Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 22, Issue 1, 2022
PRINT ISSN 2284-7995, E-ISSN 2285-3952

THE RELATIONSHIP BETWEEN YIELD AND PATHOGENS ATTACK ON THE ADVANCED BREEDING WINTER WHEAT LINES ASSESSED FOR ADULT PLANT RESISTANCE

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Abstract

During 2021-year, 155 wheat lines in various stages of breeding process were assessed in microcultures for adult plant resistance on the pathogens attack and the relationship with yielding capacity. The wheat lines Ursita and Voinic were considered as control cultivars. The assessment was performed under natural infection conditions, without the application of fungicides. The wheat lines were scored, depending on adequate scales: - Helminthosporium leaf blotch (Helminthosporium tritici repentis) - modified scale 0-9 was used for pathogens that produce leaf spots; - Septoria leaf blotch (Zymosptoria tritici sin. Septoria tritici) - the scale developed by Vrapi et al. (2012) – Septoria glume blotch (Parastagonospora nodorum - syn. Stagonospora nodorum; Septoria nodorum; Phaeosphaeria nodorum; Leptosphaeria nodorum) - the Bronnimann scale was used (1968); - Powdery mildew (Blumeria graminis f.sp.tritici sin. Erysiphe graminis) - the Saari-Prescot scale was used (1975); Leaf rust (Puccinia recondita f.sp.tritici) - the Cobb`s scale modified by Peterson was used (Peterson et al., 1948). For Helminthosporium tritici repentis, the most relevant pathogen, the attack distribution showed that most of the tested material - 32.9% was at note 3 and the lowest - 1.3% at note 6. The correlation between yield and attack of reticular spot of wheat leaves was noticed ($r = -0.14$), but not significant (the coefficients being below 0.16 - the value from which the correlation could be considered significant at $P = 5\%$). The fact that the other pathogens attacked less in the conditions in which they were present and the distribution of notes for Helminthosporium tritici repentis was mainly between 1-3 notes interval, suggests that the new breeding material showed a good adult plant resistance in natural infections in pedological and climatic conditions from Caracal Research Station.

Key words**:** *adult plant resistance, assessment, pathogen, natural infection, wheat lines*

INTRODUCTION

Worldwide natural systems and agricultural production have been affected by climate changes, epidemics and pandemics risks, biodiversity generated by invasive species, biotic and abiotic stresses, technological and genetical progress, land and crop management, cities development and world globalization [2][20][48][49][50][51].

In the last three decades technological innovations and research progress have greatly shaped Agriculture especially by new cropping systems, precision farming machineries, biotechnology, breeding for more resistant varieties, hi-tech solutions for controlling biotic and abiotic constrainers [11][12][13][14][15][16][54]. Among small grains, wheat (*Triticum aestivum* L.) is the third most produced crop in the world, behind maize and rice, and the wheat yields are projected to increase by 60% by 2050 to feed 9 billion population, while climate change is predicted to decrease production by 29% [32][35]. By 2080, global temperature is anticipated to increase by 4,5-degree Celsius declining by 6% in productivity per each degree Celsius [4][59].

Climate change constitutes also a severe threat to the health of spontaneous and crop plants, associated with changes in pathogens life cycles, increased incidence, pathogenicity, genetically recombination and aggressiveness traits, impacting both productivity and quality and resulting in food insecurity [9][24][34][52][53].

A better understanding of the factors that impact wheat yield may be the key for future increase of the production and breeding for disease resistance against already existing and emerging diseases among other measures [21][41][42][43]. Actually, the multi-disease resistance (MDR) or the "pyramiding" of resistance genes is an on-going process considering that only about 10% of the cultivars possessed superior resistance for the main diseases of wheat [37].

Among the most important foliar fungal diseases that affect wheat (*Triticum aestivum* L.) worldwide are Helminthosporium Leaf Blotch (HLB), Septoria Leaf Blotch (SLB), Septoria Glume Blotch (SGB), Powdery Mildew (PM), Tan Spot (TS), Leaf Rust (LR), Yellow Rust (YR), Stem Rust (SR), colonizing leaves, stems and internodes of wheat being associated with yield losses due to the reduction of photosynthetic aria of canopy. Also, it was observed that chlorophyll a and b concentrations were decreased in susceptible wheat cultivars [29].

Generally, the harvest losses caused by foliar diseases in the non-treated crops were 1,500 - 2,800 kg/ha [18]. Annually these diseases are responsible for 15-20% yield losses [27][45].

