FUSARIUM HEAD BLIGHT AND CROWN ROT ON WHEAT & BARLEY: LOSSES AND HEALTH RISKS

Oadi N. Matny
Dept. of Plant Protection, College of Agriculture, University of Baghdad, Iraq.

ABSTRACT: Wheat and Barley is the major production and consumption grains in the world. The necrotrophic Fusarium spp is pathogen caused many diseases on plants, the major two disease caused by Fusarium on wheat is Fusarium Crown rot (FCR) and head blight (FHB), also known as scab. These both disease caused severe damage on yield quality and quantity, and reduce yield up to 61%, as will produce mycotoxins in the grain, which lead to contamination the products that manufactured from these crops. The major FCR and FHB mycotoxins as DON, NIV, ZEN can caused many disease symptoms to consumers who consumes contaminate food, whether is human or animal, such as cancers, immunosuppression, fertilization problem, abortion and etc.

KEYWORD: Triticum spp, Hordeum vulgare, Fusarium, Mycotoxins.

INTRODUCTION

Wheat and barley is the major crops cereal produce in the world. The global statistics indicate that wheat production in the world for 2014-2015 was 707.2 million ton and for barley 135.65 million ton, which form the proportion of one-third of the world's total grain production (USDA, 2014; FAO, 2014)

Fusarium Crown Rot (FCR)

Crown rot (FCR) caused by many kinds of Fusarium spp as F. pseudograminearum and F. culmorum is a common pathogen to FCR while F. graminearum group I, F. crookwellense, F. avenaceum and F. nivale (Murray & Brennan, 1998; Dodman & wildermuth, 1987; Backhouse & Burgess, 2002; Scott et al, 2004). FCR disease infect the stem base of wheat and barley causing necrosis and dry rot of the crown bases always brown, often extending up 2-4 nodes, basal stem and root tissue commonly known as crown rot (Backhouse et al., 2004). In severe seasons Whitehead formation is wet start followed by dry climates, mycelium of the pathogen appeared in lower nodes during wet and moisture condition’s Fig 1.
Fig 1. Different symptom and sigs of Fusarium crown rot (FCR) on wheat. (A,B) Pink/red fungal mycelium and discolouration of stem bases. Photo by SIMMYT. (C) Whitehead symptom on spike right: non infected, left: infected (White head), Photo by Guihua Bai.

**Fusarium Head Blight (Scab) (FHB)**

FHB is caused by mainly fungus as *F. graminearum* group II (also known as Gibberella zeae sexual stage), *F. culmorum*, *F. poae*, *F. avenaceum* and *F. culmorum* (Snijders, 1994; Boutigny et al., 2011). Other species, can caused the disease such as *F. langsethiae*, *F. poae*, *F. sporotrichioides*, and *Microdochium nivale* (formerly known as F. nivale) (Parry et al. 1995; Xu et al. 2005) Disease symptoms are confined to the head, grain, and sometimes the peduncle (neck). Typically, the first of FHB symptom is blighting of part or all of the spikelets while heads are still green. As the fungus moves up and down of infection point in spikelets that may be caused blighting all the spike. In barley the symptom is little different, infection spikelest is located and don’t move in to rachis of spike. In the humid and wet condition, spore masses pink to orange are appeared in infection area (fig 2) (Wise & Woloshuk, 2004; Fernandez et al., 2000; Fernandez et al., 1999). Wet and warm weather during crop growing and maturation may favour to FHB (McMullen et al., 1997), and hot and dry conditions increase CR disease (Burgess et al., 2001).

Fig 2. Head blight symptom on wheat and barley caused by Fusarium (FHB). (A,D) small, shriveled pale white appearance and sometimes pink, infected (left)and healthy (right) Photographer by Department of Agriculture and Aquaculture Canada K. Lynch. (B,C) Orange sporodochia and Bluish black perithecia are formed at the base of the glumes, Photographer by Canadian Grain Commission . (E,F) Premature bleaching of Barley and wheat spikes.
Disease Cycle

The causal agent for FCR and FHB is interplay. Infection occurs when spores land on susceptible wheat and barley heads. In the flowering stage heads (spike) is the most susceptible to infection. If the flowers are infected after kernels appearance it will not develop. Spikelest is flowering stage that are infected later will produce creased seed. The seeds that infected by the pathogen in late stage may appear healthy, but be contaminated with mycotoxins. Fusarium crown and root rot can develop in the following season if infected seed (FHB) is planted. Also maize is on of the crop that infected by same Fusarium spp that infected wheat and barley, so cultivation wheat or barley near or after maize rotation will increse inoculation which leded to high disease incidence fig 3 (Bushnell et al., 2003).

