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Estimation of heritability and genetic advance for grain yield and its components in common wheat (*Triticum aestivum* L.) under genotype by environmental interaction

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Abstract

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The study was organized in order to determine the influence of environments and the real possible genetic progress after selection of traits, directly related to grain yield in wheat. A multifactor field experiment was organized which included forty samples of winter common wheat grown during the period 2017-2019 in three test locations of Bulgaria. The data collected were used to track changes in the components of productivity, their correlations and the genetic progress that could be made in each of them by selection. The variation within 10-20% of each of the traits is mainly due to the interaction of the genotype by location. As a result, the characters change extremely inadequately to the change of conditions, which is proved by applying a principle component analysis. The established inheritance coefficients, correlations between traits and their genetic progress show that by applying a differential approach by selection on specific traits, grain yield could be increased up to 20% compared to its current level. The results are an occasion to think about a new breeding strategy in terms of creating a new “ecotype” variety, in which genetic progress in grain yield will be guaranteed.

Keywords: wheat; grain productivity; correlations; heritability, genetic advances
Abbreviations: (GY) – Grain yield, t/ha; (NPT) – Number of productive tillers per m^2; (TGW) – Thousand grain weight; (NGS) – Number of grains per spike; (WGS) – Grain weight per spike; (NGm) – Number grains per m^2; (TBM) – Total aboveground biomass; (HI) – Harvest index and (HOS) – Height of stem.

Introduction

The classical breeding of wheat is based on a selection by various traits or indexes, mainly by phenotype (Fischer & Rebetzke, 2018). The traits that determine the yield directly have different correlations with each other. In pursuit of a specific “biotype” for the variety, it is important to know these dependencies in order to be able to build the right strategy to be implemented in the long run. Knowledge of biological and specifically interdependent is a prerequisite for successful genetic progress in grain productivity. It depends on the interactions of the genotype with the environment in each of the traits, which, even if they change differently, eventually have to be combined with each other, so that ultimately to determine the size of grain yield (Keser et al., 2017; Bassi & Nachit 2019). It is therefore important to collect information on each quantitative trait that changes as a result of genotype by environment interactions (GEI), because this will lead to a more successful combination between them in changing environmental conditions (Gerard et al., (2020; Muhammad et al. , 2020).

In cereals, there are a large number of studies on the establishment of genetic control over traits of productivity, their variation and possible genetic progress after selection (Taneva et al., 2019; Jaiswal et al., 2020; Ferreira et al., 2020;

Dyulgerov & Dyulgerova , 2020). This is also aimed at studies related to various aspects of grain quality (Devesh et al., 2018; Taneva et al., 2019; Singh et al., 2020). The reason for this is based on the great variety of soil and climatic conditions in which the crops are grown, as well as the diverse varietal composition by species (spring or winter) and with specific biological and economic qualities. Different conditions sometimes cause a significant change in the direction and magnitude of the correlations between the determinants of yield or quality traits, which make it difficult to gather objective information (Gubatov et al., 2016; Slafer et al., 2014; Xiong et al., 2020). The genotype by environment interaction causes additional dispersion of variation, which further "masks" the identification of correlations between traits affecting grain yield (Quintero et al., 2018; Yang et al., 2019; Xiong et al., 2020). The interaction with the environment (GEI), as well as with other technological factors for example (fertilization, predecessor, sowing density, date of sowing, etc.) specifically affects the various traits, causing changes in them with a linear or difficult to analyze nonlinear nature (Ivanova and Tsenov, 2011; Rajičić et al., 2020). Changes in each trait affect both yield and other related traits due to their existing biological proportions (Djuric et al., 2018). This refers to traits whose magnitudes are formed antagonistically (negative correlation), such as grain size (TGW) and number of grains per spike (NGS) in wheat (Mandea et al., 2019; Tsenov et al., 2020[a]). Even in the presence of factors that drastically change the correlations (fertilization, stress), the cited correlations invariably remain strongly negative with each other, despite the fact that each of them directly and significantly affects grain yield (Tsenov et al., 2021[a]). This is the case with the characteristics of productive tillers (NPT), grain size (TGW) and number of grains per spike (NGS), each of which has a strong negative relationship with each of the others. For these reasons, in order to make progress in breeding for productivity, these complex relationships must be studied in as much detail as possible in order to be used by breeding as rationally as possible. (Lichthardt et al., 2020; Passiora, 2020). All this requires the study of the limits of variation of traits related to yield, as well as their genetic control, which in turn can be associated with the effectiveness of the selection. (Al-Otayk, 2019; Yacoubi et al., 2020).

Studies on the progress of wheat yields show that success can be achieved by selecting single or a set of several traits in parallel. They vary by region, according to climate and type of wheat (common or durum). What unites a large part of the conducted studies is the essential role on the grain yield of the aboveground biomass and the harvest index traits. (Wu et al., 2013; Reynolds et al., 2017; Mathew et al., 2018). The latter is increased mainly by increasing the number of grains per unit area (Desheva, 2016; Raykov et al., 2017; Gerard et al., 2020), or by increasing the grain weight per spike (Sadras & Lawson, 2011). It is clear that the increase in yield can be done by selective pressure on traits or a set of traits that are effective but different according to the specific environmental conditions.

On the Balkan Peninsula, where the most cultivated crop is wheat, the conditions for it are extremely variable (Kazandjiev et al., 2011; Spiridonov & Valcheva, 2017; Pais et al., 2020). This affects grain yield and the traits that determine it, differently, according to the conditions of the particular season (Mihova et al., 2017; Herrera et al., 2020). The achieved plateau in the genetic control of grain yield (Tsenov et al., 2019) of 10 tons per hectare at the current combination of traits that determine it (Tsenov et al., 2021[b]) can no longer meet the expectations of farmers for more high grain yields. It is necessary to build a new vision for changing the individual traits in proportions that would provide genetic progress by 15-20 % in the long term. A number of studies have already shown that the number of grains (NGS), when successfully combined with productive tillering (number of grains per m^2) in continental growing conditions is the factor that significantly affects the grain yield (Raykov et al., 2016; Djuric et al ., 2018; Mandea et al., 2019; Bányai et al., 2020). According to the summaries in Passiora's (2020) research, the number of grains per spike is the only "universal" trait that can effectively increase yields through selection, regardless of environmental conditions. If we rely on it, as recent studies show, then its increase will be accompanied by a decrease in (TGW), and probably other traits, in order to maintain the biological balance between them (Tsenov et al., 2021[a]).