Worldwide, yield losses due to Helminthosporium Leaf Blotch (HLB) are variable but are considered to be very significant, ranging from 15% up to 90% reported in susceptible genotypes [56]. Disease severity may be aggravated by soil nutrient deficiencies, especially in potassium poor management [25].

Tan spot (TS) of wheat is caused by the necrotrophic fungal pathogen *Pyrenophora tritici-repentis* (Died.) Drechs. (anamorph: *Drechslera tritici-repentis* (Died.) Shoem.) and it occurs worldwide affecting kernels quality and leading to yield losses between 4% and 15% and even 50% in favourable conditions in susceptible cultivars [39].

Septoria Leaf Blotch (SLB) is caused by *Zymoseptoria tritici* (Desm.) (sin.*Septoria tritici* Rob. ex Desm., teleomorph Mycosphaerella graminicola) is the most damaging fungal wheat pathogen in Europe leading to yield losses up to 50% in epidemic years which were estimated to range from 800 to 2,400 million euros [28].

The fungus *Parastagonospora nodorum* is a necrotrophic fungal pathogen that causes Septoria glume blotch (SGB) of cereals, especially in wheat on adult plants. P. nodorum affects wheat quality and yield by up to 50% [26].

Powdery mildew disease caused by the obligate biotrophic fungus Blumeria graminis DC. E.O. Speer f. sp. tritici Em. Marchal (syn. Erysiphe graminis DC) is a widespread endemic disease with negative impact on grain yield which can reach 40% in susceptible cultivars, especially when infection occurs before or at flowering stage and the leaf flag is infected [3][5].

Cereal rusts are heteroecious and macrocyclic requiring two different unrelated hosts to complete a five-spore stage life cycle, being highly variable for virulence and molecular polymorphism.

Leaf rust caused by the fungus *Puccinia triticina* Eriks. (syn. *P. recondita* Rob. Ex Desm. f. sp. *tritici* Eriks. and Henn.) is the most common rust of wheat and widely distributed causing great losses in grain yield by decreasing the numbers of kernels per head and lower kernel weights. Leaf rust may reach 30% yield losses when the infection on flag leaf at spike emergence account 60-70% [36]. Other authors found that yield losses due to leaf rust ranged between 2% and 50% according to the level of resistance or susceptibility [8][44]. Also, [30] found that mean yield losses for susceptible genotypes were 51%, 5%, and 26% in the normal sowing date trial and 71%, 11% and 44% when sown late.

Stem rust (*Puccinia graminis* f. sp. *tritici*) are considered the most destructive of the three wheat rusts associated with a reduction in grain size and lodging of the plant leading to severe yield losses up to over 90% on severely infected fields on susceptible cultivars [22].

Worldwide wheat varieties are under the risk because new races of *Puccinia graminis* f. sp. *tritici* continuously evolves and these new races could be responsible for large epidemics causing big yield losses [33][58]. Ones of the most virulent races of stem rust are TTKSK and TKTTF causing up to 100% yield losses [1][40].

In the 2016 a new, highly virulent variant of race TTTTF was responsible for stem rust epidemics in Sicily, Italy [10]. Recently new virulent races, including TTRTF, were detected in North Africa and the Middle East [31][46].

Yellow rust caused by *Puccinia striiformis* f. sp. *tritici* (Pst) is other economically important disease of wheat that is frequently reported as producing epidemics in many areas of the world (2 or 3 years of every 5 years) leading to yield losses that ranged from 2% to total crop failure [19]. Some of the previous genes (Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr9, Yr10, Yr17, Yr22, Yr23, Yr26, Yr27) have lost partial or complete resistance in succession due to the emergence of new yellow rust races [7]. Currently, only genes Yr5, Yr15, Yr18 and Yr36 have maintained whole field resistance to yellow rust fungus [57].

Through years of research, it has found that yield losses due to the pathogens attack can be achieved by developing wheat varieties with complex adult-plant resistance (APR) [23]. The resistance effect conferred by all-stage resistance genes is the effect of adult plant resistance genes. However, all-stage resistance is often not durable, because new pathogens virulent races often evolve to overcome this type of resistance (race non-specific resistance).

The aim of the study was to evaluate the relationship between yield losses and pathogens attack on the advanced breeding winter wheat lines assessed adult plant resistance (APR), knowing that stability and durability of resistance is crucial to cope with wheat pathogens, unless pathogens quickly overcome the resistance.

MATERIALS AND METHODS

During, 2021-year, 155 wheat lines, with different origins, genetic background, yield potential and reaction to foliar pathogens, in various stages of breeding process, were assessed in microcultures for Adult Plant Resistance on the pathogens attack and the relationship with yielding capacity.

