Hungarian University of Agriculture and Life Sciences

Thesis of the PhD Dissertation

Josepha El Chami

Gödöllő, Hungary

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INFLUENCE OF *FUSARIUM* HEAD BLIGHT ON TECHNOLOGICAL QUALITY OF WHEAT

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Influence of *Fusarium* Head Blight on Technological Quality of Wheat

Doctoral School	Plant Sciences
Discipline	Agronomy
Head	Prof. Helyes Lajos, DSc Hungarian University of Agriculture and Life Sciences Doctoral School of Plant Sciences
Supervisors	Prof. Emeritus Jolánkai Márton, DSc Dr. Tarnawa Ákos Hungarian University of Agriculture and Life Sciences Doctoral School of Plant Sciences

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Approval of the Head of Doctoral School	Approval of the Supervisors

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1. INTRODUCTION

Cereals have been a basic agricultural product since ancient times due to their nutritional properties, moderate cost and ability to achieve immediate satiation. Wheat is a plant grown on more land area than any other commercial crop. Wheat provides carbohydrate staple foods that form the basis of most diets, both ancient and modern, around the world. Wheat flour is used in a diverse range of end use products including bread, cake, noodle, cracker, cookie, and pasta. Wheat kernel is composed of endosperm (81–84%), bran (14– 16%) and germ (2–3%). The endosperm is rich in carbohydrate, lipid and protein. The bran is the outer layer protecting the kernel. The germ is the kernel's embryo that will grow into a new plant.

Wheat is a cereal of special importance in the world cereal production. During crop production, both abiotic and biotic stresses occur, often acting in combination under field conditions and potentially increase sensitivity to pathogens. *Fusarium* head blight (FHB) is one of the most devastating fungal diseases of wheat and other small grain cereals and has caused serious epidemics worldwide. The fungal pathogen associated with this disease in wheat is *Fusarium* spp. During the wheat's flowering stage, *Fusarium* infection occurs when weather conditions become favorable. The infection begins in the middle of the wheat spike and then spreads throughout the rest of it, eventually causing the entire ear spike to turn white and the kernels to become light-weight and shriveled. Occurrence of FHB poses a serious problem because of considerable economic losses caused by lowered yield and deteriorated grain quality, and possible contamination of infested grain with mycotoxins that are known to be harmful for both consumer and livestock health.

Crop yield losses due to FHB represent a significant problem worldwide. In many regions, severe intensity of FHB occurs in cultivated wheat approximately two to three times per decade. Severe yield losses can occur during the epidemic year which are largely determined by the weather. Thus, growers use multiple control measures to protect crops against FHB infections and prevent yield loss.

FHB poses a toxicological risk due to the mycotoxin contamination of wheat. In addition, it may reduce the quality of grains, as it is manifested in their weight loss, carbohydrate and protein composition changes and the presence of fungal toxins. It can destroy starch granules, storage proteins, and grain cell wall and subsequently affect the quality of wheat flour. Additionally, *Fusarium* infection reduces gluten strength in wheat due to lower proportions of glutenin. Those biochemical changes in grain composition and subsequent changes in wheat quality traits are caused by the incomplete accumulation of the kernel constituents through the mechanical blocking of vascular bundles by fungal mycelium and the secretion of fungal enzymes. Moreover, during the invasion of the kernel, *Fusarium* spp. secretes enzymes such as carbohydrases and proteases that degrade the cell wall and the kernel components. As a result, FHB infection leads to poor end use quality. The most important method for FHB control and the reduction of mycotoxin concentration is the use of FHB resistant wheat varieties, appropriate cultural practices, fungicides, biological control and crop rotation.

Previous studies reported the effect of fertilization, storage time and transgenic plant on wheat quality. Research on the influence of *Fusarium* infection on technological quality of wheat seems relatively scarce compared to literature dealing with *Fusarium* mycotoxins, prevention strategies and epidemiology of FHB. Although it is understandable, that the management of FHB has in the past primarily focused on food safety and therefore on the avoidance of mycotoxin contamination in grain, the effects of FHB on grain quality are not to be underestimated. Researchers have just recently become aware that quality assurance in FHB affected wheat is essential for wheat marketing. Because the wheat price is directly determined by its processing attributes, influence of FHB on wheat milling performance, flour properties and endproduct quality have just recently confirmed its partially adverse effects.

1.1 Objectives

The aim of the research lies on studying the influence of *Fusarium* head blight on technological quality of wheat, while taking the following questions into account

- Is there a relationship between wheat quality parameters and *Fusarium* infection?
- In what way does *Fusarium* infection have an impact on wheat quality?
- Does the effect of *Fusarium* infection on wheat quality vary between the different wheat varieties used?

