Occurrence and Prevalence of *Fusarium* Head Blight in Winter Wheat in Anhui during 2017 – 2026

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Abstract *Fusarium* head blight (FHB) in winter wheat was continuously surveyed for ten years during 2017 to 2026 in Anhui Province. There were significant differences in incidence and severity of FHB among seasons and regions. The highest incidence of 80.03% and disease index of 36.72% were recorded in the year 2018, and the lowest incidence of 2.22% and disease index of 0.57% were observed in the year 2025. Average FHB occurrence varied from 32.68% in the southern humid region and 23.04% in the middle hilly area, to 18.72% in the northern semi-arid plain. A positive correlation between FHB incidence and disease index was observed, with a correlation coefficient of 0.921 4. Precipitation during April – May highly affected the FHB occurrence and showed different impacts; in humid southern regions, rainfall frequency played a more important role than total precipitation, while in semi-arid northern regions, total precipitation was more decisive than rainfall frequency. Longer-term and larger-scale monitoring of wheat FHB epidemics and more accurate FHB prediction platforms are needed to develop high-efficacy management strategies.

Key words *Triticum aestivum* L.; *Fusarium graminearum*; Scab; *Fusarium* crown rot; Mechanical harvest loss; Long-term monitoring

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Wheat is the biggest staple crop in Anhui Province, with its annual production of 17 million t covering 2.8 million hm^2 of arable land in recent years, corresponding to nearly 13% of the national total. Anhui is also one of the provinces where *Fusarium* head blight (FHB) was firstly noticed in China traced back to the mid-1930s[1].

It is a widely accepted concept that FHB (also called Scab) is a weather triggered fungal disease of cereal crops[2-5]. Its occurrence and prevalence are largely determined by the precipitation during wheat flowering/florescence/anthesis stage[5-6] which is normally from mid-April to early-May in Anhui, depending on the geographical location of wheat planted from south to north. Early years of this century witnessed several manifested FHB epidemics in China. For example, the year 2012 encountered a nation-wide wheat FHB prevalence of 9.89 million hm^2, covering 47.1% of all wheat planted. The year 2016 also experienced a high infection of FHB with 6.84 million hm^2 of wheat contaminated by *Fusarium* pathogens, affecting 41.5% of its acreage. Severe FHB epidemic in 2018 affected over 5.67 million hm^2 of wheat throughout the country, accounting for 37.5% of all wheat planted in that year[7]. In 2000 – 2018, wheat FHB caused average annual yield losses of more than 3.41 million t in China[1].

FHB potentially causes the reduction not only in grain yield but also in grain quality as the FHB fungi can accumulate various mycotoxins in the grain, such as deoxynivalenol (DON)[8-10]. The European Commission has already introduced regulations for DON in various food products in 2005 and implemented in July 2006, which sets the range of 1 250 – 1 750 μg/kg for unprocessed cereals. Besides the yield loss and quality deterioration caused by FHB causal agent *Fusarium graminearum*, the pathogen (along with other *Fusarium* species such as *F. pseudograminearum*) could also cause *Fusarium* crown rot (FCR) in wheat[11-14]. When crop was affected by FCR pathogens, it would lead to water-soaked spikelets, discolored and shriveled kernels, stem breakage, premature senescence and abortive tillers. Subsequently, an increased grain yield loss would come out during the mechanical harvest operation.

Breeding and deploying FHB resistant wheat varieties is considered the most economical solution in decreasing FHB occurrence and its yield impacts[1,6,15-17]. Due to its necrotrophic nature of *Fusarium* fungi, it is difficult to achieve developing wheat genotypes with very high resistance to FHB. For example, in China, at least 60% of the national registered and released wheat varieties during 2017 – 2025 were highly susceptible to FHB infection. Consequently, in agricultural practice, the control of wheat FHB is still exclusively dependent on fungicides[18-20]. Such traditional approach remains critical, but is nowadays increasingly constrained by its ecological trade-offs and regulatory pressures, *e.g.* the Ministry of Agriculture of China (MOA) issued a document in 2015 of "China's zero-growth action plan in 2020" for constraining chemical fertilizer and chemical pesticide use. Early detection and precise forecasting of fungal infections are pivotal to the future management[21-22]. The more we understand the prevalence of FHB epidemics historically, the better control decision we can make. For this purpose, a province-wide FHB survey had been continuously taken since 2017. The surveyed occurrence and prevalence of FHB in winter wheat in Anhui for the past ten years (from 2017 to 2026) will cast lights on the deployment of its future management strategies.

