Scientific Papers. Series A. Agronomy, Vol. LXVII, No. 2, 2024
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

GRAIN YIELD STABILITY ANALYSIS USING PARAMETRIC AND NONPARAMETRIC STATISTICS OF BULGARIAN AND HUNGARIAN COMMON WINTER WHEAT GENOTYPES

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Abstract

The research was conducted in the period 2020-2023 on the experimental field at the IPGR "K. Malkov", town of Sadovo. 5 Hungarian varieties, 16 advanced lines and 4 Bulgarian varieties of common winter wheat were evaluated for grain yield and stability. The stability of the grain yield was determined by the variances of stability (σi^2 and Si^2), equivalency (Wi), the criterion of phenotypic stability (Ysi), regression coefficient b_i and general adaptability. The highest average yield for the study period was obtained from MV-Nemere 864.4 kg/da, followed by RU179/1400 and MV-Nador -766.6 and 766.5 kg/da. The yield formed by the Hungarian varieties is relatively high and they are of interest for selection improvement work. In terms of grain yield, the lines RU 129/3053 and RU 177/486 have a complex stability assessment. The variety Sadovo1 is defined as very stable in different environments and valuable for selection programs.

Key words: *common winter wheat, grain yield, variances of stability, equivalency, phenotypic stability.*

INTRODUCTION

The bread wheat (*Triticum aestivum* L.) is one of the most widespread and most consumed food crops worldwide. The 2 February 2024 report of the Food and Agriculture Organization of the United Nations (FAO) updates the forecast of the global cereal balance in 2023/24 (https://www.fao.org/worldfoodsituation/csdb/en). The global winter wheat crop is expected to decline moderately in 2024. One reason for this is lower grain prices. In the European Union, the occurrence of various extreme weather conditions (heavy rains and/or rainfall deficits in various regions, as well as changes in temperatures) are contributing to a small reduction in the total area of common winter wheat (Piepho, 2019; Bocci et al., 2020). The FAO's forecast for total wheat use in 2023/24 has been raised by 2.9 million tones since December and shows a 2.0% (15.4 million tons) increase from 2022/23. The revision reflects higher than previously expected feed use, particularly in the European Union, as well as in Australia and the United States (https://www.fao.org/worldfoodsituation/csdb/en). Amid global climate change, grain consumption is increasing. Globally, as temperatures rise for every 1°C increase, productivity is projected to decline and wheat yields are expected to fall by 6% (Asseng et al., 2015; Uhr et al., 2023; Guo et al., 2024).

In a changing climate, yield stability is becoming increasingly important for grain and livestock farmers. The creation and introduction of common wheat varieties with high genetic potential for productivity and grain quality is linked to the study of the ecological plasticity of individual varieties over the years, as well as the determination of the most appropriate varietal structure for each region, and micro-region of a region (Stoyanova et al., 2020; Hufford et al., 2019; Van Frank et al., 2020; Minoli et al., 2022). In this regard, it is imperative to thoroughly investigate the dependence between the variety and the specific meteorological conditions of different growing regions (Tsenov & Atanasova, 2015; Kucek et al., 2019; Gubatov et al., 2021). The results show that the influence of genotype and its interaction with the environment has been demonstrated in all observed traits (Reckling et al., 2021; Dimitrov et al., 2023; Dimitrov et al., 2023A). In a study by Uhr et al. (2023) the strength of environmental influence ranged from 61 to 82% in terms of grain yield. Yield stability analyses have become necessary in recent years, it is particularly important in research on the impacts of climate change. Declining and associated with its changes (Müller et al., 2018; Najafi et al., 2018; Ray et al., 2015; Tigchelaar et al., 2018; Lobell et al., 2011; Webber et al., 2020). According to Tsenov et al. (2022), it is advisable that an evaluation of varieties for yield and stability be easy and efficient is to do so through statistical programs in which the possibility of genotype x environment evaluation exists. Once the specific interactions between these are revealed, one can proceed to a correct assessment of yield stability. The terms "stability" or "phenotypic stability" are used in the literature to denote the phenotypic manifestation of a trait while a particular genotype, as such, remains relatively stable (Becker & Leon, 1988; Kang, 2020). Investigating this phenotypic stability is important for any breeding program where the effects of genotype and environment need to be studied and exploited (Kang, 2020; Akcura et al., 2006; Pour-Aboughadareh et al., 2022; Weedon & Finckh, 2019).