The wheat lines Ursita and Voinic were considered as control cultivars.

The trial was conducted during winter wheat growing season 2020-2021 in on the Breeding Field of the Agricultural Research Station Caracal of the University of Craiova, Romania (44°11’N and 24°37’E), where almost every year are favourable conditions for the attack of foliar pathogens.

The trial was conducted in a split–split-plot design with the main plots arranged in a randomized complete block with three replicates.

The plot size of each replicate was $7 m^2$ (7 m × 1 m). All recommended cultural practices (i.e. fertilization, weeds control) and other management were applied.

The screening for Adult Plant Resistance (ADR) was performed under natural infection conditions, without the application of fungicides.

The assessments of leaf diseases severity were made at the growth stage 71–73 BBCH (kernel watery; early milk) and the wheat lines were scored, depending on adequate scales: Helminthosporium leaf blotch (*Helminthosporium tritici repentis*) - modified scale 0-9 pathogens that produce yellow leaf spots; Septoria leaf blotch (*Zymosptoria tritici* sin. *Septoria tritici*) - the scale developed by [60]; Septoria glume blotch (*Parastagonospora nodorum* - sin. *Stagonospora nodorum*; *Septoria nodorum; Phaeosphaeria nodorum; Leptosphaeria nodorum*) - the Bronnimann scale [17]; - Powdery mildew (*Blumeria graminis* f.sp.*tritici* sin. *Erysiphe graminis*) - the Saari-Prescot scale [55]; Leaf rust (*Puccinia recondita* f.sp.*tritici*) - the Cobb`s scale modified by Peterson [47].

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PRINT ISSN 2284-7995, E-ISSN 2285-3952

Phenotyping screening was done through visual observations under natural field conditions.

At maturity, wheat plants were harvested and threshed, and grain weight was recorded. One thousand kernels were randomly counted from each plot's seed package and weighed to determine TKW.

RESULTS AND DISCUSSIONS

Plant breeding for disease resistance is one of the most important methods to incorporate new sources of resistance into wheat for diminishing the yield loss due to pathogens attack.

The inspections in the wheat trial have been performed periodically during May and June 2021 in order to identify typical symptoms of foliar pathogens attack. Screening for Adult Plant Resistance (APR) has started for each wheat genotype at the growth stage 71–73 BBCH on leaves, stems and internodes scoring every disease severity.

Varied responses of wheat (i.e., susceptible, partially resistant and resistant) were used to determine the role of different levels of adult plant resistance in reducing the yield loss caused by foliar pathogens infection.

For screening optimization and to predict the disease development, temperatures and rainfalls were taken into account.

In general, the trends of average temperature during the evaluation period tended to increase, which is more obvious during the later growth period (+0.8^{o}C in May 2021 and +0.9^{o}C in June 2021) and together with rainfall amount (55.6 mm in May 2021 and 103.2 mm in June 2021) favoured the infection and rapid development of foliar diseases, especially on susceptible cultivars.

Humidity was determined by the amount of rain of 516.8 mm, comparatively with multiannual average rainfall of 377.7 mm, while the average temperature was +13,6^{o}C comparatively with multiannual average temperature of 11.8 ^{o}C (Fig. 1).

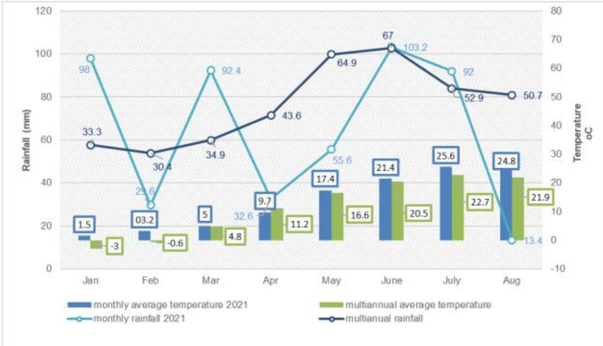

Fig. 1. Weather conditions during the study period (2020 year)
Source: Own calculation.

Data of the adult plant reaction showed a range of response levels of the tested wheat varieties to Helminthosporium leaf blotch, Septoria glume blotch, Septoria leaf blotch, Powdery mildew and Leaf rust.

Previous research showed that multi-gene pyramiding strategy has been successfully applied in many crops being an effective way to achieve durable resistance [6].

