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WHEAT QUALITY INDICES IN RELATION TO NITROGEN FERTILIZATION

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Abstract

The study analyzed the variation of quality indices of wheat grains in relation to nitrogen fertilization. The experiment was carried out at the University of Life Sciences "King Mihai I" from Timisoara, Didactic and Experimental Resort (DER), in the 2021-2022 agricultural years. The wheat 'Venezio' cultivar was cultivated in a non-irrigated system. Fertilization was done with ammonium nitrate in eight doses: 0, 40, 80, 120, 160, 200, 240 and 280 kg ha^{-1} N a.s. (a.s. – active substance). The studied quality indices showed variable values, between 13.8-16.4±0.30% in the case of the protein content (Pro), 27-34±0.83% in the case of the gluten content (Glt), 57-73±1.91% in the case of the Zeleny Index (Zel Ind), 74.6-76.5±0.20 kg hl^{-1} in the case of hectolitre weight (HW), respectively 11.5-11.8±0.04% in the case of moisture (Mstr). The variation of the quality indices values in relation to N was described by polynomial equations of the 2nd degree, under variable conditions of statistical safety ($p<0.001$ in the case of Pro, Glt, Zel Ind; $p=0.0428$ in the case of HW; $p=0.0729$ in the case of Mstr). The variation of Zel Ind in relation to other quality indices (Pro and Glt) was quantified by quadratic regression analysis ($R^2=0.996$, $p<0.001$). According to PCA, a distribution and association of the variants was obtained in relation to the level of the evaluated quality indices: variants T1 and T2 were placed independently, variants T3 and T8 were associated with humidity (Mstr); variants T4 and T7 were associated with Pro, Glt and Zel Ind indices, and variants T5 and T6 were associated with HW. PC1 explained 87.168% of variance and PC2 explained 8.0113% of variance.

Key words: *models, nitrogen fertilizer, PCA, quality indices, wheat*

INTRODUCTION

The quality indices of wheat grains are important in relation to the production destination, such as for bakery, fodder wheat, or other uses [7, 15, 33].

The quality indices depend primarily on the biological material and have been studied in relation to different cultivated wheat genotypes [1, 25].

Environmental factors (temperature and precipitation, including water and thermal stress conditions), also showe d influence on quality indices, quantified in different studies [8, 21, 31].

The quality indices of wheat production were analyzed in relation to farming system [25], agricultural practices [3, 6, 9] and key parameters [20].

As an expression of the interaction [genotype × environment × crop technology] quality indices of grain production in wheat have been increasingly studied from this perspective, as they reflect more realistically the final result of a wheat crop, regarding the quality of grain production [10, 22, 25, 34].

Within the crop technologies, fertilization occupies an important place, and nitrogen is a nutrient element with a major role in the quantitative formation, in particular, but also the quality of wheat production [4, 19, 28].

Wheat genotypes respond differently to fertilization (e.g. nitrogen fertilization), both in terms of the level of quantitative production and in terms of qualitative indices [5, 27, 30].

Knowing the (production potential) response capacity of a wheat genotype in relation to fertilization is important in order to optimize inputs, agricultural technologies and management at the farm level [12, 14, 16, 23].

The present research evaluated the main quality indices in wheat production in relation to nitrogen fertilization, and described through mathematical models the variation of the values of the quality indices considered in relation to nitrogen doses.

MATERIALS AND METHODS

The experimental study was organized within the University of Life Sciences "King Mihai I" from Timisoara, Didactic and Experimental Resort (DER), Photo 1. The wheat crop was established on a chernozem type soil, in a non-irrigated crop system, agricultural year 2021 - 2022; the climatic conditions are presented in Figure 1 [24]. The biological material was represented by the 'Venezio' wheat cultivar. Fertilization was done with granular ammonium nitrate, in doses that ensured eight levels of nitrogen (0, 40, 80, 120, 160, 200, 240 and 280 kg ha^{-1} a.s.; a.s. – active substance).