2. MATERIALS AND METHODS

2.1 Experimental design and statistical analysis

The experiment was conducted during two growing seasons 2020 and 2021 at the experimental field and laboratories of the Hungarian University of Agriculture and Life Sciences (MATE), Agronomy Institute, Gödöllő, Hungary. The experimental site is in a hilly area with a close to average climatic zone of the country (47° 35′ 40.8″ N 19° 22′ 08.4″ E, 210 m above sea level). The soil type of the experimental field is sand-based brown forest soil (Chromic Luvisol). A crop rotation of soybean, wheat and maize was implemented in the field. Prior to sowing, the field was cleared, ploughed, rotor-tilled and the seedbed was prepared. The plots were sown in October and harvested in July with plot machines. The sowing depth was 5 cm. The rate of sowing was 450-500 seeds per square meter. The wheat varieties used in the experiment were Alföld, Mv Kolompos and Mv Karéj. Each variety had a total plot area of 75 m^2. Each plot was then divided into 15 sub-plots of 5 m^2 each to create replications. At the end of the growing season, wheat grain samples were collected from each sub-plot, stored under laboratory conditions and measured for *Fusarium* infection level, protein content, gluten content, test weight, thousand kernel weight, falling number and Zeleny sedimentation index. *Fusarium* infection level percentage was calculated by counting the number of colonies that formed on wheat kernels disinfected with a solution of PCNB and chloramphenicol (100 kernels from each sample) incubated for 7 days under laboratory conditions on Nash and Snider *Fusarium* selective medium (Distilled water 1 l, Peptone 15 g, KH_2PO_4 1 g, $MgSO_47H_2O$ 0.5 g, Agar 20 g, PCNB 1 g, Chloramphenicol 100 ppm). Protein content, gluten content and Zeleny sedimentation index were measured with Mininfra Scan-T Plus 2.02 version. Falling number was measured with Perten 1400 system (ICC method No. 107/1 1995). Test weight was measured with chondrometer hectoliter grain tester (ISO 7971-3:2019). Thousand kernel weight and test weight were measured with the KERN EMS and the Sartorius MA-30 precision scales. IBM SPSS V.21 software was used for the statistical evaluation of the results, the linear regression module at 5% significance level was performed to determine the effect of *Fusarium* infection level on wheat quality parameters, and the analysis of variance (ANOVA) module at 5% significance level was performed to determine the effect of the growing season on *Fusarium* infection and wheat quality parameters.

3. RESULTS

3.1 *Fusarium* infection level

Fusarium infection in 2021 (91.47%, 94% and 95.20%) was higher than in 2020 (44.33%, 48.4% and 40.27%), the difference was statistically significant [F = 135.813, P = 0.000], [F = 62.869, P = 0.000] and [F = 100.952, P = 0.000] in the three wheat varieties Alföld, Mv Kolompos and Mv Karéj used respectively. Rainfall measurements were collected from World Weather Online Meteorological Service. Wheat heads are most susceptible to FHB infection during flowering period (May). Rainfall during the flowering period in 2021 (88.39 mm) was higher than in 2020 (42.8 mm), this increase in rainfall could explain the increase in *Fusarium* infection level. Simple linear regression is used to test the effect of *Fusarium* infection on the following wheat quality parameters: protein content, test weight, thousand kernel weight, falling number, gluten content and Zeleny sedimentation index.

3.2 Influence of *Fusarium* infection on protein content

In Alföld, protein content was lower in 2021 (13.41 %) compared to 2020 (14.75 %) the difference was statistically significant [F = 20.862, P = 0.000]. *Fusarium* infection had a strong negative effect on protein content [R = - 0.682], protein content decreased when the infection increased. The fitted regression model between *Fusarium* infection and protein content is y = - 0.027x + 15.917. The regression is statistically significant [R^2 = 0.465, F = 24.309, P = 0.000] (Figure 1).

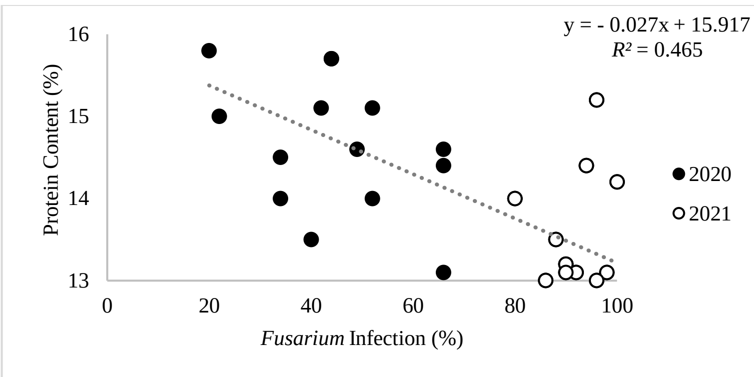

Figure 1. Influence of *Fusarium* infection (%) on protein content (%) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, protein content was lower in 2021 (14.49 %) compared to 2020 (15.2 %) the difference was statistically significant [F = 10.559, P = 0.003]. *Fusarium* infection had a moderate negative effect on protein content [R = - 0.426], protein content decreased when the infection increased. The fitted regression model between *Fusarium* infection and protein content is y = - 0.011x + 15.667. The regression is statistically significant [R^2 = 0.182, F = 6.218, P = 0.019] (Figure 2).

