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Choosing Important Traits for the Model of High-Yielding Winter Wheat Variety Based on the Results of Regional Ecological Varietal Testing

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ABSTRACT

Current study is devoted to the development of an ideotype of winter wheat variety for cultivation in the conditions of the South of Ukraine. The investigation is based on the results of regional ecological varietal testing, conducted in the Southern Steppe zone on the non-irrigated lands. Varietal traits, included in the study, embraced growing season duration, 1000 grains weight, plant height, and ear length. The results of the testing were further processed using statistical procedures of linear Pearson's correlation analysis and multiple regression analysis. As a result, the model of a winter wheat variety for the non-irrigated lands of the South of Ukraine was developed. The developed model is characterized by very high fitting quality (R^2 = 0.9476) and good prediction accuracy (MAPE = 23.27%). According to the model, the variety should be late ripening with moderate to high plant height to provide the highest grain yield. The trait of 1000 grains weight was found out to be unimportant. The main trait, providing for the grain yield increase, is growing season duration, which must be long enough. Further ecological varietal testing studies with inclusion of additional varietal traits, such as cold-resistance, drought-resistance, frost-resistance, tolerance to diseases, etc., are to be conducted to extend the ideotype of winter wheat.

Keywords: ideotype, modelling, multiple regression, productivity, varietal traits.

INTRODUCTION

Wheat is one of the most important staple crops and is on the list of the most consuming cereals in the world, occupying second place after rice in per capita consumption. Approximately 20% of food calories and protein are supplied by wheat grain [Erenstein et al., 2022]. Global annual consumption of wheat averaged to 711.5 M mt/year for the period 2014–2017. Most of the share falls on winter wheat, which is major cereal crop in Europe. Generally, Europe and Asia cover 78% of the total global wheat grain production [FAO-Stat, 2020]. Current global food crisis, connected with climate change and simultaneous deficit of natural resources and their deterioration (e.g., soil degradation, freshwater deficit, unfavorable weather phenomena), under the constant trend to the increase in global population implies a forecasted wheat consumption increase by 132 M mt/year by 2050 [Lykhovyd, 2021; Erenstein et al., 2022]. To face the challenge of global starvation, steps should be taken to increase wheat production. Apart from agrotechnological improvements, plant breeding under zonal principles is of great importance for the increase of the crop yields in major regions of wheat production. Creation of high-yielding wheat varieties with high adaptability to current climate change under the zonal principle provides an opportunity for dramatic production increase. Zonal principle means that not only productivity traits should be encountered but also specific needs depending on the zone of planned crop cultivation, e.g., if wheat is due to be cultivated in the South of Ukraine, it must possess such valuable traits, alongside with high yielding capacity, as drought tolerance and resistance to salinization stress [Lavrenko et al., 2019; Tyshchenko et al., 2020]. Also, "blind" plant selection is inappropriate nowadays because of irrational spending of economic and labor resources. To provide plant breeding scientists with concrete targets, which they must focus their efforts first, an ideotype of a wheat variety should be proposed [Semenov & Stratonovitch, 2013]. This ideotype will differ for different crop cultivation zones, as it was mentioned above. And there are various approaches to the crop ideotype formation. This study is devoted to determining a winter wheat variety ideotype by four major traits for the conditions of Southern Steppe of Ukraine using the data of ecological varietal testing of existing Ukrainian varieties by the means of multiple regression analysis.

MATERIALS AND METHODS

The results of two ecological varietal testing, conducted in the South of Ukraine on the non-irrigated lands, were enrolled in this study, namely, the trials carried out in the State Enterprise “Ilyich-Agro Zaporizhzhia”, and Private Farmers Cooperative “Zoria”. The testing embraced such winter wheat varieties as follows: Kuyalnyk, Shestopalivka, Dar Luhanshchyny, Znahidka, Khersonska bezosta, Bunchuk, Borvii, Otaman, Uzhynok, Zemliachka, Skarbnytsia, Bezmezhna, Kosovytsia, Misiya, Zorepad. All the varieties, enrolled in the study, are included into current edition of the State Register of Plant Varieties of Ukraine. Yielding data, obtained in the varietal testing (yields after harvesting with self-propelled combine harvester were accounted at the standard moisture content in wheat grain of 14%), were included in the study, alongside with the data on varietal traits, namely, duration of growing season (days), plant height (cm), ear length (cm), 1000 grains weight (g). The traits were established using common methodology of scientific work in agronomy [Ushkarenko et al., 2014]. These varietal traits were examined by the means of Pearson’s linear correlation and multiple regression in the relationship with yielding capacities of corresponding varieties, thus providing the information on the most important plant traits, resulted in higher productivity of the crop in the conditions of the South of Ukraine. Mathematical data processing was carried out using standard correlation-regression analysis procedures within BioStat v.7 software and Microsoft Excel 365 [Pedhazur, 1997; Stolzenberg, 2004]. In total, 34 data pairs were examined. As a result, multiple regression model for winter wheat productivity depending on the studied plant traits in the South of Ukraine was developed. By the results of the modeling, an ideotype for plant breeders with two major target traits required for the best productivity of the crop was proposed.