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Materials and Methods

Field survey

Each year in mid-May (about half a month before harvest), a field survey was conducted in Anhui following a consistent route, covering most of the important winter wheat production regions. A sampling site or field was randomly selected for every 30 to 40 km apart (Fig. 1). In each survey site or field (with GPS location), no less than 100 wheat ears were randomly reaped (Table 1).

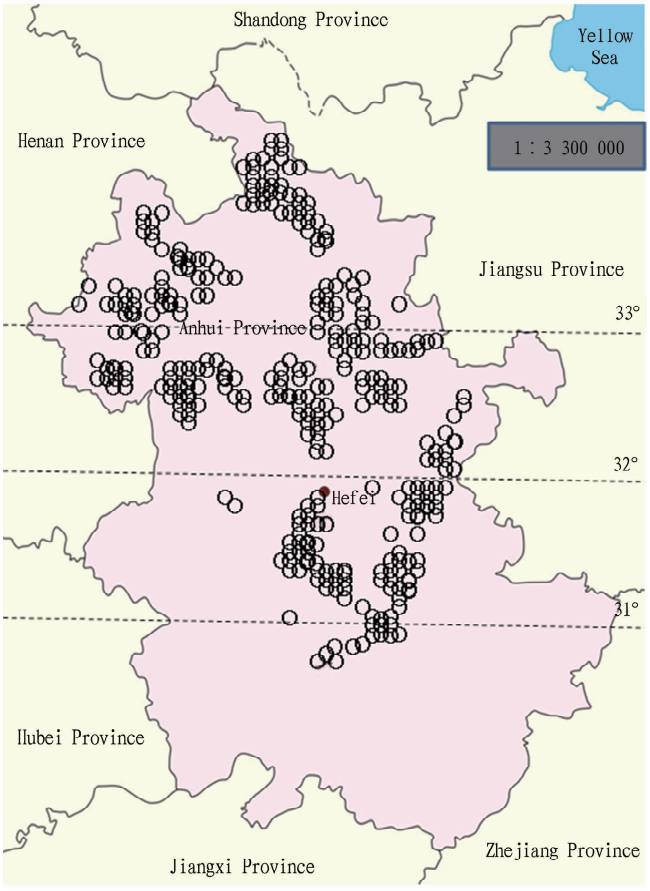


Fig. 1 Survey sites (marked in circles) of *Fusarium* head blight in wheat during 2017 – 2026 in Anhui Province

Table 1 Dates of field survey and the numbers of wheat *Fusarium* head blight sampling sites during 2017 – 2026 in Anhui province

	Survey time	No. of sampling sites
2017	May 14 – 19	40
2018	May 15 – 18	31
2019	May 17 – 21	33
2020	May 12 – 15	36
2021	May 11 – 17	38
2022	May 13 – 16	38
2023	May 16 – 19	38
2024	May 14 – 17	44
2025	May 12 – 16	45
2026	May 13 – 17	45

FHB assessments

The sampled wheat ears were classified into 5 groups according to the 0 – 4 scale *, as Grade 0 means no infection, Grade 1 means less than 25% spikelets affected within a spike, Grade 2 means 25% – 50% spikelets affected, Grade 3 means 50% – 75% spikelets affected, and Grade 4 means more than 75% spikelets affected. FHB incidences were thereafter calculated following the criteria described by Liu *et al.* [15].

* Those spikelets with only FHB 'infection point' were also determined as 'affected' and classified into Grade 1. Therefore, the 'measured' disease incidence of a field might be somewhat higher than farmers 'noticed' FHB infection.

Disease index (DI), *i. e.* index of disease severity was calculated as following formula:

$$DI = \{[\Sigma(hi \times i)]/4H\} \times 100$$

In which: i = severity of each spike (0, 1, 2, 3, or 4); hi = number of spikes in severity i (0, 1, 2, 3, or 4); H = total number of spikes assessed.

Meteorological data

Weather data were adopted from the provincial meteorological database. Based on the fact that precipitation during wheat flowering stage contributes the most to the infection of FHB causal agents, the accumulated precipitation in April and May was taken into consideration. The precipitation data of three cities (*i. e.* Tongling, Hefei and Suzhou), representing the south, middle and north of the main production region of wheat in Anhui, were chosen to analyze the correlation between precipitation and FHB occurrence. Those cities also represent three topographic regions as humid Yangtze River region (<32°N), hilly region (32° – 33°N) and semi-arid plain (>33°N).

