MODELS FOR DESCRIBING THE VARIATION IN GRAIN WEIGHT IN WHEAT EARS – ANALYSIS OF THE VENEZIO VARIETY

Cosmin GHERBAN[1], Florin SALA[1,2,*]
[1]University of Life Sciences "King Mihai I" from Timisoara, Timisoara, Calea Aradului, 300645, Romania
[2]Agricultural Research and Development Station Lovrin, Lovrin, 307250, Romania
[*]Corresponding author: florin_sala@usvt.ro

Abstract. *The study analyzed productivity elements of the wheat ear, specifically the Venezio variety, using regression analysis to model variations in grain weight in relation to the ear's morphological productivity elements. The experiment was carried out within the ULS "King Mihai I" from Timisoara, during 2021 - 2022. The ear productivity elements determined were: ear length (EL), spikelet number per ear (SpkN), grain number per ear (GNE), and grain weight per ear (GWE). The experimental data showed statistical reliability (F>Fcrit, Alpha = 0.001). A strong, positive correlation was recorded between GNE and GWE (r = 0.89). Moderate correlation was recorded between SpkN and GNE (r = 0.70). Low correlations were recorded between SpkN and GWE (r = 0.63), EL and SpkN (r = 0.57), and EL and GWE (r = 0.52). Regression analysis facilitated the estimation of the GWE parameter under varying conditions of statistical certainty; $R^2 = 0.604$, $p = 0.089$ when using EL and SpkN parameters, $R^2 = 0.892$, $p < 0.001$ when using EL and GNE parameters, and $R^2 = 0.817$, $p = 0.0038$ when using SpkN and GNE parameters. The RMSEP parameter, 0.1601, confirmed the estimation results of GWE based on EL and GNE. The results recorded, under the study conditions, are important to quantify the grain yield of the wheat ear, the Venezio variety, and to analyze the technology elements and environmental factors that contributed to the variation of productivity elements and the formation of GWE, at the level of wheat ears.*

Keywords: *grain production, morphological parameters, models, yield estimation, wheat ear*

INTRODUCTION

Increasing grain yield is a permanent concern that analyzes plant architecture, the relationship of plants with the soil, nutrients, environmental factors, as well as management practices that contribute to yield formation (Boldea and Sala, 2010; Foulkes et al., 2011). Ear density per unit area is a critical agronomic component that influences grain yield in wheat (Fernandez-Gallego et al., 2018; Zhou et al., 2018). Ear morphological parameters and thousand-grain weight are important components for the formation of grain yield (Baillot et al., 2018).

The number of grains in the per spike was analyzed in relation to indices and physiological processes at the spike level (Zhang et al., 2019). The authors recorded the differentiated contribution of the studied indices in the spike to the formation of grain number. The obtained models explained variable weight in the formation of the number of grains in the spike, with different levels of correlations.

Wheat grain yield was analyzed in relation to its underlying morphological characteristics (Korohou et al., 2020). Morphological parameters of wheat plants were used to estimate grain yield, and the recorded correlations and statistical parameters (R^2, RMSE) confirmed high levels of yield estimation in relation to the respective parameters (Korohou et al., 2020).

Grain yield in cereals was analyzed in relation to the number of spikelets (Qiu et al., 2022). The authors proposed imaging analysis as a method for phenotyping spikelets, offering an alternative to the traditional and time-consuming counting methods. The number of grains in the wheat spike was analyzed, in different genotypes, in relation to the length of the spikelet, spikelets, and certain areas on the spikelet (Backhaus et al., 2023; Tamagno et al., 2024).

Ear number assessment is important for management practices and yield estimation, and methods based on image analysis, associated with computational algorithms, have been promoted in various studies (Fernandez-Gallego et al., 2018; Zhou et al., 2018). Constantinescu et al. (2018) used image analysis (UAV) to estimate plant status (fresh biomass, chlorophyll content) and phenotyping some genotypes of grass cereals.

Plant and ear architecture in wheat have been studied to explain yield formation in cereals (Zhou et al., 2021). Morphological features of the ear are important for yield formation, and determining these features by classical methods requires time and costs (Zhou et al., 2021). Imaging analysis methods, based on X-ray computed tomography, have been tested to study ear architecture and determine morphological characters at the ear level (Zhou et al., 2021).