In this regard, information on the extent of variation and the relationships between quantitative traits would be extremely useful in constructing a climate-appropriate ecotype. For it to be successful, the balance between the main traits should be maintained at other levels of them, without having a negative impact on each other. Only in this way the new type of variety could realize high and stable grain yield for years.

The aim of the study is to determine the extent of variation, the influence of conditions and possible genetic progress after selection of traits directly related to grain yield in common wheat.

Material and Methods

This study was conducted with the participation of 40 varieties of winter common wheat, created in the Agronom breeding company over the past 20 years (Table 1). The group of varieties was studied in three growing locations, as follows: the village of Paskalevo-Dobrich region, the village of Trastenik-Ruse region and the town of Straldzha-Yambol region. The field experiments were conducted in three consecutive years 2017 – 2019. In each of the selected locations the varieties are grown in plots of 10 m^2. In each separate location the requirement for ensuring equal conditions for each variety participating in the scheme is strictly observed. This means sowing in one day, uniform feeding (fertilization) and care throughout the growing season and finally harvesting the plots. Each of the test locations has a unique combination of soil and climatic conditions, and the seasons in which the varieties were studied, have specific meteorological conditions. The most important from a breeding point of view, the characteristics related to productivity are analyzed as follows: number of productive stems per m^2 (NPT); the number of grains per spike (NGS); 1000 grains weight (TGW), weight of grains per spike (WGS), number of grains per m^2 (NGm), aboveground biomass (TBM), harvest index (HI) and grain yield itself (GY) (Table 1).

The statistical parameters, on which the analyses of the individual traits were made, were calculated according to the formulas presented in Table 2, according to the models of the cited authors. All values of the parameters were calculated

Table 1. Information on soil, meteorological characteristics, coordinates of the test locations quantitative traits and their measurement by phases, and list of studied varieties by groups during the period 2017-2019

Location	Type of Soil	Coordinates		Average daily air temperature (°C) by periods*			
		N	E	X-XII [1]	I-III [2]	IV-VI [3]	Mean
Paskalevo, Dobrich	Leached chernozem	43°38′47″	27°48′40″	7.4	1.7	15.8	8.3
Trastenik, Rousse	Leached chernozem	43°37′40″	25°51′37″	7.4	1.8	16.5	8.6
Straldha, Yambol	Chernozem	42°24′33″	26°37′33″	7.7	1.8	17.9	9.1
				Amount of precipitation (mm/m^2) by periods			
Year of study				X-XII [1]	I-III [2]	IV-VI [3]	Sum
2017				131	213	172	516
2018				140	110	132	382
2019				155	142	173	470
Groups of varieties	Number	Designation of genotypes					
In production	11	Aneta, Apogej, Presiana, Ognyana, Alisa, Bilyana, Viyara, Neven, Ralitsa, Tervel, Faktor					
New	8	Riana, ABC Alfio, ABC Lombardia, ABC Klauzius, ABC Speri, ABC Zigmund, ABC Kolino, ABC Navo					
Candidate varieties	11	A 68/64, A 48/716, A 18/74, ACR 48/615, A 27/320, ABC 27/512, ABC 28/313, A 37/215, ABC 48/716, A 47/415, ABC 37/716					
Advanced lines	7	R_A 1-4-5, 06/198-21, 06/137-22, 1/54-84, 04/255-92-2, 05/48-22-1, 05/48-22-8					
Check varieties	3	Pryaspa, LG Avenue, LG Anapurna					
Total number	40	Aneta, Apogej, Presiana, Ognyana, Alisa, Bilyana, Viyara, Neven, Ralitsa, Tervel, Faktor					
Character	Decimal code**	Measurement					
1. (HOS) Height of stem, cm.	69	On 10 plants from each plot					
2. (NPT) Number of productive tillers per m^2	73	Count in an area of 0,25 m^2 of each plot					
3. (NGS) Number of grains per spike,	83	On 20 spikes from each plot					
4. (TBM) Total aboveground biomass, t/ha	99	Cutting the entire plant mass to the soil surface in an area of 0.25 m^2 of each plot					
5. (GY) Grain yield, t/ha	99	From each harvested plot					
6. (TGW) Thousand grain weight, g	99	Counting 2 by 500 grains after harvest					
7. (WGS) Grain weight per spike, g	99	WGS = NGS * TGW / 1000					
8. (NGm) Number of grains per m^2	99	NGm = NPT * NGS					
9. (HI) Harvest index	99	HI = GY / (TBM + GY)					

*1 – vegetation in autumn, 2 – winter rest in vegetation, 3 – vegetation in the spring, ** – decimal codes by Zadoks et al. (1974)

using the computer program XLStat 2019. The analysis of the variances was done using the statistical program IBM SPSS 23, the principal component analysis (PCA) and the correlations between the characters were made using the software Statgrapics XVIII.

Results

All studied features vary widely (Table 3). The lowest variation is in the harvest index (HI, 3.9%). According to the values of the coefficient of variation, the other traits can be grouped as highly variable: grain yield (GY), number of productive stems (NPT), number of grains per m^2 (NGS), and biomass (TBM), whose values vary by about 20 %, and of medium variables: 1000 grains weight (TGW), height of stem (HOS), weight of grains per spike (WGS) and number of grains per spike (NGS), which vary within 9-12 %. Variation in the range of 18-22% in wheat is characteristic of hybrid populations, not varieties. This is an indication of the strong influence of the studied factors in the experience. For some of the traits the range of variation is huge and reaches almost 40 % of the minimum values of some of the characters (NGm, TBM, NPT).

