearum,* should be avoided[23,24,15] (Teich and Nelson, 1984; Krebs et al., 2000; Schaafsma, 2001). Dill-Macky and Jones[25] (2000) demonstrated a small but significant decrease in FHB severity and DON after planting spring wheat into soybean residues compared to residues of wheat or maize. Similarly, in a Swiss study, significantly less FHB developed on winter wheat sown into oilseed rape residues compared to maize residues[24] (Krebs et al., 2000).

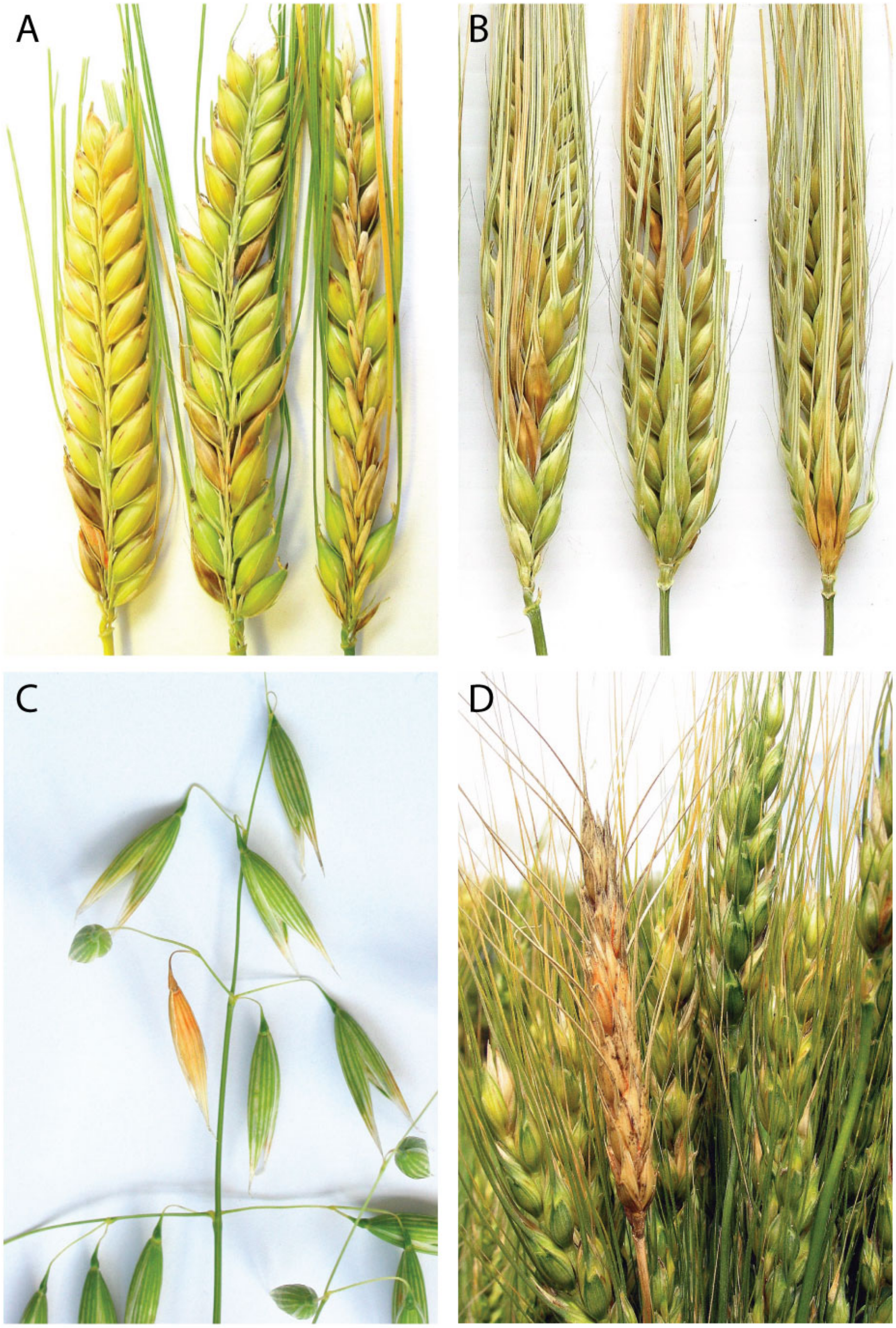

Fig. 1. Field symptoms of fusarium head blight on:
(A) 2-row barley, (B) 6-row barley, (C) oat and (D) spring wheat.