Statistical analysis

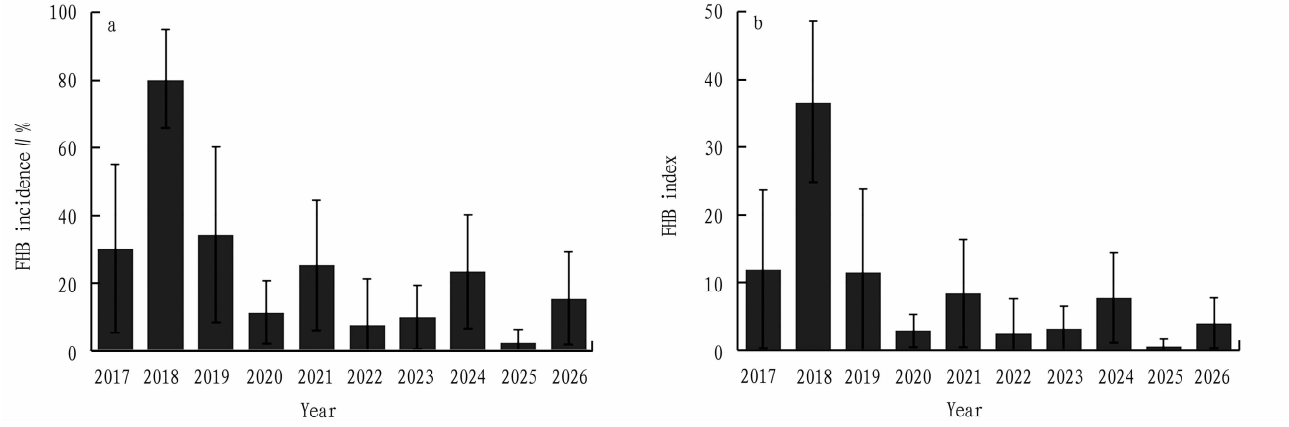
Analysis of variance and correlation in this study were calculated using Microsoft Excel 2021 (Microsoft Co, Redmond, WA, USA).

Results

Differences in FHB incidence and severity among seasons

The incidence of wheat FHB in Anhui varied from season to season (Fig. 2). Taking the province as a whole, the highest incidence was in 2018 at 80.03% and the lowest incidence appeared in 2025 at 2.22%. During the ten continuously surveyed years from 2017 to 2026, only three years showed FHB incidence higher than 30% (as 2017, 2018 and 2019), two years had FHB incidence higher than 20% (as 2021 and 2024), and other five years showed no significant infection with FHB incidence less than 20%.

Similarly, the severity of FHB (*i. e.* disease index) in Anhui also varied from season to season (Fig. 2). The highest disease index was in 2018 at 36.72% and the lowest disease index was in 2025 at 0.57%. During the ten continuously surveyed years from 2017 to 2026, only three years showed FHB DI higher than 10% (as 2017, 2018 and 2019), three years had FHB DI higher than 5% (as 2021, 2022 and 2024), and other four years showed no severe infection with FHB DI less than 5%.



Surveys were taken during mid-May and data showed the average FHB incidence and disease index of all surveyed fields. Bars were the STDEV.

Fig. 2 *Fusarium* head blight incidence (a) and disease index (b) on winter wheat in Anhui Province during 2017 – 2026

When the data of FHB incidence and DI were statistically analyzed, a significant and positive correlation between FHB incidence and DI was observed (Fig. 3). Those ten-year's surveyed data showed a positive correlation index of 0.921 4 between the two parameters which was coincident with our previous results[15]. Genetically, Mesterházy[23] had classified wheat FHB resistance into five categories as type I resistance referred to the initial pathogen infection triggering FHB resistance and type II resistance referred to the expansion of FHB within wheat ears. Results here again suggested that preventing the *Fusarium* fungal infection could effectively decrease the disease severity of wheat FHB, corresponding to the type I and type II resistance respectively.