Imaging analysis near-infrared hyperspectral imaging (NIR-HSI) was used as a non-destructive method to determine grains in the ear of winter wheat (Vincke et al., 2022). The results confirmed that the NIR-HSI method can be used to study wheat ears and evaluate grains in the ear for yield assessment.

This study analyzed the variation in grain weight in the wheat ears, the Venezio variety, in relation to morphological elements at the ear level, and generate models to describe this variation.

MATERIAL AND METHODS

The wheat crop was located within the DER (Didactic and Experimental Resort), University of Life Sciences "King Mihai I" from Timisoara (ULS). The study was conducted in the agricultural year 2021 - 2022.

The wheat crop, the Venezio variety, was located on a chernozem type soil. The land preparation was done by disking. Sowing was done at the optimal time, October 2021. Appropriate technology for the wheat crop was applied. Fertilization was done at a level of 160 kg ha^{-1} N a.s. (a.s. – active substance; the fertilizer used was ammonium nitrogen). The climatic conditions during the experimental period, for the area where the field experiments were located, are presented in figure 1.

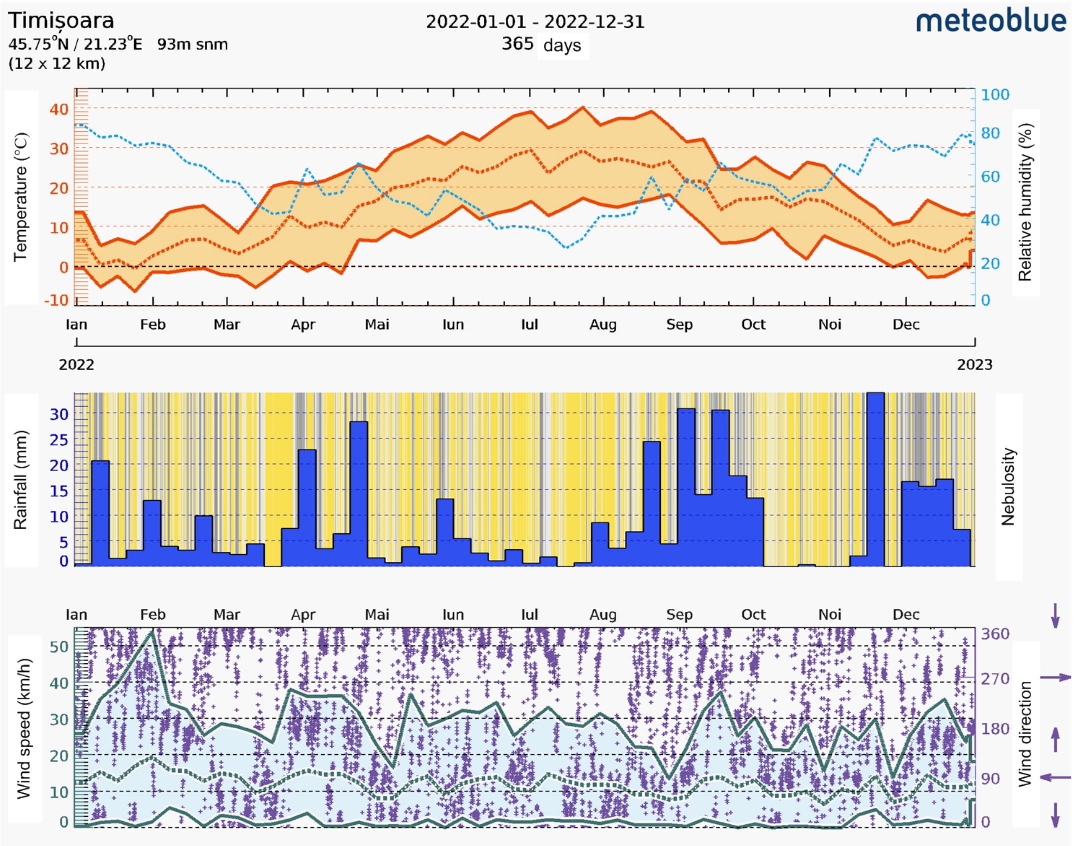


Figure 1. Climatic conditions for Timisoara, during the study period (Meteoblue)

Spike samples were randomly taken from 15 plants within the experimental variant, at the physiological maturity of the plants (Meier, 2001). Spike length (EL, cm), number of spikelets per spike (SpkN), number of grains per spike (GNE), and weight of grains per spike (GNE, g) were determined. Grains were weighed with a laboratory balance, accuracy ±0.002 g.

