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Correlation and path analyses of the performance elements in spring barley cultivars

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ABSTRACT

The article presents the results of studying the influence of quantitative traits on the barley plant performance. Thirty typical plants were selected for each of the 28 genotypes spring two-row barley cultivars and their height, productive tillering capacity, spike length, number and weight of kernels from the main spike, 1000-kernel weight, and performance were measured. As a result, we found significant positive correlations between the performance and productive tillering capacity and weight of kernels from the main spike. Path analysis showed that the weight of kernels from the main spike had the greatest direct effect on the plant performance (0.61). We have established that the paths "spike length – weight of kernels from the main spike – performance" and "kernel number per spike – weight of kernels from the main spike – performance" are of the greatest importance in select for the barley plant performance.

Keywords: *Hordeum vulgare* L., path coefficient, direct and indirect effects, correlation between performance traits

INTRODUCTION

Selection by any trait changes the organism as a whole, as no trait can be changed in isolation from others. Correlation is one of the parameters characterizing relationships between traits. Therefore, correlation analysis plays an important role in breeding programs. However, results of many studies indicate that correlation coefficients depend on the genotype and growing conditions, therefore, their use in breeding may be effective if the absolute value of the correlation coefficient is significant and sufficiently high. Selection by 1 trait can lead to deterioration of other traits. In addition, negative correlations, which are caused by competition for macronutrients between two traits determining performance, are frequent. This competing effect often remains hidden when pair correlations are assessed, and here one should also take into account indirect effects of other parameters. For this reason, to evaluate the yield capacity or performance, pathway analysis, along with correlation analysis, is used. Path analysis enables not only determining the parameter that has the greatest influence on the yield variability, but can also evaluating the strength and direction of causalities with traits for a given accession (Wright, 1934). However, there is another opinion – that path analysis does not prove causality in a model, it is an extension of the regression model used to verify the corresponding correlation. Significance of the path coefficient is identical to that of the regression coefficient (Bryman and Cramer, 1990), i.e. it is a standardized regression coefficient of an independent trait versus a dependent function. Path analysis provides clues as to whether a particular trait is important for the yield capacity (or performance), or whether it should be left unaddressed when breeding material is selected. In this way, path analysis allows evaluation of direct and indirect effects of certain features, therefore, it is widely used in breeding to select components for crossing.

When the yield variability is determined, the biological yield, yield index, number of spikes/m^2, 1000-kernel weight, and number of kernels per spike are most often investigated as structural elements. In some studies, the effects of the plant height, spike length, kernel weight per spike, straw weight, productive tillering capacity, vegetation length, resistance to lodging, and awn length on the performance are also taken into account. Here, the spike length, weight and number of kernels per spike, 1000-kernel weight, and productive tillering capacity are structural elements of the barley plant performance. Thus, performance is one of the main elements that determine the yield capacity. This should be taken into account when one selects starting material for breeding.

Since the effectiveness of selection in breeding depends on mutual influence of traits, a lot of researchers study plant performance and yield capacity by correlation and path analyses. In studies on barley, the most common positive significant correlations are found between the yield capacity and the kernel number per spike, 1000-kernel weight, the number of spikes/m^2, yield index and biological yield (Budacli Carpici and Celik, 2012; Setotaw et al., 2014; Mohtashami, 2015; Arpali, & Yagmur, 2015; Bocianowski et al., 2016; Tawfiq et al., 2016; Mirosavljević et al., 2016; Shrimali et al., 2017; Amardeep et al., 2017; Marzougui and Chargui, 2018; Đekić et al., 2019; Fatemi et al., 2019; Madić et al., 2019; Matin et al., 2019; Tanaka and Nakano, 2019; Rajičić et al., 2021). There is also evidence of negative correlations between the yield capacity and 1000-kernel weight (Budacli Carpici and Celik, 2012; Gebru et al., 2018), kernel number per spike (Marzougui and Chargui, 2018), and plant height (Gebru et al., 2018).