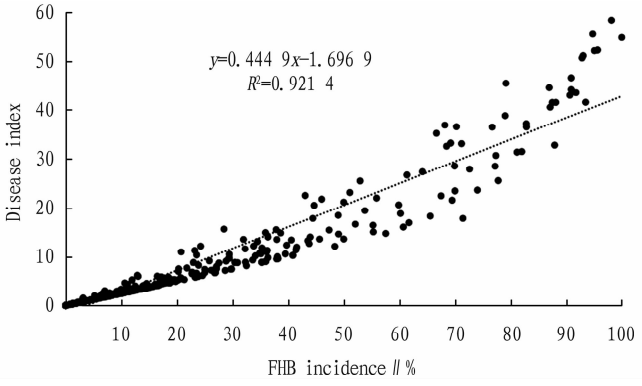
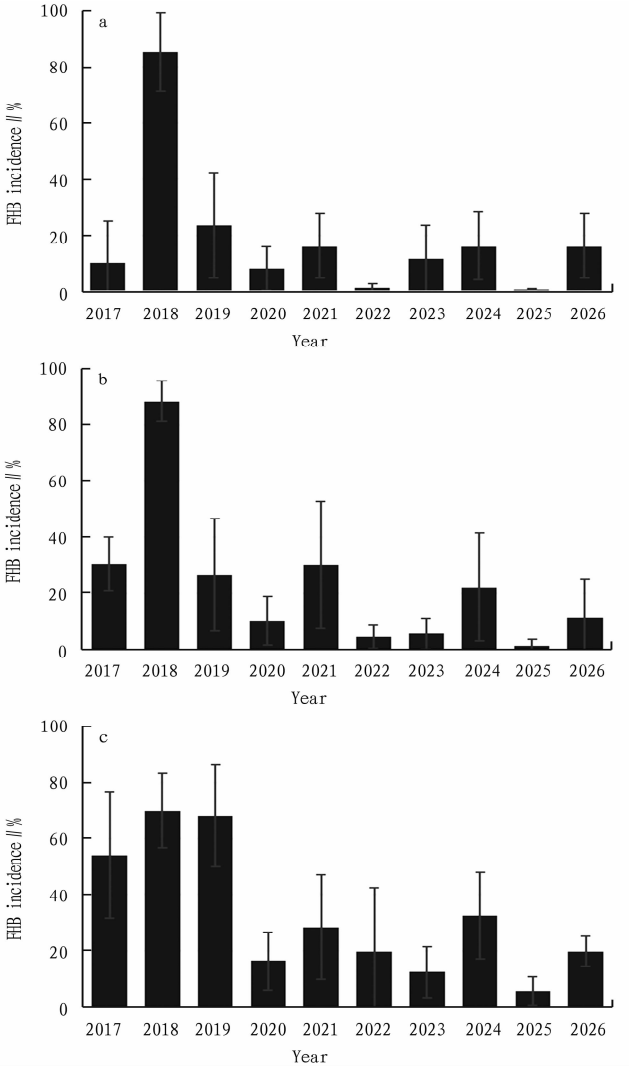


Fig. 3 Correlation between *Fusarium* head blight incidence and disease index according to the field surveys of FHB in Anhui Province wheat fields during 2017 – 2026

From this present study, it was suggested that wheat FHB in Anhui came into a less severe period after 2019. During 2020 – 2026, 56.49% of the surveyed wheat fields in Anhui had their FHB incidence less than 10%, whilst during 2017 – 2019, 44.23% of the surveyed fields had FHB incidence more than 50%.

Differences in FHB incidence among regions

Regional differences in FHB incidence were also found (Fig. 4). On the whole, semi-arid region (*i.e.* > 33° N) showed the lowest in field FHB incidence, and along Yangtze River region (*i.e.* <32°N) had the highest FHB incidence. This



Surveys were taken during mid-May and data showed the average incidence of surveyed fields. Bars were the STDEV.

Fig. 4 *Fusarium* head blight incidence (%) during 2017 – 2026 in the north (a, >33°N), the middle (b, 32 – 33°N) and the south (c, <32°N) of Anhui Province