Two of the three factors (A and C) have a significant effect on almost all traits except the harvest index (HI) trait. The conditions of the year (B) do not have a direct effect on the performance of most of the traits. The factor "year" affects grain yield (GY), grain size (TGW) and harvest index (HI), and does not affect all others. In these same traits the interaction between the factors (B x C) is proved, while in the other traits it is insignificant as an effect. The factor "location" (A) has a strong interaction with the "variety"

Table 2. All genetic parameters and formulas for their respective calculation

Symbol	Meaning	Source of reference
$\sigma^2_g = (MS_g - MS_{gy})/y$	Genotypic variance	Burton et al. (1953)
$\sigma^2_{gy} = (MS_{gy} - MS_e)/r$	Variance of interaction between G and Y	Burton et al. (1953)
$\sigma^2_e = MS_e$	Variance of error	Burton et al. (1953)
$\sigma^2_{ph} = \boldsymbol{\sigma}^2_g + \boldsymbol{\sigma}^2_{gy}/y + \boldsymbol{\sigma}^2_e)/r$	Phenotypic variance	Burton et al. (1953)
$H^2_{BS} = (\sigma^2_g / \boldsymbol{\sigma}^2_{ph}) *100$	Broad sense heritability	Allard (1999)
$GA = K * (\sigma^2_{ph})^{0.5} * H^2_{BS}$	Genetic advance K – selection intensity – 2.06 %	Allard (1999)
$GAM = GA/GM*100$	Genetic advance, %	Allard (1999)
$CV_p = \sqrt{\boldsymbol{\sigma}^2_{ph}} / (\bar{x} * 100)$	Phenotypic coefficient of variation	Burton et al. (1953)
$CV_g = \sqrt{\sigma^2_g}/(\bar{x} * 100)$	Genotypic coefficient of variation	Burton et al. (1953)
GM	Grand mean	
MS_g	Mean squares of genotype, g	Johnson et al. (1955)
MS_{gy}	Mean squares of interaction, g*y	Johnson et al. (1955)
MS_e	Mean squares of error	Johnson et al. (1955)
y	Number of locations	
r	Number of replications	

Table 3. Main Descriptive statistics of grain yield traits

Trait*	Minimum	Maximum	Range	Mean	Standard deviation (n)	Variation coefficient
GY	4.16	10.80	6.64	8.10	1.563	19.3
NPT	381	880	499	616	118.2	19.2
TGW	36.5	57.1	20.53	45.4	4.15	9.1
WGS	0.99	1.70	0.71	1.34	0.166	12.4
NGS	21.0	42.6	21.60	29.6	3.79	12.8
NGm	10586	27205	16619	18012	3570.9	19.8
TBM	2.73	7.81	5.08	5.12	1.043	20.4
HI	0.36	0.44	0.08	0.40	0.0153	3.9
HOS	59.7	100.0	40.3	83.4	8.35	10.0

* (GY) – Grain yield, (NPT) – Number of productive tillers per m^2, (TGW) – Thousand grain weight, (NGS) – Number of grains per spike, (WGS) – Grain weight per spike, (NGm) – Number of grains per m^2, (HOS) – Height of Stem, (TBM) – Total aboveground biomass, (HI)-Harvest index

Table 4. Analysis of variances for yield related traits- Type III Sums of Squares

Source	Df	GY	NPT	TGW	WGS	NGS	NGm	TBM	HI	HOS
A:Location	2	360.530	1705370.00	145.94	0.467	367.15	1.6E+09	100.76	0.004 *(ns)*	1079.25
B:Variety	39	2.068	26852.70	141.29	0.135	63.47	2.1E+07	3.73	0.001 *(ns)*	503.72
C:Year	2	1.343	1486.04 *(ns)*	26.11	0.080 *(ns)*	12.13 *(ns)*	3.2E+06 *(ns)*	0.06 *(ns)*	0.036	5.52 *(ns)*
A x B	78	1.157	7028.09	5.39	0.052	24.56	6.5E+06	0.69	0.001	54.52
A x C	4	1.698	24476.50	19.67	0.133	102.25	5.3E+06	1.67	0.018	16.47 *(ns)*
B x C	78	0.248 *(ns)*	3319.12 *(ns)*	4.03	0.022 *(ns)*	10.33 *(ns)*	1.6E+06 *(ns)*	0.28 *(ns)*	0.004	10.82 *(ns)*

Values in bold are not significant *(ns)* at level = 0.05*,* * (GY) Grain yield, (NPT) Number of productive tillers per m^2, (TGW) Thousand grain weight, (NGS) Number of grains per spike, (WGS) Grain weight per spike, (NGm) Number of grains per m^2, (HOS) Height of Stem, (TBM) Total aboveground biomass, (HI) Harvest index

factor (C) and "year" of cultivation (B), as well. Stem height (HOS) and harvest index (HI) are an exception to this situation. Variety (C) is a factor that affects the traits alone and in combination with the conditions of "location" (A).

The interaction between the characters, after the established strong influence of the factors, presented by the principle component analysis, has a pronounced nonlinear character of variation. There are three significant main components (Table 5). The second and third components are related precisely to inadequate conditions and nonlinear variation ($PC_2 + PC_3 = 48.6\%$), which is more than that of $PC_1 = 35.6\%$.

Table 5. Eigenvalues by Principal Component Analysis

Component	F_1	F_2	F_3
Eigenvalue	3.20	2.61	1.77
Variability, %	35.60	28.97	19.71
Cumulative %	35.60	64.56	84.27

The characteristics that determine the grain yield are related to the trait (NPT) and its derivative number of grains per m^2 (NGm). The role of aboveground plant biomass (TBM) is also important. The arrangement of the vectors in the figure 1 shows that the most effective trait for yield is (NGm) that is effected by a greater extent of (NPT), than by (NGS). The other index – grain weight per spike (WGS) is determined significantly more strongly by the number of grains (NGS) compared to their size (TGW) (Figure 2). Ultimately, the number of productive tillering, expressed by the number of grains per m^2, is the most significant for the level of grain yield in this experiment. Similar results were reported by Tsenov et al., (2020[a], 2021[a]) in the analysis of various databases from several multi environment field trials.

The vectors of the individual traits have different values for the reliable three components of the analysis. With a predominant linear interaction, it is logical that the values of the components gradually decrease from PC_1 to PC_3. Grain yield has a similar "classic" behaviour according to the variation. The situation is similar with the characteristics – productive tillering (NPT) and number of grains per m^2 (NGm). They have the most significant effect on the size of grain yield, compared to others. The change in the traits of 1000 grain weight (TGW) and stem height (HOS) at which the third component is the highest is highly nonlinear, which creates an additional dispersion, which in turn reduces their correla-