As to path analysis, the direct positive effects of the kernel and spikelet numbers per spike, yield index, the spike number/m^2, productive tillering capacity, biological yield, and 1000-kernel weight (Budacli Carpici and Celik, 2012; Setotaw et al., 2014; Arpali and Yagmur, 2015; Mohtashami, 2015; Bocianowski et al., 2016; Dimitrova-Doneva et al., 2016; Tawfiq et al., 2016; Kompanets et al., 2016; Shrimali et al., 2017; Amardeep et al., 2017; Demydov et al., 2017; Malik et al., 2018; Fatemi et al., 2019; Sandhya et al., 2019), on the barley yield capacity and performance are most often observed. Analysis of the yield capacity and performance fulfillment paths revealed that the direct effect of biological yield is enhanced by the indirect effects of the 1000-kernel weight, number of spikes/m^2, plant height, the kernel weight per spike and spike length (Tofiq et al., 2015; Tawfiq et al., 2016; Kohan et al., 2016; Sandhya et al., 2019). Some researchers noted the indirect positive effects of the spike length via the kernel number per spike (Bocianowski et al., 2016), productive tillering capacity and spike length (Dimitrova-Doneva et al., 2016) on the performance.

There is also evidence of the direct negative effects of the 1000-kernel weight and plant height (Gebru et al., 2018; Malik et al., 2018) on the barley yield capacity and performance. Thus, some results have shown discrepant information, for example, positive or negative correlations between the performance and plant height, significant or insignificant correlations between the yield capacity and 1000-kernel weight, direct or indirect effects of the spike length, number of spikes/m^2, direct positive or negative effects of the growing period length, etc. Hence, studies of relationship between the barley yield capacity and plant performance and other quantitative traits remain essential.

MATERIALS AND METHODS

Experimental site and treatment details

The experiments were carried out at the Plant Production Institute named after V.Ya. Yuriev of NAAS of Ukraine (Kharkiv) in 2018-2021. The experimental plot area was 10 m^2; the plot arrangement was randomized, in 4 replications. Twenty-eight spring two-row barley cultivars, including 16 chaffy cultivars (Vzirets, Parnas, Incliuzyv, Komandor, Sviatohor, Donetskyi 15, Donetskyi 14, Reserv, Stepovyk, Ratnyk, Abalak, Sofiara, Shakira, Pasadena, Prestige, and Novosadsky 294) and 12 naked cultivars (Golozyornyy 1, Omskiy Golozyornyy 1, Oskar, Mayskiy, Akhilles, Hatunok, Mebere, CDC Candle, CDC Alamo, Millhouse, Merlin, and Richard), were taken as the test material. Thirty typical plants of each cultivar were selected for measurements. We determined the plant performance and other quantitative parameters: plant height, spike length, productive tillering capacity, kernel number per spike, kernel weight per spike, and 1000-kernel weight (Table 1).

Table 1. Mean values of the breeding traits in the spring barley cultivars (2018–2021)