Yield Losses

Fusarium infection reduces quality and crop yield, both FHB and FCR become an endemic disease in wheat and barley grower’s area in the world wide (Goswami & Kistler, 2004). *F. pseudograminearum* is the predominant CR pathogen in the 11million/ha wheat growing region in Australia (Backhouse, et al 2004) where, nearly $80 million each year is lost from reduced grain yield and quality due to CR (Murray & Brennan, 2009). Both *F. graminearum* and *F. pseudograminearum* improved by bioassays that can caused equally severe CR disease (Akinsanmi, et al 2004).

In the Pacific Northwest of the United States, *F. pseudograminearum* can reduce winter wheat yield by up to 61% (Smiley et al, 2005). While in during 1998–2000 FHB inflicted an estimated US$ 2.7 billion loss due to reduced yield and price discounts from lowered grain quality in the northern Great Plains and central USA (Goswami & Kistler, 2004). It has been reported that FCR could reduce wheat yield by up to 35% in the Pacific North- West of the United States (Smiley et al, 2005).

Recent study found crown rot infestation causes an average of 25 percent yield loss in bread wheat and 58% loss in durum wheat across a wide range of environments in Australia, estimated annual yield loss of $23 million Australian dollars per year in barley and in wheat and barley combined in Australia (Murray & Brennan, 2009; Nicol et al 2001).
The malting barley market in North and South Dakota, and Minnesota have lost 73% since 1993, with losses in Minnesota alone approaching 95%. In barley, losses have been calculated from 1993 to 1999 was totaling in excess of $400 million (Windels, 2000). Since 1990 yield losses in wheat have exceeded 13 Tg (500 million bushels) with economic losses estimated at $2.5 billion (Windels, 2000).

FCR losses in yield arising on grain heads will be partially or half filled (fig 2), or no grain in the head (preventing grain from forming in the heads of wheat) in severe infestation, as will reduction in grain quality and infected plants may also contaminated with mycotoxins (Liu & Jill, 2009).

FHB can caused significant yield losses from floret sterility and light weight kernel are produced as a result of infection. Quality reduction may occurrence if the pathogen produce mycotoxins in seed face (McMullen et al 2008; Matny et al, 2012 a).

**Mycotoxin Contamination and Risk**

The mycotoxin risks connected with the consumption of contaminated forage, grain and straw by livestock must not be ignored (LBP. 2000, Matny 2013 (b)). Fusarium head blight (FHB) and crown rot disease in wheat and barley by spread and production spores in infected residue, in high humidity and frequent rainfall, the optimum temperatures for infection are between 75°F and 85°F (Burrows et al. 2012).

Chemically and thermally stable of mycotoxins contaminants which give it the toxicity effects in animals and humans (Champeil et al. 2004). They can accumulate in the grain and, when contaminated grain is consumed via feed or food products, cause a potential risk to human and animal health (Pestka 2010). Matny et al (2012 b) found that most samples of animal feed that collected from market and animal farm in Iraq was contaminated with DON toxin at 722 µg/kg.

Toxigenic strains of *F. culmorum* have been divided into two types, the main type B trichotheccenes produced that is DON and NIV chemotypes, strains of DON-types also produced AcDON (3-AcDON) (Miller et al., 1991; Gang et al., 1998; D'Mello et al., 1997), while strains of NIV-type were also able to produce FUS. In field trials, DON and NIV chemotypes exhibited different aggressiveness toward winter rye (Gang et al., 1998).

FHB in wheat is widespread disease caused losses up to 25–50%, and high amounts of DON and its derivatives were frequently found in freshly harvested infected grains. In particular, a very high occurrence of DON incidence of 100%, range 7.25–36.25 mg kg–1 was founding on wheat affected by FHB predominantly caused by *F. graminearum*, associated with consistent levels of 4,7-dideoxy-NIV (0.16–1.25 mg kg–1) (Leonov et al., 1990)

Most frequently encountered mycotoxins in field surveys in Europe infected wheat with FHB is deoxynivalenol (DON) and zearalenone (ZON) produced by *F. graminearum* and *F. culmorum* (Bottalico and Perrone 2002; Miller 2008; Matny 2013 a,b).