We analyzed the variation of the grain weight per ear (GWE) parameter in relation to the spike's morphological parameters using regression analysis. Data analysis was performed using dedicated software applications, namely PAST (Hammer et al., 2001) and Statistica (2022).

RESULTS AND DISCUSSIONS

The components of the wheat ear were determined in ear samples taken randomly from the experimental variant, under fertilization conditions with N 160 kg ha^{-1} a.s. (active substance). The statistical values resulting from the analysis of the recorded data series are presented in table 1. The determined parameters recorded specific values, EL = 8.50 – 11.00±0.18 cm, SpkN = 17.00 – 20.00±0.21, GNE = 52.00 – 74.00±1.64, respectively GWE = 2.0723 – 3.8922±0.1301 g. The results, presented in Table 1, include detailed statistical measurements such as ear length (EL), number of spikelets per spike (SpkN), number of grains per spike (GNE), and grain weight per spike (GWE).

The experimental data presented statistical reliability, according to Anova Test (Alpha = 0.001), table 2.

Table 1. Statistical values of parameters in wheat ear, Venezio variety

Statistical parameters	Ear parameters			
	EL	SpkN	GNE	GWE
N	15	15	15	15
Min	8.50	17.00	52.00	2.0723
Max	11.00	20.00	74.00	3.8922
Sum	144	280	939	43.6603
Mean	9.60	18.67	62.60	2.9107
Std. error	0.18	0.21	1.64	0.1301
Variance	0.4714	0.6667	40.1143	0.2538
Stand. dev	0.69	0.82	6.33	0.5038
Median	9.50	19.00	63.00	2.9479
25 prcntil	9.00	18.00	59.00	2.6679
75 prcntil	10.00	19.00	66.00	3.1312
Skewness	0.3514	-0.1682	-0.0886	-0.0446
Kurtosis	-0.4376	-0.0330	-0.4941	0.1172
Geom. mean	9.5773	18.6499	62.2968	2.8685
Coeff. var	7.1522	4.3741	10.1176	17.3098

Table 2. Anova Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32539.33	3	10846.44	1045.283	4.11E-49	6.229585
Within Groups	581.0872	56	10.37656			
Total	33120.42	59				

From the analysis of the coefficient of variation values (CV), low variability was found for all studied parameters, with CV values = 7.1522 for EL, CV = 4.3741 for SpkN, CV = 10.1176 for GNE, and CV = 17.3098 for GWE, respectively. The comparative analysis of the CV values showed, however, better homogeneity for the SpkN and EL parameters, and heterogeneity within the GNE and GWE parameters. This suggests that the formation of grains in the spike recorded certain variations given by external factors, compared to the spike potential.

A correlation map (Figure 2) highlighted varying intensities of relationships between productivity elements.