To evaluate the quality of wheat production, the following indices were considered: protein content (Pro, %), gluten content (Glt, %), Zeleny Index (Zel Ind, %), hectolitre weight (HW, kg hl^{-1}), moisture (Mstr, %). The determination of the considered indices was done by non-destructive methods (NIR), with the AGRI CHECK and PFEUFFER GRANOMAT devices.

Photo 1. Aspect from the experimental field, agricultural year 2021 - 2022
Source: Original photo of the field (made by authors).

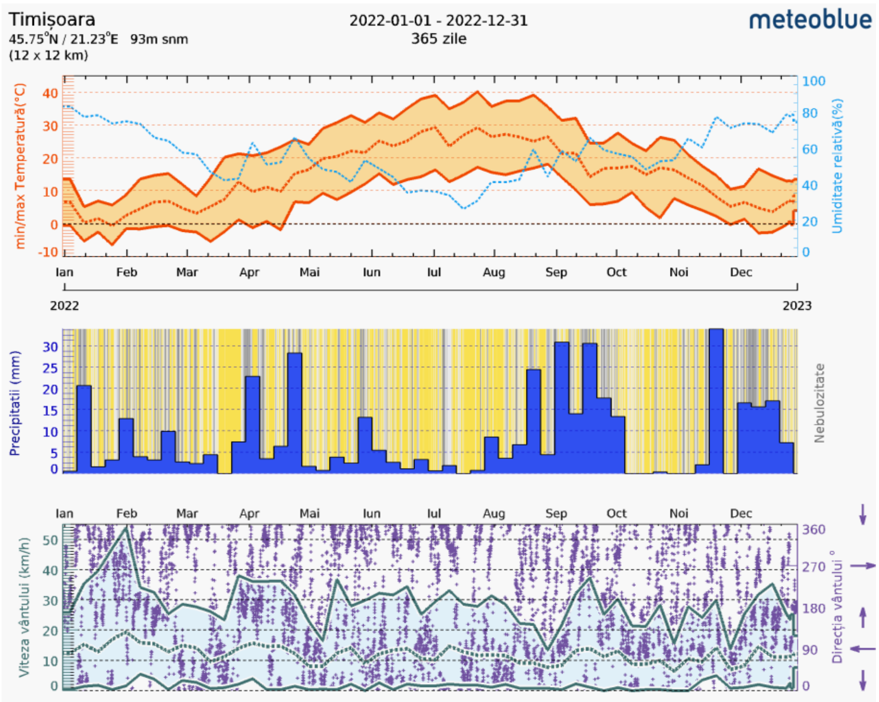

Fig. 1. Climatic conditions for the area of the experimental field during the study period [24]
Source: Original figure.

The experimental data resulting from the analyzes were evaluated by appropriate mathematical and statistical methods, for the evaluation of the variance, the statistical certainty, the level of correlations and interdependencies between the analyzed indices and the doses of N, as well as between certain quality indices [11, 13, 32].

RESULTS AND DISCUSSIONS

The quality of wheat production, the 'Venezio' cultivar was analyzed in relation to nitrogen doses in terms of quality indices, respectively protein content (Pro, %), gluten content (Glt, %), Zeleny Index (Ind Zel, %), hectolitre weight (HW, kg hl^{-1}), and grain moisture (Mstr, %). The studied quality indices showed variable values, between 13.8-16.4±0.30% in the case of the protein content, 27-34±0.83% in the case of the gluten content, 57-73±1.91% in the case of the Zeleny Index, 74.6-76.5±0.20 kg hl^{-1} in the case of hectolitre weight, respectively 11.5-11.8±0.04% in the case of moisture, table 1. The Anova single factor test confirmed the presence of variance in the experimental data set, and the safety of the data (F>Fcrit, p<0.001, Alpha=0.001).

