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Editorial

Evaluation of Effective System for Tracing FHB Resistance in Wheat: An Editorial Commentary

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A Special Issue of *Agronomy* titled "Treatment and Management of Fusarium Disease in Wheat" published five articles addressing the resistance of winter wheat varieties/lines to Fusarium head blight (FHB). Various approaches were used in these studies, including investigating the effects of different artificial inoculation methods on FHB symptom evaluations, determining the levels of mycotoxins/metabolites produced by *Fusarium* spp., and studying the influence of FHB on protease activity, technological and rheological quality [1–5]. Furthermore, *Fusarium* infection affects plant development and triggers different morphological, physiological, biochemical and molecular changes. In this context, two articles published in this Special Issue investigated the response of different wheat varieties to *Fusarium* infection in terms of their photosynthetic efficiency, and observed chemical and physiological parameters that might be related to the activation of the defense mechanism against FHB [6,7]. One article was focused on spring wheat lines' susceptibility/resistance to crown and root rot caused by *Fusarium culmorum* and *F. pseudograminearum* [8], and one article reported the antifungal activity of *Tamarix gallica* bark extract against *F. acuminatum*, *F. culmorum*, *F. equiseti* and *F. graminearum* associated with FHB [9]. Finally, this Special Issue includes a review on the role of secondary metabolites and antioxidants in wheat defense against FHB [10]. Undoubtedly, all the articles published in this Special Issue highlight FHB as one of the most damaging wheat diseases, leading to a reduction in grain yield and quality [1–10]. Almost all articles mention that FHB is caused by several *Fusarium* species—mainly *F. graminearum*, *F. culmorum* and *F. avenaceum*—and that the predominance of species within the FHB complex is determined by meteorological and agronomical factors [1–6]. However, in one study, another *Fusarium* species was used as a source of inoculum, namely, *F. equisety*, of which can be found in subtropical and warm temperate regions [7].

Besides grain yield, FHB affects the grain protein content by destroying starch granules, storage proteins and cell walls, and consequently decreases the quality of dough. It is also associated with mycotoxin contamination and is a significant threat to animal and human health [2,3,10]. The two articles and the review paper on *Fusarium* mycotoxins/metabolites in this Special Issue mention the main consequences of the consumption of contaminated food (alimentary hemorrhage, vomiting, dermatitis, gastroenteritis, nausea, anorexia, growth retardation, endocrine damage, immunosuppression and reproductive toxicity) depending on *Fusarium* spp. and the mycotoxins/metabolites produced. Current climate change scenarios predict an increase in the number of epidemics caused by this disease, and many different disease control strategies are currently being investigated. Weather conditions at the local level can influence the outbreak of new pests and pathogens due to the rapid emergence of races, their epidemic infection, and the ability to break down host resistance, which also refers to FHB [5]. In this Special Issue, the authors of articles reported that the selection for FHB resistance in high disease pressure environments is more easily achieved by using different methods of artificial inoculation with

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Fusarium spp. [1]. They also indicated that maize debris on the soil surface could serve as a good source of inoculation where wheat is planted afterwards. Still, in the same research, FHB severity was significantly lower in natural infections compared to two methods of artificial inoculation used (spray method and infected maize stalks).

Wheat plants are most vulnerable to FHB infection during flowering to the early dough stage [3]. Optimal temperatures for FHB infection are between 10 and 30 °C, while humidity is a critical factor for the success of pathogen infection [4,5]. FHB symptoms are located on wheat spikes within the spikelets, and consequently the grain, and sometimes the peduncle. A few days after infection, healthy spikes will stay green, while diseased spikelets will start bleaching and the infection will gradually spread through the spike [5]. Sometimes, at high humidity, even pink-to-orange masses of spores may become visible. There are different types of FHB resistance in wheat reported: (1) resistance to initial infection; (2) resistance to spreading within the spike; (3) resistance to the accumulation of mycotoxins; (4) resistance to grain infection; and (5) grain yield tolerance [3,5,6,10]. Plants also can possess passive resistance to FHB encompassing plant morphology and development (earlier flowering, taller plants, spike compactness, degree of anther extrusion, and the presence or absence of awns) [10]. Other ways that plants can participate in the natural defense against FHB are via the production of secondary metabolites including phenolic acids, anthocyanins and flavonoids, alkylresorcinols, benzoxazinoids, volatile organic compounds, phytohormones, carotenoids, etc. [10]. However, it is difficult to find FHB-resistant sources as host resistance is conditioned by numerous low-effect quantitative trait loci (QTL) that are strongly affected by environmental conditions and genetic bases [4]. Multi-mycotoxins produced by toxic *Fusarium* spp. are also significantly influenced by genotypes and the environment [2]. Thus, to combat FHB and minimize the accumulation of *Fusarium* mycotoxins, integrated management is needed by combining resistant wheat varieties, good agronomical practice, the application of fungicides [2,5], and the use of biological agents [4,10]. To minimize the application of fungicides, especially in the context of the Green deal proposed by the EU commission to reduce the use and risk of chemical pesticides, an article in this Special Issue covered this topic by characterizing the phytochemicals found in *T. gallica* bark extract and evaluating its antifungal activity for the control of *Fusarium* spp. [9]. In the same article, two fungicides were tested, and it was observed that the effectiveness of the fungicides against *Fusarium* spp. was substantially lower than that of the *T. gallica* bark extract. Further, the in vitro mycelial growth of *Fusarium* spp. was inhibited by the extract and four phytochemicals (1-(2,4,6-trihydroxyphenyl)-2-pentanone, sinapinaldehyde, trans-squalene and syringaldehyde) [9].