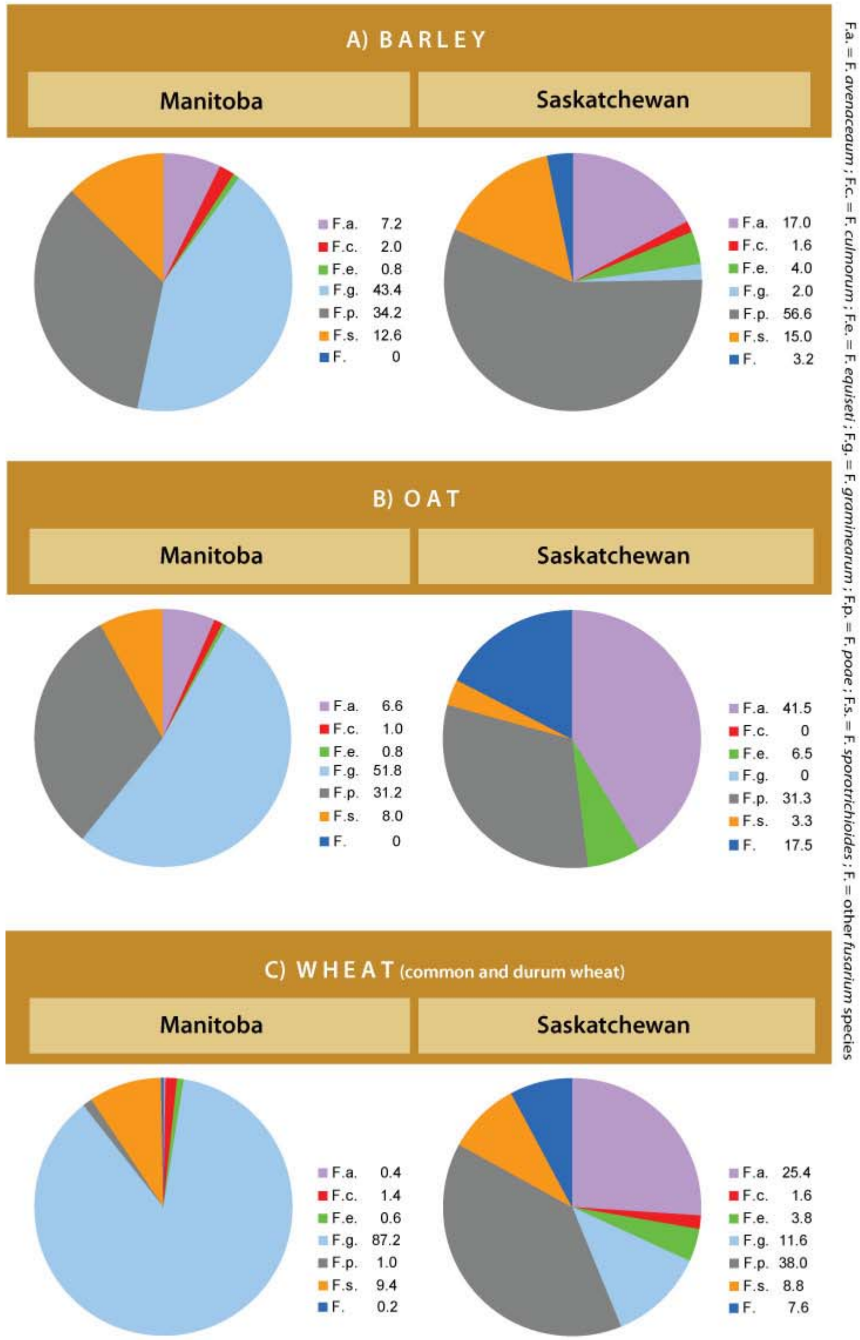

Fig. 2. *Fusarium* species on seed of: a) barley, b) oat and c) spring wheat crops in Manitoba and Saskatchewan, 2003-2007 (2004-2007 for SK oat).