Table 1. Values of quality indices for wheat, 'Venezio' cultivar

Trial	**Nitrogen doses**	**Quality indices**				
		Pro	Glt	Zel Ind	HW	Mstr
	(kg ha^{-1} a.s.)	(%)			(kg hl^{-1})	(%)
T1	0	13.8	27	57	74.6	11.8
T2	40	15.2	31	65	74.9	11.6
T3	80	15.7	32	69	75.3	11.7
T4	120	16.1	33	71	75.4	11.6
T5	160	16.1	34	72	75.8	11.4
T6	200	16.2	34	73	76.5	11.5
T7	240	16.4	34	73	75.5	11.6
T8	280	15.5	32	68	75.2	11.7
SE		±0.30	±0.83	±1.91	±0.20	±0.04

Sources: Original data from the experiment.

Table 2. Correlation table (Kendall’s Tau B)

Variable		N	Pro	Glt	Zel Ind	HW	Mstr
N	Kendall's Tau B	—					
	p-value	—					
Pro	Kendall's Tau B	0.618*	—				
	p-value	0.034	—				
Glt	Kendall's Tau B	0.617*	0.904**	—			
	p-value	0.040	0.003	—			
Zel Ind	Kendall's Tau B	0.618*	0.963**	0.943**	—		
	p-value	0.034	0.001	0.002	—		
HW	Kendall's Tau B	0.500	0.837**	0.926**	0.909**	—	
	p-value	0.109	0.004	0.002	0.002	—	
Mstr	Kendall's Tau B	-0.231	-0.511	-0.708*	-0.589	-0.694*	—
	p-value	0.441	0.093	0.024	0.052	0.021	—
* p < .05, ** p < .01, *** p < .001							

Source: Original data.

The correlation analysis led to the values in Table 2. In relation to the doses of N, there were positive correlations (* p<0.05) in the case of the protein content (r=0.618), for the gluten content (r=0.617) and the Zeleny index (r=0.618). Very strong correlations were recorded between protein and gluten (r=0.904), between protein and the Zeleny Index (r=0.963), between gluten and the Zeleny Index (r=0.943), between gluten and hectolitre weight (r=0.926) and between Zeleny index and hectolitre weight (r=0.909), under conditions of p<0.01 (**p). Moderate correlation was recorded between Glt and Mstr (r=-0.708), and weak correlation was recorded between Zel Ind and Mstr (r=-0.694).

The variation of the values of the studied quality indices was analyzed in relation to the nitrogen doses. Thus, the variation of protein content (Pro) in relation to N was described by equation (1), under conditions of R^2= 0.940, p<0.001, F=39.3213, RMSE=0.1916. The variation of gluten content (GLT) in relation to N was described by equation (2), under conditions of R^2=0.961, p<0.001, F=61.03113, RMSEP= 0.4373. The variation of the Zeleny Index (Zel Ind) in relation to N was described by equation (3), under conditions of R^2=0.971, p<0.001, F=84.2206, RMSE=0.8574. The variation of hectolitre weight (HW, kg hl^{-1}) in relation to N was described by equation (4) under conditions of R^2=0.716, p=0.0428, F=6.3133, RMSE= 0.2868. The variation of humidity (Mstr, %) in relation to N doses was described by equation (5), under conditions of R^2=0.649, p=0.0729, F=4.6255, RMSE=0.0691.

$$\text{Pro} = -7.4\text{E}-05x^2 + 0.026607x + 13.9833 \quad (1)$$

$$\text{Glt} = 0.000205x^2 + 0.07256x + 27.45833 \quad (2)$$

$$\text{Zel Ind} = -0.000476x^2 + 0.17202x + 57.75 \quad (3)$$

$$\text{HW} = -46\text{E}-05x^2 + 0.01625x + 74.4166 \quad (4)$$

$$\text{Mstr} = 1.15\text{E}-05x^2 - 0.00368x + 11.8042 \quad (5)$$

The variation of the Zeleny Index (Zel Ind) in relation to protein and gluten (as a direct and interaction effect) in wheat grains, 'Venezio' cultivar was described by equation (6), under conditions of R^2=0.996, p<0.001, F=119,899, with graphic representation in figures 3 and 4.