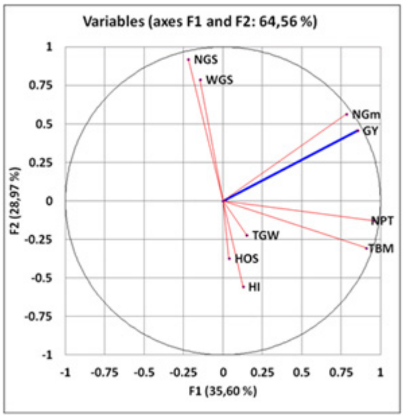

Fig. 1. Scatter plot of Principal Component Analysis of all characters

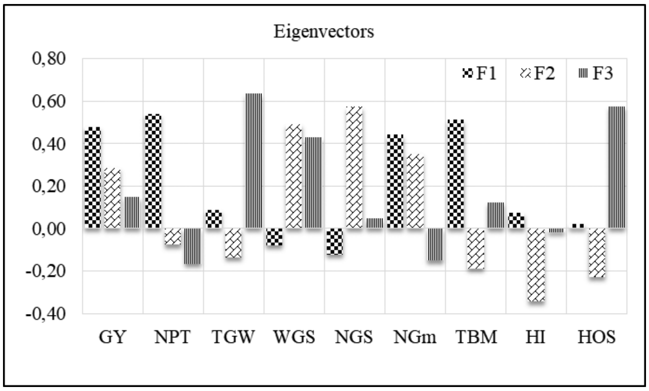

Fig. 2. Eigenvectors of traits for the three significant principal components

tions with the yield. In the case of the number of grains per spike (NGS) and the weight of the grain per spike (WGS), the second component of variation is most pronounced against the background of negative PC_1 values.

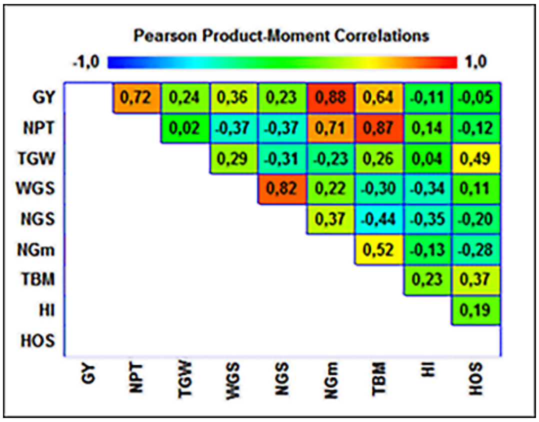

Fig. 3. Person correlations between the studied quantitative traits

Grain yield is most strongly influenced by Number of productive tillers per m², (NPT, r = 0.72), number of grains per m² (NGm, r = 0.88) and total aboveground biomass (TBM, r = 0.64). Grain weight per spike (WGS, r = 0.36) has a proven weak effect and positive, but the direct influence of the both main traits – (TGW, r = 0.24) and (NGS, r = 0.23) is weak one. The harvest index (HI) and stem height (HOS) assume that they do not affect grain yield. Although the number of grains (NGS) has no direct effect on yield, its effect on the most effective traits is evident (NGS-WGS, r = 0.82) (NGS-NGm, r = 0.37). In practice, the performance of exactly these two traits determines the yield – NPT and NGS, directly and through the values of (NGm), although there is a negative correlation between them (r = -0.37).

Significant variation caused by the interaction of the genotype with the environment was found in all studied traits. (σ^2gy). It leads to variation that is stronger than that of the genotype, in all traits, without exception. In the predominant part of the traits the genotype variant is larger than that of the error (σ^2g / σ^2e), which in turn shows the stability of the trait performance. Evidence of this statement are the high values of the coefficient of heritability (H^2), with small exceptions for the trait (HI), with values of $H^2 = 0.34$. In all other traits, the values of the coefficient (H^2) are high and show strong genetic control in the performance of their values. Accordingly, the values of the coefficient of variation of the genotype (VCg) are lower than those of the phenotype (VCp), which is logical, given the influence of conditions on each of the traits.

In the case of grain yield (GY), grain weight per spike (WGS), number of grains per spike (NGS) and harvest index (HI), the difference between the two parameters is more significant than for the other traits. This is reflected in their relatively lower inheritance rates in a broad sense (H^2).

The genetic progress (GA) of each trait is the parameter that is most important in the breeding of any crop. It shows

Table 6. Grand means (GM), components of variance (σ^2), broad-sense heritability (H2), genetic advances (GA, GAM) and coefficients of variation (VC) of each examined trait

Traits	GY,	NPT,	TGW,	WGS,	NGS,	NGm	TBM,	HI	HOS,
Measure	t ha^{-1}	№	g	No	g	№	t ha^{-1}		cm
Grand Mean	8.10	611	45.4	1.34	29.7	17906	5.08	0.40	83.4
σ^2_g	0.30	6608	45.30	0.028	12.97	4986473	1.012	0.000	149.734
σ^2_{gy}	0.30	3903	23.21	0.019	8.73	3294457	0.575	0.000	81.917
σ^2_e	0.24	3437	2.05	0.022	11.10	1691460	0.283	0.001	12.217
σ^2_g / σ^2_e	1.25	1.92	22.07	1.259	1.17	2.95	3.578	0.048	12.256
σ^2_{ph}	0.49	9055	53.72	0.041	19.58	6648446	1.298	0.001	181.112
H^2	0.79	0.85	0.92	0.82	0.81	0.87	0.88	0.34	0.91
GA	1.14	167	13.9	0.34	7.42	4600	2.1	0.017	25.2
GAM	14.04	27.4	30.6	25.6	25.0	25.7	40.8	4.3	30.2
VC_p	8.85	1208	93.0	2.580	56.15	32722	14.460	0.306	170.8
VC_g	6.99	1032	85.4	2.113	45.70	28338	12.769	0.105	155.3
Potential (GM ± GA)	9.22	779	32.0	0.99	37.08	22506	7.16	0.414	58
By breeding	9.24	779	32.0	1.19	37.08	28873	6.80	0.420	70.0
Difference, %	0.18	0.00	0.00	16.00	0.00	22.05	-5.23	1.51	16.86

how much a given trait could be changed, in its respective units, by a selection. This, of course, is only a potential possibility, for each of the traits according to its variation, inheritance and interaction with the environment. Grain yields of 114 kg / ha more than the current level could be obtained provided that the indicative number of productive tillering increased by 167 ears, as well as the number of grains by 7.42 grains. According to the established correlations, these two traits have a strong negative correlation with (TGW) (Figure 2). Therefore, in order to maintain the balance between each of these two pairs of traits (NPT-TGW) and (NGS-TGW), it is necessary to reduce the grain size by (GA = 13.9 g), according to the data in the table. A reduction by selection should also be made for the characteristics stem height (GA = 25.2 cm) and grain weight per spike (WGS, GA = 0.34 g). The harvest index and aboveground biomass should be increased according to the values in the table, by 2.1 and 0.017, respectively.