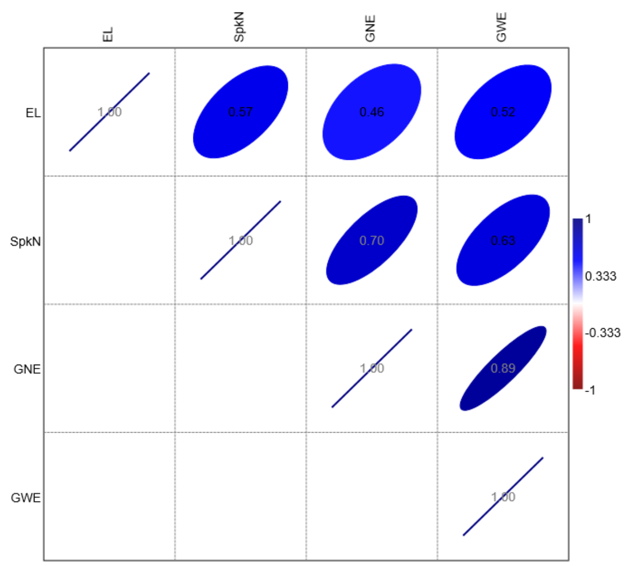


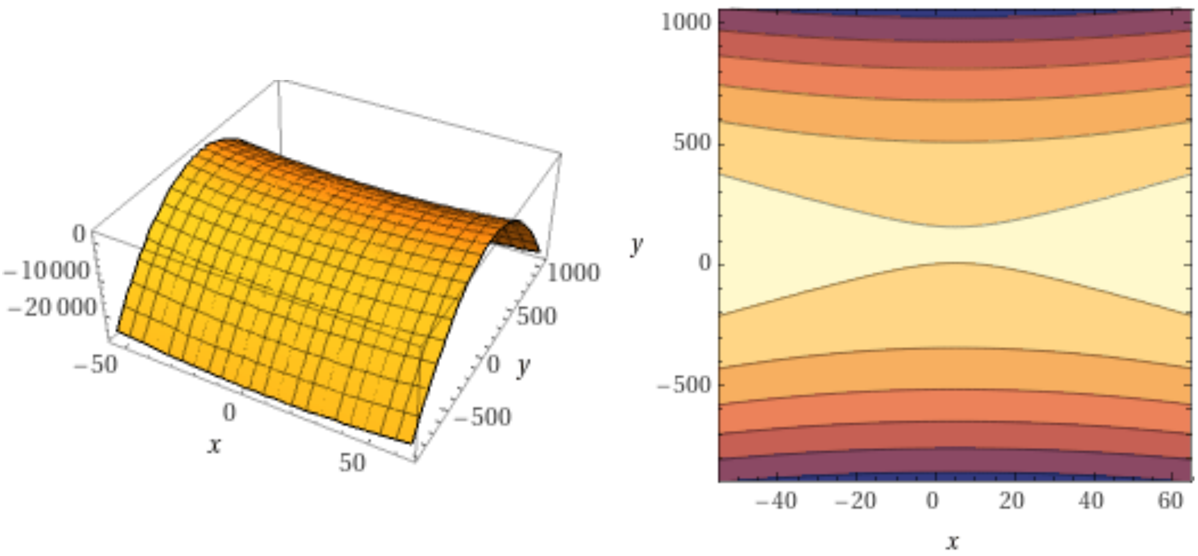
Figure 2. Correlation map between productivity elements in the ear, Venezio variety

Strong, positive correlation was recorded between GNE and GWE (r = 0.89). Moderate correlation was recorded between SpkN and GNE (r = 0.70). Low correlation was recorded between SpkN and GWE (r = 0.63), between EL and SpkN (r = 0.57) and between EL and GWE (r = 0.52), respectively.

The variation of the GWE parameter in relation to the other determined productivity elements was evaluated. The variation of GWE in relation to EL and SpkN was described by equation (1), under conditions of $R^2 = 0.604$. The graphical distribution of GWE in relation to EL and SpkN is represented in figure 3. According to equation (1) and the graphical models, the two morphological elements, EL and SpkN, presented a divergent action in achieving GWE.

$$GWE = ax^2 + by^2 + cx + dy + exy + f \quad (1)$$

where: GWE – Grain weight in ear (g);
x – ear length (EL, cm);
y – number of spikelets (SpkN);
a, b, c, d, e, f – coefficients of the equation (1);
a= 0.63680520;
b= -0.02844029;
c= -6.35785996;
d= 4.63695227;
e= -0.32348092;
f= -13.58607816