In Poland, samples collected from wheat naturally infected with *F. graminearum* and *F. culmorum* were founded to be contaminated with DON and 3AcDON 100% and 80% respectively at very high concentrations up to 30.4 and 29.54 mg kg–1 respectively, the levels of DON and 3AcDON in the chaff were 5-50 times higher than in kernels (Visconti et al., 1986).
Table 1. Mycotoxigenic species isolated from FHB of wheat in Europe. (Bottalico & Perrone, 2002)

| Fungus Species   | Mycotoxins             |
|------------------|------------------------|
| 1. *F. graminearum* | DON, NIV, ZEN, AcDON  |
| 2. *F. avenaceum*    | MON, ENS, BEA          |
| 3. *F. culmorum*     | DON, ZOH, NIV, ZEN     |
| 4. *F. poae*         | NIV, FUS, BEA, DAS     |
| 5. *F. equiseti*     | DAS, ZOH, ZEN          |
| 6. *F. tricinctum*   | MON                    |
| 7. *F. cerealis*     | NIV, ZOH, FUS, ZEN     |
| 8. *F. sporotrichioides* | T2, NEO, HT2, T2ol   |
| 9. *F. acuminatum*   | T2, NEO                |
| 10. *F. subglutinans* | MON                   |

**AcDON =** Monoacetyl-deoxynivalenols (3-AcDON, 15-AcDON); **BEA =** Beauvericin; **DAS =** Diacetoxyscirpenol; **DON =** Deoxynivalenol (Vomitoxin); **ENS =** Enniatins; **FUS =** Fusarenone-X (4-Acetyl-NIV); **HT2 =** HT-2 toxin; **MON =** Moniliformin; **NEO =** Neosolaniol; **NIV =** Nivalenol; **T2 =** T-2 toxin; **T2ol =** T-2 tetraol; **ZEN =** Zearalenone; **ZOH =** zearalenols (α and β isomers).

The could place accompanied epidemics infection with *F. sporotrichioides* and *F. poae* may be lead to occurrence of T-2 derivatives (T2, HT2, T2ol), and DAS and MAS, respectively in infected grain, NIV and FUS toxin has also been founded to correlate to the activity of *F. poae* and *F. cerealis* in Sweden and other northern countries in cereals from central to northeast Europe (Bottalico et al., 1990; Eriksen and Alexander, 1998).

MON was reported to be founded in freshly harvested durum wheat in Austria up to 0.88 mg kg⁻¹ (Adler et al., 1995). In all these surveys, the MON contamination in kernels was well correlated with the *F. avenaceum* infection (Kostechi et al., 1995).

Zearalenone is secondary metabolite produce by many Fusarium species, especially by *F. graminearum* and *F. culmorum*, this toxin has known as estrogenic properties, which means it can cause infertility, abortion, or other breeding problems. As little as 1 to 5 ppm zearalenone in a feed ration may produce an estrogenic effect in swine (Minervini & Maria, 2008).

Study done by Matny (2014) about companion Fusarium pathogens to FCR and FHB to wheat, it’s found that *F. verticillioides* and *F. proliferatum* can produce with high amount of several kind of mycotoxin like DON, Fumonosin, ZEN and T2 toxin.

**Economic Impact of Mycotoxins**

Mycotoxins have significant economic impacts in many crops, especially in grain like wheat, maize, peanuts and other nut crops, cottonseed, and coffee. Each year 25% of the world’s crops are contaminated by mycotoxins, with annual losses of around 1 billion metric tons of foods and food products, this statically were has estimated by FAO. The economic losses occur by mycotoxins is: yield loss because of diseases infections by toxigenic fungi, lower quality of crop value because of mycotoxin contamination, health problems to animal productivity from mycotoxin-related and human health costs. And there are additional costs like research and scientific studies. These impacts are effective on food and feed supply chains: farmers, grain handlers and distributors, processors, consumers, and society as a whole (due to health care...
impacts and productivity losses). Reduced crop quality and quantity value is a significant related to the losses caused by mycotoxins. This affects crops entered into local trade as well as crops intended for export (Schmäle, & Munkvold, 2014).