Planting Date and Seeding Rate

Staggered planting dates or sowing several varieties with different heading dates or maturity may help[26] (McMullen, 2002), but as the weather during flowering cannot be predicted, early or late planting *per se* is not an assured option to protect crops. In eastern Saskatchewan, neither planting date nor seeding rate had any effect on FHB severity[17] (Fernandez et al., 2005).

Residue Management

Crop residues enable the pathogen to over-winter and these can therefore act as a source of inoculum for the following crop. Conventional tillage is now rarely seen on the prairies, but studies examining the effects of tillage operations that left varying levels of residues at the soil surface documented a significant, albeit small decrease in disease incidence, severity and DON accumulation following moldboard ploughing. However, no differences between chisel plough and no till operations were observed[25] (Dill-Macky and Jones, 2000). Krebs et al.[24] (2000), on the other hand, reported reductions of 80% and 45% in incidence of *F. graminearum* and DON levels, respectively, in mouldboard and chisel plough compared to no-till plots. Tillage does not bury all residues, and seeding operations can bring buried residues to the surface; when in contact with the moist soil surface, such *Fusarium*-infested residues will produce inoculum. It is possible that chopping and spreading residues may speed their decomposition and eliminate this source of inoculum more rapidly. Infested seed may be an additional source of inoculum. Studies have revealed that *F. graminearum* in or on buried seed may survive for at least 24 months[27] (Inch and Gilbert, 2003b). However, a dry heat treatment of 70 C for 5 days was found to be an effective method of eradicating *F. graminearum* and other *Fusarium* species from wheat and barley seed[28,29] (Gilbert et al., 2005; Tekauz et al., 2004). Chemical seed treatments generally improved germination, but efficacy was dependent on the temperature at germination and the variety[30] (Gilbert and Tekauz, 1995).

Foliar Fungicide Treatments

A foliar fungicide application is recommended in FHB-endemic regions when warm, wet conditions prevail after head emergence, disease forecasting indicates that conditions are favourable for disease development, and the expected yield return justifies the cost of application. Several registered products are currently available (including Caramba ®, Folicur®, Proline®, Prosaro®) for suppression of the disease.

Biological Control

Biocontrol agents also appear to be promising in controlling FHB, but researchers usually indicate that they may be effective primarily as a means to lower the amount of chemical fungicide required to effectively control FHB[31] (Xue et al., 2009). Isolates of *Trichoderma harzianum* Rifai have been shown to reduce *G. zeae* perithecial formation on wheat straw residues in the field and might have the potential to reduce inoculum development[32] (Inch and Gilbert, 2007). The fungus, *Clonostachys rosea* (Link:Fr.) Schroers, Samuels, Serfert and Gams (syn. *Gliocladium roseum* Bainier) has been shown to reduce FHB severity by 58%, FDK by 49% and DON by 21%. These effects were significant but of lesser magnitude than those achieved by tebuconazole fungicide[31] (Xue et al., 2009). The *C. rosea* isolate is currently undergoing trials for potential registration as a biocontrol agent in Canada[31] (Xue et al., 2009).

Nutrient Status

Rate and type of nitrogen (N) fertilizer can influence FHB severity, but the results have been inconsistent. An early survey indicated that N applied at higher than recommended levels reduced FHB in winter wheat[23] (Teich and Nelson, 1984). However, under conditions of natural inoculum, Lemmens et al.[33] (2004) demonstrated an increased level of FHB with increasing rates of N, while in an artificially-inoculated trial, the latter concluded that at the higher rates of N tested, levels that would benefit the crop, both disease severity and DON accumulation remained at constant levels[33] (Lemmens et al., 2004). Subedi et al.[34] (2007) observed no consistent effect over site-years, but concluded that incidence of FHB in spring wheat appeared to be reduced if adequate application of N was combined with early planting.

