VARIATION OF THE THOUSAND KERNEL WEIGHT IN WHEAT IN RELATION TO NPK MINERAL FERTILIZATION

Alina Laura AGAPI1, Florin SALA2*  
1Agricultural Research and Development Station Lovrin, Lovrin, 307250, Romania  
2University of Life Sciences "King Michael I" from Timisoara, Timisoara, Calea Aradului, 300645, Romania  
*Corresponding author: florin_sala@asab-tm.ro

Abstract. The study evaluated the variation of the thousand kernel weight (TKW), as an index of wheat quality, in relation to NPK mineral fertilization. The research took place at the Agricultural Research and Development Station Lovrin, Timis County, Romania. The Ciprian wheat variety was cultivated, on a chernozem type soil with medium fertility, under non-irrigated conditions. Nitrogen, phosphorus and potassium fertilizers were applied. Nitrogen (N) was applied in three fertilization levels 0, 60 and 120 kg ha⁻¹; phosphorus (P) was applied in two fertilization levels, 0 and 60 kg ha⁻¹; potassium (K) was applied in four fertilization levels, 0, 40, 80 and 120 kg ha⁻¹. From the combination of nutritional elements and applied doses, 16 experimental variants was evaluated, and the experiments were organized in four repetitions. The thousand kernel weight (TKW) was evaluated by measurement, with a laboratory balance with a precision of ±0.002 g. The ANOVA test confirmed the safety of the data and the presence of the variance in the data set (F=11.19783, Fcrit=2.80349, p<0.001), under conditions of Alpha=0.001. Strong correlations were identified between TKW and P (r=0.833) and weak correlations between TKW and N (r=0.672). The variation of TKW in relation to the nutritional elements applied was described by different equations, under statistical safety conditions, in relation to the elements taken into analysis. The direct and interaction effect of NPK on TKW variation was observed, under conditions of R²=0.898, p<0.001. 3D models and in the form of isouquants were generated, which graphically described the variation of TKW in relation to N (x-axis) and PK (y-axis). The cluster analysis facilitated the grouping of the experimental variants based on the Euclidean distances, in relation to the TKW values, under statistical safety conditions (Coph. corr. =0.806).

Keywords: Cluster analysis, mineral fertilizers, model, TKW, wheat

INTRODUCTION

Wheat quality indices vary in relation to the genotype, soil and climate conditions, culture technologies, etc. and were studied in relation to factors of influence or to the valorization of production (Mangini et al., 2018; Hou et al., 2020; Kulyk et al., 2020; Wang and Fu, 2020). Among the wheat quality indices, thousand kernel weight (TKW) is of high importance and varies in relation to the biological material and growth conditions.

In specific experimental conditions (wheat durum, monoculture, specific climate conditions in Tunisia), Bouatrous et al. (2022) reported that TKW did not register significant variations in relation to the crop season compared to other analyzed production indices, under statistical safety conditions (p>0.001). They also communicated that no significant differences were recorded for TKW in the first three years of cultivation.

Among the influencing factors of the TKW index, fertilization, respectively plant nutrition has an important role (Moitzi et al., 2020). Bouacha et al. (2014) recorded as significant (p<0.05) the interaction of Environment x Fertilizers on some parameters studied in wheat culture, including TKW. The authors reported the increasing influence of N on the protein content and the reduction of TKW, while K had an increasing effect on both protein and TKW under the study conditions. Xu et al. (2021) reported the variation of TKW in wheat in relation to N management and cropping system.

Associated with other indices, TKW was used as a wheat quality index, for the development of fertilization strategies and optimization of fertilization in order to increase the efficiency of nitrogen use, in specific experimental conditions from the Mediterranean basin (Plaza-Bonilla et al., 2021). Different mathematical models have been found to optimize crop fertilization, in relation to yields or quality indices (Boldea et al., 2015; Sala et al., 2015; Li et al., 2022; Wang et al., 2022).

Along with other wheat quality indices, TKW was studied in relation to the soil, better results by about 3% being obtained in conditions of cambisol, compared to vertisol (Gesseseew et al., 2022). Koppensteiner et al. (2022) reported the variation of some productivity elements, including TKW, in wheat in relation to environmental conditions, sowing time, and nitrogen fertilization.