Discussion

The characteristics that are fundamental in the performance of grain yield: productive tillering (NPT), grain size (TGW) and number of grains per spike (NGS) vary, depending on the conditions, in a wide range (13-19%), which is essential for wheat. For all others, the variation is lower (9-13%). The performance of only the trait harvest index (3.9%) is stable, probably due to the fact that it is much less affected by the growing conditions. The expression of each of the traits is influenced by the “variety”, the “location” of study and the interaction between them. The “year” is a factor that influences the traits by interacting with the “location”, but not independently, as the main effect.

The expression of the characters has a linear and nonlinear character of variation under the GEI of the three factors influencing them. This means that some varieties react by the expression of their characteristics inadequately to the change of conditions caused by the interaction between the “location” and the “year” (A x B). The traits that demonstrate the highest positive correlation with yield have a similar change, expressed through the main components of the principal component analysis. The data of Desheva & Kyosev, (2015) show that the individual varieties react in a specific way through their traits in the course of yield formation, which is a prerequisite for their inclusion in the selection to pay attention to different groups of traits.

The data show that in order to make genetic progress in grain yield, the increase in several basic traits must be accompanied by a similar decrease in others. Only in this way would the relative balance between antagonistically performed traits such as couples of (NPT) – (NGS) and (NGS) – (TGW) be maintained and would ensure success by selection. There are few studies looking for a similar balance between the components of productivity, especially between the number of grains (NGS) and their size (TGW), which are considered highly competitive in their formation during the growing season (Bustos et al., 2020; Ferrante et al., 2017; Stoyanov, 2019; Calderini et al., 2020). On all three traits, the H^2 is high enough, despite the significant GEI, to apply an effective selection to them. When the breeding is focused on a selection on the three main traits (NGS, TGW, NPT) at the same time, the picture of the connections between them becomes more complicated. Therefore, the invisible biological balances between their values at the level of a single plant must be observed. The increase in productive tillering per m^2 must be accompanied by a decrease in grain size, with similar extent. If the number of grains per spike is increased according to the established regularities, this would reduce the weight of the grain per spike, but the value of the trait number of grains per m^2 will increase due to the simultaneous increase in (NPT) and (NGS). This trait is considered essential in the selection of productivity by many researchers in different parts of the world (Fischer & Rebetzke (2018; Bassi & Nachit (2019; González et al., (2019). This integral trait (NGm) is positively related to the magnitude of the total biomass (TBM), which is a prerequisite for effective selection without conflict between them. Correlations with the harvest index (HI) and stem height (HOS) are negative but weak as an effect. According to Reynolds et al., (2017) the harvest index is main criterion of breeding for productivity in optimal and stressful conditions and therefore it must be consistently taken into account with increasing (NGm). Stem height (HOS) can be reduced to increase the resistance to lodging, as well as the harvest index. This is the conclusion of a study by Beche et al., (2014), which traced the genetic progress of wheat grain production in Brazil over the past 70 years (1940-2009). The increase in yield annually was due to an increase in the harvest index, the number of grains per spike, the total biomass and a significant reduction in stem height.

The only trait to consider when increasing (NGm) is grain size (TGW), due to their strong negative correlation. The genetic progress that can be achieved in it is the highest compared to any of the other traits studied and can be very easily and quickly changed by selection. The reason it is genetically very stable, despite proven interactions with all factors of cultivation. Its magnitude changes inadequately to the change of conditions (the interaction with them is mainly of a nonlinear nature). This in turn is a prerequisite for changing its effect on other components of productivity. Combining the number of grains per spike (NGS) and weight of grain per spike (WGS) at the highest possible levels has long been a concern of breeding in wheat and other cereals. Recently, new facts have been established that show that it is somewhat possible to combine these two traits successfully, as it has been found that a number of genetic factors determining their magnitudes are on different chromosomes (Mangini et al., (2018; Muhammad et al., 2020).

Saleh et al., (2020) accept phenotypic correlations as a breeding criterion in breeding. They found completely similar correlations in rice, the use of which they considered to be the only correct way in the selection to increase the yield. In principle, this is the opinion of Gerema et al., (2020) from a study of durum wheat in Africa. They believe that by selecting specific traits that have positive correlations with yield, it can be increased in a short time and effectively by more than 20%.

The study here clearly shows the magnitude of the phenotypic correlations between the traits that effect grain yield and through which its continuous progress takes place. Their values and correlations between them have been studied against the background of a significant influence of the conditions in multi environment field experiments proven recently (Tsenov et al., 2020[a]; Tsenov et al., 2021[b]). In them, the traits, in addition to the natural conditions of the environment, were provoked by technological factors such as basic fertilization and nitrogen nutrition. The observed dispersion of variation in each trait is large enough in these experiments to assume that correlations between them nevertheless exist.

The magnitude and direction of change of each individual trait must be taken into account in order to make progress in grain yield. It would only be possible if a new biotype is built in which these results are accounted for and used correctly by the selection in future hybrid combinations. In addition to these patterns, it must provide a number of physiological properties and morphological parameters to help extend the period to ear emergence by a few days, which has a positive effect on the formation of high yields by more grains per unit area, even in the semi-arid climate of the country (Tsenov et al., 2020[b]). If this is applied in practice, the real increase in grain yield could reach plus 15-20%, compared to the current level of 10 tons per hectare. This is fully achievable after Donmez et al., (2001) reported a twofold increase in yield in newly created historically important wheat varieties, precisely through selective intervention on the traits number of grains per spike, number of grains per m^2, reduction in stem height and increasing the tolerance to lodging.

Conclusions

The traits associated with grain yield vary greatly as a result of the interaction of the genotype by location. This change of traits is very specific against the background of the others, having a complex linear and nonlinear character, according to the principle component analysis. The established correlations between the traits that make up the yield directly TGW, NGS and NPT show that if the balance between them is observed, it is quite possible for the yield to be increased progressively by selection. The most effective for this are the characters number of productive stems m^2, as well as the number of grains per m^2. The latter trait is positively related to the value of total biomass (TBM), which is a prerequisite for an effective selection without conflict between them. Their breeding increase, however, must be accompanied by a similar decrease in the 1000 grains weight.