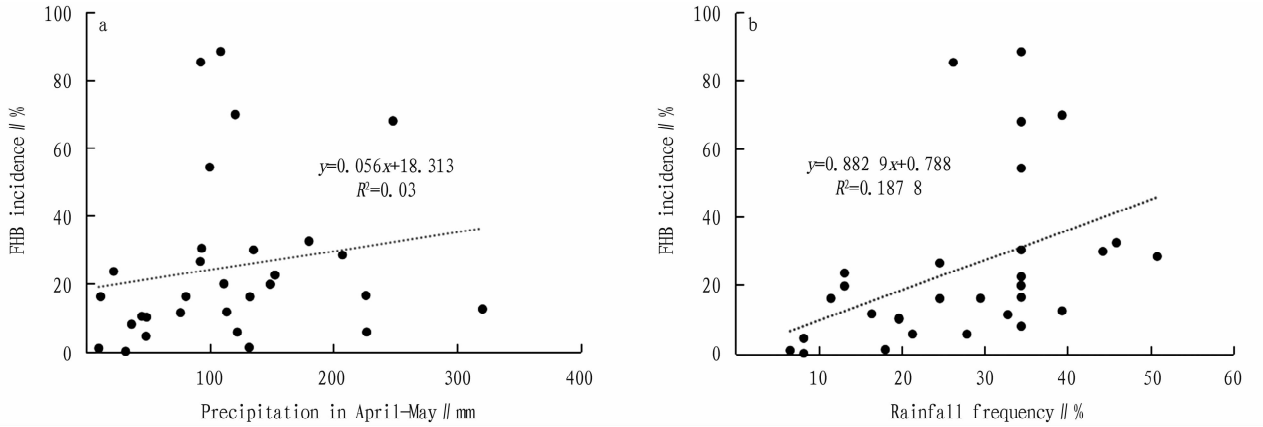
was coincident with the humid climate conditions along Yangtze River region which trigged the high risk of FHB contamination. Ten-year's average incidence of wheat FHB varied from 32.68% in the southern fields and 23.04% in mid-Anhui fields, to 18.72% in the northern fields. Three of the ten surveyed years showed FHB incidence over 50% in the south, and only two years showed FHB incidence over 20% in the north.

Noticeably, the year 2018 was the very 'special' year for FHB and nearly all wheat fields throughout the whole province were severely affected. The highest in-field FHB incidence in the south was 86.95% (69.79% on average), in the middle was 95.65% (88.34% on average) and in the north was 100% (85.17% on average). Wheat fields in the south showed relatively 'the lowest' FHB incidence and severity. That was also the year produced wheat with the worst grain quality within the past ten years.

Relationship between precipitation and FHB incidence

In the main region of wheat production in Anhui, late April to early May is the stage of wheat florescence and grain filling. It is also the 'infection window' for FHB whereas rains in April determine the pathogen infection and in May determine the pathogen expansion in the ears. Correlation analysis of precipitation and FHB incidence revealed that rainfall in April and May positively related to FHB occurrence (Fig. 5). Taking the province as a whole, FHB incidence (y) was linked to the total amount of precipitation (x_1) and the rainfall frequency (x_2) within April and May in the following equations:

$y = 0.056x_1 + 18.313$; and $y = 0.882\ 9x_2 + 0.788$



FHB incidence was during 2017 – 2026 and the precipitation data were from three cities of Tongling, Hefei and Suzhou in Anhui.

Fig. 5 Correlation between total precipitation in April – May and FHB incidence (a) and between precipitation frequency in April – May and FHB incidence (b)

The ten-year-long survey revealed that FHB occurrence and severity were more correlated to the rainfall's frequency than the total precipitation *per se* during the 'sensitive' stage, as the correlation between precipitation and FHB incidence was 0.173 2 and between precipitation frequency and FHB incidence was 0.433 4.

Following the regional analysis of FHB incidence and precipitation, either total precipitation or rainfall frequency was more important for FHB initiation gave different insights (Table 2). In the south, with normally wheat-rice rotation, soil moisture in most seasons is not a constraint factor for initiating FHB. In this case, the frequency affected more than the total amount of rains (correlation index was 0.262 2 in comparison with 0.024 6). However, in the north, more rainfall amount might mean the soil could hold relative higher humidity for longer time, which triggered the occurrence of FHB (correlation index was 0.440 2), while the rainfall frequency might be less important as the correlation index was 0.243 4.

Table 2 Correlation of precipitation during April – May and wheat *Fusarium* head blight incidence during 2017 – 2026 in Anhui Province among regions

	Correlation between precipitation and FHB incidence	Correlation between precipitation and FHB severity	Correlation between precipitation frequency and FHB incidence	Correlation between precipitation frequency and FHB severity
North, >33°N	0.440 2	0.396 5	0.243 4	0.178 4
Middle, 32 – 33°N	−0.336 0	−0.358 8	0.084 4	0.001 4
South, <32°N	0.024 6	0.021 3	0.262 2	0.217 8

The specialty in FHB of the year 2018 might be linked to the precipitation conditions, especially in May. Tongling experienced 16 raining days with 107.5 mm precipitation, Hefei had 15 raining days with 86.8 mm precipitation and Suzhou got 10 d of rains at 66.6 mm precipitation. High frequent rainfalls in that month might have triggered the secondary infection of FHB.