MATERIALS AND METHODS

The trial was carried out in the experimental field of IPGR - Sadovo in the period 2020-2023. The yield and its stability were studied in twenty-five genotypes of common winter wheat, originating from Bulgaria and Hungary. The varietal trials were conducted in a block design in three replications, with a trial plot size of 10 m^2, and the studied genotypes were compared with the country's complex standard variety Sadovo1. Of note is the fact that the hailstorm that fell in 2022 resulted in compromised yield. In order to present more reliable results, the mentioned year was excluded from the overall statistical treatment of the results. Yield data were processed by applying analysis of variance (Lidanski, 1988), where the strength of influence of the sources of variation - genotype, environment and their interaction - were estimated. Yield stability and adaptability of common winter wheat cultivars were evaluated by stability variance σ_i^2 and S_i^2 according to Shukla (1972), eco valence W_i according to Wricke, phenotypic stability criterion (Ysi) according to Kang (2020), regression coefficient b_i according to Finlay & Wilkinson (1963), general adaptability GA according to Eberhart & Russell (1966). Statistical and mathematical processing of the data was performed using Microsoft Excel and Stability soft software.

RESULTS AND DISCUSSIONS

Table 1 shows the mean values by year of the grain yield trait. In the first year, grain yield ranged from 658.6 kg/da to 1092.4 and the average yield was 863.6 kg/da. In the second year, the average yield was 800.48 kg/da, with a minimum of 638.87 and a maximum of 924.9 kg/da. In the third year, the average yield was 484.73 kg/da, the minimum was 321.8 and the maximum was 575.9 kg/da. The highest average yield of the genotypes was formed in the first year of testing.

Table 1. Mean Grain yield values by year

Genotype/Year	2020	2021	2023
1.MX 270/ 28	960.475	705.375	540.5
2.MX 270/ 50	1016.525	800.125	547.25
3.РУ 129/3053	930.15	863.875	543.575
4.РУ 33/3244	821.425	769.05	506.75
5.MX 270/ 3461	874.425	720.825	448.375
6.MX 285/1058	959.7	794.95	502.125
7.РУ 48/2553	768.925	775.45	517.8
8.MX 286/1759	767.35	749.125	416.925
9.MX 286/1777	846.75	708.5	464.45
10.Avenue	777.975	828.975	375.075
11.Anapurna	797.85	829.1	321.8
12.Sadovo1	798.425	771.7	449.85
13.Enola	695.825	791.475	474.675
14.MX 272/3872	658.6	857.425	451.425
15.MX 215/3	832.35	638.875	534.85
16.РУ134/1343	802.975	789.6	476.325
17.РУ177/486	934.8	803.975	525.45
18.РУ135/1456	834.475	730.975	520.3
19.РУ179/1400	990.5	794.4	514.925
20.РУ134/1370	869.975	866.9	547.325
21.MV-Nador	934.775	856.85	507.95
22.MV-Nemere	1092.375	924.925	575.95
23.MV-MENROT	854.6	902.125	395.3
24.MV-MENTE	838.525	883.3	456.575
25.MV-KAPLAR	931.25	854.275	502.825
Mean	863.64	800.48	484.73
Standard error of mean	20.09	13.67	12.11
Min.	658.6	638.87	321.8
Max.	1092.4	924.9	575.95
CV%	11.63	8.54	12.49

The analysis of variance presented (Table 2), shows that the trait grain yield was highly significantly influenced by genotypes, environments and genotype-environment interaction. Most of the phenotypic variation in grain yield trait was due to environment (79.7%). Genotypes and genotype-environment interaction have equal proportion of influence. For the trait grain yield, there is a very well established genotype-environment interaction. This allows the stability analysis of the studied materials. The genotype-environment influence found indicates that genotypes respond differently when changing environments.