$$\text{Ind Zel} = a\,x^2 + b\,y^2 + c\,x + d\,y + ex\,y + f \quad (6)$$

where: Ind Zel – Zeleny Indices (%);
x – Pro – protein content (%);
y – Glu – Gluten content (%);
a, b, c, d, e, f – coefficients of the equation (6);

a= -19.18893355;
b= -1.33510877;
c= 264.05119413;
d= -81.18275597;
e= 10.67439110;
f= -744.66604398

Based on the PCA, the diagram in Figure 4 was generated, in which the experimental variants (T1 and T9) were distributed in relation to the association with the quality indices considered in the study (as biplot in the PCA diagram).

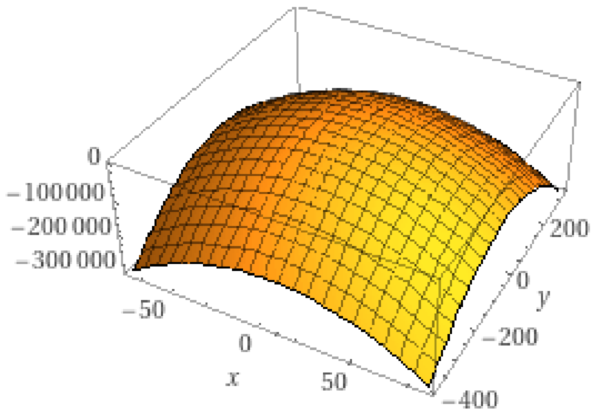

Fig. 2. 3D model of variation of Zel Ind in relation to Pro (x-axis) and Glt (y-axis), 'Venezio' wheat cultivar
Source: Original figure.

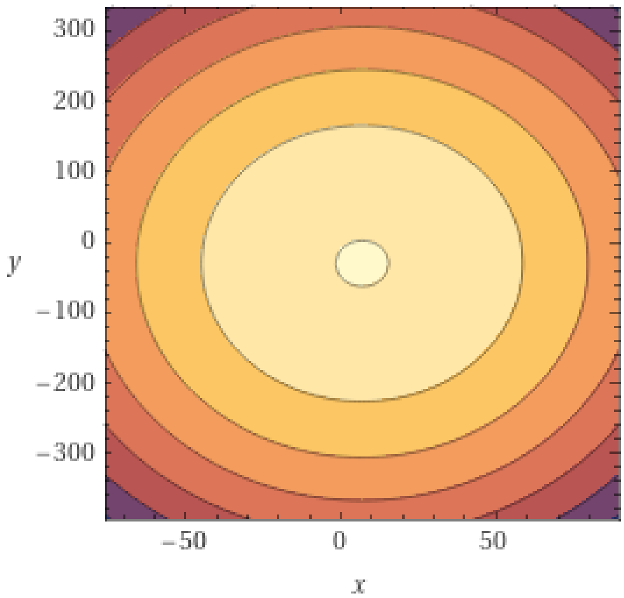

Fig. 3. Model in isoquants format of variation of Zel Ind in relation to Pro (x-axis) and Glt (y-axis), 'Venezio' wheat cultivar
Source: Original figure.