Fusarium head blight caused losses in barley producers in (1992-1997), upper Midwest of the USA more than $364 million. Contamination of barley with Deoxynivalenol reduces barley quality, prices, and industrial characteristic of barley for malting and brewing, conditions of malting increased Fusarium growth, that lead to containing higher level of Deoxynivalenol. The malting and brewing industry in the U.S. had effects during 1994-1995, which paid and extra $200 million to get non-infected grain from Canada (Dahleen 1997).

Mycotoxins losses costs estimation studies in US is dissimilar, one report show that $0.5 to $1.5 billion/year and another $5 billion/year for the U.S. and Canada. Deoxynivalenol caused losses in crop production at $655 million/year in US, the major losses in wheat, but in the developing countries, few estimates studies are available (Schmäle, & Munkvold, 2014).

The most difficult to quantify impacts of mycotoxins is effected of human health. These effects mycotoxins act (single exposure) toxicoses and immunosuppression and chronic (repeated exposure) effects. In 1993 World Bank report that 40% of lost disability adjusted life years because of mycotoxins in the world, and $900 million impact of mycotoxin in Southeast Asia, $500 million of the costs were related to human health effects (Schmäle & Munkvold, 2014).

Swine are the most effective by Fusarium mycotoxins, where Deoxynivalenol minimize feed intake, loss body weight. Studies showed that Deoxynivalenol also responsible on abortions, stillbirths, and weak piglets. Immunosuppresion can caused increases infection and disease incidence and increases production costs (Pestka, 2007). Reproduction of swine have highly affects by Zearalenone toxin, it can caused a major economic effects in number of pigs offspring per sow per year. Based on 1991 prices, a study showed that 10 or 20% reduction in farrowing rate combined with a 10 or 20 % reduction in growth (as may occur if deoxynivalenol and zearalenone contaminated feed was consumed) would result in a 17 to 44% reduction in profit margins, due to costs increased feeding and veterinary per head, and a reduction number of pigs marketed (Charmley et al. 1995).

REFERENCES

Adler A, Lew H, Brodacz W, Edinger W and Oberforster M (1995) Occurrence of moniliformin, deoxynivalenol, and zearalenone in durum wheat (Triticum durum Desf.). Mycotoxin Research 11: 9–15.

Akınsanmi, O. A., Mitter, V., Simpfendorfer, S., Backhouse, D., and Chakraborty, S. (2004) Identity and pathogenicity of Fusarium spp. isolated from wheat fields in Queensland and northern New South Wales. Aust. J. Agric. Res. 55:97-107.

Backhouse D., Burgess L.W. (2002) Climatic analysis of the distribution of Fusarium graminearum, F. pseudograminearum and F.culmorum on cereals in Australia. Australasian Plant Pathology 31: 321-327.
Bottalico A and G Perrone (2002) Toxigenic Fusarium species and mycotoxins associated with head blight in small-grain cereals in Europe. European Journal of Plant Pathology 108: 611–624.

Bottalico A, Logrieco A and Visconti A (1990) Mycotoxins produced by Fusarium crookwellense Burgess, Nelson and Toussoun. Phytopathologia Mediterranea 29: 124–127.

Bottalico A, Perrone G. (2002) Toxigenic Fusarium species and mycotoxins associated with head blight in small-grain cereals in Europe. Eur J Plant Pathol. 108:611–624.

Boutigny A-L, Ward TJ, Van Coller GJ, Flett B, Lamprecht SC, O’Donnell K & Viljoen A (2011) Analysis of the Fusarium graminearum species complex from wheat, barley and maize in South Africa provides evidence of species-specific differences in host preference. Fungal Genet Biol 48: 914–920.

Burgess LW, Backhouse D, Summerell BA & Swan LJ (2001) Crown Rot of Wheat. Fusarium: Paul E. Nelson Memorial Symposium. (Summerell BA, Leslie JF, Backhouse D, Bryden WL & Burgess LW, eds), pp. 271–294. APS Press, St. Paul, MN.

Burrows M, W Grey & A Dyer (2012) Fusarium Head Blight (scab) of Wheat and Barley. Montana State University Extension.

Bushnell WR, Hazen BE, Pritsch C (2003) Histology and physiology of Fusarium head blight. In KJ Leonard, WR Bushnell, eds, Fusarium Head Blight of Wheat and Barley. APS Press, St. Paul, MN, pp 44–83

Champeil A, Dore T, Fourbet JF. (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 Sci.166:1389–1415.