Table 2. Grain yield variance analysis

Source	SS	df	MS	Sign.	η^2, %
Genotype	659218.8	24	27467.5	***	8.5
Environment	6181437.8	2	3090718.9	***	79.7
Interaction G x E	668391.3	48	13924.8	***	8.6
Error	250000.0	150	1666.7		3.2

***Significant at $p < 0.001$

Table 3 shows the reported mean yield as well as the calculated parametric and non-parametric estimates of the stability of the test samples with respect to the grain yield trait. For seven wheat lines and varieties (MX 270/ 28, MX 270/ 50, RU 129/3053, MX 285/1058, RU 177/486, RU 179/1400, RU 134/1370, MV-Nador, MV-Nemere, MV-KAPLAR), the reported average yield for the study period was above 750 kg/day. The yield formed is relatively high and these genotypes are of interest for breeding improvement work. The Hungarian variety MV-Nemere has the highest yield on average over the three years. The average yield of the genotypes was 716.3 kg/da. Eleven genotypes (MX 270/28, MX 270/50, RU 129/3053, MX 285/1058, RU 177/486, RU 179/1400, RU 134/1370, MV-Nador, MV-Nemere, MV-MENTE, MV-KAPLAR) had yields above the average of all genotypes in total for the three years.

The grain yield trait increasing is a major objective of breeding programs. The stability is not left behind and its importance is essential for newly developed varieties. Low values for the nonparametric estimates $S^{(1)}$ and $S^{(2)}$ determine the stability of genotypes. Eight genotypes RU 129/3053, MX 286/1751, Sadovo1, RU 134/1343, RU 177/486, MV-Nador, MV-Nemere and MV-KAPLAR showed low values for $S^{(1)}$, while four genotypes MX 286/1759, Sadovo1, RU 134/1343 and MV-Nemere showed low values for $S^{(2)}$. Low values for the $NP^{(1)}$ and $NP^{(2)}$ indices determined a higher stability of the genotypes. Two genotypes (RU 129/3053 and Sadovo 1) have low values for $NP^{(1)}$ and seven (MX 270/50, RU 177/486, RU 179/1400, RU 134/1370, MV-Nador, MV-Nemere and MV-KAPLAR) for $NP^{(2)}$. Notably, the MV-Nemere genotype has three low nonparametric stabilities and realizes the highest yield of all genotypes studied. The cultivar Sadovo1 also possesses three non-parametric stabilities and an average grain yield slightly below the mean.

The Wricke equilibrium (Wi^2) measures the contribution of genotype to the genotype x environment interaction. A W_i^2 value of zero or close to zero is an indicator of stability and conversely high Wi^2 values are an indicator of instability. A genotype with a low value for Eco valance is considered ideal in terms of grain yield stability. Low Wi^2 suggests that this genotype is stable given its weak contribution to the interaction. On the quantitative assessment of Wricke's Wi^2 parameter, two genotypes (RU 129/3053 and Sadovo 1) had a low stability value and on Shukla's $\sigma^2 i$ parameter, five (RU 129/3053, Sadovo1, RU 134/1343, MV-Nador and MV-KAPLAR).

The genotypes RU 129/3053 and Sadovo1 have low values for both parameters and possess high stability. Five genotypes (RU 129/3053, RU 33/3244, Sadovo1, MV-Nador and MV-KAPLAR) have low values for s^2d_i and are defined as stable according to this parameter. The bi parameter is one of the most commonly used to assess stability. In terms of yield, genotypes with values equal to one should be noted as having agronomic or dynamic stability and those with values greater than one as being responsive to specific conditions of favorable environments. The genotypes RU 129/3053, MX 270/3461, MX 286/175, Sadovo1 and RU 177/486 have values around or equal to one and possess agronomic stability. They are extremely valuable in this growing area. The genotypes MH 285/1058, Anapurna, RU 179/1400, MV-Nador, MV-Nemere, MV-MENROT, MV-MENTE and MV-KAPLAR have values above one and they are responsive to the specific conditions of favorable environments. These genotypes are valuable in terms of the regression coefficient bi for the grain yield trait.

