Exploration of fungicide resistance to Fludioxonil and Tebuconazole of *Fusarium pseudograminearum*, the causal agent of wheat Fusarium crown rot

Na Zhang[#], Yiying Xu, Qi Zhang, Yanan Zhu, Yanhui Wu, Zhen Li, Wenxiang Yang[#]

College of Plant Protection, Hebei Agricultural University, Baoding 071000, China; Technological Innovation Center for Biological Control of Crop Diseases and Insect Pests of Hebei Province, Baoding 071000, China

[#]Corresponding Authors:
Na Zhang, Wenxiang Yang
2596 Lekai South Street, Baoding, Hebei Province, 071001, China
Email address: Na Zhang, zn0318@126.com; Wenxiang Yang, wenxiangyang@hebau.edu.cn

Abstract

The damage caused by wheat soil-borne diseases, especially Fusarium crown rot (FCR), affect the yield and quality of wheat increasingly. In year 2020, a total of 297 *Fusarium pseudograminearum* strains were isolated and purified from diseased FCR wheat samples in Hebei Province. Baseline sensitivity of *F. pseudograminearum* to Fludioxonil (0.0610±0.0367 μg/mL) and Tebuconazole (0.2328±0.0840 μg/mL) were constructed based on in vitro tests of 61 and 82 strains, respectively. No resistance isolate to Fludioxonil was detected, while 2 low resistance isolates to Tebuconazole were detected based on the resistance index analysis. There was no cross-resistance between Fludioxonil and Tebuconazole. This study provides theoretical and practical value to monitor resistance of *F. pseudograminearum* to fungicides and control of FCR.

Introduction

Fusarium crown rot (FCR), a soil-borne disease, causes major devastating diseases of wheat (*Triticum aestivum* L.) worldwide. The occurrence of FCR has been reported in many arid and semi-arid wheat growing continents and countries including Australia (Magee, 1957), America (Smiley, 2005), Africa (Gargouri et al., 2011), Europe (Agustí-Brisach, 2018), the Middle East (Hameed et al., 2012; Shikur Gebremariam et al., 2018), as well as China (Li et al., 2012; Zhang et al., 2015b; Xu et al., 2018). The infected wheat resulting in brown necrosis at the first two or three internodes or the production of white blighted heads and abortive seeds in the case of a severe attack (Scherm et al., 2013). As a consequence, significant yield losses are reported all over the world.

Hebei province, among the wheat-corn rotation region in the North China Plain, account for about 10% and 11.4% on the planting area and gross product, respectively. FCR has been spreading in Hebei and leading to a potential yield loss. *F. pseudograminearum* was the most commonly reported damaging Fusarium species causing crown rot of wheat, and with strong pathogenicity in China (Deng et al. 2020). This species has been repeatedly reported to be associated with Fusarium head blight (FHB) as well (Xu et al., 2015, 2018; Ji et al., 2016). There are representative dressing agents for controlling FCR diseases in China, such as Qingxiu (10% Difenoconazole), Cruiser (2.2% Fludioxonil + 2.2% Difenoconazole), Dividan (3% Difenoconazole), Raxil (6% Tebuconazole), Celest (2.5% Fludioxonil), Aobairui (1.1% Tebuconazole). The main active ingredient to fungus of these agent including Tebuconazole, Difenoconazole and Fludioxonil. Chemical control of FCR exhibits the most effective method to limit disease, but repeated fungicidal applications reduced sensitivity to strains of *Fusarium* spp., when fungicides were employed, thus increase the risk of severe plant disease and bring a series of problems such as environmental pollution and residual toxicity. Determination of the susceptibility of Fusarium pathogen to fungicides in wheat most focused on the prevalent *F. graminearum* causing Fusarium head blight (FHB) (de Chaves et al. 2022; Breunig and Chilvers, 2021). Yin et al (2021) showed that Carbendazim had a strong inhibitory effect on *F. pseudograminerum* population from Henan, China, with baseline sensitivity of (0.755±0.336) μg/mL. Little information is available about the activity and risk of resistance to Fludioxonil and Tebuconazole in *F. pseudograminearum*. Consequently, this study aimed to evaluate the susceptibility and cross-resistance of *F. pseudograminearum* from field populations to Fludioxonil and Tebuconazole. The results will provide reference for the resistance monitoring of FCR predominant pathogen and the rational application of Trizole and Fludioxonil in the control of wheat crown rot in Hebei, China and/or all over the world.