Integrated Management Strategies

Recently, a number of studies have reported on the effects of using two or more of the strategies outlined above. Dill-Macky and Jones[25] (2000) examined the effects of rotation and tillage practices on FHB severity and DON accumulation. They demonstrated that wheat grown after soybeans had a reduced incidence and severity of FHB compared with wheat grown after wheat or maize, regardless of tillage practice. However, in other studies, mouldboard ploughing significantly reduced FHB and DON levels, especially in winter wheat sown into maize residues[24] (Krebs et al., 2000). This may not be relevant in western Canada where conservation tillage practices are most often applied to conserve soil moisture and reduce erosion. The combination of moderately resistant barley varieties and tebuconazole was inconsistent in reducing FHB severity and DON accumulation[35] (Horsley et al., 2006). However, the use of a fungicide is probably advantageous; in a winter wheat study, the highest FHB field severity and DON levels (mg kg^{1}) were observed with highly susceptible varieties and no fungicide treatment[12] (McMullen, 2008), while adding a fungicide treatment to moderately resistant varieties at flowering resulted in the greatest FHB and DON reduction and the highest yield. The most promising results have been observed under natural conditions by McMullen et al. [12] (2008) who demonstrated the incremental benefits of multiple strategies (varietal resistance, rotation and fungicide application) in reducing FHB severity and DON accumulation and simultaneously increasing yields (Fig. 3).

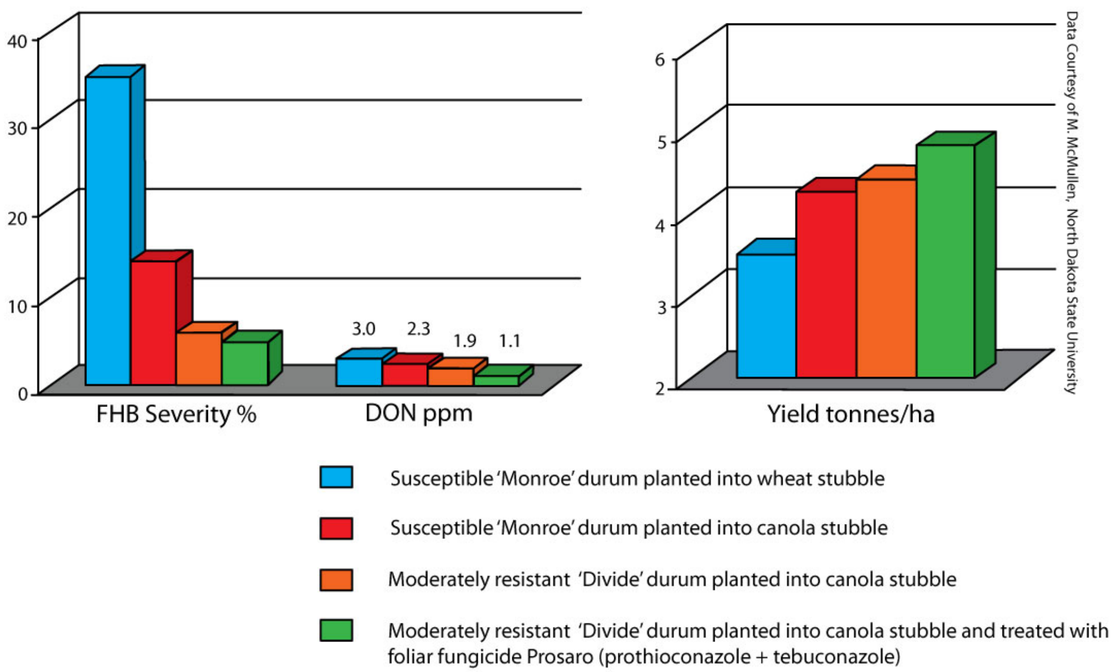

Fig. 3. Effect of integrated managment strategies (varietal selection, rotation, fungicide) on fusarium head blight (FHB) severity, deoxynivalenol (DON) accumulation and yield of durum wheat.