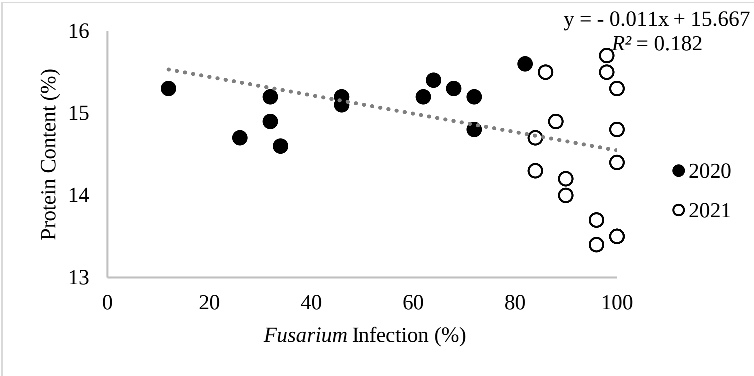

Figure 2. Influence of *Fusarium* infection (%) on protein content (%) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, there was no statistically significant difference in protein content in 2020 and 2021 [F = 3.443, P = 0.074]. *Fusarium* infection had no effect on protein content [R = - 0.310]. The fitted regression model between *Fusarium* infection and protein content is y = - 0.007x + 15.047. The regression is not statistically significant [R^2 = 0.096, F = 2.974, P = 0.096] (Figure 3).

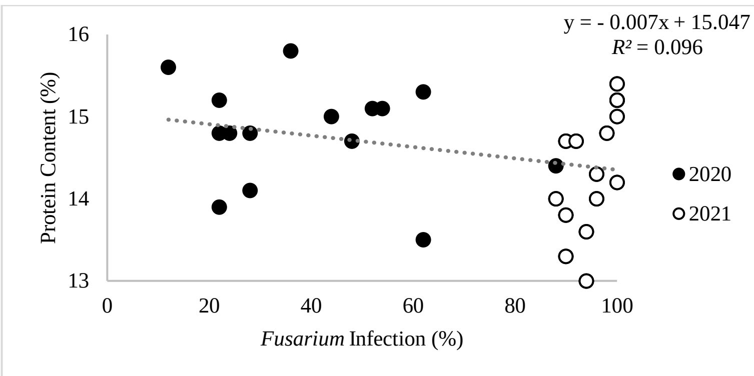

Figure 3. Influence of *Fusarium* infection (%) on protein content (%) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

3.3 Influence of *Fusarium* infection on test weight

In Alföld, test weight was lower in 2021 (72.76 kg/hl) compared to 2020 (75.10 kg/hl) the difference was statistically significant [$F = 25.338$, $P = 0.000$]. *Fusarium* infection had a strong negative effect on test weight [$R = -0.626$], test weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and test weight is y = - 0.041x + 76.714. The regression is statistically significant [$R^2 = 0.391$, $F = 18.005$, $P = 0.000$] (Figure 4).

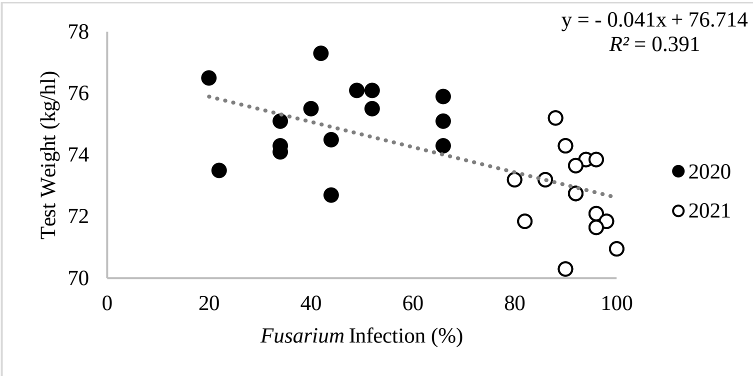

Figure 4. Influence of *Fusarium* infection (%) on test weight (kg/hl) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, test weight was lower in 2021 (79.44 kg/hl) compared to 2020 (81.15 kg/hl) the difference was statistically significant [$F = 71.975$, $P = 0.000$]. *Fusarium* infection had a strong negative effect on test weight [$R = -0.770$], test weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and test weight is y= - 0.028x + 82.304. The regression is statistically significant [$R^2 = 0.592$, $F = 40.701$, $P = 0.000$] (Figure 5).