Materials & Methods

F. pseudograminearum isolates collection

In late April to late May of 2020, when wheat stem exhibiting remarkable crown rot symptoms, FCR diseased samples were collected at different wheat grown regions in Hebei Province, China (Table 1). The infected stalks were sampled randomly, with each region at least 30 isolates, and geographical distance at least 10 km. A total of 297 field isolates of *F. pseudograminearum* was isolated according to Deng et al. (2020). The single-spore isolation was performed and pure strains were re-cultured on the PDA medium.

Fungicide-containing medium preparation

Technical grade Fludioxonil (98% active ingredient [a.i.]) and Tebuconazole (97% a.i.) applied for the in vitro sensitivity assay were kindly supplied by Hebei Weiyuan Biochemical Co. Ltd. Stock solutions of Fludioxonil was obtained by dissolving it in methyl alcohol to yield a concentration of 1000 mg/mL. Tebuconazole was dissolved in acetone. PDA plates was amended with Fludioxonil to give serially final concentrations of 0.015, 0.03, 0.06, 0.12, 0.24 and 0.48 μg a.i./mL, Tebuconazole with concentration of 0.025, 0.1, 0.4, 1.6, 6.4 μg a.i./mL, PDA plates amended with 0.1% (v/v) methyl alcohol or acetone were served as control.

Baseline sensitivity of *F. pseudograminearum* to Fludioxonil and Tebuconazole

For sensitivity test, at least 7 isolates from each wheat geographic region were randomly selected to form a subset poapulation. 61 *F. pseudograminearum* isolates were assessed to Fludioxonil and 82 isolates to Tebuconazole by mycelial growth rate method (Secor and Rivera, 2012). In short, 0.7 cm mycelial plugs from the edge of pre-cultured colonies were transferred upside down onto the center of PDA plates amended with Fludioxonil. Mean radial mycelial growth was measured for each treatment by criss-cross after 3-4 days of incubation at 27℃ in the dark. Effective concentration for 50% growth inhibition (EC_{50}) was calculated using the fungicide concentrations and the corresponding inhibition rate of mycelial growth.

Colony diameter (cm) = measured colony diameter-fungal plug diameter (0.7 cm)

Relative inhibition (%) = [(colony diameter of control - colony diameter of treatment)/colony diameter of control] × 100

Fungicide concentration (μg/mL) converted into a base-10 logarithmic value (x) and inhibition of mycelial growth subjected to the Statistical Package of the Social Science (SPSS21.0) software to make a linear regression line to obtain the virulence regression equation ($y = a + bx$) and the correlation coefficient (r) (Stein and Kirk, 2003).

The baseline sensitivity was established using the frequency distribution of EC_{50} values (Hu et al. 2020).

Fungicides resistant strains and their occurrence frequency

The fungicides resistance index of each strain was assessed by the formula below, and then *F. pseudogramineum* to Fludioxonil and Tebuconazole can be divided according to the following criteria, sample classified LR, MR and HR were all taken as fungicide resistant strains.

Resistance index (RI) = EC_{50} of the tested isolate/ baseline sensitivity

Sensitive strain (S): $0 < RI \leq 5$, Low resistance strain (LR): $5 < RI \leq 10$, Middle resistance strain (MR): $10 < RI \leq 40$, High resistance strain (HR): $40 < RI$.

Frequency of resistant strains (%) = (resistant strains/tested whole strains) × 100

Cross-resistance analysis

A subset of 54 *F. pseudograminearum* isolates were used to assess their cross resistance. The linear regression analysis was carried out by using EC_{50} of Fludioxonil to strain as X-axis and EC_{50} of Tebuconazole to strain as Y-axis, the linear regression equation y = bx + a was constructed. According to the determination coefficient (R^2), the significance level of independent sample T test (P value) and Pearson correlation analysis, cross resistance between Fludioxonil and Tebuconazole were analyzed.

Data analysis

The SPSS version 21 and Microsoft Office Excel 2010 program package were used for statistical analysis. The in vitro experimental design was completely randomized consisting of three replications for each treatment and were repeated twice. Average of results were calculated for no significant difference ($P>0.05$) was observed in mycelium growth among the two experiments. Means comparison of the treatments was performed by LSD test ($P \leq 0.05$).

Pearson correlation analysis was carried out by SPSS 21., and Duncan's new complex range method was used to test the significance of differences.