Discussion

Long-term monitoring of wheat FHB epidemics

The values of long-term observations and field experiments in agriculture are world-widely recognized, especially in areas such as invasion ecology and community ecology. However, large

spatial-scale surveys of some certain plant diseases over large areas, in different regions and over years are still inadequate. Following the changes of global weather conditions (*i. e.* climate change) and the development of agricultural practices, plant diseases are changing among seasons and regions, sometimes unpredictably. Long-term and large-scale surveys of a certain disease are of great academic significance (though costly) in providing information on the understanding of the disease and the evolution of the causal agents. Furthermore, the surveyed data can help the growers to improve their management strategies. For example, in the United States, the USDAARSled Wheat and Barley Scab Initiative (WBSI) project has already utilized the survey data to ensure crop advisors receiving the latest and best information on FHB management.

Sporadic surveys of wheat FHB had been made in limited seasons and regions. Provincial-wide or nation-wide FHB monitoring was still very rare in China. Existing surveys had captured mostly short-term fluctuations and failed to provide a nation-wide vision of the status quo of wheat FHB and its future scenarios. Our present study provides some data and information on wheat FHB occurrence during the past 10 years in Anhui Province, one of China's key wheat-producing provinces and a region subject to highest FHB epidemic risk. Our findings are helpful for understanding wheat FHB's 'ebbs-and-flows' from a historical perspective.

Precise FHB prediction and forecasting

In China, some prediction models of wheat FHB have been developed[24-25], based on the notion that weather is the main variable in determining the FHB epidemic. However, due to the saprophytic nature of *Fusarium* pathogens, the actual contamination and prevalence of FHB are complicated. Though precipitation or field humidity during the wheat anthesis stage is the most important driver for FHB infection, our 2017 – 2026 survey suggested that precipitation *per se* might have different impacts on initiating FHB. For the humid southern regions, rainfall frequency could be more important than total rainfall. For the arid and semi-arid northern regions, total precipitation might be more effective than frequency since heavy rainfall maintained higher soil humidity for a longer time, which contributed to the infection of *Fusarium* inoculum.

More precise and accurate prediction in wheat FHB is still to be developed. Some other factors (*e. g.* ecological parameters) besides precipitation are still needed to be taken into consideration. In this study, the precipitation during anthesis could only explain no more than 50% of the FHB occurrence. Only good prediction models can give farmers economically and ecologically effective guidance for FHB control, since the efficiency of fungicides on managing FHB is largely dependent on the treatment timing. Once the plants have been affected, though asymptomatically, the efficacy of chemical control declines. In practice, some local farmers still rely on 2 – 3 times of chemical sprays. By doing so, side-effects as higher costs, reduced grain quality and elevated ecological risks all arise. With the rapid advances in modern technologies, a new generation of method based on computer vision for plant disease monitoring and forecasting is promising[22].

Highly efficient management strategies

Entering the new era, China's efforts to secure food production capacity is now by far the top priority to feed its 1.4 billion population with adequate and safe foodstuffs. The country is establishing a diversified food supply system to guarantee grain security and to build up the country's strength in agriculture. Reducing grain losses caused by pests as well as pre-harvest and post-harvest losses are among the key priorities.

China is highly concerned about the impacts of FHB and attaches great importance to its control. In Anhui Province, a Unified Pest and Disease Prevention and Control (UPDPC) policy has recently been adopted by some local authorities. The relatively low incidence and severity of FHB observed in 2020 – 2026 might partly attribute to that policy. However, due to the fact that most of the current practices have their shortcomings, such as inadequate genetic resistance, less-accurate forecasting, and difficulties in determining the optimal fungicide application timing, the efficiency of wheat FHB management remains unsatisfactory, at least in some certain regions or seasons. For instance, even though 2026 was not a severe epidemic year of FHB, 7 out of 45 surveyed fields still exhibited over 30% incidence. These observations highlight the need for further critical evaluation of the UPDPC policy.

Host, environment and pathogen are the three factors in a 'plant disease triangle'[26]. A broader framework of plant disease management, which integrating avoidance, exclusion, eradication and protection into one 'solution panel', is necessarily to be developed. Under this framework, multidisciplinary knowledge on agronomy, biology, phytopathology, ecology and informatics should be integrated to develop highly efficient control strategies and shift from reactive to proactive disease management.