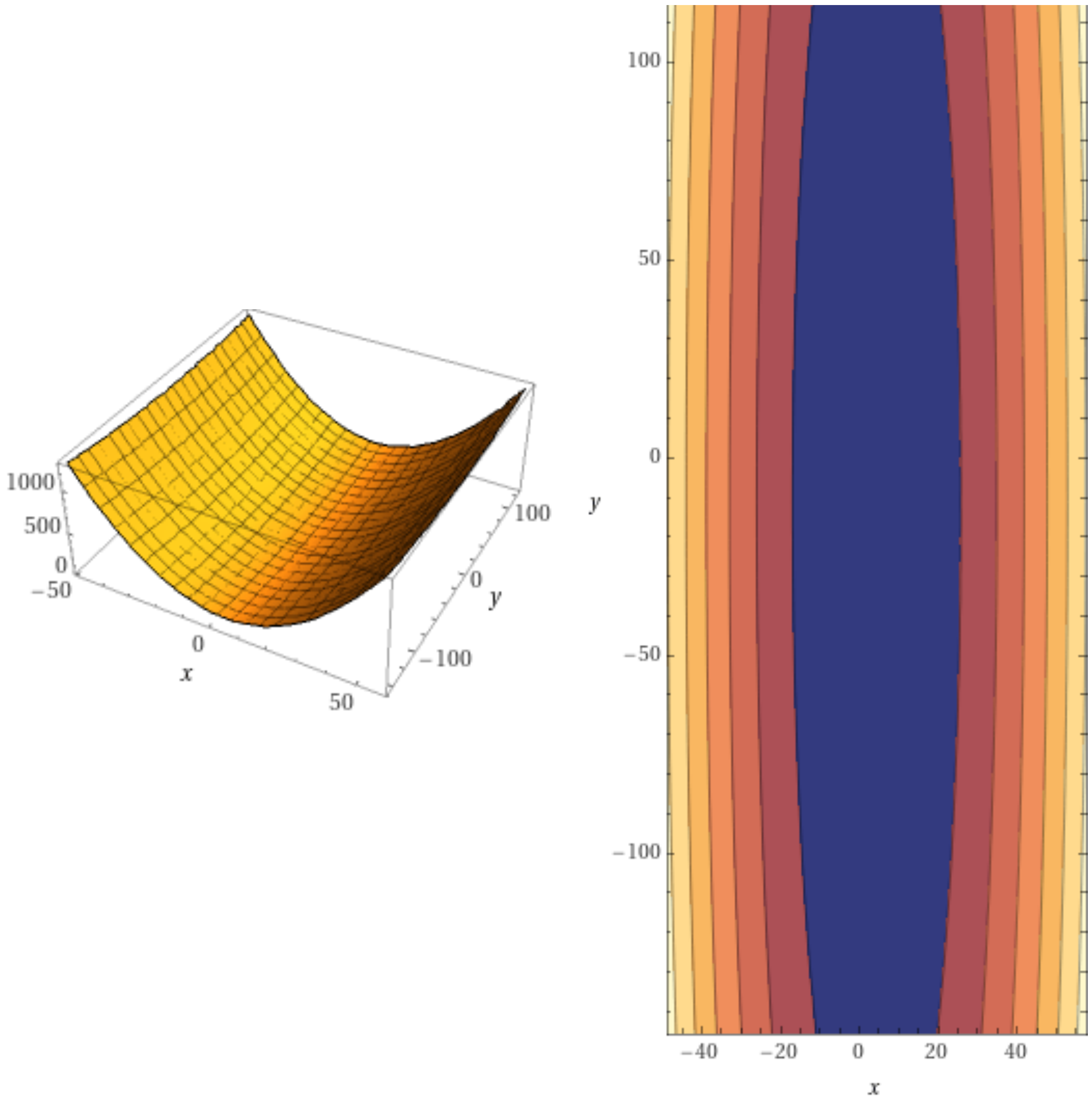
(a) (b)
Figure 3. Graphical distribution of GWE in relation to EL and SpkN; (a) 3D model, (b) isoquant model

The variation of GWE in relation to EL and GNE was described by equation (2), under conditions of $R^2 = 0.892$, $p<0.001$. The graphical distribution of GWE in relation to EL and GNE is represented in figure 4. According to equation (2), and the graphical models, figure 4, the EL parameter (x-axis) presented a much wider variation compared to GNE (y-axis), in the formation of the GWE parameter.