TKW determination is often done by classical methods, based on counting and weighing, but imaging methods have also been tested, including mobile applications (Android) useful in the case of large series of determination samples (Wu et al., 2018).

The combined effect of climatic conditions and multiple diseases led to a decrease in the quality of wheat grains, in terms of TKW values (Jevtić et al., 2018). TKW variation in relation to stress factors, such as water
stress, heat stress, has been studied, associated with physiological processes and other quality indices, such as protein content (Kulyk et al., 2020). In relation to the experimental conditions, and other indices determined for wheat grains, very strong correlations were recorded between TKW and grain area (GA, r=0.904), respectively between TKW and grain diameter (GD, r=0.906), according to Fan et al. (2020).

The present study evaluated the variation of thousand kernel weight, as an index of wheat quality, in relation to mineral fertilization with NPK, and found patterns of variation of TKW in relation to the considered mineral elements.

**MATERIAL AND METHODS**

The study analyzed the variation of thousand kernel weight (TKW), as an index of wheat quality, in relation to the applied mineral fertilization. The experiment took place within SCDA Lovrin, Romania, under the conditions of a cambic chernoziom type soil, medium fertility, non-irrigated culture system. The Ciprian wheat variety, produced by SCDA Lovrin, was cultivated, and the 2019-2020 agricultural year was taken into account.

The mineral fertilization included the main macroelements, NPK, and was done within 16 experimental variants, in four repetitions. Nitrogen (N) was applied in three fertilization levels 0, 60 and 120 kg ha⁻¹; phosphorus (P) was applied in two fertilization levels, 0 and 60 kg ha⁻¹; potassium was applied in four fertilization levels, 0, 40, 80 and 120 kg ha⁻¹. Phosphorus and potassium fertilizers were applied in autumn and were incorporated into the soil with the basic tillage. Nitrogen fertilizers were applied in spring, in two rounds.

In relation to the purpose of the study, the variation of thousand kernel weight (TKW, g) in relation to the nutrients applied through fertilization (NPK) was evaluated. The determination of TKW (g) was made by counting and weighing, with a laboratory balance with a precision of ±0.002 g. The determinations were made on each experimental variant and repetition, and the average values and the standard error (SE) are presented in the study.

The ANOVA test verified the statistical reliability of the experimental data series recorded for TKW, as well as the presence of the variance in the data set. A series of mathematical and statistical analyzes and tests were used in relation to the purpose of the study (ANOVA test, correlation analysis, regression analysis). For the statistical reliability of the results, the correlation and regression coefficient (r, R²), the p parameter (p<0.05), the F test, the RMSEP parameter, equation (1) were used.

\[
RMSEP = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (y_j - \bar{y})^2}
\]  

(1)

In order to analyze and process the experimental data, the software PAST (Hammer et al., 2001) and Wolfram Alpha (2020) were used, as well as the calculation mode from EXCEL (Microsoft Office).

**RESULTS AND DISCUSSIONS**

The fertilization variants led to the nutrition of the wheat plants, the Ciprian variety, in a different way, a fact that was reflected in the values of the TKW quality index, table 1. Values between TKW=41.694±0.79 g (V4) and TKW=45.263±0.28 g (V9) were recorded.

The ANOVA test (Alpha=0.001) confirmed the reliability of the experimental data and the presence of the variance in the data set, table 2.

The correlation analysis highlighted certain interdependence relationships between TKW and applied nutrients (NPK) in the form of mineral fertilizers to the soil, under the conditions of the study period. Thus, strong correlations were recorded between TKW and P (r=0.833) and weak correlations between TKW and N (r=0.672).

The regression analysis was used to evaluate the variation of TKW values in relation to the administered NPK doses, as a direct relationship. For calculation safety, up to 16 decimal places of the values of the coefficients of equations (2) - (5) were used.

In relation to the three nutritional elements, as a direct relationship, the TKW variation in the experimental conditions was described by equation (2), under statistical safety conditions (R²=0.801, p<0.001, F=17.4611).