According with the symptoms exhibited and disease severity, the most relevant pathogen that affected wheat lines in 2021 was *Helminthosporium tritici repentis*, followed by *Zymosptoria tritici* and *Puccinia recondita* f.sp.*tritici*.

Screening for Adult Plant Resistance (APR) showed that 32.9% of wheat lines were resistant to the attack of *Helminthosporium tritici repentis* (note 3 - Resistant: Light infection of lower third of plant; lower most leaves infected at moderate to severe levels), while only 1.3% of wheat lines were moderately susceptible (note 6 - Moderately susceptible: Severe infection on lower third of plant, moderate on middle leaves and scattered lesions beyond the middle of the plant) and 2.6% of wheat lines were susceptible (note 7 - Susceptible: Lesions severe on lower and middle leaves with infection extending to the leaf below the flag leaf, or with trace infection on the flag leaf).

Among all wheat lines assessed for resistance to *Helminthosporium tritici repentis* in 2021 year, 69% were resistant, 21.3% were moderately resistant, 7.1% were moderately susceptible and 2.6% were susceptible (Fig.2).

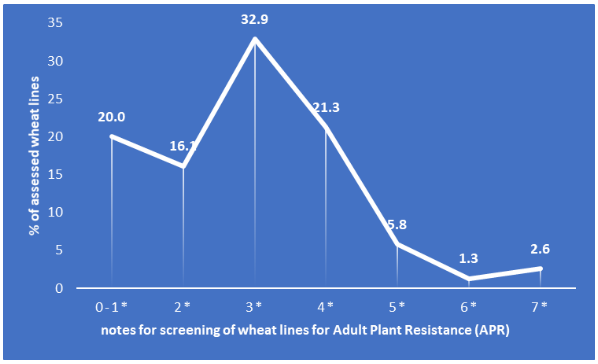

Fig. 2. Distribution of the notes for screening for wheat lines for Adult Plant Resistance to *Helminthosporium tritici repentis*
Source: Own calculation.

The results of screening for Adult Plant Resistance to *Helminthosporium tritici repentis* emphasized that the most resistant lines, with notes 1 or 2, were 18078G, 18090G, 18306G, 18319, 18022G, 18038G, 18001G, 13248G4-001, 13248G01022, with both descendants. On the other pole were the wheat lines 17054G1 and 17054G5, with common genealogy (VOINIC"S"/13248G4), which suggest that both lines have a genetic background for susceptibility to *Helminthosporium tritici repentis.*

All the wheat lines which showed resistance to Helminthosporium *tritici repentis* did not exhibited symptoms for powdery mildew (free of infection) and few of them showed small sized powdery speaks infecting less than 1% leaf area (note 1-resistant). Previous research showed that Adult Plant Resistance (APR) to powdery mildew is more durable than race-specific resistance [38].

The screening for the pathogens *Helminthosporium tritici repentis, Zymosptoria tritici, Parastagonospora nodorum, Blumeria graminis* f.sp.*tritici, Puccinia recondita* f.sp.*tritici*. showed that all wheat lines that exhibited specific attack symptoms, possess Adult Plant Resistance, being resistant, moderately resistant or moderately susceptible. Among assessed lines 13248G4-001 and 13248G01022 exhibited good Adult Plant Resistance to Septoria Leaf Blotch, having as genitors the wheat varieties Nogal and Otilia. Nogal has French origin and good resistance to foliar diseases and stay green for longer time, which has a great impact on the grain yield even under abiotic stress. The wheat variety Otilia, created at NARDI Fundulea, Romania, has as genitors F96052G16 -2/Faur, being remarkable by high yielding capacity and resistance to Fusarium Head Blight (FHB), Stripe Rust (SR) and Septoria Leaf Blotch (SLB).

The wheat lines show different levels of Adult Plant Resistance to Leaf rust (*Puccinia recondita* f.sp.*tritici*) and this aspect was noticed even for the lines (18306G, 17054G1, 17054G5) which have common genitors.

The screening for Multi Disease Resistance emphasized that in 2021-year conditions, the most resistant wheat lines were 18306G, 18039G, 18074G, 18041G and 8254G, while the most susceptible were 17321G2, 17282G3 and 17075G4.

The high prediction ability obtained for Multi Disease Resistance implies that genomic prediction could be used in future, thereby eliminating the necessity to separately screen large numbers of lines in breeding programs for several diseases. However, selection on phenotypic basis under natural infection does not give satisfactory results and often leads toward selection of false positive plants. Thus, selection efficiency can be improved by use of artificial inoculation. Therefore, to obtain a better selection of the resistant cultivars and to have a better approach on the impact of pathogens attack on grain yield are necessary investigations under both natural and artificial infections.