$$GWE = ax^2 + by^2 + cx + dy + exy + f \quad (2)$$

where: GWE – Grain weight in ear (g);
x – ear length (EL, cm);
y – grains number in ear (GNE);
a, b, c, d, e, f – coefficients of the equation (2);
a= 0.42475758;
b= 0.00516783;

c= -3.75599259;
d= 0.11585874;
e= -0.07111038;
f= 14.80563493



(a) (b)

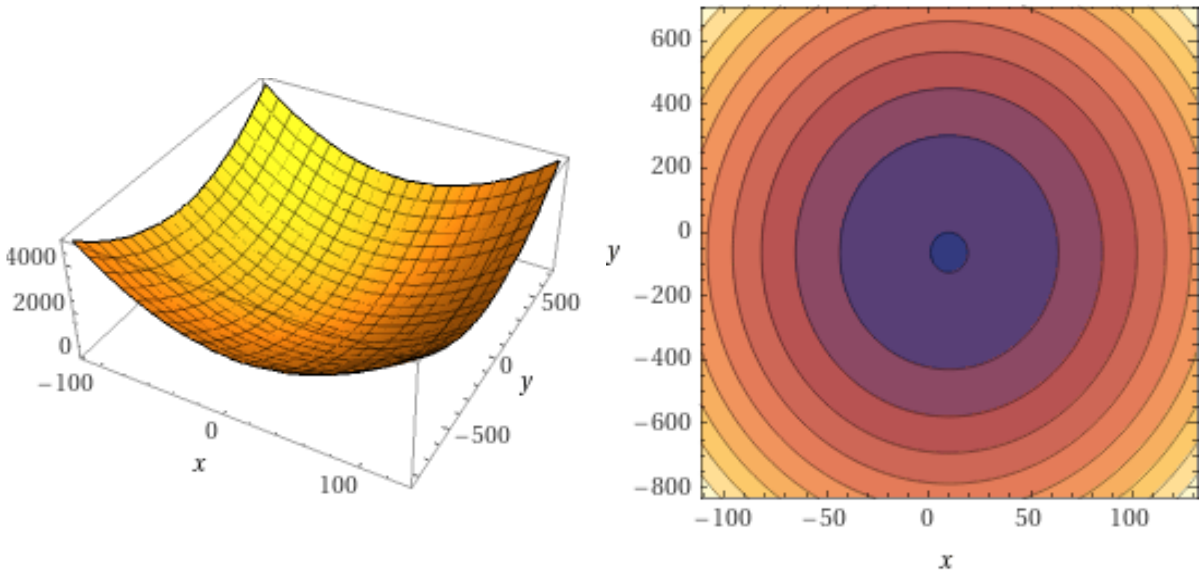
Figure 4. Graphical distribution of GWE in relation to EL and GNE; (a) 3D model, (b) isoquant model

The variation of GWE in relation to SpkN and GNE was described by equation (3), under conditions of $R^2 = 0.817$, p=0.0038. The graphical distribution of GWE in relation to SpkN and GNE is represented in figure 5. According to equation (3), and the graphical models, figure 5, the two parameters SpkN (x-axis) and GNE (y-axis) presented a convergent action in the formation of the GNE parameter.

$$\text{GWE} = ax^2 + by^2 + cx + dy + exy + f \quad (3)$$

where: GWE – Grain weight in ear (g);
x – number of spikelets (SpkN);
y – grains number in ear (GNE);
a, b, c, d, e, f – coefficients of the equation (3);

a= 0.17910399;
b= 0.00384124;
c= -3.62086992;
d= 0.49301147;
e= -0.04865763;
f= 18.94527696



(a) (b)

Figure 5. Graphical distribution of GWE in relation to SpkN and GNE; (a) 3D model, (b) isoquant model

The RMSEP parameter was calculated to verify the reliability of the GWE parameter estimation based on equations (1), (2), and (3). The recorded values were RMSEP = 0.3062 in the case of GWE estimation based on EL and SpkN parameters, equation (1), RMSEP = 0.1601 in the case of GWE estimation based on EL and GNE parameters, and RMSEP = 0.2079 in the case of GWE estimation based on SpkN and GNE parameters, equation (3).

According to the values of the regression coefficients (R^2) of equations (1), (2), and (3), and the values of the RMSEP parameter, it was concluded that the estimation of the variation of the GWE parameter based on the EL and GNE parameters, equation (2), had the highest level of statistical certainty.