In relation to nitrogen (N) and phosphorus (P), the TKW variation was described by equation (3), under conditions of R²=0.682, p=0.001, F=15.0718.

In relation to nitrogen (N) and potassium (K), the TKW variation was described by equation (4), under conditions of R²=0.747, p=0.001, F=20.6729.

In relation to phosphorus (P) and potassium (K), the TKW variation was described by equation (5), under conditions of R²=0.747, p=0.001, F=20.6729.
Table 1. TKW values for wheat, the Ciprian variety, in relation to mineral fertilization

<table>
<thead>
<tr>
<th>Experimental Variant</th>
<th>N (Kg ha(^{-1}) a.s.)</th>
<th>P</th>
<th>K (g)</th>
<th>MMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>42.363±0.53</td>
</tr>
<tr>
<td>V2</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>42.050±0.32</td>
</tr>
<tr>
<td>V3</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>42.319±0.68</td>
</tr>
<tr>
<td>V4</td>
<td>0</td>
<td>0</td>
<td>120</td>
<td>41.694±0.79</td>
</tr>
<tr>
<td>V5</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>43.031±0.28</td>
</tr>
<tr>
<td>V6</td>
<td>60</td>
<td>0</td>
<td>40</td>
<td>43.456±0.47</td>
</tr>
<tr>
<td>V7</td>
<td>60</td>
<td>0</td>
<td>80</td>
<td>44.081±0.33</td>
</tr>
<tr>
<td>V8</td>
<td>60</td>
<td>0</td>
<td>120</td>
<td>42.675±0.90</td>
</tr>
<tr>
<td>V9</td>
<td>60</td>
<td>80</td>
<td>0</td>
<td>45.263±0.28</td>
</tr>
<tr>
<td>V10</td>
<td>60</td>
<td>80</td>
<td>40</td>
<td>44.944±0.35</td>
</tr>
<tr>
<td>V11</td>
<td>60</td>
<td>80</td>
<td>80</td>
<td>45.138±0.37</td>
</tr>
<tr>
<td>V12</td>
<td>120</td>
<td>80</td>
<td>0</td>
<td>44.344±0.55</td>
</tr>
<tr>
<td>V13</td>
<td>120</td>
<td>80</td>
<td>40</td>
<td>43.769±0.41</td>
</tr>
<tr>
<td>V14</td>
<td>120</td>
<td>80</td>
<td>80</td>
<td>44.319±0.47</td>
</tr>
<tr>
<td>V15</td>
<td>120</td>
<td>80</td>
<td>120</td>
<td>44.79±0.24</td>
</tr>
<tr>
<td>V16</td>
<td>120</td>
<td>80</td>
<td>120</td>
<td>44.79±0.24</td>
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Table 2. ANOVA test

<table>
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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>167.727</td>
<td>15</td>
<td>11.1818</td>
<td>11.19783</td>
<td>3.82E-16</td>
<td>2.803493</td>
</tr>
<tr>
<td>Within Groups</td>
<td>111.8397</td>
<td>112</td>
<td>0.998569</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>279.5667</td>
<td>127</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Alpha=0.001

Figure 1. Graphical representation of TKW data series, in matrix plot format, Ciprian wheat variety

\[
TKW_{NPK} = 0.3005 \cdot N + 0.0201 \cdot P + 0.2654 \cdot K \tag{2}
\]

\[
TKW_{NP} = 0.4775 \cdot N + 0.0201 \cdot P \tag{3}
\]

\[
TKW_{NK} = 0.3140 \cdot N + 0.2265 \cdot K \tag{4}
\]

\[
TKW_{PK} = 0.3049 \cdot P + 0.3364 \cdot K \tag{5}
\]
From the analysis of the values of the statistical safety parameters p, R², F-test, as well as the RMSEP parameter, it was found that the variation of the TKW index in relation to all three nutrients (NPK), equation (2) presented a higher statistical safety (RMSEP = 19.4688) compared to the situation when only two nutritional elements were considered, equations (3) - (5).