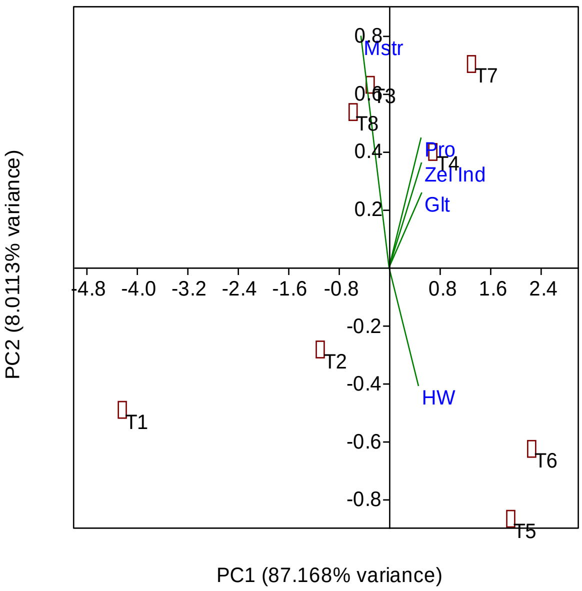

Fig. 4. PCA diagram in the study variants, 'Venezio' wheat cultivar, in relation to quality indices
Source: Original figure

The T1 and T2 variants were placed independently. The variants T3 and T8 were associated with grains moisture (Mstr). The T4 and T7 variants were associated with Zel Ind, Pro and Glt indices, and the T5 and T6 variants were associated with HW. PC1 explained 87.168% of variance, and PC2 explained 8.0113% of variance.
The Cluster Analysis led to the dendrogram in figure 6, in which the variants were associated based on similarity in relation to the values of the considered quality indices (Coph.corr. =0.925).

The T1 variant was placed in an independent position, with the lowest values of the considered quality indices.
The other variants were grouped into two sub-clusters, based on similarity. Based on the calculated SDI values, a high level of similarity was recorded between variants T3 and T8, and between variants T6 and T7, respectively (SDI=1.0247), Table 3.

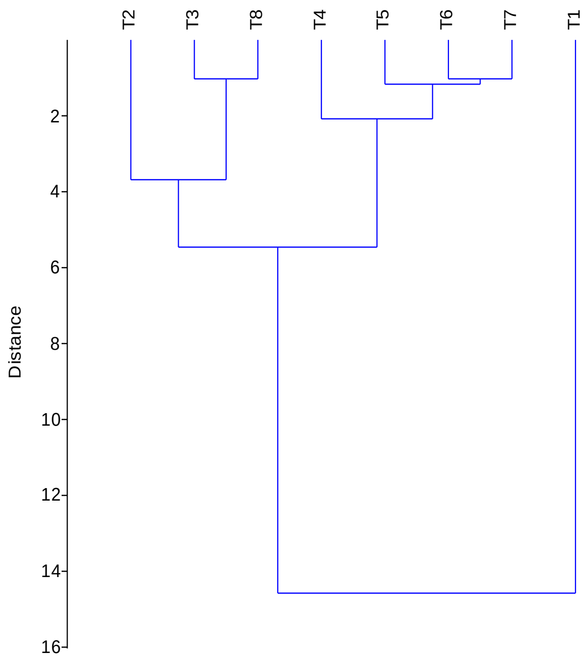

Fig. 5. Dendrogram of wheat variants grouping based on Euclidean distances, in relation to quality indices
Source: Original figure.

Table 3. SDI values for fertilization variants in wheat, 'Venezio' cultivar, in relation to the considered quality indices

	T1	T2	T3	T4	T5	T6	T7	T8
T1		9.0604	13.1570	15.4260	16.7600	17.7330	17.6810	12.2170
T2	9.0604		4.1737	6.4078	7.7240	8.7504	8.6487	3.1922
T3	13.1570	4.1737		2.2760	3.6742	4.6615	4.5321	1.0247
T4	15.4260	6.4078	2.2760		1.4832	2.4960	2.2583	3.2265
T5	16.7600	7.7240	3.6742	1.4832		1.2288	1.1045	4.5618
T6	17.7330	8.7504	4.6615	2.4960	1.2288		1.0247	5.5875
T7	17.6810	8.6487	4.5321	2.2583	1.1045	1.0247		5.4690
T8	12.2170	3.1922	1.0247	3.2265	4.5618	5.5875	5.4690	

Source: Original data.