Variability was differentiated for morphological parameters analyzed at the level of the wheat spike, the Venezio variety, under the study conditions. The recorded CV values showed low variability. The analysis on each parameter, however, showed the lowest value in the case of SpkN, followed by EL, GNE and GWE.

Grain yield per ear is of great importance, as it, together with ear density, has a major contribution to the formation of wheat yield (Baillot et al., 2018; Fernandez-Gallego et al., 2018; Korohou et al., 2020). Wheat yield has been analyzed in relation to nutrient imbalances through fertilization in order to optimize fertilizer allocation (Sala et al., 2016). Grain yield and quality indices in wheat have been analyzed in relation to fertilization, dynamics and nitrogen use efficiency (Sieling and Kage, 2021; Agapie et al., 2023; Zhang et al., 2024).

The fact that the GWE parameter presented a variability at the CV = 17.3098 level, higher compared to the other morphological parameters studied, showed that the formation of wheat grains in the spike of the Venezio variety under the study conditions, depended more strongly on internal and external factors to the plants.

The GWE correlation showed variable values in relation to the other morphological parameters analyzed. GWE showed strong correlation with GNE, and weak correlation with SpkN and EL. This showed the differentiated way in which morphological parameters contributed to the formation of GWE.

The models obtained for describing the variation of GWE in relation to EL, SpkN, and GNE parameters presented different levels of statistical certainty, which showed the diferentiated contribution of the parameters to the formation of GWE.

The recorded information is important for adjusting agricultural technologies, but also for wheat breeding programs.

CONCLUSIONS

Morphological parameters of the wheat spike in the Venezio variety exhibited significant variability under our study conditions. Specifically, the coefficient of variation (CV) was 7.1522 for EL, 4.3741 for SpkN, 10.1176 for GNE, and 17.3098 for GWE.

The estimation of grain weight in the ear (GWE) was possible based on the EL, SpkN, and GNE parameters, under different conditions of statistical reliability. Statistical parameters confirmed that the GWE estimation based on EL and GNE had a high level of statistical reliability (R^2 = 0.892, $p<0.001$, RMSEP = 0.1601), compared to the other estimation variants.

Analysis of the equations and graphical models indicated that EL and SpkN parameters (as per Equation 1) contributed divergently to the GWE values, necessitating a tailored approach for optimizing cultivation practices. Other elements and their combinations displayed a convergent influence on GWE formation, contributing variably to the outcomes.

ACKNOWLEDGMENTS

The authors thank the DER, ULS "King Mihai I" from Timisoara for facilitating this study.