RESULTS AND DISCUSSION

As a result of ecological varietal testing, yielding data and traits of the cultivated winter wheat plants were generalized (Table 1). Further, Pearson’s linear correlation coefficient (R) was calculated for each pair of traits – yield, e.g., for the pairs “growing season – yield of grain” (1); “1000 grains weight – yield of grain” (2); “plant height – yield of grain” (3); “ear length – yield of grain” (4). The values of the coefficient are: R_1 = 0.36, R_2 = 0.03, R_3 = 0.27, R_4 = -0.26. According to the interpretation, proposed by Evans (1996), the connection between the yield of winter wheat and the studied traits is weak, and for the pair 2 it is absent. Another interesting fact is that there is reverse correlation between the ear length and grain yields of winter wheat.

At the same time, multiple regression analysis testifies about strong relationship between the combination of the studied traits and winter wheat yields, as the coefficient of multiple correlation is 0.9735 (Table 2). The calculation of the mean absolute percentage error (MAPE) for the developed regression model of the varietal traits and grain yield testifies about good accuracy of the yield prediction by the model according to the classification of MAPE proposed by Blasco et al. (2013).

An interesting fact about the multiple regression model (Eq. 1) is that regression coefficients have negative values for such traits as 1000 grains weight and ear length. This result supports the results of pairwise linear correlation analysis, and in addition fins out that an increase in 1000 grains weight, surprisingly, does not lead to the yield increase.

$$Y = 3.6579\times10^{-2}X_1 - 1.1405\times10^{-1}X_2 + 5.0334\times10^{-2}X_3 - 6.1818\times10^{-1}X_4 \quad (1)$$

where: Y – winter wheat grain yield, t/ha; $X_{1...4}$ – the arguments that represent the growing season (days), 1000 grains weight (g), plant height (cm), and ear length (cm), respectively.

The approximation graph for the developed model is presented in the Figure 1. According to

Table 1. Yields of winter wheat and corresponding plant traits

No.	Growing season, days	1000 grains weight, g	Plant height, cm	Ear length, cm	Yield of grain, t/ha
1	275.0	41.0	90.0	8.5	4.11
2	275.0	43.5	90.0	10.0	2.28
3	283.0	43.4	86.5	11.0	4.40
4	283.0	43.4	86.5	11.0	1.82
5	275.0	43.5	90.0	10.0	2.66
6	283.0	43.4	86.5	11.0	3.02
7	275.0	43.5	90.0	10.0	2.86
8	260.5	38.5	83.0	10.0	1.66
9	275.0	43.5	90.0	10.0	2.96
10	283.0	43.4	86.5	11.0	2.24
11	260.5	38.5	83.0	10.0	2.38
12	275.0	46.0	87.5	8.5	4.60
13	260.5	38.5	83.0	10.0	2.80
14	275.0	46.0	87.5	8.5	3.53
15	275.0	46.0	87.5	8.5	4.25
16	275.0	41.0	90.0	8.5	4.10
17	277.5	40.0	90.0	10.0	4.56
18	287.5	38.9	77.0	8.3	3.96
19	275.0	41.5	102.5	10.0	3.49
20	278.5	38.8	89.0	10.0	4.50
21	283.0	41.0	99.5	10.1	3.76
22	279.5	39.5	98.0	11.0	3.24
23	275.0	38.6	82.0	10.0	3.62
24	281.5	43.5	105.0	10.0	3.30
25	275.0	41.0	90.0	8.5	3.97
26	277.5	40.0	90.0	10.0	5.40
27	283.0	43.0	99.5	10.1	4.97
28	278.5	38.8	89.0	10.0	4.34
29	275.0	38.6	82.0	10.0	4.97
30	283.0	43.0	99.5	10.1	5.06
31	278.5	38.8	89.0	10.0	5.12
32	277.5	40.0	90.0	10.0	5.14
33	285.0	50.0	99.5	9.6	5.60
34	273.0	40.0	95.0	10.0	5.33

the results of modeling, an ideotype of a winter wheat variety for the South of Ukraine (non-irrigated conditions) was proposed: it should be the late-ripening variety with moderate to high plant height. Besides, it should not have big ears, and 1000 grains weight is almost not important for the variety. The main trait, providing for the grain yield increase, is long enough growing season.

In this regard, it is suggested that the farmers, who cultivate winter wheat on the non-irrigated lands of the South of Ukraine, should avoid early varieties with big ears. It is highly likely that such varieties will be less productive, than late ones with small or moderate ears.