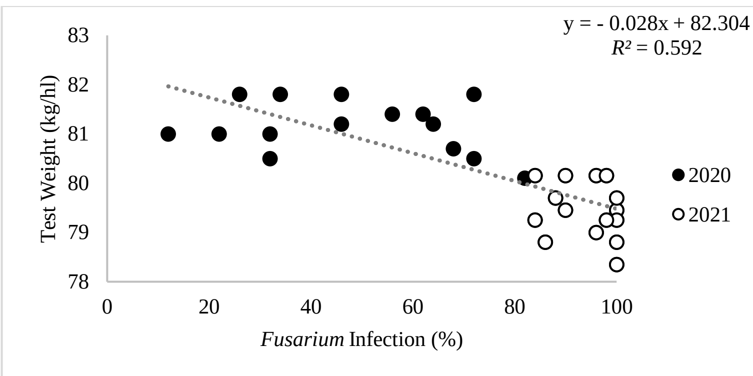

Figure 5. Influence of *Fusarium* infection (%) on test weight (kg/hl) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, test weight was lower in 2021 (79.33 kg/hl) compared to 2020 (81.04 kg/hl) the difference was statistically significant [F = 48.936, P = 0.000]. *Fusarium* infection had a strong negative effect on test weight [R = - 0.692], test weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and test weight is y = - 0.024 + 81.802. The regression is statistically significant [R^2 = 0.479, F = 25.724, P = 0.000] (Figure 6).

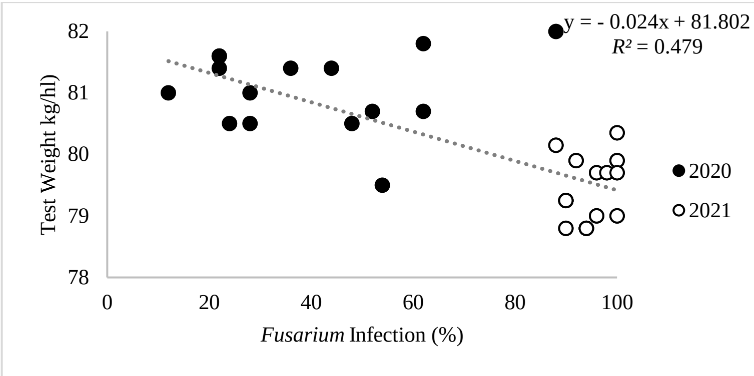

Figure 6. Influence of *Fusarium* infection (%) on test weight (kg/hl) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

3.4 Influence of *Fusarium* infection on thousand kernel weight

In Alföld, thousand kernel weight was lower in 2021 (39.65 g) compared to 2020 (45.91 g) the difference was statistically significant [F = 96.249, P = 0.000]. *Fusarium* infection had a strong negative effect on thousand kernel weight [R = - 0.765], thousand kernel weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and thousand kernel weight is y = - 0.105x + 49.920. The regression is statistically significant [R^2 = 0.585, F = 39.441, P = 0.000] (Figure 7).

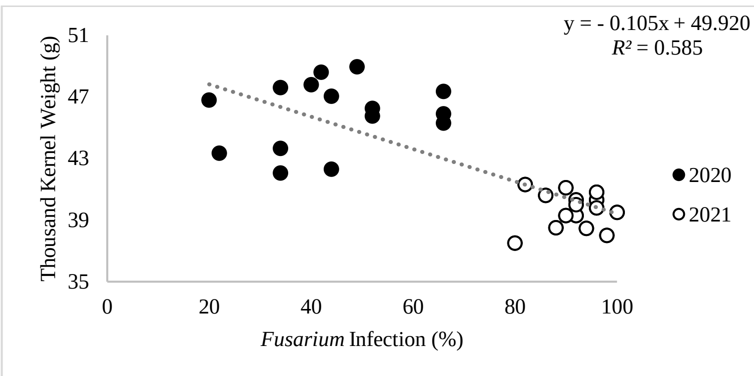

Figure 7. Influence of *Fusarium* infection (%) on thousand kernel weight (g) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, thousand kernel weight was lower in 2021 (38.68 g) compared to 2020 (42.48 g) the difference was statistically significant [F = 26.306, P = 0.000]. *Fusarium* infection had a moderate negative effect on thousand kernel weight [R = - 0.516], thousand kernel weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and thousand kernel weight is y = - 0.051x + 44.230. The regression is statistically significant [R^2 = 0.266, F = 10.155, P = 0.004] (Figure 8).

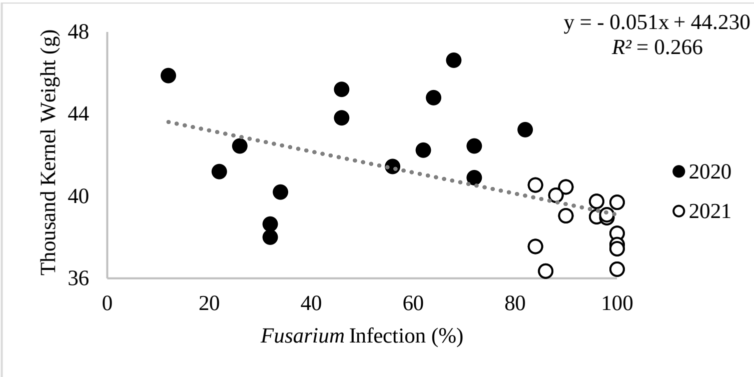

Figure 8. Influence of *Fusarium* infection (%) on thousand kernel weight (g) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, there was no statistically significant difference in thousand kernel weight in 2020 and 2021 [F = 3.743, P = 0.063]. *Fusarium* infection had a moderate negative effect on thousand kernel weight [R = - 0.454], thousand kernel weight decreased when the infection increased. The fitted regression model between *Fusarium* infection and thousand kernel weight is y = - 0.031x + 44.483. The regression is statistically significant [R^2 = 0.206, F = 7.264, P = 0.012] (Figure 9).