Results

Sensitivity of mycelial growth of *F. pseudograminearum* to Fludioxonil

EC_{50} values for all the 61 isolates were combined to establish sensitivity baseline. The EC_{50} values of the corresponding isolates for mycelial growth assays were continuous, range from 0.0165 to 0.1789 μg/mL, with mean value of (0.0610 ± 0.0367) μg/mL (Fig. 1A). The variation factor (the ratio of the maximum to the minimum EC_{50} values) was 10.84. Based on the EC_{50} value of the tested strains, the frequency distribution showed a unimodal curve with a positive skew (Fig. 1B). The strains with EC_{50} values in the range of 0.03-0.06 μg/mL showed the highest frequency (55.74%). The average EC_{50} value of 0.0610 μg/mL was preliminarily determined as the baseline sensitivity for Fludioxonil of *F. pseudograminearum*. No resistance isolate of *F. pseudograminearum* was observed in the field subset papulation from those we tested.

The mean EC_{50} values of *F. pseudograminearum* strains collected from different geographic regions were with significant different (Table 1). The strains with the most sensitivity (<0.03 μg/mL) were ~~form~~ from Shijiazhuang, Baoding and Cangzhou of Hebei, China. The strains with the highest EC_{50} were from Shijiazhuang and Handan. Strains from Baoding showed the lowest sensitivity variation on Fludioxonil, while strains from Shijiazhuang showed the highest.

Sensitivity of mycelial growth of *F. pseudograminearum* to Tebuconazole

The EC_{50} values of 82 isolates for mycelial growth assays to Tebuconazole were continuous, range from 0.0417 to 1.5072 μg/mL. The variation factor was 50.21. Based on the EC_{50} value of the tested strains, the frequency distribution showed a unimodal curve but with a non-positive skew (Fig. 2A). 55 strains with EC_{50} values in the range of 0.04-0.40 μg/mL showed the highest frequency (67.07%). When further analysis the frequency distribution of these 54, a unimodal curve with a positive skew was constructed (Fig. 2B). The average EC_{50} value of 0.2328 μg/mL for these subset of 55 *F. pseudograminearum* isolates was preliminarily determined as the baseline sensitivity for Tebuconazole of *F. pseudograminearum*, 2 low resistance (LR) isolates was observed from those we tested.

The strains with LR were collected form Tangshan and Shijiazhuang respectively. Strains from Hengshui showed the lowest sensitivity variation on Tebuconazole, while strains from Tangshan sowed the highest (Table 2). There was significantly different ($p>$ 0.01) while with low correlation ($r=0.402$) between Fludioxonil and Tebuconazole (Fig. 3), that is, there was no cross-resistance between the two agents.

Discussion

Baseline sensitivity data of a phytopathogenic fungus to a fungicide are useful to evaluate the risk of resistance development in sensitive populations of the fungi (Zhang et al. 2015a). Fludioxonil belongs to the phenylpyrrole class of chemistry and has a unique mode of action, it inhibits the phosphorylation of glucose, thus results in the inhibition of the growth of fungal mycelium, which can also increase the seed emergence rate (Hysing and Wiik, 2014), it is commercialized in 2013 in China. In this study, the EC_{50} of Fludioxonil to *F. pseudograminearum* ranged from 0.0165 to 0.1789 μg/mL, the differences may be related to the natural differences of the strains in different regions, the physiological differences in the strains themselves, as well as the population structure of the strains of *F. pseudograminearum* under control level in each wheat region (Feng et al. 2020). In addition, *F. pseudograminearum* isolates from different regions were clustered in the same group based on EC_{50}, indicating that the sensitivity of *F. pseudograminearum* to Fludioxonil was independent of the source and geographical location of the strain.

Fungal pathogens may develop resistance to different fungicides under certain selection pressures or under conditions of adversity (Feng et al. 2020). Resistance to Fludioxonil has been reported in a broad range of plant pathogenic fungi such as *Colletotrichum gloeosporioides* from fruit (Schnabel et al. 2021), *Sclerotinia sclerotiorum* from oilseed rape (Kuang et al. 2011), *Botrytis cinerea* from apple (Zhao et al. 2010) and strawberry (Fernandez-Ortuno et al. 2016), as well as Fusarium (Peters et al. 2008). In this research, the variation factor between the most sensitive strain and the least sensitive strain was 10.42, indicating that *F. pseudograminearum* was sensitive to Fludioxonil in nature. Based on the baseline sensitivity in this study (0.0610 μg/mL), there was no Fludioxonil resistant *F. pseudograminearum* isolate detected. The baseline sensitivity could be used for monitoring any future sensitivity shifts to Fludioxonil in the field populations of *F. pseudograminearum*. Meanwhile it provides evidence to suggest efficient fungicides and future methods for control of fungicide-resistant mutants.