References

Allard, R.W. (1999). Principles of plant breeding. Wiley, New York

Al-Otayk, S. M. (2019). Evaluation of agronomic traits and assessment of genetic variability in some popular wheat genotypes cultivated in Saudi Arabia. *Australian Journal of Crop Science 13(6),* 847-856. https://doi: 10.21475/ajcs.19.13.06.p1329

Bányai, J., Kiss, T., S. Gizaw, A., Mayer, M., Spitkó, T., Tóth, V., Kuti, C., Mészáros, K., Láng, L. Karsai I., & Vida, G. (2020). Identification of superior spring durum wheat genotypes under irrigated and rain-fed conditions. *Cereal Research Communications, 48(3)*, 355–364. https://doi.org/10.1007/s42976-020-00034-z

Bassi, F. M. & Nachit, M. M. (2019). Genetic Gain for Yield and Allelic Diversity over 35 Years of Durum Wheat Breeding at ICARDA, *Crop Breeding, Genetics & Genomics 1*, e190004, https://doi.org/10.20900/cbgg20190004

Bastos, L. M., Carciochi, W., Lollato, R. P., Jaenisch, B. R., Rezende, C. R., Schwalbert, R., P. Prasad, V., Zhang, G., Fritz, A. K., Foster, C., Wright, Y., Young, S., Bradley, P. & Ciampitti, I. A. (2020). Winter wheat yield response to plant density as a function of yield environment and tillering potential: a review and field studies. *Frontiers in Plant Science 1,* 54. https://doi.org/10.3389/fpls.2020.00054

Beche, E., Benin, G., da Silva, C. L., Munaro, L. B. and Marchese. J. A. (2014). Genetic gain in yield and changes associated with physiological traits in Brazilian wheat during the 20th century. *European Journal of Agronomy, 61*, 49–59. https://doi.org/10.1016/j.eja.2014.08.005

Burton, G. W. and De vane, E. H. (1953). Estimating heritability in Tall Fescue (*Festuca arundinacea*) from replicated clonal material. *Agronomy Journal, 45*, 487-488, https://doi.org/10.2134/agronj1953.00021962004500100005x

Calderini, D.F., Castillo, F.M., Arenas-M, A., Molero, G., Reynolds, M.P., Craze, M., Bowden, S., Milner, M.J., Wallington, E.J., Dowle, A., Gomez, L.D. and McQueen-Mason, S.J.

(2021), Overcoming the trade-off between grain weight and number in wheat by the ectopic expression of expansin in developing seeds leads to increased yield potential. *New Phytol.* https://doi.org/10.1111/nph.17048

Chairi, F., Vergara-Diaz, O., Vatter, T., Aparicio, N., Nieto-Taladriz, M. T., Kefauver, S. Bort, C. J., Serret, M. D. and Araus, J. L. (2018). Post-green revolution genetic advance in durum wheat: The case of Spain. *Field Crops Research 228*, 158-169, https://doi.org/10.1016/j.fcr.2018.09.003

Desheva, G. (2016). Correlation and path-coefficient analysis of quantitative characters in winter bread wheat varieties. *Trakia Journal of Sciences, 1,* 24-29, http://www.uni-sz.bg/

Desheva, G. & Kyosev, B. (2015). Genetic diversity assessment of common winter wheat (*Triticum aestivum* L.) genotypes. *Emirates Journal of Food and Agriculture*, *27*(3), 283. https://doi.org/10.9755/ejfa.v27i3.19799

Devesh, P., Moitra P.K., , Shukla, R.S., Shukla, S.S., Pandey, S. & Arya, G. (2018). Analysis of Variability, Heritability and Genetic Advance of Yield, its Components and Quality Traits in Wheat, International Journal of Agriculture, *Environment and Biotechnology,* Special Issue: 855-859.

Djuric, N., Prodanovic, S., Brankovic, G., Djekic, V., Cvijanovic, G., Zilic, S., Dragicevic, V., Zecevic, V. & Dozet, G. (2018). Correlation-regression analysis of morphological-production traits of wheat varieties, *Romanian Biotechnological Letters, 23(2)*, 13457-13465. http://rik.mrizp.rs/handle/123456789/729

Donmez, E., Sears, R. G., Shroyer, J. P. & Paulsen, G. M. (2001). Genetic gain in yield attributes of winter wheat in the great plains. *Crop Science, 41(5)*, 1412–1419. https://doi.org/10.2135/cropsci2001.4151412xv

Dyulgerov, N. & Dyulgerova, B. (2020). Heritability and genetic advance of yield and yield related traits in winter feed barley varieties, *Trakia Journal of Sciences, 18(S_1),* 40-46, http://www.uni-sz.bg

Ferrante, A., Cartelle, J., Savin, R. & Slafer, G. A. (2017). Yield determination, interplay between major components and yield stability in a traditional and a contemporary wheat across a wide range of environments. *Field Crops Research 203,* 114– 127, https://doi.org/10.1016/j.fcr.2016.12.028

Ferreira, C. I., Peixoto, M.A., Santana, P. C. E., Silva, A. R., Sales, S., Resende, M.D.V., Jefferson, F. N. P,. Edesio, F. R. & Bhering, L. L. (2020). Multiple-trait, random regression, and compound symmetry models for analyzing multi-environment trials in maize breeding. *Plos One 15(11),* e0242705, https://doi.org/10.1371/journal.pone.0242705

Fischer, R. A. & Rebetzke, G.J. (2018). Indirect selection for potential yield in early-generation, spaced plantings of wheat and other small-grain cereals: a review. *Crop and Pasture Science, 69(5),* 439, https://doi.org/10.1071/cp17409

Gerard, G. S., Crespo-Herrera, L. A., Crossa, J., Mondal, S., Velu, G., Juliana, P., Huerta-Espino, J., Vargas, M., M. Rhandawa, S., Bhavani, S., Braun H. & Singh, R. P. (2020). Grain yield genetic gains and changes in physiological related traits for CIMMYT's High Rainfall Wheat Screening Nursery tested across international environments. *Field Crops Research, 249*, 107742, https://doi.org/10.1016/j.fcr.2020.107742

Gerema, G. (2020). Evaluation of durum wheat (*Triticum turgidum*) genotypes for genetic variability, heritability, genetic advance and correlation studies. *Journal of Agriculture and Natural Resources, 3(2),* 150–159. https://doi.org/10.3126/janr.v3i2.32497

González, F. G., Capella, M., Ribichich, K. F., Curín, F., J. Giacomelli, I., Ayala, F., Watson, G., Otegui M. E. & Chan, R. L. (2019). Field-grown transgenic wheat expressing the sunflower gene HaHB4 significantly outyields the wild type. *Journal of Experimental Botany, 70(5),* 1669–1681. https://doi.org/10.1093/jxb/erz037