The effect of foliar diseases on the grain yield in 2021-year conditions was estimated to characterize and determine the capacity of wheat lines to tolerate these infections. Knowing that biotic and abiotic factors are correlated not just to the yield loss but also with each other (multicollinearity), regression models were used to estimate relationship between disease indices, abiotic factors and yield losses. However, multicollinearity is problematic because it can increase the variance of the regression coefficients, making it difficult to evaluate the individual impact that each of the correlated predictors has on the response of the wheat line.

The correlation (r = -0.14) between % disease severity of the most prevalent disease in 2021-year (Helminthosporium leaf blotch-

Helminthosporium tritici repentis) and % loss in grain yield component (1,000-kernel weight) due to the natural infection was not significant (the coefficients being below 0.16 - the value from which the correlation could be considered significant at P = 5%) (Fig.3)

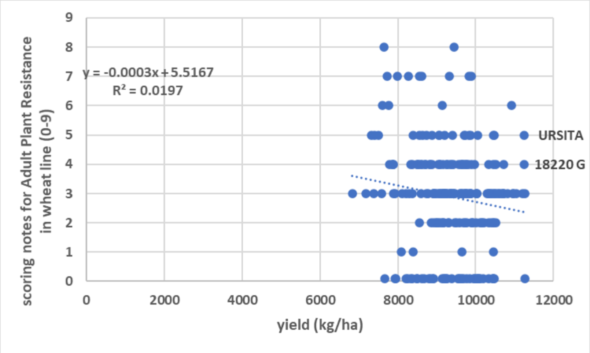

Fig. 3. Relationship between Helminthosporium leaf blotch disease severity and wheat lines yield under natural infection
Source: Own calculation.

Wheat lines Ursita and 18220 recorded high yields despite elevated Helminthosporium leaf blotch severity.

A significant negative correlation (r=-0.161) was observed between % disease severity and yield (kg/ha) among winter wheat lines investigated during 2020-2021 growing seasons for all pathogens assessed (P=5%> 0.16).

The value of determination coefficient (R^2 = 0.026), for all wheat lines assessed, indicated that only 2.6% of variation in grain yield could be explained by cumulated effect of pathogens attack (Fig.4).

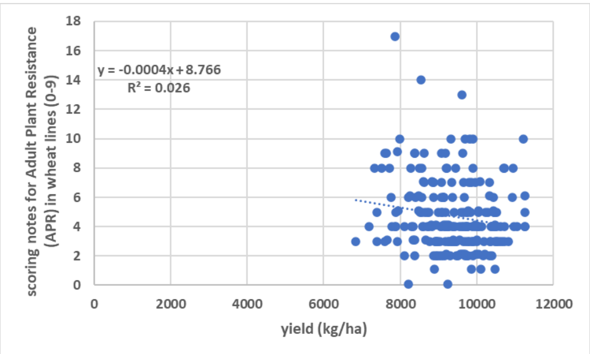

Fig. 4. Relationship between foliar diseases severity and wheat lines yield under natural infection
Source: Own calculation.

The results in this study also suggested that screening of wheat lines for Adult Plant Resistance (APR) in the field under natural infection and yield loss prediction should be constructed using data from few years trial period for a better quantification of visible diseases symptoms taking into account the variations in growing conditions that occur between seasons.

CONCLUSIONS

The research on the impact of foliar pathogens on Adult Plant Resistance (APR) in wheat genotypes form breeding program must be given special attention in the next years in the climatic conditions from Agricultural Research Station Caracal, Romania.

During 2021-year there was noticed a negative correlation between the attack of *Helminthosporium tritici repentis* and grain yield, but not significant one (r=-0.140). On the other side, a significant negative correlation (r=-0.161) was observed between % disease severity and yield (kg/ha) among winter wheat lines investigated during 2020-2021 growing seasons for all foliar pathogens assessed (P=5%>0.16). These findings suggested that in the present pathosystem most wheat lines assessed on phenotypic basis for Adult Plant Resistance (APR) emphasized resistance/tolerance to foliar pathogens attack under natural infection and may be selected for the next steps in the breeding program. The screening for Multi Disease Resistance emphasized that in 2021-year conditions, the most resistant wheat lines were 18306G, 18039G, 18074G, 18041G and 8254G, while the most susceptible were 17321G2, 17282G3 and 17075G4.

Climatic elements influencing yield loss and disease indices are correlated, thus, the screening for impact of each should be analyzed as part of a complex environmental system.

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