Triazole fungicide, Tebuconazole and Difenoconazole for instance, is fungicide with the characterization of high efficiency, wide spectrum, safety, long duration, strong internal absorption. It belongs to a sterol 14α- demethylase inhibitors (DMIs), and affects ergosterol biosynthesis, DMIs has been considered the most effective fungicide for the control of diseases caused by *Fusarium* spp. (Delen, 2016; Hellin et al*.,* 2017). They can also prevent the formation of mycotoxins produced by *F. culmorum* and *F. graminearum* (Shah et al*.,* 2018). It has been used for many years in the USA and Europe as well as in China. The registered commercial agents with Tebuconazole as active ingredient including Raxil (6% Tebuconazole), Liangshi (1.1% Tebuconazole·19.9% Imidacloprid), Oberi (1.1% Tebuconazole·30.8% Imidacloprid). They have been applied to control diseases including sharp eyespot, Fusarium head blight, powdery mildew etc. for many years, it also registered in FCR control by seed dressing. DMI resistant fungal pathogens have been reported in populations of *Botrytis cinerea* (Zhang et al. 2020), *Pseudocercospora fijiensis* (Chong et al., 2021), *F. graminearum* (de Chaves et al., 2022), *Monilinia fructicola* (Lesniak et al. 2020), *Cercospora beticola* (Trkulja et al. 2017), *Venturia nashicola* (Ishii et al. 2021). A low LR frequency (2.44%) on *F. pseudograminearum* detected in this research implied that rotational and substitution strategy for fungicides with other site of action should be implemented to delay development of serious resistance.

Much should be done to reduce the use of fungicides in controlling of FCR, such as providing detailed information (active ingredient, potential targets and risk exposures) for different types of pesticides used for seed treatments (Lamichhane and Laudinot. 2020). Clarifying cross-resistance of a pathogen to different fungicides will help to provide a theoretical basis for scientific application of fungicides on the control of the pathogen (Feng et al. 2020). Based on our results, there is no cross-resistance between Fludioxonil and Tebuconazole. Population of *F. pseudograminearum* was most sensitive to Fludioxonil in vitro. The high variation factor of Tebuconazole (50.21) implied that there may be different control level on wheat disease in different wheat region. In the meantime, low resistance isolates from the field population to Tebuconazole implied that further consideration should be done to prohibit Tebuconazole as active gradient in wheat dressing agent. Our former research also indicated that Raxil and Dividend (Difenoconazole as active ingredient) showed lower control efficacy in the field compared with Celest (2.5% Fludioxonil) (unpublished data). Applying Fludioxonil in mixtures with newly fungicides, such as pydiflumetofen or biocontrol agents, other than Triazole fungicide, maybe generally applicable for control of FCR and fungicide resistance management of *F. pseudograminearum*.

Conclusions

This is the first report about the baseline sensitivity of *F. pseudograminearum* populations from China to Fludioxonil and Tebuconazole. The fungicide with active ingredients of Fludioxonil can be applied reasonable in the control of wheat crown rot in recent years. The baseline sensitivity (0.0610 μg/mL for Fludioxonil, 0.2328 μg/mL for Tebuconazole) constructed in this study can be used to detect the resistance level of field populations in the future, so we can provide guidance for rational use of fungicides.

Acknowledgements

The study was funded by Modern Agricultural Industry System of Wheat Industry in Hebei Province Innovation Team (HBCT2018010204) and Key Research and Development Project Hebei Province (19226507D).

References

Agustí-Brisach C, Raya-Ortega MC, Trapero C, Roca LF, Luque F, López-Moral A, Fuentes M, Trapero A. 2018. First report of *Fusarium pseudograminearum* causing crown rot of wheat in Europe. *Plant Disease* 102(8): 1670 DOI org/10.1094/PDIS-11-17-1840-PDN

Breunig M, Chilvers MI. 2021. Baseline sensitivity of *Fusarium graminearum* from wheat, corn, dry bean and soybean to pydiflumetofen in Michigan, USA. *Plant Protection* 140: 105419 DOI org/10.1016/j.cropro.2020.105419

Chong P, Essoh JN, Isaza REA, Keizer P, Stergiopoulos I, Seidl MF, Guzman M, Sandoval J, Verweij PE, Scalliet G, Sierotzski H, de Bellaire LL, Crous PW, Carlier J, Cros S, Meijer HJG, Peralta EL, Kema GHJ. 2021. A world-wide analysis of reduced sensitivity to DMI fungicides in the banana pathogen *Pseudocercospora fijiensis*. *Pest Management Science* 77: 3273-3288 DOI10.1002/ps.6372