References

1. Windels, C.E. 2000. Economic and social impacts of Fusarium head blight: Changing farms and rural communities in the Northern Great Plains. Phytopathology 90:17-22.
2. Gilbert, J. and A. Tekauz. 2000. Review: Recent developments in research on Fusarium head blight of wheat in Canada. Can J. Plant Pathol. 22:1-8.
3. 27. Gilbert, J., A. Tekauz, R. Kaethler, K. Slusarenko, J. Hamilton, T. Unrau, E. Mueller, M. Stulzer, and M. Beyene. 2008. 2007 survey of fusarium head blight of spring wheat in Manitoba. Can. Plant Dis. Surv. 88:85.
4. Tekauz, A., B. McCallum, and J. Gilbert. 2000. Review: fusarium head blight of barley in western Canada. Can. J. Plant Pathol. 22:9-16.
5. Tekauz, A., B. McCallum, N. Ames, and J. Mitchell Fetch. 2004. Fusarium head blight of oat – current status in western Canada. Can. J. Plant Pathol. 26:473-479.
6. Tekauz, A., M.R. Fernandez, J. Gilbert, P.G. Pearse, and T.K. Turkington, 2009. Differences in the Fusarium spp. affecting cereal crops in western Canada. Can. J. Plant Pathol. 31:128-129.
7. Fernando, W.G.D., T.C. Paulitz, W.L Seaman, P. Dutilleul, and J.D. Miller. 1997. Head blight gradients caused by Gibberella zeae from area sources of inoculum in wheat field plots. Phytopathology 87:414-421.
8. Maldonado-Ramirez, S. L., D.G. Schmale III, E.J. Shields, and G.C. Bergstrom. 2005. The relative abundance of viable spores of Gibberella zeae in the planetary boundary layer suggests the role of long-distance transport in regional epidemics of Fusarium head blight. Agric. For. Meteorol. 132:20-27.
9. Tekauz, A., and J. Mitchell Fetch. 2009. Testing the WCORT oat entries for reaction to fusarium head blight. P. 77 In Proceedings 6th Canadian Workshop on Fusarium Head Blight, Ottawa, Nov 1-4, 2009.
10. McCallum, B.D., and A. Tekauz. 2002. Influence of inoculation method and growth stage on fusarium head blight in barley. Can. J. Plant Pathol. 24:77-80.
11. Miller, J.D., J. Culley, K. Fraser, S. Hubbard, F. Meloche, T. Ouellet, W.L Seaman, K. Turkington, and H. Voldeng. 1998. Effect of tillage practice on fusarium head blight of wheat. Can J. Plant Pathol. 20:95-103.
12. McMullen, M., S. Halley, B. Schatz, S. Meyer, J. Jordahl, and J. Ransom. 2008. Integrated strategies for Fusarium head blight management in the United States. Cereal Res. Commun. 36:563-568 Suppl. B.
13. Buerstmayr, H., T. Ban, and J.A. Anderson. 2009. QTL mapping and marker-assisted selection for Fusarium head blight resistance in wheat: a review. Plant Breeding 128:1-26.
14. Miedaner, T., F. Wilde, V. Korzun, E. Ebmeyer, M. Schmolke, L. Hartl, and C. Schoen. 2009. Marker selection for Fusarium head blight resistance based on quantitative trait loci (QTL) from two European sources compared to phenotypic selection in winter wheat. Euphytica DOI 10.1007/s10681-008-9832-0
15. Schaafsma, A. 2001. Agronomic considerations for reducing deoxynivalenol in wheat grain. Can. J. Plant Pathol. 23:279-285.
16. Champeil, A., T. Dore, and J.F. Fourbet. 2004. Fusarium head blight: epidemiological origin of the effects of cultural practices on head blight attacks and the production of mycotoxins by Fusarium in wheat grains. Plant Science 166:1389-1415.
17. Fernandez, M.R., F. Selles, D. Gehl, R.M. DePauw, and R.P. Zentner. 2005. Crop production factors associated with Fusarium head blight in spring wheat in eastern Saskatchewan. Crop Sci. 45:1908-1916.
18. Inch, S. and J. Gilbert. 2003a. The incidence of Fusarium species recovered from inflorescences of wild grasses in southern Manitoba. Can. J. Plant Pathol. 25:379–383.
19. Pereyra,S.A. and R. Dill-Macky. 2008. Colonization of the residues of diverse plant species by Gibberella zeae and their contribution to Fusarium head blight inoculum. Plant Dis. 92:800-807.
20. Obst, A., J. Lepschy-von Gleissenthall, and R. Beck. 1997. On the etiology of Fusarium head blight of wheat in south Germany – preceding crops, weather conditions for inoculum production and head infection, proneness of the crop to infection and mycotoxin production. Cereal Res. Commun. 25:699-703.
21. Golkari, S., J. Gilbert, K. Slusarenko, W.G.D. Fernando, and A. Brülé-Babel. 2008. Effect of rotation on colonization of field stubble by Fusarium species. Cereal Res. Commun. 36:555-561 Suppl. C.
22. Fernandez, M.R., R.P. Zentner, R.M. DePauw, D. Gehl, and F.C. Stevenson. 2007. Impacts of crop production factors on Fusarium head blight in barley in eastern Saskatchewan. Crop Sci. 47:1574-1584.
23. Teich, A. and K. Nelson. 1984. Survey of fusarium head blight and possible effects of cultural practices in wheat fields in Lambton County in 1983. Can. Plant Dis. Surv. 64:11-13.
24. Krebs, H., Streit, B., and Forrer, H-R. 2000. Effect of tillage and preceding crops on Fusarium infection and deoxynivalenol content of wheat. P. 13. *In* T. Alföldi et al. (eds.) IFOAM 200: The World Grows Organic. Proceedings 13th International Federation of Organic Agricultural Movements. Basel, Switzerland, August 28-31, 2000.