References

[1] MA HG, LIU Y, ZHANG S, *et al.* Wheat resistance to *Fusarium* head blight and breeding strategies[J]. Crop Health, 2025, 3: 9.

[2] MCMULLEN M, JONES R, GALLENBERG D. Scab of wheat and barley: A re-emerging disease of devastating impact[J]. Plant Disease, 1997, 81(12): 1340 – 1348.

[3] GOSWAMI RS, KISTLER HC. Heading for disaster: *Fusarium graminearum* on cereal crops[J]. Molecular Plant Pathology, 2004, 5(6): 515 – 525.

[4] KAZAN K, GARDINER DM, MANNERS JM. On the trail of a cereal killer: recent advances in *Fusarium graminearum* pathogenomics and host resistance[J]. Molecular Plant Pathology, 2012 13(4), 399 – 413.

[5] KHAN MK, PANDEY A, ATHAR T, *et al.* Fusarium head blight in wheat: contemporary status and molecular approaches[J]. 3 Biotech, 2020, 10: 172.

[6] MA Z, XIE Q, LI G, *et al.* Germplasms, genetics and genomics for better control of disastrous wheat *Fusarium* head blight[J]. Theoretical and Applied Genetics, 2020, 133: 1541 – 1568.

[7] HUANG C, JIANG Y, WU J, *et al.* Occurrence characteristics and reason analysis of wheat head blight in 2018 in China[J]. Plant Protection, 2019 45(2): 160 – 163 (in Chinese).

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Quality, 2018, 9(5): 1038 - 1044. (in Chinese).
[11] LEON N, ROCA M, IGUALADA C, *et al.* Wide-range screening of banned veterinary drugs in urine by ultra high liquid chromatography coupled to high-resolution mass spectrometry[J]. Journal of Chromatography A, 2012, 1258: 55 - 65.
[12] GAVAGE M, DELAHAUT P, GILLARD N. Suitability of high-resolution mass spectrometry for routine analysis of small molecules in food, feed and water for safety and authenticity purposes: A review[J]. Foods, 2021, 10(3): 601.
[13] CHEN G, SCHNEIDER MJ. A rapid spectrofluorometric screening method for enrofloxacin in chicken muscle[J]. Journal of Agricultural and Food Chemistry, 2003, 51(11): 3249 - 3253.
[14] SU Y. High-throughput screening method for hundreds of veterinary drug residues in animal-derived foods[D]. Sichuan: Sichuan Agricultural University, 2019. (in Chinese).
[15] HOU ML, DONG XB, LI HL, *et al.* Simultaneous determination of antibiotics and tranquilizers veterinary drugs residues in livestock and poultry meat by ultra high performance liquid chromatography-tandem mass spectrometry[J]. Food and Fermentation Sciences & Technology, 2020, 56(3): 113 - 117. (in Chinese).
[16] WU YN, LI JG, ZHENG MH, *et al.* Research on trace and ultra-trace detection techniques for dioxins, polychlorinated biphenyls, and chloropropanols[Z]. 2004. (in Chinese).
[17] WANG W, CAI WS, SHAO XG. Progress in fourier transform ion cyclotron resonance mass spectroscopy[J]. Progress in Chemistry, 2005(2): 336 - 342. (in Chinese).
[18] SENYUVA HZ, GOKMEN V, SARIKAYA EA. Future perspectives in Orbitrap-high-resolution mass spectrometry in food analysis: A review[J]. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 2015, 32(10): 1568 - 1606.
[19] ZHANG X, YANG GX, KONG C, *et al.* Determination of tranquilizer and their metabolites residues in aquatic products by high performance liquid chromatography-tandem mass spectrometry[J]. Chinese Journal of Analytical Chemistry, 2021, 49(3): 460 - 469. (in Chinese).
[20] ZHANG QM. Determination of diazepam and other four kinds of banned drugs in pork by HPLC-MS[J]. Journal of Anhui Agricultural Sciences, 2016, 44(25): 71 - 75. (in Chinese).