It should be stressed that the mentioned ideotype is relevant only for the cultivation in the conditions of the South of Ukraine on the non-irrigated lands, and in the areas with similar soil-climate features, while on the irrigated lands or in the areas with different soil and climate this ideotype might be not suitable, as Austin (1988) has mentioned in his work, pointing out that winter wheat varieties should be bred under the consideration of environmental and agrotechnological conditions

Table 2. Regression statistics for the model of winter wheat yields depending on the studied varietal traits

Regression statistics	Value of the index
Multiple correlation coefficient (R)	0.9735
Multiple determination coefficient (R^2)	0.9476
Multiple determination coefficient adjusted (R^2_{adj})	0.9424
Multiple determination coefficient predicted (R^2_{pred})	0.9286
Mean square error (MSE)	0.9368
Standard deviation (S)	0.9679
Mean absolute percentage error (MAPE)	23.27%

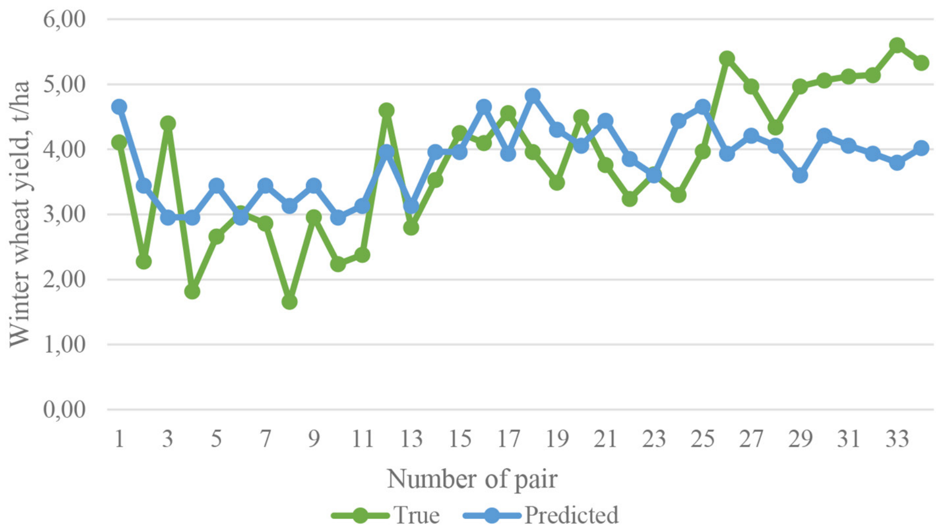

Figure 1. Approximation of the developed winter wheat grain yield model by the studied varietal traits

of the areas, which they are targeted for. Besides, as recommended by Semenov et al. (2014), ideotypes should take into account the features related to climate change, e.g., water availability and connected with it drought tolerance and resistance to osmotic stress, as these factors affect most crops much [Tyshchenko et al., 2020]. Apart from these features, frost and cold resistance, resistance to lodging is also important for winter wheat [Berry et al., 2007; Kolomiets & Bulavka, 2015]. And in the South of Ukraine, it is also crucial that the variety possess some level of tolerance to soil salinity, as far as great share of the lands in the area are saline to some extent [Lavrenko et al., 2018].

It is also desirable that the ideotype propose the traits related to the suitability for organic and carbon farming, as well as its technological requirements and possibilities to be cultivated in the systems of low input agriculture [Lammerts van Bueren et al., 2002; Konvalina et al., 2007]. Therefore, our study provides the suggestions considering only productivity factor, with a limited number of varietal traits, and in further investigations it is due to be extended by the inclusion of additional traits and additional goals to provide the most comprehensive ideotype for the variety of winter wheat of the Southern Ukrainian ecotype.

Apart from the improvements that must be achieved through the extension of inputs and outputs for ideotype modelling, it could be reasonable to extend the approaches to modelling through the implementation of the algorithms of deep learning analysis within the framework of artificial neural networks. However, the introduction of artificial intelligence closes the way of getting clear mathematical equation for the description of desirable varietal traits, therefore, this mathematical instrument could be only additional one in this field of research [Vozhehova et al., 2019].

CONCLUSIONS

Multiple regression analysis, supported by the results of linear pairwise correlation analysis, suggests that the winter wheat variety for the South of

Ukraine should be late-ripening, with high plants possessing small or moderate in size ears, regardless the weight of 1000 grains. Further ecological varietal testing and investigations in this field are required to extend the ideotype by the traits of drought, cold, frost resistance, resistance to lodging, susceptibility to common insects and diseases, as well as suitability for low input, carbon, and organic farming practices. Complicated novel algorithms of deep learning could also be helpful in the enhancement of modelling results quality.

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