Variety	Plant height, cm	Productive tillering capacity,	Spike length, cm	Kernel number per spike,	Kernel weight per spike, g	1000-kernel weight, g	Plant performance, g
Vzirets	62	2.6	8.2	23.5	1.32	45.0	3.33
Parnas	64	2.5	8.0	23.8	1.36	48.4	2.62
Incliuzyv	69	2.5	8.1	23.3	1.36	50.0	2.78
Komandor	67	2.7	8.1	23.5	1.24	46.1	2.71
Sviatohor	62	2.8	7.4	23.0	1.26	45.3	2.62
Donetskyi 15	63	2.7	7.2	19.8	1.3	52.9	2.49
Donetskyi 14	66	2.5	6.8	18.0	1.17	49.8	2.46
Reserv	68	2.7	7.0	18.8	1.26	50.4	3.06
Stepovyk	64	3.0	6.4	18.5	1.17	49.3	2.75
Ratnyk	67	2.9	7.9	22.5	1.40	48.6	3.00
Abalak	68	2.0	7.3	23.8	1.3	46.1	2.53
Sofiara	59	2.5	7.9	23.3	1.31	49.1	2.67
Shakira	57	2.2	7.2	21.8	1.23	49.1	2.4
Pasadena	61	2.7	7.7	23.8	1.27	43.8	2.73
Prestige	58	2.4	8.1	25.5	1.45	48.1	2.65
Novosadsky 294	67	2.6	8.7	24.8	1.36	47.8	3.07
Golozyornyy 1	70	2.6	8.5	22.8	1.41	47.8	3.39
Omskiy Golozyornyy 1	69	2.8	8.1	24.0	1.4	46.8	3.05
Oskar	70	2.4	8.8	27.0	1.36	45.5	2.5
Mayskiy	73	2.3	8.4	24.8	1.36	45.8	2.47
Akhilles	74	2.3	8.2	22.0	1.25	46.1	2.37
Hatunok	74	2.5	9.2	24.5	1.42	43.1	2.7
Mebere	67	2.6	8.3	25.0	1.32	41.2	2.64
CDC Candle	76	2.3	8.4	24.8	1.26	39.8	2.44
CDC Alamo	69	2.8	9.5	27.8	1.45	45.9	2.99
Millhouse	73	2.9	9.7	30.0	1.41	43.6	3.14
Merlin	58	2.7	7.9	22.3	1.12	40.9	2.42
Richard	71	3.1	8.6	25.0	1.36	41.1	3.37

Statistical analysis

Significance of differences was assessed by ANOVA; *post hoc* comparison – by Homogenous groups (Fisher LSD) in STATISTICA 10. The pair correlation coefficients (r) between the quantitative traits were calculated in STATISTICA 10; path analysis was conducted by the Wright's method (1934).

Dependence of the barley plant performance on other traits can be expressed through the multiple regression equation: (1)

$$Y = Y_c + b_1(X_1 - X_{1c}) + b_2(X_2 - X_{2c}) + \ldots + b_n(X_n - X_{nc}) + E \quad (1)$$

where

Y – plant performance, g;

Y_c – mean plant performance, g;

$X_1 \ldots X_n$ – values of the 1^{st} – n^{th} traits;

$X_{1c} \ldots X_{nc}$ – mean values of the 1^{st} – n^{th} traits;

$b_1 \ldots b_n$ – regression coefficients perpeciї $X_1 \ldots X_n$ vs. Y;

E – the total error of the equation that includes the error of the experiment.

Let us designate:

$$y = Y - Y_c;\ x_1 = X_1 - X_{1c};\ x_2 = X_2 - X_{2c};\ \ldots;\ x_n = X_n - X_{nc}$$

Then we normalize the variables, that is, divide their deviations from the means by their standard deviations:

$$x_i = (X_i - X_{ic}) / \sigma_i,$$

where

x_i – normalized value of the i^{th} trait;

X_i – observed value of the i^{th} trait;

X_{ic} – mean value of the i^{th} trait;

σ_i – standard deviation of the i^{th} trait;

$i = 1, 2, \ldots, n$

n – the total number of traits that significantly influence the performance.

Then equation (1) takes the form (2):

$$y/\sigma_y = b_1(\sigma_1/\sigma_y)(x_1/\sigma_1)+b_2(\sigma_2/\sigma_y)(x_2/\sigma_2)+\ldots+b_n(\sigma_n/\sigma_y)(x_n/\sigma_n) + \sigma_e/\sigma_y)(E/\sigma_e) \quad (2)$$

Let us designate: $P_i = b_i\ (\sigma_i / \sigma_y)$. P_i is called the coefficient of the path of a trait xi to a dependable variable ***y*** (in our case it is the plant performance).

To compute S. Wright's path coefficients, let us compose the following set of ***n*** linear equations with ***n*** unknown variables:

$$\sum_{j=1}^{n} P_i r_{ij} = r_{yi} \quad (3)$$

where

P_j – coefficient of the path from the j^{th} trait to the y^{th} trait;

r_{ij} – coefficient of correlation between the i^{th} trait and the the j^{th} trait;

$i = 1, 2, \ldots \boldsymbol{n}$.