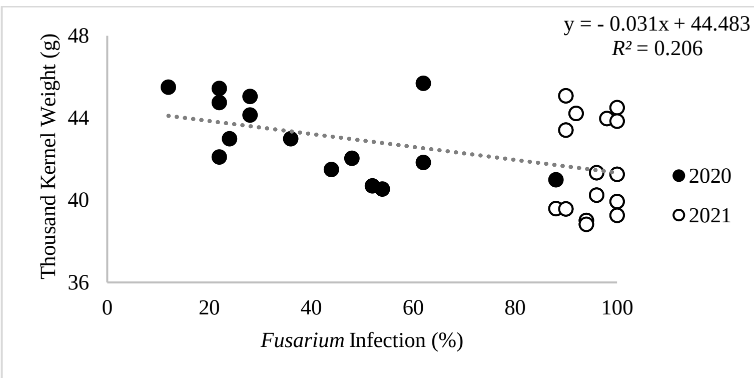

Figure 9. Influence of *Fusarium* infection (%) on thousand kernel weight (g) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

3.5 Influence of *Fusarium* infection on falling number

In Alföld, there was no statistically significant difference in falling number in 2020 and 2021 [F = 0.449, P = 0.508]. *Fusarium* infection had no effect on falling number [R = - 0.142]. The fitted regression model between *Fusarium* infection and falling number is y = - 0.238x + 441.002. The regression is not statistically significant [R^2 = 0.020, F = 0.580, P = 0.453] (Figure 10).

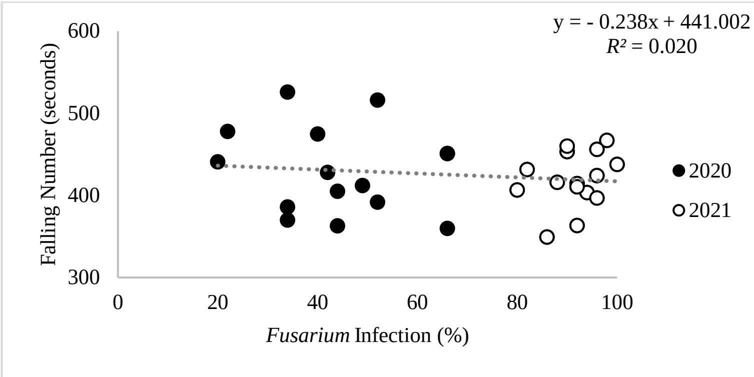

Figure 10. Influence of *Fusarium* infection (%) on falling number (seconds) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, falling number was lower in 2021 (358.87 seconds) compared to 2020 (544.93 seconds) the difference was statistically significant [F = 101.038, P = 0.000]. *Fusarium* infection had a strong negative effect on falling number [R = - 0.758], falling number decreased when the infection increased. The fitted regression model between *Fusarium* infection and falling number is y = - 2.908x + 658.924. The regression is statistically significant [R^2 = 0.575, F = 37.831, P = 0.000] (Figure 11).

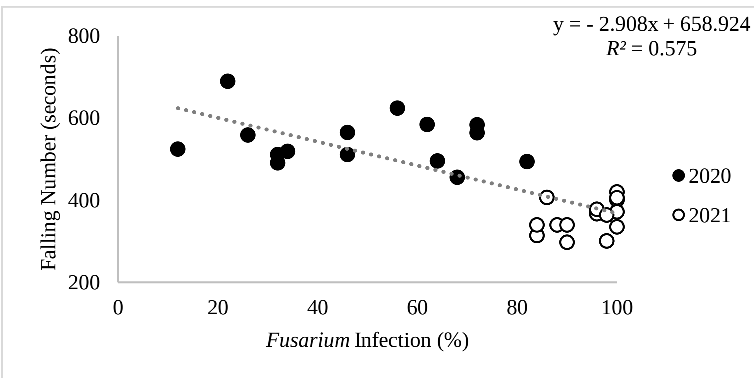

Figure 11. Influence of *Fusarium* infection (%) on falling number (seconds) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, falling number was lower in 2021 (364.30 seconds) compared to 2020 (415.67 seconds) the difference was statistically significant [F = 16.984, P = 0.000]. *Fusarium* infection had a moderate negative effect on falling number [R = - 0.428], falling number decreased when the infection increased. The fitted regression model between *Fusarium* infection and falling number is y = - 0.578x + 429.057. The regression is statistically significant [R^2 = 0.183, F = 6.285, P = 0.018] (Figure 12).

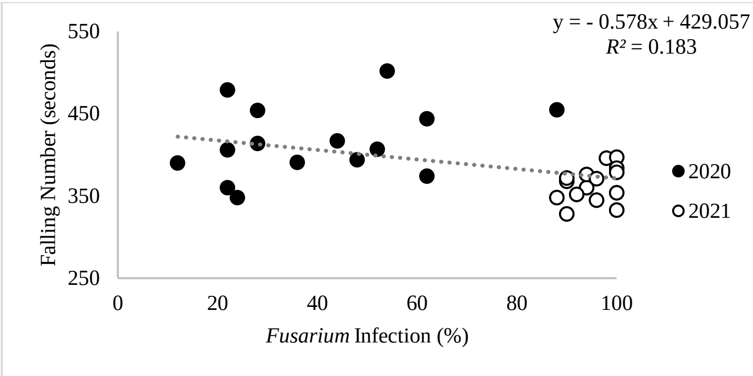

Figure 12. Influence of *Fusarium* infection (%) on falling number (seconds) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

3.6 Influence of *Fusarium* infection on gluten content

In Alföld, gluten content was lower in 2021 (24.79 %) compared to 2020 (30 %) the difference was statistically significant [F = 29.351, P = 0.000]. *Fusarium* infection had a strong negative effect on gluten content [R = - 0.716], gluten content decreased when the infection increased. The fitted regression model between *Fusarium* infection and gluten content is y = - 0.101x + 34.234. The regression is statistically significant [R^2 = 0.512, F = 29.383, P = 0.000] (Figure 13).

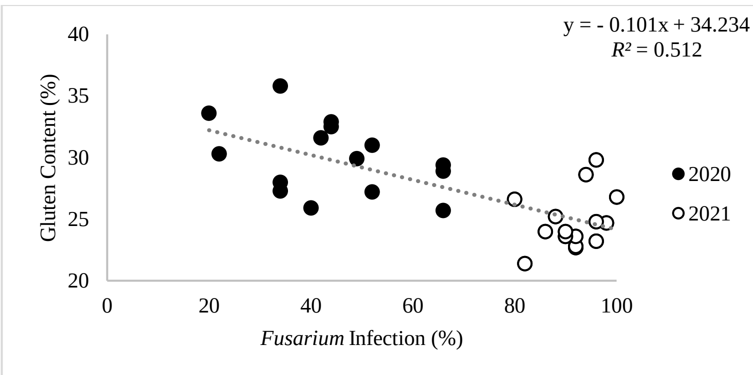

Figure 13. Influence of *Fusarium* infection (%) on gluten content (%) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, gluten content was lower in 2021 (29.07%) compared 2020 (31.25%) the difference was statistically significant [*F* = 8.235, *P* = 0.008]. *Fusarium* infection had a moderate negative effect on gluten content [*R* = - 0.432], gluten content decreased when the infection increased.The fitted regression model between *Fusarium* infection and gluten content is y = - 0.036x + 32.727. The regression is statistically significant [R^2 = 0.186, *F* = 6.414, *P* = 0.017] (Figure 14).

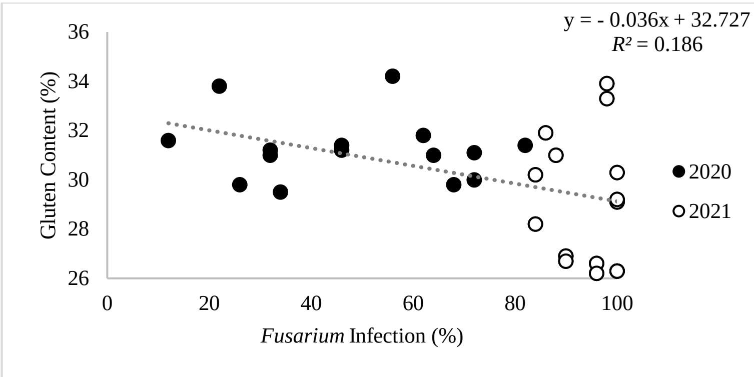

Figure 14. Influence of *Fusarium* infection (%) on gluten content (%) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, there was no statistically significant difference in gluten content in 2020 and 2021 [*F* = 0.557, *P* = 0.462]. *Fusarium* infection had no effect on gluten content [*R* = - 0.009] The fitted regression model between *Fusarium* infection and gluten content is y = - 0.001x + 28.944. The regression is not statistically significant [R^2 = 0.000, *F* = 0.002, *P* = 0.962] (Figure 15).

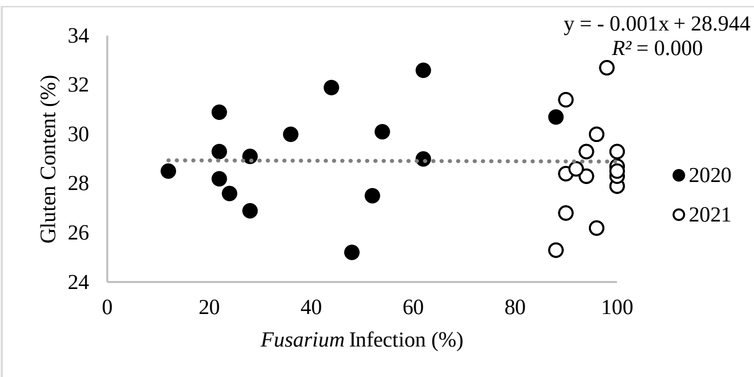

Figure 15. Influence of *Fusarium* infection (%) on gluten content (%) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

3.7 Influence of *Fusarium* infection on Zeleny sedimentation index

In Alföld, Zeleny sedimentation index was lower in 2021 (38.40 ml) compared to 2020 (53.5 ml) the difference is statistically significant [$F = 52.412$, $P = 0.000$]. *Fusarium* infection had a strong negative effect on Zeleny sedimentation index [$R = -0.747$], Zeleny sedimentation index decreased when the infection increased. The fitted regression model between *Fusarium* infection and Zeleny sedimentation index is $y = -0.270x + 64.266$. The regression is statistically significant [$R^2 = 0.557$, $F = 35.257$, $P = 0.000$] (Figure 16).

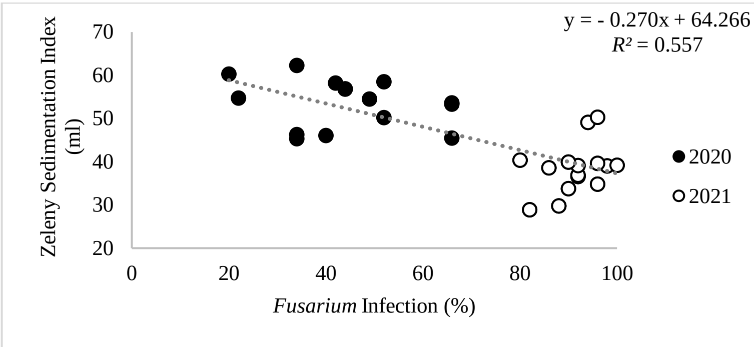

Figure 16. Influence of *Fusarium* infection (%) on Zeleny sedimentation index (ml) in 2020 and 2021 growing seasons in Alföld wheat variety

In Mv Kolompos, Zeleny sedimentation index was lower in 2021 (42.37 ml) compared to 2020 (63.09 ml) the difference was statistically significant [$F = 67.705$, $P = 0.000$]. *Fusarium* infection had a strong negative effect on Zeleny sedimentation index [$R = -0.678$], Zeleny sedimentation index decreased when the infection increased. The fitted regression model between *Fusarium* infection and Zeleny sedimentation index is $y = -0.305x + 74.443$. The regression is statistically significant [$R^2 = 0.460$, $F = 23.879$, $P = 0.000$] (Figure 17).

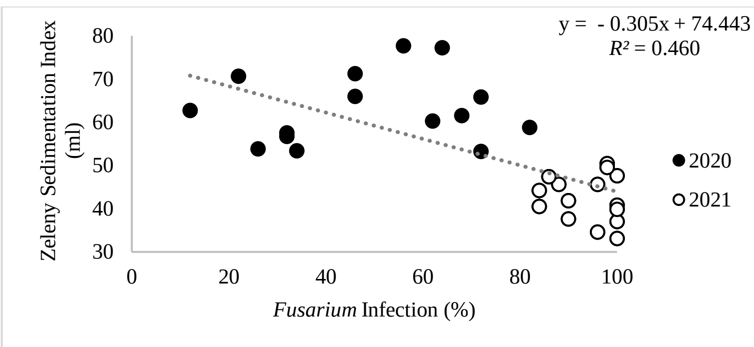

Figure 17. Influence of *Fusarium* infection (%) on Zeleny sedimentation index (ml) in 2020 and 2021 growing seasons in Mv Kolompos wheat variety

In Mv Karéj, Zeleny sedimentation index was lower in 2021 (49.47 ml) compared to 2020 (60.57 ml) the difference was statistically significant [F = 17.748, P = 0.000]. *Fusarium* infection had a strong negative effect on Zeleny sedimentation index [R = - 0.613], Zeleny sedimentation index decreased when the infection increased. The fitted regression model between *Fusarium* infection and Zeleny sedimentation index is y = - 0.176x + 66.938. The regression is statistically significant [R^2 = 0.375, F = 16.823, P = 0.000] (Figure 18).

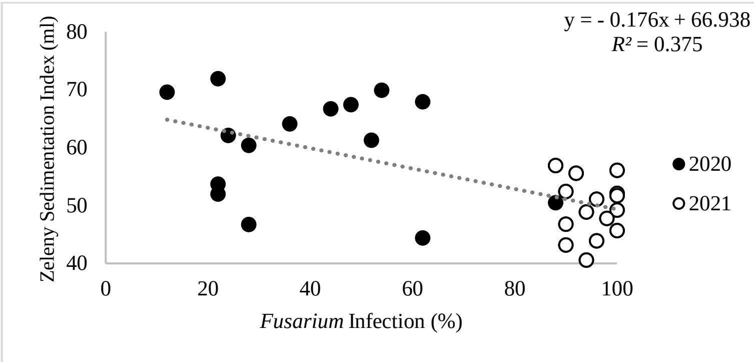

Figure 18. Influence of *Fusarium* infection (%) on Zeleny sedimentation index (ml) in 2020 and 2021 growing seasons in Mv Karéj wheat variety