The variation of TKW in relation to N and PK, as a direct and interaction effect, was described by equation (6), under statistical safety conditions (R²=0.898, p<0.001, F=19.5668). The graphic distribution of TKW values in the form of a 3D model is represented in figure 2, and in the form of isoquants it is shown in figure 3.

\[
TKW = ax^2 + by^2 + cx + dy + exy + f
\]  

(6)

where:

- TKW – thousand kernel weight, g;
- \(x\) – N fertilizer (kg a.s. ha\(^{-1}\));
- \(y\) – PK fertilizers (kg a.s. ha\(^{-1}\));
- a, b, c, d, e, f – coefficients of the equation (6);
- a= -0.00057492;
- b= -0.00086835;
- c= 0.50516017;
- d= 0.47753668;
- e= -0.00334457;
- f= 0

Based on the recorded TKW values, table 1, figure 4, the increase in thousand kernel weight (I-TKW) was calculated in relation to the control variant. The values of the increase in TKW (I-TKW) varied between -
0.356 g (V4) and 3.213 g (V9). On the NOPO fertilization background, increasing fertilization with K generated increased variations in TKW between 0.356 g (V4) and 0.313 g (V2).

On the N60 fertilization background, fertilization with K generated increases of MMB between 0.625 g (V8) and 2.031 g (V7).

Under the conditions of fertilization with the three nutrients (NPK), the increase in MMB was between 1.719 g (V14) and 3.213 g (V9). The values of the TKW increase in wheat, the Ciprian variety, in relation to the applied mineral fertilization, are shown graphically in figure 5.

![Figure 4: Distribution of TKW values on experimental variants, the Ciprian wheat variety](image)

![Figure 5: The increase of the TKW index (I-TKW) in relation to mineral fertilization (NPK), the Ciprian wheat variety](image)

The cluster analysis led to the grouping of the experimental variants based on the Euclidean distances in relation to the TKW values under statistical safety conditions Cophcorr=0.806, figure 6. The formation of two clusters was found, each with several sub-clusters, within which the variants were grouped based on similarity in the generation of TKW values.
From the analysis of SDI values, table 3, as well as the obtained dendrogram, figure 6, a very high level of similarity was found between variants V12 and V15 (SDI=0.025), followed by variants V7 and V13 (SDI=0.038) and variants V1 and V3 (SDI=0.044).

**Figure 6.** Dendrogram of grouping of fertilization variants based on similarity in relation to TKW values, Ciprian wheat variety