Thus, S. Wright's path coefficient is the standardized regression coefficient of an independent trait versus a dependent function. In contrast to the correlation coefficient, the path coefficient is a vector value.

RESULTS AND DISCUSSION

To determine the path coefficients, we calculate the pair correlation coefficients for the quantitative traits listed in Table 1. We calculated the pair correlation coefficients (r) between the performance and other quantitative morphological traits of the barley cultivars (Table 2).

Correlation analysis demonstrated that the barley plants performance was most closely correlated with the productive tillering capacity and the weight of kernels from the main spike, slightly weaker, however significantly, with the spike length, kernel number per spike and plant height. The only insignificant correlation was between the performance and 1000-kernel weight.

The graph illustrating the correlations between the performance and other quantitative morphological traits shows the correlation cluster "performance – spike length – kernel number per spike – kernel weight per spike", which consists of separate clusters "performance – spike length – kernel number per spike", "performance – kernel number per spike – kernel weight per spike" and "spike length – kernel number per spike – kernel weight per spike" (Figure 1).

Table 2. Pair correlation coefficients between quantitative traits in the spring barley cultivars

№ of trait	Plant height	Productive tillering capacity	Spike length	Kernel number per spike	Kernel weight per spike	1000-kernel weight	Plant performance
	1	2	3	4	5	6	7
1	**1.00**	0.01	0.53*	0.33*	0.34*	-0.32*	0.18*
2	–	**1.00**	0.12	0.03	0.08	-0.09	0.60*
3	–	–	**1.00**	0.88*	0.69*	-0.51*	0.35*
4	–	–	–	**1.00**	0.67*	-0.54*	0.22*
5	–	–	–	–	**1.00**	0.01	0.49*
6	–	–	–	–	–	**1.00**	-0.03

Note. * – correlation coefficients are significant at the significance level P = 0.05

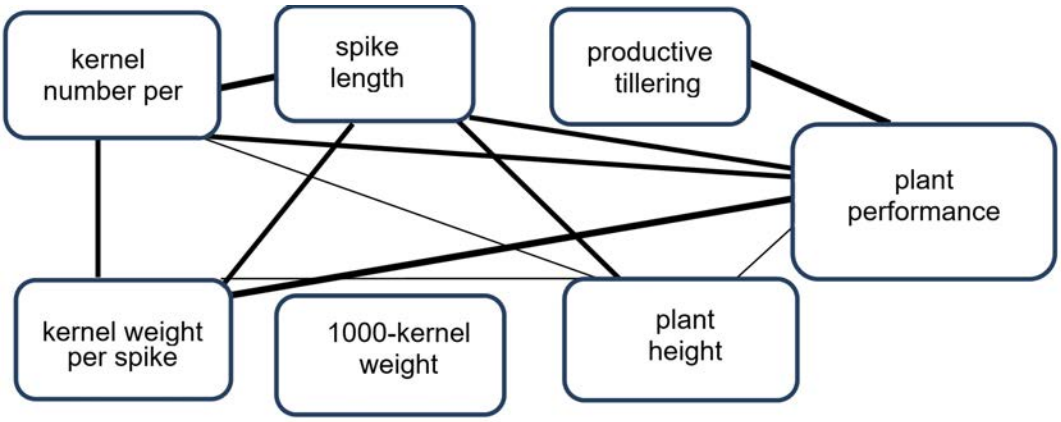

Figure 1. Significant positive correlations between the performance and other quantitative traits (the line thickness indicates relationship closeness)

Nevertheless, relationships between plant quantitative characteristics seem illogical, for example, significant correlation between the performance and plant height, or insignificant correlation between the performance and 1000-kernel weight. This assumes influence of some other (third) traits, and in order to evaluate it, we conducted path analysis.

By substituting the values of the correlation coefficients, we obtain a set of 6 linear equations with 6 unknown variables P_i (i = 1, 2, 3, 4, 5, 6). This equation set was solved by Bryman and Cramer's method (1990).