Gubatov, T., Yanchev, I. & Tsenov, N. (2016). Effect of the environments on the productivity-related characters in common winter wheat. *Bulgarian Journal of Agricultural Science, 22(6),* 927-935. https://journal.agrojournal.org/page/download.php?articleID=278

Herrera, J. M., L. Mascher, F., Hiltbrunner, J., Fossati, D., Brabant, C., Charles R. & Pellet, D. (2020). Lessons from 20 years of studies of wheat genotypes in multiple environments and under contrasting production systems. *Frontiers in Plant Science, 10*. https://doi.org/10.3389/fpls.2019.01745

Ivanova, A. & Tsenov, N. (2011). Winter wheat productivity under favourable and drought environments, I An overall effect. *Bulgarian Journal of Agricultural Science 176,* 777-782. http://agrojournal.org/

Jaiswal, R., Gaur, S. C., Jaiswal, S. K. & Kumar, A. (2020). An Estimate of Variability, Heritability and Genetic Advance for Grain Yield and Yield Components in Bread Wheat (*Triticum aestivum* L.). *Current Journal of Applied Science and Technology, 39(12)*, 1-6. https://doi.org/10.9734/cjast/2020/v39i1230657

Johnson, H. W., Robinson, H. F. & Comstock, R. E. (1955). Estimates of genetic and environmental variability in soybeans. *Agronomy Journal 47,* 314-318. https://doi.org/10.2134/agronj1955.00021962004700070009x

Kazandjiev, V., Georgieva, V., Joleva, D., Tsenov, N., Roumenina, E., Filchev, L., Dimitrov, P. & Jelev, G. (2011). Climate variability and change and conditions for Winter wheat production in northeast Bulgaria, *Field Crop Studies 7(2),* 195-220. (Bg)

Keser, M., Gummadov, N., Akin, B., Belen, S., Mert, Z., Taner, S., Topal, A., Yazar, S., Morgounov, A., Sharma, R. C. & Ozdemir, F. (2017). Genetic gains in wheat in Turkey: Winter wheat for dryland conditions. *The Crop Journal, 5(6),* 533–540. https://doi.org/10.1016/j.cj.2017.04.004

Lichthardt, C., Chen, T-W. S. & H. Stützel, (2020). Co-evolution of sink and source in the recent breeding history of winter wheat in Germany. *Frontiers in Plant Science 10,* 1771. https://doi.org/10.3389/fpls.2019.01771

Mandea, V., P. Mustățea, C-M. Marinciu, G. Șerban**, C. Meluca, G. Păunescu, S-F. Isticioaia, C. Dragomir, G. Bunta, Filiche, E. Voinea, L., Lobonțiu, I., Domokos, Z., Voica, M., Ittu G. & Săulescu, N. N.** (2019). Yield components compensation in winter wheat (*Triticum aestivum* L.) is cultivar dependent. *Romanian Agricultural Research, 36,* 1-7.

Mangini, G., Gadaleta, A., Colasuonno, P., Marcotuli, I., Signorile, A. M., Simeone, R., De Vita, P., Mastrangelo, Laidò, A. M., Pecchioni, G. N. & Blanco, A. (2018). Genetic dissection of the relationships between grain yield components by genome-wide association mapping in a collection of tetraploid wheats. *Plos ONE, 13(1),* e0190162. https://doi.org/10.1371/journal.pone.0190162

Mathew, I., Shimelis, H., Mwadzingeni, L., Zengeni, R., Mutema, M. & Chaplot, V. (2018). Variance components and heritability of traits related to root: shoot biomass allocation and drought tolerance in wheat. *Euphytica, 214(12),* 225, https://doi.org/10.1007/s10681-018-2302-4

Mihova, G, Baychev, V., Chamurliyski, P. & Stoyanov, H. (2017). Yield formation in winter cereals under contrasting conditions of the environment, In: *Proceedings of 2nd International Balkan Agriculture Congress,* Namık Kemal University, Faculty of Agriculture, Tekirdağ, Turkey. pp. 351-358

Muhammad, A., Hu, W., Li, Z., Li, J., Xie, G., Wang J., & Wang, L. (2020). Appraising the genetic architecture of kernel traits in hexaploid wheat using GWAS. *International Journal of Molecular Sciences, 21(16)*, 5649. https://doi.org/10.3390/ijms21165649

Pais, I. P., Fernando, H., Reboredo, J., Ramalho, C., Pessoa, M. F., Lidon, F. C. & Silva, M. M. (2020). Potential impacts of climate change on agriculture – A review. *Emirates Journal of Food and Agriculture 32(6)*, 397–407. https://doi.org/10.9755/ejfa.2020.v32.i6.2111

Passioura, J.B. (2020). Translational research in agriculture. Can we do it better? Farrer Review. *Crop & Pasture Science 71,* 517–528, https://doi.org/10.1071/CP20066

Quintero, A., Molero, G., Reynolds, M. P. & Calderini, D. F. (2018). Trade-off between grain weight and grain number in wheat depends on GxE interaction: A case study of an elite CIMMYT panel (CIMCOG). *European Journal of Agronomy, 92,* 17–29. https://doi.org/10.2135/cropsci1998.0011183X003800050015x

Rajičić, V., Terzić, D., Perišić, V., Dugalić, M., Madić, M., Dugalić, G. & Ljubičić, N. (2020). Impact of long term fertilization on yield in wheat grown on soil type vertisol. *Agriculture & Forestry, 663,* 127-138, http://dx.doi.org/10.17707/AgricultForest.66.3.11

Raykov, G, Chamurliyski, P. Doneva,, S., Penchev, E. and Tsenov, N. (2016). Productivity performance of bread winter wheat genotypes of local and foreign origin. *Agricultural Science and Technology 8(4)*, 276 – 279. http://dx.doi.org/10.15547/ast.2016.04.052