Delen N. 2016. *Fungicides.* p534, No. 1441. Nobel Press, Turkey de Chaves MA, Reginatto P, da Costa BS, Paschoal RI, Teixeira ML, Fuentefria AM. 2022. Fungicide resistance in *Fusarium graminearum* species complex. *Current Microbiology* 79, 62 DOI org/10.1007/s00284-021-02759-4

Deng YY, Li W, Zhang P, Sun HY, Zhang XX, Zhang AX, Chen HG. 2020. *Fusarium pseudograminearum* as an emerging pathogen of crown rot of wheat in eastern China. *Plant Pathology* DOI 10.1111/PPA.13122

Feng H, Wang S, Liu ZY, Miao JQ, Zhou MX, Huang LL. 2020. Baseline sensitivity and resistance risk assessment of *Valsa mali* to pyraclostrobin. *Phytopathology Research* 2:31 DOI org/10.1186/s42483-020-00072-9

Fernandez-Ortuno D, Tores JA, Perez-Garcia A, & Vicente AD. 2016. First report of fludioxonil resistance in *Botrytis cinerea*, the causal agent of gray mold, from strawberry fields in Spain. *Plant Disease* 100(8): 1779

Gargouri S, Mtat I, Gargouri KL, Zid M, Hajlaoui MR. 2011. Molecular genetic diversity in populations of *Fusarium pseudograminearum* from Tunisia. *Journal of Phytopathology* 159: 306-313

Kuang J, Hou YP, Wang JX, Zhou MG. 2011. Sensitivity of *Sclerotinia sclerotiorum* to fludioxonil: In vitro determination of baseline sensitivity and resistance risk. *Crop Protection* 30: 876-882

Hameed MA, Rana RM, Ali A. 2012. Identification and characterization of a novel Iraqi isolate of *Fusarium pseudograminearum* causing crown rot in wheat. *Genetics and Moleculae Research* 11(2): 1341-1348 DOI 10.4238/2012.May.15.4

Hellin P, Scauflaire J, van Hese V, Munaut F, Legrève A. 2017. Sensitivity of *Fusarium culmorum* to Triazoles: impact of trichothecene chemotypes, oxidative stress response and genetic diversity. Pest Managment Science 73 (6): 1244-1252. DOI 10.1002/ps.4450

Hu J, Wu JX, Gu MR, Geng JM, Guo C, Yang ZM, Lamour K. 2020. Baseline sensitivity and control efficacy of fluazinam against *Clarireedia homoeocarpa. Crop Protection* 137, 105290. DOI org/10.1016/j.cropro.2020.105290

Hysing SC, Wiik L. 2014. Fusarium seedling blight of wheat and oats: Effects of infection level and fungicide seed treatments on agronomic characters. *Acta Agriculturae Scandinavica Section B* 64: 537-546. DOI 10.1080/09064710.2014.929731.

Ishii H, Cools HJ, Nishimura K, Borghi L, Kikuhara K, Yamaoka Y. 2021. DMI-fungicide resistance in *Venturia nashicola*, the causal agent of Asian Pear Scab—How reliable are mycelial growth tests in culture? *Microorganisms* 9: 1377 DOI org/10.3390/ microorganisms9071377

Lamichhane JR, Laudinot V. 2020. Unveiling the unknown: knowledge and risk perceptionabout the planting of pesticide-treated seed among French arablefarmers. *Journal of Plant Disease and Protection* DOI org/10.1007/s41348-020-00400-3

Lesniak K, Peng JY, Peoffer TJ, Outwater CA, Eldred LI, Rothwell NL, Sundin GW. 2020. Survey and genetic analysis of Demethylation inhibitor fungicide resistance in *Monilinia fructicola* from Michigan orchards. *Plant Disease* 105(4) DOI 10.1094/PDIS-07-20-1561-RE

Ji LJ, Kong LX, Li QS, Wang LS, Chen D, Ma P. 2016. First report of *Fusarium pseudograminearum* causing Fusarium head blight of wheat in Hebei Province, China. *Plant Disease* 100: 220

Li HL, Yuan HX, Fu B, Xing XP, Sun BJ. 2012. First report of *Fusarium pseudogrumineurum* causing crown rot of wheat in Henan, China. *Plant Disease* 96(7): 1065 DOI 10.1094/PDIS-01-12-0007-PDN

Magee CJ. 1957. News from New South Wales. Commonwealth Phytopathological News 3: 26.