After decomposing the correlation between the performance and each of its components into the direct effect of one trait and the indirect effects of the others, we obtain a matrix of the path coefficients and the effect of each trait on the performance of the spring barley cultivars (Table 3).

Analysis showed that the weight of kernels from the main spike had the greatest direct effect on the plant performance (0.61), but this effect was offset by the negative effect of the kernel number per spike. The productive tillering capacity (0.52) also had a significant direct effect on the performance, without any significant indirect effects.

The spike length significantly affected the performance, and the direct positive effect was 0.19. This effect was augmented by the strong side positive effect of the weight of kernels from the main spike (0.42) and attenuated by the negative effect of the kernel number per spike (-0.38). As a result, the performance significantly correlated with the spike length (0.35).

The significant negative direct effect of the kernel number per spike (-0.44) on the performance productivity was noted, however, this effect was offset by the significant side positive effects of the weight of kernels from the main spike (0.41) and the spike length (0.17). As a result, the performance significantly correlated with the kernel number per spike (0.22).

Using graphic images of path analysis results, one can determine the weight (significance) of each path, taking into account indirect effects (Figure 2). This is achieved via the path multiplication rule. It was found that in selection for barley performance the paths “spike length – weight of kernels from the main spike – performance” and “kernel number per spike – weight of kernels from the main spike – performance” were of the greatest importance. The paths "1000-kernel weight – kernel weight per spike – productivity" and "kernel weight per spike – kernel number per spike – performance" were the second most important. These paths generally coincided with the correlation clusters identified. However, only path analysis demonstrated the significant indirect effect of the 1000-kernel weight on the performance.

The path significance can also be confirmed by regression analysis, which showed that a gain in the weight of kernels from the main spike by 1 g led increased the plant performance on average by 2.19 g; in the productive tillering capacity by 1 shoot – by 0.67 g; in the spike length by 1 cm – by 0.08 g. At the same time, when the kernel number was higher than the optimum by 1 kernel, the plant performance decreased on average by 0.05 g.

Thus, correlation, path and regression analyses of the mutual influence of the quantitative traits in barley showed that the performance closely correlated with the productive tillering capacity, kernel number and weight per spike and spike length. As path analysis demonstrated, the productive tillering capacity, weight of kernels from the main spike, and spike length had the direct positive effects on the performance. The kernel number per spike and 1000-kernel weight indirectly, through the kernel weight per spike, affected the performance.

Correlations between the performance and its structural elements were investigated by several researchers. Thus, studies showed significant positive correlations between the performance and productive tillering capacity, kernel grain weight per spike, 1000-kernel weight, biological yield, and plant height, with a direct positive effect on performance.

Table 3. Path analysis of the plant performance in the spring barley cultivars

Nº of trait	Trait	Plant height	Productive tillering capacity	Spike length	Kernel number per spike	Kernel weight per spike	1000-kernel weight	Unaccounted factors (residuals)	Plant performance
		X1	*X2*	*X3*	*X4*	*X5*	*X6*		*Y*
X1	Plant height	**-0.03**	0.01	0.1	-0.1	0.21	0.04	-0.04	0.18
X2	Productive tillering capacity	-0.00	**0.52**	-0.02	-0.01	0.05	0.01	0.00	0.6
X3	Spike length	-0.02	0.06	**0.19**	-0.38	0.42	0.07	0.00	0.35
X4	Kernel number per spik	-0.02	0.02	0.17	**-0.44**	0.41	0.07	0.00	0.22
X5	Kernel weight per spike	-0.01	0.04	0.13	-0.29	**0.61**	0.07	-0.07	0.49
X6	1000-kernel weight	-0.01	-0.12	0.08	-0.1	0.31	**-0.15**	-0.03	-0.03