The testing of different wheat lines and varieties in the growth chamber, greenhouse and field conditions revealed new material sources for improving wheat resistance to *Fusarium* fungi that can cause root and crown rot [8]. However, new technology-based approaches (e.g., QTL and GWAS studies) should be implied. Due to the complex quantitative nature and difficult selection for FHB resistance, marker-assisted selection and analyses at physiological and cellular levels could be useful. Therefore, several techniques are used to study the effects of *Fusarium* infestation and their interactions with host plants. One of these is the measurement of photosynthesis, a process that provides the material basis and energy supply for multiple physiological metabolic processes in plants and can be disrupted by biological stress caused by pathogens. The findings of Katanic et al. [6] indicate that the difference in the degree of photosynthetic changes, particularly the analysis of L-band appearance, in the early stages of FHB infection in spikes and leaves could be an indicator of infection. A positive L-band was detected in flag leaves before any visible FHB symptoms, while a negative L-band occurred in spikes, thus indicating an increase in the energetic connectivity in infected spikes between the PSII photosynthetic units. However, location was shown to be a more important factor than genotypes in modulating the response of wheat to FHB [6]. Furthermore, the expression of different genes in defense mechanisms is triggered when physical stress is converted into a biochemical response [7]. The over-expression of some genes, such as pathogenesis-related (*PR-1*), thaumatin-like protein

(*TLP*), chitinase and β-1,3-glucanase, may have created FHB resistance in wheat material by activating a defense mechanism and enhancing the production of different biochemicals. To date, many PR proteins are known, which are classified into 17 families based on their protein sequence similarities, enzymatic activities and biological functions [10].

As mentioned above, grain yield losses and a reduction in technological and rheological parameters are usually observed in winter wheat as a result of *Fusarium* infection. In this Special Issue, an article reported that *Fusarium* inoculation decreased the duration of dough resistance and increased dough softening, but winter wheat varieties were affected to different degrees depending on their FHB resistance/susceptibility [5]. Therefore, dough strength was much more reduced in FHB-susceptible varieties due to alterations in traits measured by extensographs showing a decrease in the average energy value and resistance to extension. In the group of technological quality traits, the sedimentation value and gluten index were primarily affected. The strength of this research lies in the detection of technological and rheological quality changes due to *Fusarium* infections. Another article dealing with wheat quality losses due to FHB showed that extensograph values were strongly affected by FHB, indicating a lower resistance to stretching, extensibility and total stretching energy, thus suggesting that dough functionality and volume loss can be attributed to exogenous fungal proteases [4]. This is related to the reactivation of *Fusarium* proteases during the dough-making process, resulting in negative effects on the rheological properties of dough. Both protein and wet gluten content were significantly influenced by genotype, environment and their interaction. Furthermore, elastic properties of the dough were under gluten influence, whereas a lower degree of softening was reported in more FHB-resistant varieties [4]. The importance of gluten is due to the fact that it is a protein responsible for the baking properties of wheat flour, with gliadins and glutenins being the main protein fractions present in gluten. Overall, both articles related to technological and rheological quality observed that the differences in wheat quality between FHB-resistant and -susceptible varieties are due to genetic and environmental factors (year and location) [4,5].

Fusarium infections also degrade grain quality by increasing the proportion of shriveled grains, and most importantly, by accumulating mycotoxins, that pose a health risk to humans and animals after the consumption of diseased grains or end-use products. The results in this Special Issue highlight the influence of environmental variations on *Fusarium* mycotoxin production where FHB initial resistance (Type I resistance) had a higher impact on the accumulation of mycotoxins than general resistance [3]. Deoxynivalenol (DON) was one of the most abundant mycotoxins [2,3]. In the FHB-inoculated treatment, the DON concentration in the FHB-susceptible variety at two locations was 22,800 μg kg^{-1} and 25,500 μg kg^{-1}, respectively, thus exceeding the permitted level of 200–1750 μg kg^{-1} for DON [3]. Also, DON co-occurred with culmorin and hydroxyculmorins, with a potential role in *Fusarium* virulence. Another article in this Special Issue reported the production of various mycotoxins/metabolites during a three-year study [2]. Twenty-eight *Fusarium* mycotoxins/metabolites were detected and were highly correlated to each other. Special attention should be paid to emerging mycotoxins such as moniliformin (MON), beauvericin (BEA) and enniatins (ENNs), which contribute substantially to the overall contamination of wheat grains. The greatest concentration in the three investigated years was observed for DON (found in 100% of the wheat samples) with mean values of 3245, 5380 and 6743 μg kg^{-1} in 2014, 2015 and 2016, respectively. Herein, in possible epidemic conditions provoked by artificial inoculations, the maximum limits of DON were exceeded. Both articles published in this Special Issue emphasize the need to set limits for modified, masked and emerging forms of mycotoxins as they represent potential health risks for animals and humans [2,3]. As *Fusarium* species *F. graminearum* and *F. culmorum* were used for artificial inoculations in both studies, a number of mycotoxins were expected to be produced, including zearalenone (ZEN), MON, BEA, ENNs and trichothecenes such as DON, nivalenol (NIV), 3- and 15-acetyl-DON (3-AcDON, 15-AcDON), HT-2 and T-2 toxin.

The important fact is that toxin-producing abilities correlate positively with the level of a pathogen's aggressiveness [10].

The articles in the Special Issue on FHB in wheat have provided a wealth of information on the genetic, molecular and physiological mechanisms of resistance to FHB infection. Some gaps in knowledge about FHB were fulfilled, and we hope that these articles provided new ideas for strategies to control this complex plant disease. The search for additional sources of phytochemicals against FHB should be continued to avoid the use of excessive amounts of fungicides. Wheat breeders should keep developing and expanding the range of FHB resistance in wheat material available to market, especially with regard to cost effectiveness and environmental safety.

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