Charmley L.L., Trenholm H.L., Prelusky D.B., and Rosenberg A. (1995) Economic losses and decontamination. Natural Toxins, 3, 199-203.

D’Mello JPF, MacDonald AMC, Postel D and Hunter EA (1997) 3-Acetyl deoxynivalenol production in a strain of Fusarium culmorum insensitive to the fungicide difenoconazole. Mycotoxin Research 13: 73–80.

Dahleen L.S. (1997) ARS Fusarium Workshop, Richard Russell Research Center, Athens, Georgia, USA, September 16-17, pp. 19-20.

Dodman R. L. and G. B. wildermuth (1987) Inoculation Methods for Assessing Resistance in Wheat to Crown Rot Caused by Fusarium gramineurn Group 1. Aust. J. Agric. Res. 38: 473-86.

Eriksen GS and Alexander G (1998) Fusarium toxins in cereals –a risk assessment. TemaNord Food 1998: 502, Nordic Council of Ministers. Expressen Tryk & Kopicenter, Copenaghen, Denmark, 146 pp.

FAO, (2014) World Food Situation. http://www.fao.org.

Fernandez, M. R., Holzgang, G., Celetti, M. J., and Hughes, G. (1999) The incidence of Fusarium head blight in barley, common wheat and durum wheat grown in Saskatchewan during 1998. Can. Plant Dis. Surv. 79:79-82.

Fernandez, M. R., Pearse, P. G., Holzgang, G., and Hughes, G. (2000) Fusarium head blight in common and durum wheat in Saskatchewan in 1999. Can. Plant Dis. Surv. 80:57-59.

Gang G, Miedaner T, Schuhmacher U, Schollenberger M and Geiger HH (1998) Deoxynivalenol and nivalenol production by Fusarium culmorum isolates differing in aggressiveness toward winter rye. Phytopathology 88: 879–884.

Goswami, R. S., and Kistler, H. C. (2004) Heading for disaster: Fusarium graminearum on cereal crops. Mol. Plant Pathol. 5:515-525.

Kostechi M, Szczesna J, Chelkowski J and Wisniewska H (1995) Beauvericin and moniliformin production by Polish isolates of Fusarium subglutinans and natural co-
occurrence of both mycotoxins in cereal grain samples. Microbiologie, Aliments, Nutrition 13: 67–70.

LBP – Bayerische Landesanstalt für Bodenkultur und Pflanzen- bau (2000) Risiken durch den Ahrenparasiten “ Fusarium graminearum “ – Ergebnisse eines LBP-Forschungsverbunds. Bodenkultur und Pflanzenbau Vol 3, 107 pp

Leonov AN, Kononenko GP and Soboleva NA (1990) Production of DON-related trichothecenes by Fusarium graminearum Schw. from Krasnodarski krai of the USSR. Mycotoxin Research 6: 54–60.

Liu C and Jill G. (2009) Finding the jewels in crown rot research. CSIRO Plant Industry, No. 215.

Matny ON (2013 a) Mycotoxin production by Fusarium spp isolates on wheat straw in laboratory condition. Research Journal of Biotechnology. 8(7): 35-41.

Matny ON (2013b). Detection of Deoxynivalenol, Zearalenone and T2-Toxin produced by Fusarium species in different cultures. Intl. J. Agri. Crop Sci. 5(20):2385-2389.

Matny ON (2014) Screening of Mycotoxin Produced by Fusarium verticilloides and F. proliferatum in Culture Media. Asian Journal of Agriculture and Rural Development. 3(12) 2013: 1001-1006.

Matny, ON, J.A. Tawfeeq, S.H. Alorchan, S.T. Abdul-Malik1, A. Adab, S.T. Kassid and A. Al-Gaboury (2012) Investigation on the deoxynivalenol in rations and some imported and local ingredients in Iraq and its effect on the in vitro degradation. J. Food Industries & Nutr. Sci. 2(1):77-85.

Matny, ON S, Chakraborty, F, Obanar and R, A. AL-Ani (2012) Molecular identification of Fusarium spp causing crown rot and head blight on winter wheat in Iraq. Journal of Agricultural Technology. 8(5): 1677-1690.