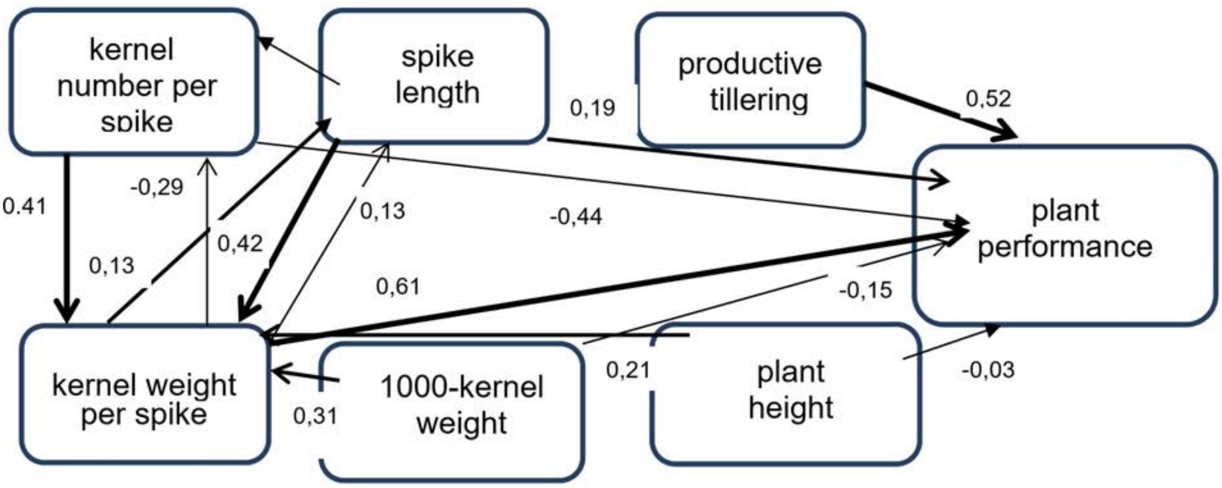

Figure 2. Wright's path coefficients for the spring barley cultivars (the line thickness reflects the effect significance)

In this path, the effect is augmented by the indirect effects of the kernel weight per spike, spike length and 1000-kernel weight (Amardeep et al., 2017).

Polish researchers experimented on 99 two-row barley lines and their parents, Roland and Apex, and found that the plant height, spike length, spikelet and kernel numbers per spike, productive tillering capacity, kernel number per plant, and 1000-kernel weight had the greatest effects on the performance. Path analysis showed that the kernel number per plant had a direct positive effect, and, through this trait, the spikelet numbers per spike and plant and spike length had significant indirect effects (Bocianowski et al., 2016).

The performance in the experiments of Malik et al. (2018) significantly positively correlated with the plant height, productive tillering capacity, spike length, 100-kernel weight, biological yield, yield index, and spikelet number per spike. As path analysis demonstrated, the biological yield had the strongest direct effect on the performance; the effect of the yield index was the second strong, and no significant indirect effects were noted in these two paths. The productive tillering capacity had a weak direct effect, it was enhanced by the biological yield and yield index; the weal effect of the spike length was enhanced by the biological yield. The negative direct effect of the 1000-kernel weight was offset by the strong indirect effect of the biological yield, and the correlation coefficient became significantly positive.

The experimental data of Sandhya et al. (2019) showed that the performance of 114 barley genotypes positively correlated with the biological yield, spike length and 1000-kernel weight. Path analysis demonstrated that the biological yield and yield index were the main factors influencing the performance. The 1000-kernel weight and plant height had indirect significant effects through the biological yield. Kompanets et al. (2016) experimented with 11 two-row barley cultivars and determined a close positive correlation between the performance and straw weight (r = 0.81) and between the performance and productive tilleting capacity.

Bulgarian researchers found positive correlations between the performance and the 1000-kernel weight and between the performance and kernel weight per spike. Here, 1000-kernel weight had a direct positive effect. In this path, there were indirect positive effects of the productive tillering capacity and spike length, and the same traits are recommended for selection (Dimitrova-Doneva, 2016).