25. Dill-Macky, R., and R.K. Jones. 2000. The effect of previous crop residues and tillage on Fusarium head blight of wheat. Plant Dis. 84:654-660.
26. McMullen, M. 2002. An integrated approach to cereal disease management. P.1-5 In Proceedings of the Manitoba-North Dakota Zero Tillage Farmer's Association 24th Annual Meeting. Minot, North Dakota, February 2002.
27. Inch, S. and J. Gilbert. 2003b. Survival of Gibberella zeae in Fusarium-damaged wheat kernels. Plant Dis. 87:282-287.
28. Gilbert, J., S.M. Woods, T.K. Turkington, and A. Tekauz. 2005. Effect of heat treatment to control Fusarium graminearum in wheat seed. Can. J. Plant Pathol. 27:448–452.
29. Tekauz. A., T.K. Turkington, and J. Gilbert. 2004. Eradication of Fusarium graminearum from infested barley seed by heat treatment. Can. J. Plant Pathol. 26:219-220.
30. Gilbert, J. and A. Tekauz. 1995. Effects of fusarium head blight and seed treatment on germination, emergence, and seedling vigour of spring wheat. Can. J. Plant Pathol. 17: 252-259.
31. Xue, A.G., H.D. Voldeng, M.E. Savard, G. Fedak, X. Tian, and T. Hsiang. 2009. Biological control of fusarium head blight of wheat with Clonostachys rosea strain ACM941. Can. J. Plant Pathol. 31:169-179.
32. Inch S. and J. Gilbert. 2007. Effect of Trichoderma harzianum on perithecial production of Gibberella zeae on wheat straw. Biocontrol Sci. and Technol.17:635-646.
33. Lemmens, M., K. Haim, H. Lew, and P. Ruckenbauer. 2004. The effect of nitrogen fertilization on Fusarium head blight contamination in wheat. J. of Phytopathol. 152:1-8.
34. Subedi, K.D., B.L. Ma, and A. Xue.G. 2007. Planting date and nitrogen effects on Fusarium head blight and leaf spotting diseases in spring wheat. Agron. J. 99:113-121.
35. Horsley, R.D., J.D. Pederson, P.B. Schwarz, K. McKay, M.R. Hochhalter, and M.P. McMullen. 2006. Integrated use of tebuconazole and Fusarium head blight-resistant barley genotypes. Agron. J. 98:194-197.