Reynolds, M. P., Sonder, K., Payne, T., Pask, A. J. D., Sukumaran, S., Terrile, I. I., Fan, Zh., Singh, R. P., Hoppitt, W. J. E., Molero, G., Braun, H-J., N. Barma, C. D., Novoselovic, D., E Galal,. Kumar, G., U., Biradar, S., Panchabhai, K., Hagras, A., Singh, G. P., Saint Pierre, C., Gonzalez, F. G., Hakim, A., Maghraby, M., Sai Prasad, S. V., Balasubramaniam, A., Dastfal, M., Nikzad, A. R., Mehraban, A., Figueroa-Lopez, P., Borbo-Gracia, A., Pandey, D., Hussain, M., Sohu, V. S., He, Zh., Gad, Kh. I. M., Mohamed, M. M., Naik, R., A. Morad, A., Kalappanavar, I. K., Chatrath, R., Mavi, G. S., Jalal-Kamali M. R., Tabib-Ghaffari, S. M., Moghaddam, H. A., Solıs-Moya, E., Ireta-Moreno, J., Torres A., Imtiaz, M., M. Mujahid, Y., Mustatea, P., Ud-Din, R., Sharma, I., Mishra V. K.,, Khodarahmi, M., Jafarby, J., Ghojogh, H., M. Camacho-Casas, A., J. Alvarado-Padilla, I., Quiche, Y. N., Rehman, M. U., Qamar, M., Ahmad, G., von Well, E., Hussein, Ab. H. A., Elamein, H. M. M., Khan, A. J., Ncala M., I. S. Tahir, A., Manes, Y., Joshi, A. K., Upadhyay, Sh. R., Hussain, M., Kundi, M., Sial, M. A. de Groot, S. & Idris, A. A. M. (2017). Strategic crossing of biomass and harvest index—source and sink—achieves genetic gains in wheat, *Euphytica 213*, 257, https://doi.org/10.1007/s10681-017-2040-z

Sadras, V. O. & Lawson, C. (2011). Genetic gain in yield and associated changes in phenotype, trait plasticity and competitive ability of South Australian wheat varieties released between 1958 and 2007. *Crop and Pasture Science, 62(7)*, 533. https://doi.org/10.1071/cp11060

Saleh, M.M., Salem, K. F. M. and Elabd, A.B. (2020). Definition of selection criterion using correlation and path coefficient analysis in rice (*Oryza sativa* L.) genotypes. *Bull Natl Res Cent 44,* 143 https://doi.org/10.1186/s42269-020-00403-y

Singh, K. P., Singh, V., Singh, T., Tripathi, R. M., Gupta, P., Chauhan, M. P. & Sharma, G. (2020). Analysis of variability, heritability and genetic advance of yield, its components and quality traits in wheat. *Journal of Pharmacognosy and Phytochemistry 9(6),* 380-383.

Slafer, G. A., Savin, R. & Sandras, V. (2014). Coarse and fine regulation of wheat yield components in response to genotype and environment, *Field Crop Research, 157,* 71-83, https://doi.org/10.1016/j.fcr.2013.12.004

Spiridonov, V. & Valcheva, R. (2017). Stability of climate change at a given interval in a 30-year future period. Example for the territory of Bulgaria. *Comptes rendus de l'Acad´emie Bulgare des Sciences 70(3),* 405-410

Stoyanov, H. (2019). Correlation between the Spike Parameters of Bulgarian Triticale Cultivars under Contrasting Conditions of the Environment, *Journal of Mountain Agriculture on the Balkans, 22 (6),* 53-73, http://www.rimsa.eu/images/Genetics_Breeding_and_Seed_Production_vol_22-6_part_2_2019.pdf

Taneva, K., Bozhanova, V. & Petrova, I. (2019). Variability, heritability and genetic advance of some grain quality traits and grain yield in durum wheat genotypes, *Bulgarian Journal of Agricultural Science, 25(2),* 288-295

Tsenov, N., Gubatov, T. & I. Yanchev, (2019). Estimation the productivity of new wheat varieties in multi environmental trails, In: Radulov, I and Poposku, I. (eds.), *Multidisciplinary Conference on Sustainable Development:* Proceedings of Filodiritto Editore, Banat's University of Agricultural Sciences and Veterinary Medicine, Timisoara, Romania, pp. 1043-1053.

Tsenov, N., Gubatov, T. & Yanchev, I. (2020[a]). Correlations between grain yield and yield related traits in winter wheat under multi environmental traits, *Agricultural Science and Technology 12(4),* 295-300, DOI: 10.15547/ast.2020.04.047.

Tsenov, N., Gubatov, T. and Yanchev, I. (2020[b]). Effect of date of heading on variation of basic components of productivity of winter wheat. *Journal of Central European Agriculture, 21(4),* 751–762. https://doi.org/https://doi.org/10.5513/JCEA01/21.4.2819

Tsenov, N., Gubatov, T. and Yanchev, I. (2021[a]). Correlations between quantitative traits of winter common wheat – breeding tool for increasing grain yield. *Agricultural Science and Tech-*

nology 13: accepted

Tsenov, N., Nankova, M., Gubatov, T. (2021[b]). Analysis of productivity related traits of common wheat (*Triticum aestivum* L) when using organic fertilizers. *Bulgarian Journal of Crop Science, 58*: accepted

Wu, W., Li, C., Ma, B., Shah, F., Liu, Y. and Liao, Y. (2013). Genetic progress in wheat yield and associated traits in China since 1945 and future prospects. *Euphytica 196(2)*, 155–168. https://doi.org/10.1007/s10681-013-1033-9

Xiong, W., Reynolds, M., Crossa, J., Payne, T., Schulthess, U., Sonder, K., Addimando, N., Singh, R., Ammar, K. & Gerard, B. (2020). Climate change has increased genotype-environment interactions in wheat breeding, *Nature Research*, https://doi.org/10.21203/rs.3.rs-69475/v1

Yacoubi, I., Nigro, D., Sayar, R., Masmoudi, K., Seo, Y. W., Brini, F., Giove, S. L., Mangini, G., Giancaspro, A., Marcotuli, I., Colasuonno, P. & Gadaleta, A. (2020). New insight into the North-African durum wheat biodiversity: phenotypic variations for adaptive and agronomic traits. *Genetic Resources and Crop Evolution 67,* 445–455, https://doi.org/10.1007/s10722-019-00807-4

Yang, J., Shi, Y., Shi, H., Wang, Y., Guan, W., Yan, X., Wang, S. & Sun, D. (2019). Screening of wheat *Triticum aestivum* L. varieties with high nitrogen use efficiency under rainfed and irrigated conditions, *Turkish Journal of Field Crops, 242*, 121-131. https://doi.org/10.17557/tjfc.615174

Zadoks, J. C., Chang, T. T. & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Research, 14(6),* 415–421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x

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