Our results on the positive significant correlation between the performance and productive tillering capacity are in agreement with those of Arpali and Yagmur (2015), Bocianowski et al. (2016), Demydov et al. (2017), Malik et al. (2018). As to correlation between the performance and the weight of kernels from the main spike – with the results of Kompanets et al. (2016); as to correlation between the performance and spike length –

with the results of Bocianowski et al. (2016), Malik et al. (2018); as to correlation between the performance and kernel or spikelet number per spike – with the results of Arpali and Yagmur (2015), Malik et al. (2018); as to correlation between the performance and plant height – with the results of Arpali and Yagmur (2015), Marzougui and Chargui (2018), Malik et al. (2018). However, Gebru et al. (2018) found negative significant correlations between the barley plant performance and plant height, which is contrary to many studies, including ours.

According to data of Arpali and Yagmur (2015), Bocianowski et al. (2016), Kompanets et al. (2016), Marzougui & Chargui (2018), Malik et al. (2018), the performance positively correlates with the 1000-kernel weight. On the contrary, in our study this correlation was insignificantly negative, which is partially consistent with data of Budacli Carpici and Celik (2012) and Gebru et al. (2018) on a negative correlation between the performance and 1000-kernel weight. Such results may be attributed to the increased productive tillering capacity of barley plants in our experiments, which led to the formation of relatively small kernels, but as a result, to the increased plant performance.

There is evidence of a significant negative correlation between the performance and the kernel number per spike (Marzougui and Chargui, 2018), which disagrees with results of the vast majority of studies, including ours.

Our results of path analysis on the direct positive effect of the productive tillering capacity on performance are consistent with those of Amardeep et al. (2017), Malik et al. (2018). However, in our experiments in the path "productive tilleing capacity – performance" there were no indirect effects, and the experiments of Amardeep et al. (2017) there were indirect positive effects of the kernel weight per spike, spike length and 1000-kernel weight. Dimitrova-Doneva (2016) reported that the productive tillering capacity had only an indirect positive effect on the performance through the 1000-kernel weight.

The spike length had a direct positive effect on the performance both in our study and in Malik et al.'s study (2018). Here, our data partially agree with the data of Dimitrova-Doneva (2016), Bocianowski et al. (2016), Amardeep et al. (2017), in which the spike length had only an indirect positive effect through the productive tillering capacity or through the 1000-kernel weight.

It should be noted that our results on the direct positive effect of the kernel weight per spike on the performance do not agree with Amardeep et al.'s (2017), where the kernel weight per spike had an indirect positive effect, which augmented the effect of the productive tillering capacity. This can be explained by the fact that in our study the 1000-kernel weight had a direct negative effect on the performance, and in Amardeep et al.'s study (2017), this parameter had an indirect positive effect, which augmented the effect of the productive tillering capacity. In addition, our results on the effect of the 1000-kernel weight are partially consistent with Malik et al.'s data (2018), where this parameter had an indirect negative effect, but contradict to the data published by Dimitrova-Doneva (2016), who noted a direct positive effect of the 1000-kernel weight on the plant performance.

In our experiments, the significant positive correlation between the performance and the kernel number per spike with the direct negative effect of the kernel number is achieved through the indirect positive effect of the kernel weight per spike and spike length. At the same time, in the experiments of Bocianowski et al. (2016) the kernel number per spike had a direct positive effect on the performance.

Thus, results of studying correlations and path coefficients between the barley performance and other quantitative traits depend on genotypes and experiment locations, and our results lead to conclusions, some of which are in agreement with published data, while the others prove differences from them, and this stresses the topic relevance.

CONCLUSIONS

The productive tillering capacity, the weight of kernels from the main spike and spike length are recommended as criteria for selection for the performance of spring barley plants. The kernel number per spike can be an additional trait when one takes into account the kernel weight per spike. Path analysis demonstrated that the paths "spike length – weight of kernels from the main spike – performance" and "kernel number per spike – weight of kernels from the main spike – performance" are of the greatest importance in selection for the barley performance.

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