Fertilization with N generated a different variation in the values of the studied quality indices, equations (1) – (5) and a variable growth rate (Δ) for quality index creation, Table 4.

Fertilizers contribute variably to achieving quality indices in wheat grains. The variation of quality indices was analyzed in relation to different types, doses and application conditions of fertilizers [3, 14, 25].

Table 4. Growth rate values (Δ) in relation to N dose in wheat, 'Venezio' cultivar

Trial	N	Δ-Pro	Δ-Glt	Δ-Zel Ind	Δ-HW
T1	0	-	-	-	-
T2	40	1.4	4	8	0.3
T3	80	1.9	5	12	0.7
T4	120	2.3	6	14	0.8
T5	160	2.3	7	15	1.2
T6	200	2.4	7	16	1.9
T7	240	2.6	7	16	0.9
T8	280	1.7	5	11	0.6

Source: Original data

Different models of variation in wheat production and quality indices, resulting from regression analysis, were communicated in relation to the fertilization applied to the wheat crop, or within the interaction [genotype × environment × technology] [2, 18, 20, 23, 34]. Response models of wheat production and protein content in relation to the optimization of nitrogen fertilization in climatic conditions specific to the Mediterranean basin were communicated by Ortuzar-Iragorri et al. (2010) [26]. The authors communicated quadratic models to describe the variation of production and protein content based on 13 experiments, under statistical safety conditions.

Zhu et al. (2012) [35] communicated models of variation in production and some wheat quality indices, obtained through regression analysis, in relation to applied fertilization, under statistical safety conditions (e.g. $R^2>0.900$, $p<0.001$). Lamlon et al. (2023) [17] communicated the variation of production, some productivity and quality indices in wheat in relation to organic substance and biofertilizers ($p \leq 0.005$).

Sala and Herbei (2023) [29] communicated models of variation and estimation of wheat production (Alex cultivar) in relation to 11 fertilization options, and the model based on applied fertilizers (F model) facilitated the estimation of production in conditions of statistical safety ($R^2=0.763$ based on applied fertilization; $R^2=0.717$ when checking the model based on production and fertilization communicated by other studies).

The present study described, with statistical certainty, the variation of the quality indices considered in the wheat analysis, the 'Venezio' cultivar, through models obtained through quadratic regression analysis, as well as through 3D models and in the form of isoquants, and the multicriteria analysis (PCA, CA) facilitated the classification of fertilization variants in relation to the considered quality indices.

CONCLUSIONS

Differentiated fertilization with nitrogen, 8 variants, range 0 - 280 kg ha^{-1} (variation rate of 40 kg ha^{-1}) led to specific values of the quality indices for the 'Venezio' wheat cultivar.

High amplitude of variation was recorded at the Zeleny index, $CV_{Zel\ Ind}=7.8808$, followed by gluten content $CV_{Glt}=7.3357$, protein content $CV_{Pro}=5.3628$ and hectolitre weight $CV_{HW}=0.76352$. In the case of humidity, the value of the coefficient of variation was $CV_{Mstr}=1.0733$.

The variation of the values of the quality indices in relation to nitrogen was described by polynomial equations of the 2nd degree, under conditions of statistical safety.

According to PCA, T4 and T7 variants were associated with Pro, Glt and Zel Ind indices, T5 and T6 variants were associated with HW, T3 and T8 variants were associated with moisture (Mstr), while variants T1 and T2 were placed independently, with the lowest values for the analyzed quality indices.

On the basis of the CA, the dendrogram of cluster grouping of the variants on the basis of similarity was obtained in relation to the values of the evaluated quality indices. The dendrogram has practical applicability to select fertilization options that lead to similar results in relation to quality indices, but in different fertilization conditions, a useful fact for optimizing fertilizer inputs and agricultural technologies.

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