McMullen M, Jones R & Gallenberg D (1997) Scab of wheat and barley: a re-emerging disease of devastating impact. Plant Dis 81: 1340–1348.

McMullen M., S. Zhong, S. Neate. (2008) Fusarium head blight (Scab) of small seed. Plant Disease Management. NDSU, N.D. Agriculture Experiment Station.

Miller JD, Greenhalgh R, Wang YZ and Lu M (1991) Trichothecene chemotype of three Fusarium species. Mycologia 83: 121–130.

Miller JD. (2008) Mycotoxins in small grains and maize: old problems, new challenges. Food Addit Contam. 25:219–230.

Minervini F and M E Dell’Aquila. (2008) Zearalenone and Reproductive Function in Farm Animals. Int. J. Mol. Sci. 9:2570-2584.

Murray G, Brennan J (1998) Economic importance of wheat disease in Australia. (NSW Agriculture: Orange, NSW).

Murray, G., and Brennan, J. (2009) Estimating disease losses to the Australian wheat industry. Australas Plant Pathol. 38:558-570.

Murray, G.M. and Brennan, J. P. (2009) Estimating disease losses to the Australian wheat industry. Australas. Plant Pathol. 38: 558-570.

Murray, G.M., Rivoal, R., Trethowan, R.M., Van Ginkel, M., Mergoum, M., and Singh, R.P. (2001) CIMMYT’s approach to identify and use resistance to nematodes and soil fungi developing superior wheat germplasm. Pages. 381-389. In: Wheat in global environment. Z. Bedo, and L. Lango, Eds. Edition of Kluwer Academic, Dordrecht, The Netherlands.

Parry DW, Jenkinson P, McLeod L. (1995) Fusarium ear blight (scab) in small grain cereals – A review. Plant Pathol. 44:207–238.

Perkowski J, Jelen H, Kiecania I and Goli´nski P (1997) Natural contamination of spring barley with group A trichothecene mycotoxins in south-eastern Poland. Food Additives and Contaminants 14: 321–325
Pestka J J. 2007. Deoxynivalenol: Toxicity, mechanisms and animal health risks. Animal Feed Science and Technology. 137: 283–298.
Pestka JJ. (2010) Toxicological mechanisms and potential health effects of deoxynivalenol and nivalenol. World Mycotoxin J. 3:323–347.
Schmale D G., & G P Munkvold. (2014) Mycotoxins in Crops: A Threat to Human and Domestic Animal Health. American Phytopathological Society. https://www.apsnet.org/edcenter/intropp/topics/Mycotoxins/Pages/EconomicImpact.aspx
Scott J., Akinsanmi O., Mitter V., Simpfendorfer S., Dill-Macky R., S. C. (2004) Prevalence of Fusarium crown rot pathogens of wheat in southern Queensland and northern New South Wales. CSIRO Plant Industry, Queensland Bioscience Precinct, St. Lucia Qld 4067, Australia.
Smiley, R., Gourlie, J., Easley, S., Patterson, L.M., and Whittaker, R. (2005) Crop damage estimates for crown rot of wheat and barley in the Pacific Northwest. Plant Dis. 89:595-604.
Snijders, C.H. A., (1994) Breeding for resistance to Fusarium in wheat and maize. In: J .D. Miller & H .L. Trenholm (Eds). Mycotoxins in Grain - Compounds other than Aflatoxin, pp 37-58. Eagan Press, St. Paul, Minnesota, USA.
USDA, (2014) Global Barley Production. http://www.usda.gov/.
Visconti A, Chełkowski J and Bottalico A (1986) Deoxynivalenol and 3-acetyldeoxynivalenol – mycotoxins associated with wheat head fusariosis in Poland. Mycotoxin Research 2: 59-64.
Windels, C.E. (2000) Economic and social impacts of Fusarium head blight: Changing farms and rural communities in the northern Great Plains. Phytopathology 90:17–21.
Wise K., & C. Woloshuk (2004) Fusarium Head Blight (Head Scab). Purdue Extension.
Xu X-M, Parry DW, Nicholson P, Thomset MA, Simpson D, Edwards SG, Cooke BM, Doohan FM, Brennan JM, Moretti A, (2005) Predominance and association of pathogenic species causing Fusarium ear blight in wheat. Eur J Plant Pathol. 112:143–154.