The genotypes RU 129/3053 and RU 177/486 realized high yields and a regression coefficient b_i approximately equal to 1.00, respectively. In terms of coefficient of variation (CV%) with values below ten are stable, on the other hand, ten to twenty indicate higher grain yield under better conditions. All the genotypes in the study had coefficient of variation above 20. The Kang parameter combines yield and stability simultaneously and genotypes with low ranks have high stability. Four genotypes are considered stable: RU 129/3053, RU 177/48633, MV-Nador and MV-KAPLAR. These genotypes are very valuable in terms of complex evaluation against stability and grain yield. They should be included in breeding improvement work. Genotype RU 129/3053 and RU177/4863, have the lowest stability and grain yield parameters above the overall average. They appear to be extremely valuable for selection in terms of grain yield. Variety Sadovo1 has seven stability scores, although not high yielding and defined by the Kang score, its value is strongly emphasized.

Table 3. Parametric and non-parametric stabilities for grain yield

N	Mean Y	$S^{(1)}$	$S^{(2)}$	NP^1	NP^2	W_i^2	σ^2_i	s^2d_i	b_i	CV_i	Ys_i
1.	735.4	13.3	127	8.33	0.5	20431.3	10902.1	2842.0	0.91	28.7	33
2.	787.9	6.7	30.3	12.3	0.2	11868.1	6248.2	1583.9	1.09	29.8	21
3.	779.2	3.3	7	1.7	0.3	29.7	185.6	0.3	1.01	26.5	4
4.	699.6	4.7	13	7.7	0.8	2366.3	1084.2	0.0004	0.83	24.1	22
5.	681.2	8	44.3	7	0.7	4092.7	2022.5	565.8	1.04	31.6	28
6.	752.2	6	24.3	8.3	0.3	5678.7	2884.5	649.4	1.11	30.8	22
7.	687.4	8.7	43	10.7	0.8	8186.3	4247.3	194.2	0.71	21.3	31
8.	644.5	2	2.3	4.3	2.3	1033.4	359.84	133.9	0.96	30.6	28
9.	673.2	6.6	25.3	4.3	0.7	3597.7	1753.3	460.8	0.93	28.7	29
10.	660.7	9.3	54.3	11	0.9	10897.2	5720.6	1157.9	1.18	37.6	39
11.	649.6	10.7	67	10.7	0.9	18346.6	9769.1	1014.6	1.36	43.7	45
12.	673.3	1.3	1	2.3	1.1	761.4	212.00	81.6	0.95	28.8	20
13.	653.9	6	24.3	7.3	1.3	16702.2	8875.5	1456.5	0.71	24.8	43
14.	655.8	12.6	94.3	10	0.8	35423.2	19049.9	4517.0	0.78	30.9	47
15.	668.7	12.6	90.3	11	0.7	22812.9	12196.5	1717.4	0.63	22.5	44
16.	689.6	2	2.3	3.7	0.7	1738.2	742.9	139.9	0.90	26.8	21
17.	754.7	3.3	7	5.3	0.1	2297.3	1046.7	325.0	1.01	27.7	16
18.	695.2	8.6	42.3	9.3	0.6	5619.7	2852.4	216.9	0.77	23.0	26
19.	766.6	7.3	31	10.7	0.2	9445.2	4931.4	1132.2	1.13	31.1	20
20.	761.4	6	22.3	6	0.2	2262.9	1028.0	213.2	0.90	24.3	14
21.	766.5	2.6	5.3	3.7	0.1	1204.4	452.7	3.8	1.11	29.6	9
22.	864.4	0	0	11.7	0.04	10297.6	5394.7	549.3	1.27	30.4	18
23.	717.3	14	110	11.7	0.4	18407.3	9802.2	1277.0	1.33	39.0	34
24.	726.1	10	60.3	10.7	0.3	7990.9	4141.1	975.5	1.11	32.2	25
25.	762.8	3.3	8.3	4.3	0.1	1305.8	507.9	2.6	1.12	29.9	11

CONCLUSIONS

The grain yield is most strongly influenced by environment and less strongly by genotype and genotype-environment interaction. For this trait, the genotypes with complex stability scores were RU 129/3053 and RU 177/486. These are of great importance for breeding and improvement work.

Variety Sadovo1 has a large number of low parametric and non-parametric stabilities. This defines it as very stable in different environments and valuable for breeding programs.

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