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(Continued from page 34)

[8] BECHER R, MIEDANER T, WIRSEL SGR. Biology, diversity, and management of FHBcausing *Fusarium* species in smallgrain cereals[M]// Kempken F. Agricultural Applications[M]. Berlin, Heidelberg: Springer, 2013.
[9] JOHNS LE, BEBBER DP, GURR SJ, *et al.* Emerging health threat and cost of *Fusarium* mycotoxins in European wheat[J]. Nature Food, 2022, 3: 1014 - 1019.
[10] BENCHEIKH A, BELABED I, ROUAG N. *Fusarium* head blight of wheat: Current knowledge on associated species and their mycotoxins, pathogenicity diversity, and management strategies[J]. Australasian Plant Pathology, 2024, 53: 457 - 471.
[11] DYER AT, JOHNSTON RH, HOGG AC, *et al.* Comparison of pathogenicity of the *Fusarium* crown rot (FCR) complex (*F. culmorum*, *F. pseudograminearum* and *F. graminearum*) on hard red spring and durum wheat[J]. European Journal of Plant Pathology, 2009, 125: 387 - 395.
[12] MATNY ON. *Fusarium* head blight and crown rot on wheat & barley: Losses and health risks. Advances in Plants & Agriculture Research, 2015, 2(1): 38 - 43.
[13] ZHANG X, SUN HY, SHEN CM, *et al.* Survey of *Fusarium* spp. causing wheat crown rot in major winter wheat growing regions of China[J]. Plant Disease, 2015, 99: 1610 - 1615.
[14] YANG X, ZHANG L, WEI J, *et al.* A TaSnRK1α-TaCAT2 model mediates resistance to *Fusarium* crown rot by scavenging ROS in common wheat[J]. Nature Communications, 2025, 16: 2549.
[15] LIU Z, ZHAO L, HE XF, *et al.* Screening winter wheat germplasm for *Fusarium* head blight resistance[J]. Agricultural Science & Technology, 2015, 16(8): 1924 - 1929.
[16] MA HX, WANG YG, GAO YJ, *et al.* Review and prospect on the breeding for the resistance to *Fusarium* head blight in wheat[J]. Scientia Agricultura Sinica, 2022, 55(5): 837 - 855.
[17] BOYLES RE, TABORDA CB, GUEDIRA GB, *et al.* Approaching 25 years of progress towards *Fusarium* head blight resistance in southern soft red winter wheat (*Triticum aestivum* L.)[J]. Plant Breeding, 2023, 143(1): 68 - 81.
[18] BLANDINO M, MINELLI L, REYNERI A. Strategies for the chemical control of *Fusarium* head blight: Effect on yield, alveographic parameters and deoxynivalenol contamination in winter wheat grain[J]. European Journal of Agronomy, 2006, 25(3): 193 - 201.
[19] CHEN Y, ZHANG AF, GAO TC, *et al.* Integrated use of pyraclostrobin and epoxiconazole for the control of *Fusarium* head blight of wheat in Anhui Province of China[J]. Plant disease, 2012, 96(10): 1495 - 1500.
[20] LIU Z, ZHAO L, HE XF, *et al.* Screening fungicides for controlling *Fusarium* head blight of winter wheat[J]. Agricultural Science & Technology, 2017, 18(12): 2495 - 2502.
[21] FRANCO MF, LORI GA, CENDOYA MG, *et al.* Using anthesis date as a covariate to accurately assessing type II resistance to *Fusarium* head blight in field-grown bread wheat[J]. Crop Protection, 2021, 142: 105504.
[22] DING W, ABDEL-BASSET M, ALRASHDI I, *et al.* Next generation of computer vision for plant disease monitoring in precision agriculture: A contemporary survey, taxonomy, experiments, and future direction[J]. Information Sciences, 2024, 665: 120338.
[23] MESTERHáZY A. Types and components of resistance to *Fusarium* head blight of wheat[J]. Plant Breeding, 1995, 5: 377 - 386.
[24] SUN X, SU S, WANG Q, *et al.* Prediction of wheat fusarium head blight severity levels in southern Henan based on K-means-SMOTE and XGBoost algorithms[J]. Journal of Computer science, 2025, 11: e2638.
[25] XU M, XU Y, XU J, *et al.* Construction of a comprehensive meteorological risk index for wheat *Fusarium* head blight prediction based on more than a half-century of monitoring data[J]. Plant Disease, 2025, 109(3), 698 - 708.
[26] LEVEAU JHJ. Re-envisioning the plant disease triangle: Full integration of the host microbiota and a focal pivot to health outcomes[J]. Annual Review of Phytopathology, 2024, 62: 31 - 47.

Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU