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INFLUENCE OF TEMPERATURE ON COMMON WHEAT – *Fusarium culmorum* (W.G. Smith) SACCARDO INTERACTIONS

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Abstract

The paper presents data on the reaction of common wheat genotypes to Fusarium culmorum isolates. By treating the grains with culture filtrates, under controlled conditions, it was found that low temperature contributes to increasing the virulence of F. culmorum isolates and to changing the factorial weight of phytopathosystem components in the source of variation in growth organs. The lowest values of the heritability coefficient (h^2) were recorded in the case of the embryonic radicle length for both thermal variants under study (I – control: 18-19°C, II – 18-19 / 8-9 / 18-19°C). In contrast to the radicle, the stem recorded much higher h^2 values at both temperatures, which is evidence of its more pronounced genetic determinism and the weaker influence of fungal culture filtrates and temperature. The vigor index recorded relatively high values of heritability coefficient (0.65-0.70) and genetic progress (21.8-27.6%) for both thermal conditions, which denotes additive control of growth and development characters and, at the same time, opportunities to create wheat genotypes resistant to F. culmorum in short terms.

Key words: *wheat, Fusarium culmorum, temperature, character.*

INTRODUCTION

Root rot remains a major global warning to agricultural crop productivity. The disease is caused by several pathogens, often named as root rot complex. Fungal and oomycete species are predominant in these complexes, although bacteria and viruses are also known as root rot pathogens. Incorporating genetic resistance in crop plants is considered the most effective and sustainable solution to combat root rot, however resistance is often of a quantitative nature (Williamson-Benavides & Amit, 2021). Some of the most important genera of fungi capable of developing root rot in cereal crops are *Fusarium* spp. and *Bipolaris* spp. which not only cause direct economic losses but also pollute grains with mycotoxins harmful to human consumers and animals (Dinolfo et al., 2017). In recent years, the incidence of the species *F. culmorum* as the causative agent of wheat root rot has increased in the conditions of the Republic of Moldova. Starting from the mentioned, the particularities of the *common wheat – F. culmorum* interaction, the variability and heritability of plant growth and development characters are of interest for study. *F. culmorum* is an important pathogen of wheat, which causes seedling wilting, root rot, stem base rot, spike disease (shattering and bleaching of grains), mycotoxin accumulation (Bentley et al., 2006). The pathogen is dominant in colder and semiarid areas such as North Dakota (USA) (Shrestha et al., 2021), northern, central and western Europe (Wagacha & Muthomi, 2007). The fungus reproduces asexually by means of conidia, which form the main mode of dispersion. *F. culmorum* produces short, stout, thick-walled macroconidia that have curved ventral and dorsal surfaces. On Potatoe Dextrose Agar (PDA) medium, growth is rapid with dense aerial mycelium. The mycelium is generally white, but often yellow to tan. Orange to red-brown sporodochia appear as the crop ages. The underside is carmine red (Sempere & Santamarin, 2009). The main mycotoxins produced by *F. culmorum* are deoxynivalenol, nivalenol and zearalenone, which pose a potential health hazard to both humans and animals. The available management options for Fusarium head blight include the use of fungicides, cultural practices, resistant cultivars and biological agents. However, no wheat variety is completely resistant to this disease, while fungicides are at most 70% effective against natural infections. It was found that the susceptibility of wheat genotypes to this pathogen varies (Friscop, 2017). Lately, special attention is granted to *plant - fungi* interactions that can have strong effects on plant density, both through direct effects on plant performance and through indirect effects on fungi/plant competition and selective promotion of some species. Most of the evidence demonstrating certain linkages between plant abundance derives from direct fungal effects on initial growth, but with little evidence linking fungal effects on *plant - plant* interactions in intact communities. By researching a wide variety of plant species, fungi have been found to have net indirect effects - by influencing *plant - plant* interactions within intact plant communities (Bennett & Cahill, 2016). Interactions between plants and fungi can have either beneficial or detrimental effects on host plants and can give rise to various changes in both the plant and the fungus. Fungal plant pathogens are economically important due to the threat they pose to agricultural crop production and yield. Reducing or preventing fungal plant diseases depends on resistant crop varieties or fungicide treatment. *Plant - fungus* interactions need to be known to understand the mechanisms of plant diseases caused by fungi, their prevention and to improve plant productivity (Geetha & Dathar, 2022). The purpose of the present research consisted in establishing the particularities of the reaction of common wheat genotypes to the *F. culmorum* fungus under controlled conditions, with optimal temperature and thermal alternation, and the influence of *plant - pathogen* interactions on the variability and heritability of growth organs.

MATERIALS AND METHODS

F. culmorum strains were isolated in aseptic conditions on PDA (Potatoes Dextrose Agar) medium, being later identified based on macro - and microscopic characteristics according to the mycological determinant (Barnett & Hunter, 1998) (Figure 1).


A

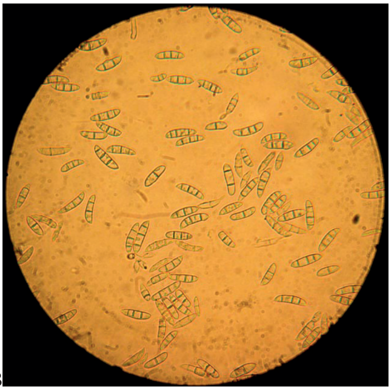
B

Figure 1. Macro- and microscopic aspects of the *F. culmorum* fungus
Colony (A), conidia (B), 300x

Four common winter wheat genotypes – Moldova 66, L Cub.101/Bas., L Bas./M30, L Sel./Accent and 4 culture filtrates (CF1, CF2, CF3, CF4) of the *F. culmorum* fungus as objects of study they served. Culture filtrates were prepared based on Cszapek liquid medium (g/l distilled water): $NaNO_3$ – 2; KH_2PO4 – 1; $MgSO_4$ 7 H_2O – 0.5; KCl – 0.5; $FeSO_4$ 7 H_2O – 0.01; sucrose – 20.0 (Methods…, 1982).

Wheat grains were treated for 18 hours with CF, after which they were rinsed with distilled water and placed in Petri dishes on filter paper moistened with water, the seedlings being grown for 6 days under different thermal conditions. In variant I, the temperature was constant: 18-19°C for 6 days, in variant II the seedlings were maintained on day 2 at a temperature of 8-9°C for 6 hours. The experiment was performed in 3 repetitions.

Genetic variance (σ^2_G), phenotypic (σ^2_{Ph}), heritability coefficient (h^2), genetic coefficient of variation (GCV, %), phenotypic coefficient of variation (PCV, %), genetic progress (GAM, %) were calculated on based on the formulas proposed by Balkan, 2018. The data were statistically processed through variance, factorial analyzes in the STATISTICA 7 software package.

RESULTS AND DISCUSSIONS

The action of F. culmorum culture filtrates on the growth of wheat seedlings. In relation to the fact that temperature significantly influences *plant x pathogen* interactions, research was carried out in view of the particularities of response of wheat genotypes to the action of culture filtrates (FC) of 4 *F. culmorum* strains. Biometric measurements demonstrated different reactions of wheat genotypes to grains treatment with CF – from no reaction to mild, medium or strong inhibition, the effect depending on the genotype, the analyzed character, the fungal isolate and the temperature.

At the optimal temperature (18-19°C), the germination capacity did not suffer any significant influences from the action of the 3 CFs in the case of genotypes M66 and L Bas./M30, but inhibition was recorded in L Cub.101/Bas. under the influence of FC1 (-14.5%) and L Sel./Accent – in the FC2 variant (-18.9%) (Figure 2).

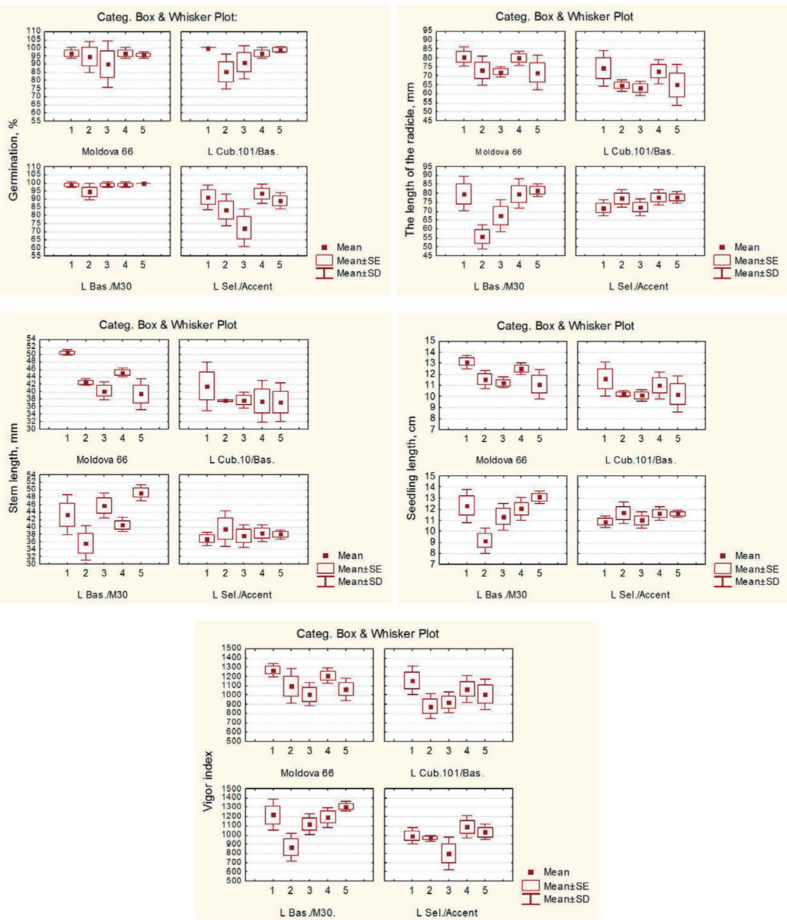

Figure 2. The influence of *F. culmorum* culture filtrates on the growth and development characteristics of common wheat, at a temperature of 18-19°C
1 - Control, 2 - CF1, 3 - CF2, 4 - CF3, 5 - CF4

In our previous research (Lupascu, 2020), it was found that compared to other growth and development organs of wheat, the embryonic radicle shows the highest sensitivity to CFs of Fusarium fungi. According to the obtained data, at the optimal temperature (18-19°C), statistically veridical inhibitions ($p<0.05$) were recorded for: i) *embryonic radicle length* at M66 (FC2: -10.5%) and L Bas./M30 (FC1: -30.4%); ii) *stem length* – at M 66 (FC1-FC4: -10.6 … -22.1%); iii) *seedling length* – M66 (FC1, FC2: -12.0, -14.3%, respectively), L Bas./M30 (FC1: -25.7%), *vigor index* – M66 (FC1, FC2: -12.0, -14.3% , respectively), L Bas./M30 (FC1: -28.8%).

At alternating temperatures 18-19 / 8-9 / 18-19°C, statistically significant inhibitions ($p<0.05$) were found in the action of *F. culmorum* CFs in the following variants: i) *germination capacity* – L Sel./ Accent, FC1, FC4 (-21.2%, -20%, respectively); ii) *the length of the embryonic radicle* – M 66 (FC2: -12.0%), L Cub.101/Bas. (FC1: - 19.9%), L Bass / M30 (FC1, FC2, FC4: -10.2%, -15.7%, -11.7%, respectively), L Sel./Accent (FC1, FC2, FC3, FC4: -31.4 %, -27.4%, -16.0%, -26.3%, respectively); iii) *stem length* – M66 FC1 (-17%), L Cub.101/Bas. (FC1: - 23.3%), L Sel./Accent (FC1, FC2, FC3, FC4: -28.2%, -23.0%, -18.9%, -24.9%, respectively); iv) *seedling length* – M 66 (FC2: - 12.0%), L Cub.101/Bas. (FC1: - 21.1%), L Bass / M30 (FC1: -6.9%), L Sel./Accent (FC1, FC2, FC3, FC4: -30.3%, -25.8%, -16.9%, -25.8%, respectively); iv) *vigor index* – L Cub.101/Bas. (FC1: - 25.2%), L Sel./Accent (FC1, FC2, FC3, FC4: -45.1%, -44.6%, -25%, -40.6%, respectively) (Figure 3).

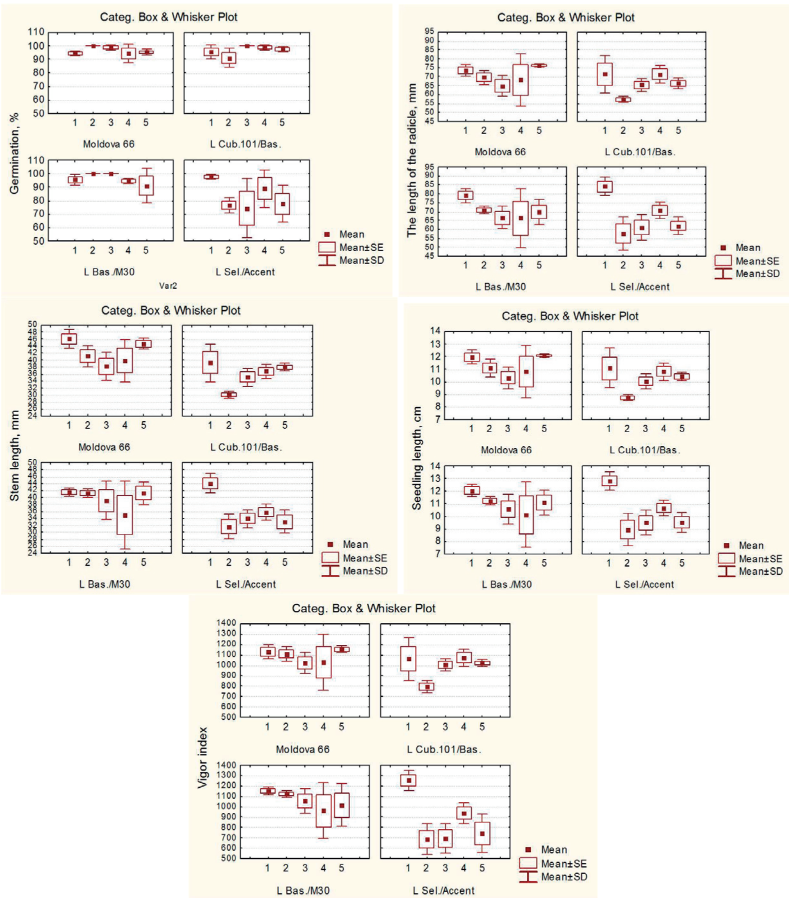

Figure 3. The influence of *F. culmorum* culture filtrates on the growth and development characteristics of common wheat, at temperature alternation 18-19/8-9/18-19°C
1 - Control, 2 - CF1, 3 - CF2, 4 - CF3, 5 - CF4

Starting from recent approaches to the virulence phenotypes of pathogen isolates (Kosman et al., 2019), we can make the assumption that the virulence potential of *F. culmorum* isolates has a multidimensional expression that manifests itself through the differentiated phenotypic plasticity of organs of growth and development as a function of genotype, isolate, temperature, determining a wide functional variation of *common wheat - F. culmorum* interactions.

Factorial analysis of wheat genotype x F. culmorum relationships. It was found that at the temperature of 18-19°C the factorial weight of the genotype, the isolate, their interaction was different in the source of variation of wheat growth characters. For example, the role of the wheat genotype constituted 57.69%; 32.83%; 61.25%; 38.54%; 40.37%, and of the isolate: 28.82%; 42.52%; 13.09%; 33.4%; 44.28%, respectively, of germination capacity, embryonic radicle length, stem length, seedling length, vigor index (Table 1).

Table 1. Factor share of wheat genotype and *F. culmorum* isolate in the growth and development of plants at a temperature of 18-19°C

Source of variation	**Degree of freedom**	**Mean sum of squares**	**F**	**p**	**Share in the source of variation, %**
Germination					
Wheat genotype	3	420.4*	8.79	0.000	57.69
Fungus isolate	4	210.0*	4.39	0.005	28.82
Genotype x isolate	12	50.5	1.06	0.420	6.93
Random effects	40	47.8			6.56
The length of the embryonic radicle					
Wheat genotype	3	189.1*	4.182	0.012	32.83
Fungus isolate	4	244.9*	5.417	0.001	42.52
Genotype x isolate	12	96.8*	2.140	0.036	16.81
Random effects	40	45.2			7.84
The length of the stem					
Wheat genotype	3	128.43*	10.545	0.000	61.25
Fungus isolate	4	27.44	2.253	0.080	13.09
Genotype x isolate	12	41.62*	3.417	0.002	19.85
Random effects	40	12.18			5.81
The length of the seedling					
Wheat genotype	3	4.456*	4.680	0.007	38.54
Fungus isolate	4	3.862*	4.056	0.008	33.40
Genotype x isolate	12	2.293*	2.408	0.019	19.83
Random effects	40	0.952			8.23
Vigor index					
Wheat genotype	3	107564*	6.674	0.001	40.37
Fungus isolate	4	117993*	7.321	0.000	44.28
Genotype x isolate	12	24799	1.539	0.151	9.31
Random effects	40	16117			6.04

*- $p<0.05$.

So at the optimal temperature, the wheat genotype factor had the highest weight for stem growth (61.25%), but the lowest – for embryonic radicle length (32.83%). The isolate factor had a greater influence for the vigor index (44.28%), but the least – for the stem length (13.09%). In the conditions in which the seedlings grew on the background of temperature alternation, a change in the factorial weight of the components of the phytopathosystem in the source of variation of the characters under study was observed. Thus, the weight of the genotype constituted 75.0%; 13.36%; 52.39%; 27.89%; 48.32%, and the isolate – 5.47%; 61.67%; 33.29%, 51.49%; 29.75%, respectively, of germination, radicle length, stem length, seedling length, vigor index (Table 2).

Thus, it can be observed that the low temperature significantly contributed to the reduction of the role of the genotype and the increase of the isolate factor in the growth of the embryonic radicle and stem, which was reflected on the whole seedling, a fact that denotes: i) *F. culmorum* isolates have a higher pathogenic potential against the background of the unfavorable temperature; ii) the virulence polymorphism of *F. culmorum* isolates, specific to plant growth organs, has a more pronounced phenotypic manifestation under these conditions.

Table 2. Factor share of wheat genotype and *F. culmorum* isolate in the growth and development of plants at temperature alternation 18-19° / 8-9 / 18-19°C

Source of variation	Degree of freedom	Mean sum of squares	F	p	Share in the source of variation, %
Germination					
Wheat genotype	3	676.3*	11.256	0.000	75.00
Fungus isolate	4	49.3*	0.820	0.520	5.47
Genotype x isolate	12	116.0	1.930	0.060	12.86
Random effects	40	60.1			6.67
The length of the embryonic radicle					
Wheat genotype	3	72.1*	1.389	0.260	13.36
Fungus isolate	4	332.9*	6.413	0.000	61.67
Genotype x isolate	12	82.9*	1.596	0.132	15.36
Random effects	40	51.9			9.61
The length of the stem					
Wheat genotype	3	144.49*	9.829	0.000	52.39
Fungus isolate	4	91.81*	6.245	0.000	33.29
Genotype x isolate	12	24.79*	1.686	0.107	8.99
Random effects	40	14.70			5.33
The length of the seedling					
Wheat genotype	3	4.067*	3.514	0.024	27.89
Fungus isolate	4	7.509*	6.488	0.000	51.49
Genotype x isolate	12	1.850	1.598	0.131	12.69
Random effects	40	1.157			7.93
Vigor index					
Wheat genotype	3	150451*	8.002	0.000	48.32
Fungus isolate	4	92623*	4.926	0.003	29.75
Genotype x isolate	12	49502*	2.633	0.011	15.90
Random effects	40	18802			6.03

*- $p<0.05$.

Variability and heritability of quantitative growth characters of wheat in the interaction with F. culmorum under the influence of temperature. The calculation of genetic parameters of variability and heritability demonstrated that the magnitude of genotypic (σ^2_G) and phenotypic (σ^2_{Ph}) variances of the analyzed characters was different and strongly influenced by temperature. This was reflected on the h^2 index, i.e. on the capacity for hereditary transmission (Table 3). For example, in the case of the fungus *F. culmorum*, h^2 varied between 0.52-0.76 and 0.12-0.77 at temperatures 18-19°C and 18-19 / 8-9/ 18-19°C, respectively.

The lowest values of the coefficient h^2 were recorded in the case of the length of the embryonic radicle for both thermal variants, which denotes the pronounced dependence of the character on the biotic environment. In contrast to the radicle, the stem recorded much higher h^2 values at both temperatures, which is evidence of its more pronounced genetic determinism and the weaker influence of fungal CFs and temperature.

Table 3. Variability and heritability of common wheat growth characters in interaction with *F. culmorum*

Parameter	Germination	The length of the radicle	The length of the stem	The length of the seedling	Vigor index
18-19°C					
σ^2_G	124.2	47.97	38.75	1.17	30482.67
σ^2_{Ph}	172.0	93.17	50.93	2.12	46599.33
h^2, %	0.72	0.52	0.76	0.55	0.65
GCV, %	11.95	9.50	15.3	9.52	16.44
PCV, %	14.06	13.24	17.54	12.82	20.32
GAM, %	14.11	12.73	19.3	12.71	21.76
18-19 / 8-9 /18-19°C					
σ^2_G	205.4	6.73	43.26	1.74	43883
σ^2_{Ph}	265.5	58.63	57.96	2.90	62685
h^2, %	0.77	0.12	0.75	0.40	0.70
GCV, %	15.38	3.78	17.18	12.33	20.91
PCV, %	17.49	11.15	19.88	15.91	24.99
GAM, %	17.28	3.05	21.47	10.66	27.59

Considering that the reaction of plants to fungal attack is more relevant at the stage of active growth, probably radicle and stem growth is more informative than germination, the grain presenting more of a nutrient substrate for fungal growth.

The h^2 coefficient for radicle length and stem length is directly correlated with the genotypic coefficient of variation (GCV, %), which is in all cases much higher for the stem than for the radicle.

The vigor index (*germination, % x seedling length, cm*) recorded high values of the coefficient h^2 and genetic progress (GAM, %) which denotes the significant control of additive genes in the formation of characters and the high opportunities of creating in narrow terms the genotypes of wheat, resistant to these pathogens that have recently been observed with relatively high frequency in common autumn wheat under the conditions of the Republic of Moldova.

CONCLUSIONS

Treatment of grains with the culture filtrates of *F. culmorum* isolates demonstrated a varied response of common wheat genotypes, function of isolate, growth and development character, isolate, temperature contributing to increase the virulence of the pathogen.

The differentiated phenotypic plasticity of the growth and development organs (embryonic radicle, stem) to the action of *F. culmorum* isolates denotes both the peculiarities of adaptation of wheat seedlings to the pressure of the biotic factor, and the phenotypic virulence of *F. culmorum* isolates.

The factorial analysis of the relationships between wheat genotype and *F. culmorum* isolate demonstrated that the temperature factor modifies the share of the components of the phytopathosystem in the source of variation in the growth and development characteristics of the wheat seedling (radicle, stem), the low temperature diminishing the role of the genotype and increasing that of the isolate.

The relatively high values of the heritability coefficient (0.65-0.70) and genetic progress (21.8-27.6%) for the vigor index (*germination, % x seedling length, cm*) against the background of different conditions thermals denote the additive control of growth and development characters and, at the same time, the opportunities to create wheat genotypes, resistant to *F. culmorum* in restricted terms.

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