Peters RD, Platt HW, Drake KA, Coffin RH, Moorehead S, Clark MM, Al-Mughrabi KI, Howard RJ. 2008. First report of fludioxonil-resistant isolates of *Fusarium* spp. causing potato seed-piece decay. *Plant Disease* 92(1): 172

Scherm B, Balmas V, Spanu F, Pani G, Delogu G, Pasquali M, Mighli Q. 2013. *Fusarium culmorum*: causal agent of foot and root rot and head blight on wheat. *Molecular Plant Pathology* 14, 323-41

Schnabel G, Tan Q, Schneider V, Ishii H. 2021. Inherent tolerance of *Colletotrichum gloeosporioides* to fludioxonil. *Pesticide Biochemistry and Physiology* 172 DOI org/10.1016/j.pestbp.2020.104767

Shah L, Ali A, Yahya M, Zhu Y, Wang S, Si H, Rahman H, Ma C. 2018. Integrated control of Fusarium head blight and deoxynivalenol mycotoxin in wheat. *Plant Pathology* 67(3): 532-548

Secor GA, Rivera VV. 2012. Fungicide resistance assays for fungal plant pathogen. in Plant Fungal Pathogen. Bolton MD, Thomma BPHJ. pp385-392

Shikur Gebremariam E, Sharma-Poudyal D, Paulitz TC, Erginbas-Orakci G, Karakay A, Dababat AA. 2018. Identity and pathogenicity of *Fusarium* species associated with crown rot on wheat (*Triticum* spp.) in Turkey. *European Journal of Plant Pathology* 150(2): 378-399

Smiley RW, Gourlie JA, Easley SA, Patterson LM. 2005. Pathogenicity of fungi associated with the wheat crown rot complex in Oregon and Washington. *Plant Disease* 89(9): 949-957

Stein JM, Kirk WW. 2003. Variations in the sensitivity of *Phytophthora infestans* isolates from different genetic backgrounds to dimethomorph. *Plant Disease* 87, 1283-1289

Trkulja NR, Milosavljević AG, Mitrović MS, Jović JB, Toševski IT, Khan MFR, Secor GA. 2017. Molecular and experimental evidence of multi-resistance of *Cercospora beticola* field populations to MBC, DMI and QoI fungicides. *European Journal of Plant Pathology* 149: 895-910

Xu F, Song YL, Yang GQ, Liu LL, Li HL. 2015. First report of *Fusarium pseudograminearum* from wheat heads with Fusarium head blight in North China Plain. *Plant Disease* 99, 156

Xu F, Yang GQ, Wang JM, Song YL, Liu LL, Zhao K, Li YH, Han ZH. 2018. Spatial distribution of root and crown rot fungi associated with winter wheat in the North China Plain and its relationship with climate variables. *Frontier in Microbiology* 9: 1054 DOI 10.3389/fmicb.2018.01054

Yin XR, Sun Y, Zhu K, Yang X, Xiong Z, Zheng W, Hou Y, Xu JQ. 2021. Sensitivity of the isolates of *Fusarium pseudograminearum* to carbendazim in Henan Province. *Journal of Pesticide Science* 0145 DOI 10.16801/j.issn.1008-7303.2021.0145

Zhang C, Li TJ, Xiao L, Zhou SL, Liu XL. 2020. Characterization of tebuconazole resistance in *Botrytis cinerea* from tomato plants in China. *Phytopathology Research* 2:25 DOI org/10.1186/s42483-020-00064-9

Zhang Y, Lu JL, Wang JX, Zhou MG, Chen CJ. 2015a. Baseline sensitivity and resistance risk assessment of *Rhizoctonia cerealis* to thifluzamide, a succinate dehydrogenase inhibitor. *Pesticide Biochemistry and Physiology* 124: 97-102

Zhang XX, Sun HY, Shen CM, Li W, Yu HS, Chen HG. 2015b. Survey of *Fusarium* spp. causing wheat crown rot in major winter wheat growing regions of China. *Plant Disease* 99: 1610-1615

Zhao H, Kimb YK, Huanga L, Xiao CL. 2010. Resistance to thiabendazole and baseline sensitivity to fludioxonil and pyrimethanil in *Botrytis cinerea* populations from apple and pear in Washington State. *Postharvest Biology and Technology* 56:12-18