REFERENCES

1. Agapie A.L., Horablaga N.M., Bostan C., Popa L.-D., Istrate-Schiller C.-M., Rechitean D., Sala F. The dynamics of nitrogen valorification in wheat crop under the influence of the used agrofound. Romanian Agricultural Research, 2023, 40, 1-13.
2. Backhaus A.E., Griffiths C., Vergara-Cruces A., Simmonds J., Lee R., Morris R.J., Uauy C., Delayed development of basal spikelets in wheat explains their increased floret abortion and rudimentary nature. Journal of Experimental Botany, 2023, 74(17), 5088-5103. doi. https://doi.org/10.1093/jxb/erad233
3. Baillot N., Girousse C., Allard V., Piquet-Pissaloux A., Le Gouis J. Different grain-filling rates explain grain-weight differences along the wheat ear. PLoS One, 2018, 13(12), e0209597. doi. 10.1371/journal.pone.0209597
4. Boldea M., Sala F. Optimizing economic indicators in the case of using two types of state-subsidized chemical fertilizers for agricultural production. AIP Conference Proceedings, 2010, 1281(1), 1390-1393. doi. https://doi.org/10.1063/1.3497988
5. Constantinescu C., Herbei M., Rujescu C., Sala, F. Model prediction of chlorophyll and fresh biomass in cereal grasses based on aerial images. AIP Conference Proceedings, 2018, 1978(1), 390003. doi. https://doi.org/10.1063/1.5043987
6. Fernandez-Gallego J.A., Kefauver S.C., Gutiérrez N.A., Nieto-Taladriz M.T., Araus J.L. Wheat ear counting in-field conditions: high throughput and low-cost approach using RGB images. Plant Methods, 2018, 14, 22. https://doi.org/10.1186/s13007-018-0289-4
7. Foulkes M.J., Slafer G.A., Davies W.J., Berry P.M., Sylvester-Bradley R., Martre P., Calderini D.F., Griffiths S., Reynolds M.P. Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance. Journal of Experimental Botany, 2011, 62(2), 469-486. doi. https://doi.org/10.1093/jxb/erq300
8. Hammer Ø., Harper D.A.T., Ryan P.D. PAST: Paleontological Statistics software package for education and data analysis. Palaeontologia Electronica, 2001, 4(1), 1-9.
9. Korohou T., Okinda C., Li H., Cao Y., Nyalala I., Huo L., Potcho M., Li X., Ding Q. Wheat grain yield estimation based on image morphological properties and wheat biomass. Journal of Sensors, 2020, 2020(1), 571936. doi. https://doi.org/10.1155/2020/1571936
10. Meier U. Growth stages of mono-and dicotyledonous plants e BBCH monograph. Federal Biological Research Centre for Agriculture and Forestry, 2001, 158 pp.
11. Meteoblue - https://www.meteoblue.com (accessed on the date: 23.03.2023)
12. Qiu R., He Y., Zhang M. Automatic detection and counting of wheat spikelet using semi-automatic Labeling and Deep Learning. Frontiers in Plant Science, 2022, 13, 872555. doi: 10.3389/fpls.2022.872555
13. Sala F., Rujescu C., Constantinescu C. Causes and solutions for the remediation of the poor allocation of P and K to wheat crops in Romania. AgroLife Scientific Journal, 2016, 5(1), 184-193.
14. Sieling K., Kage H. Apparent fertilizer N recovery and the relationship between grain yield and grain protein concentration of different winter wheat varieties in a long-term field trial. European Journal of Agronomy, 2021, 124, 126246. doi. https://doi.org/10.1016/j.eja.2021.126246
15. Tamagno S., Carrera C.S., Marchese S.I., Savin R., Slafer G.A. Sterility of basal spikelets in wheat: predetermined fate or a matter of resources? Journal of Experimental Botany, 2024, erae373. doi.

https://doi.org/10.1093/jxb/erae373

16. Vincke D., Mercatoris B., Eylenbosch D., Baeten V., Vermeulen P. Assessment of kernel presence in winter wheat ears at spikelet scale using near-infrared hyperspectral imaging. Journal of Cereal Science, 2022, 106, 103497. doi. https://doi.org/10.1016/j.jcs.2022.103497
17. Wolfram, Research, Inc., Mathematica, Version 12.1, Champaign, IL (2020).
18. Zhang H., Richards R., Riffkin P., Berger J., Christy B., O'Leary G., Acuña T.B., Merry A. Wheat grain number and yield: The relative importance of physiological traits and source-sink balance in southern Australia. European Journal of Agronomy, 2019, 110, 125935. doi. https://doi.org/10.1016/j.eja.2019.125935
19. Zhang J., Li S., Jiang P., Wang R., Guo J., Xiao H., Wu J., Shaaban M., Li Y., Huang M. Organic fertilizer substituting 20% chemical N increases wheat productivity and soil fertility but reduces soil nitrate-N residue in drought-prone regions. Frontiers in Plant Science, 2024, 15, 1379485. doi: 10.3389/fpls.2024.1379485
20. Zhou C., Liang D., Yang X., Yang H., Yue J., Yang G. Wheat ears counting in field conditions based on multi-feature optimization and TWSVM. Frontiers in Plant Science, 2018, 9, 1024. doi: 10.3389/fpls.2018.01024
21. Zhou H., Riche A.B., Hawkesford M.J., Whalley W.R., Atkinson B.S., Sturrock C.J., Mooney S.J. Determination of wheat spike and spikelet architecture and grain traits using X-ray Computed Tomography imaging. Plant Methods, 2021, 17, 26. doi. https://doi.org/10.1186/s13007-021-00726-5