4. CONCLUSION AND RECOMMENDATIONS

- FHB has a substantial negative influence on the technological quality of wheat, impacting protein content, gluten content, Zeleny sedimentation index, falling number, test weight, and thousand kernel weight.
- FHB infection leads to a reduction in protein content. This decrease in protein levels can have implications for the overall quality of wheat-based products.
- Gluten content, a critical aspect of wheat quality, is negatively impacted by FHB. The reduction in gluten content can lead to poor dough strength, reduced volume, and undesirable texture in baked goods.
- Zeleny sedimentation index, is typically lower in FHB infected wheat. A lower index indicates poorer flour quality and potential baking challenges.
- FHB infected wheat grains often exhibit a decrease in falling number. A low falling number indicates starch degradation, affecting flour functionality and leading to poor bread quality.
- Test weight, a measure of grain weight per unit volume, is significantly reduced in FHB affected wheat due to the presence of lightweight and shriveled kernels. This reduction in test weight has implications for grain quality and market value.
- Thousand kernel weight, which reflects seed size and weight, is also negatively affected by FHB. Infected kernels tend to be smaller and lighter, resulting in a decrease in thousand kernel weight. This reduction can impact overall yield potential, grain quality and economic value.
- FHB can have significant economic impacts on wheat quality, as well as implications for the agricultural industry. FHB infected wheat kernels often exhibit quality issues, including discoloration, reduced test weight and damaged kernels. These factors can result in downgrading of the grain, limiting its marketability and potentially leading to lower prices for affected farmers. Grain quality issues can also disrupt export opportunities, affecting the overall competitiveness of the agricultural industry.
- Addressing the economic impact of FHB on wheat quality requires a comprehensive approach. This includes the development and adoption of resistant wheat varieties, improved disease management practices, effective monitoring and forecasting systems and educational programs to promote best management practices among farmers. Collaborative efforts between farmers, researchers, policymakers, and the industry are essential to minimize the economic losses in the face of FHB outbreaks.

5. NEW SCIENTIFIC RESULTS

- The effect of *Fusarium* infection on wheat quality varies between the three different wheat varieties used (Alföld, Mv Kolompos and Mv Karéj) as they show different response patterns against *Fusarium* head blight.

- In Alföld, *Fusarium* infection had a negative effect on protein content, gluten content, test weight, thousand kernel weight and Zeleny sedimentation index, whereas falling number was not affected.

- In Mv Kolompos, *Fusarium* infection had a negative effect on all wheat quality parameters used protein content, gluten content, falling number, test weight, thousand kernel weight and Zeleny sedimentation index.

- In Mv Karéj, *Fusarium* infection had a negative effect on test weight, thousand kernel weight, falling number and Zeleny sedimentation index, whereas protein content and gluten content were not affected.

- Although *Fusarium* infection reduced wheat quality, Mv Karéj showed a stable protein and gluten content whereas Alföld showed a stable falling number. Thus, Mv Karéj is the most tolerant to *Fusarium* infection, followed by Alföld and then Mv Kolompos being the least tolerant.

6. SCIENTIFIC PUBLICATIONS

El Chami, J., El Chami, E., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2023). Influence of *Fusarium* head blight on technological quality of wheat. *Acta Phytopathologica et Entomologica Hungarica*. https://doi.org/10.1556/038.2023.00179

El Chami, E., El Chami, J., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2023). *Fusarium* head blight in wheat: impact of growing season, wheat variety and nitrogen fertilization under natural infection. *Acta Phytopathologica et Entomologica Hungarica.*

El Chami, E., El Chami, J., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2023). Influence of nitrogen fertilization on technological quality of wheat. *Acta Agraria Debreceniensis.*

El Chami, J., El Chami, E., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2022). Effect of *Fusarium* infection on wheat quality parameters. *Cereal Research Communications* 51(1): 179–187. https://doi.org/10.1007/S42976-022-00295-W

El Chami, E., El Chami, J., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2022). Influence of growing season, nitrogen fertilisation and wheat variety on *Fusarium* infection and mycotoxin production in wheat kernel. *Acta Alimentaria* 51 : 282–289. https://doi.org/10.1556/066.2022.00036

El Chami, E., El Chami, J., Tarnawa, Á., Kassai, K.M., Kende, Z., Jolánkai, M., (2022). Agronomic impact on *Fusarium* infection and mycotoxin contamination of wheat grain. *Georgikon for Agriculture* 26 (1): 96–104.

Abd Ghani, R., Omar, S., El Chami, E., El Chami, J., Jolánkai, M., (2021). Agri-environmental impacts on yield formation of soybean crop. *Columella : Journal of Agricultural and Environmental Sciences* 8: 5–10. https://doi.org/10.18380/SZIE.COLUM.2021.8.2.5