**Table 3.** SDI values for TKW in wheat, the Ciprian variety, in relation to mineral fertilization

<table>
<thead>
<tr>
<th></th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
<th>V7</th>
<th>V8</th>
<th>V9</th>
<th>V10</th>
<th>V11</th>
<th>V12</th>
<th>V13</th>
<th>V14</th>
<th>V15</th>
<th>V16</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>0.313</td>
<td>0.044</td>
<td>0.669</td>
<td>0.668</td>
<td>1.093</td>
<td>1.718</td>
<td>0.312</td>
<td>2.900</td>
<td>2.581</td>
<td>2.775</td>
<td>1.981</td>
<td>1.756</td>
<td>1.406</td>
<td>1.956</td>
<td>2.431</td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td>0.313</td>
<td>0.269</td>
<td>0.356</td>
<td>0.981</td>
<td>1.406</td>
<td>2.031</td>
<td>0.625</td>
<td>3.213</td>
<td>2.894</td>
<td>3.088</td>
<td>2.294</td>
<td>2.069</td>
<td>1.719</td>
<td>2.269</td>
<td>2.744</td>
<td></td>
</tr>
<tr>
<td>V3</td>
<td>0.044</td>
<td>0.269</td>
<td>0.625</td>
<td>0.712</td>
<td>1.137</td>
<td>1.762</td>
<td>0.356</td>
<td>2.944</td>
<td>2.625</td>
<td>2.819</td>
<td>2.025</td>
<td>1.800</td>
<td>1.450</td>
<td>2.000</td>
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<tr>
<td>V4</td>
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<td>0.356</td>
<td>0.625</td>
<td>1.337</td>
<td>1.762</td>
<td>2.387</td>
<td>0.981</td>
<td>3.569</td>
<td>3.250</td>
<td>3.444</td>
<td>2.650</td>
<td>2.425</td>
<td>2.075</td>
<td>2.625</td>
<td>3.100</td>
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<tr>
<td>V5</td>
<td>0.668</td>
<td>0.981</td>
<td>0.712</td>
<td>1.337</td>
<td>0.425</td>
<td>1.050</td>
<td>0.356</td>
<td>2.232</td>
<td>1.913</td>
<td>2.107</td>
<td>1.313</td>
<td>1.088</td>
<td>0.738</td>
<td>1.288</td>
<td>1.763</td>
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<tr>
<td>V6</td>
<td>1.093</td>
<td>1.406</td>
<td>1.137</td>
<td>1.762</td>
<td>0.425</td>
<td>0.625</td>
<td>0.781</td>
<td>1.807</td>
<td>1.488</td>
<td>1.682</td>
<td>0.888</td>
<td>0.663</td>
<td>0.313</td>
<td>0.863</td>
<td>1.338</td>
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<tr>
<td>V7</td>
<td>1.718</td>
<td>2.031</td>
<td>1.762</td>
<td>2.387</td>
<td>1.050</td>
<td>0.625</td>
<td>1.406</td>
<td>1.182</td>
<td>0.863</td>
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<td>3.569</td>
<td>2.232</td>
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<td>1.182</td>
<td>2.588</td>
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<tr>
<td>V10</td>
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<td>2.625</td>
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<td>1.913</td>
<td>1.488</td>
<td>0.863</td>
<td>2.269</td>
<td>0.319</td>
<td>0.194</td>
<td>0.600</td>
<td>0.825</td>
<td>1.175</td>
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<td>2.819</td>
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<td>1.057</td>
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<td>0.888</td>
<td>0.263</td>
<td>1.669</td>
<td>0.919</td>
<td>0.600</td>
<td>0.794</td>
<td>0.225</td>
<td>0.575</td>
<td>0.025</td>
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<td>1.800</td>
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<td>1.088</td>
<td>0.663</td>
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<td>1.444</td>
<td>1.144</td>
<td>0.825</td>
<td>1.019</td>
<td>0.225</td>
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<td>1.025</td>
<td>0.475</td>
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</table>
The high values of TKW are of great interest, both for consumption wheat, but especially for seed wheat (biological material) for the establishment of crops. Thus, the grouping of variants V9, V10, V11, V16 was found within a sub-cluster, with the highest values for TKW.

In relation to the NPK doses related to the four variants, it is possible to choose one of the variants, the results being comparable, or you can choose the variant that generated the highest TKW value. The aspect is important both for research (fertilization systems, breeding programs etc.) but also for agricultural practice in order to obtain effective results.

As a practical aspect, a certain fertilization can be chosen in relation to the budget allocated to the culture technology and the TKW quality index framing group whose value is estimated to be reached.

CONCLUSIONS

Mineral fertilization with NPK in the 16 variants of combinations and doses, led to the TKW variation between 41.694±0.79 g (V4) and 45.263±0.28 g (V9).

Different equations described the variation of TKW in relation to the applied fertilizing elements, under conditions of statistical safety, and the situation in which all three elements (NPK) were taken into analysis was obtained with the highest predictive level (RMSEP=19.4688).

The direct and interactive effect of NPK in the formation of the TKW quality index was described by an equation under conditions of \( R^2=0.898\), \( p<0.001\), and from the mathematical analysis it was possible to generate 3D graphic models and in the form of isoquants that represented varied TKW in relation to the fertilizing elements (NPK).

The increase in TKW values (I-TKW) in relation to the applied fertilization was between 1.719 g (V14) and 3.213 g (V9).

The cluster analysis facilitated the grouping of fertilization variants based on similarity in the generation of TKW values, and based on the generated dendrogram, fertilization variants with similar effect, but different costs, can be selected, in relation to the budget allocated to the wheat culture technology.

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