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INTERACTIVE EFFECTS MODEL OF NITROGEN AND SILICON IN MAIZE QUALITY INDICES

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Abstract

The purpose of the study was to evaluate the influence of nitrogen (N) and silicon (Si) on quality indices in maize grains, the Lovrin 400 hybrid. Nitrogen (ammonium nitrate) was applied in the range of 0-200 kg ha^{-1}, with the 40 kg variation unit (N0, N40, N80, N120, N160, N200). Silicon (silicic acid) was applied foliar (0, 0.5%, 1.0%, 1.5%, 2.0%) in the main growth stage I: Leaf development BBCH Code, at 4 leaves, 6-8 leaves and 10 leaves, respectively.The combination of the two treatments resulted in 30 variants, in three repetitions. Corn grain quality indices such as starch (ST), protein (PRO), fat (FAT), fiber (FIB), ash (ASH) and moisture (MSTR) have been evaluated. Determinations were made using non-destructive NIR methods. Based on a general model of the type f = (N, Si), the PRO index indicated the strongest correlation (R^2=0.800, with p<0.001), and the FAT index strongly correlation (R^2=0.763 with p<0.001), with the two independent variable (N, Si). The ASH and FIB indices correlation had a average intensity (0.4<R2<0.5), and the MSTR correlation had a low intensity relative to N and Si. For the PRO index, the optimal dose was found for N=144.4 kg ha^{-1}, and for Si=1.26%. In the case of the FAT index, the contribution of N was negligible, and for Si was found the optimal Si=1.46%. The PCA analysis identified the association of some N × Si fertilization variants with the PRO index, and other N × Si variants with ST and FAT quality indices, which facilitates decisions in fertilization practice. PC1 (ST) explained 76.136% of variance, and PC2 (PRO) explained 21.798% of the variance. Clustering analysis has led to the formation of three distinct clusters in relation to afinity of respons expressed through PRO index values determined by N and Si treatments. This has practical importance in the management of fertilization in maize with the two fertilizers.

Key words: *FAT, FIB, maize, nitrogen, PCA, PRO, silicon.*

INTRODUCTION

Nitrogen is a macroelement with an important role in the vegetative growth of plants, in the synthesis of amino acids, protein substances, nucleic acids, some vitamins, enzymes, phytohormones and others (Marschner, 1995; Mengel and Kirkby, 2001). It is also the nutrient element applied in the form of fertilizers in the largest quantities to the fertilization of agricultural crops (Amanullah et al., 2016; Boldea et al., 2015; Yousaf et al., 2016).

Optimization of nitrogen doses, applied singularly or in combination with PK, has been the subject of numerous research on the main agricultural crops such as corn, wheat, sunflower, and other (Boldea and Sala, 2010; Sala and Boldea 2011; Sala et al., 2015; 2016).

Silica is a microelement with an important role in the pectocellulosic structure of plants, having an important role in the resistance structure of cell walls, cells and tissues (Liu et al., 2009; Song et al., 2014). It also has an important role in increasing the resistance and tolerance of plants to stress condition such as hydric, thermal, saline stress (Moussa, 2006; Habibi, 2016; Abdel Latef and Tran, 2016; Delavar et al., 2017; Sacala, 2017; Amin et al., 2018), increasing plant tolerance to pathogens (Liang et al., 2005; Pozo et al., 2015).

Although microelements such as Fe, Zn, B, Mn or Cu have been much more studied in relation to plant requirements, nutrition status and production quality (Jivan and Sala, 2014; Rawashdeh and Sala 2014; 2015; 2016), silicon is an important micronutrient for superior plants, and for crops (Chen et al., 2011; Marafon and Endres, 2013).

Silicon has gained increased attention in various studies and research on the favorable influence on plant life (Marafon and Endres, 2013), the influence on enzymatic, metabolic processes, chlorophyll content, photosynthetic rate (Xie et al., 2014), and influence on some physiological indices, productivity, production and quality in maize (Sacala, 2017; Delavar et al., 2017; Amin et al., 2018; Căbăroiu et al., 2018a; 2018b).

The present study evaluated the influence of nitrogen and silicon, applied in different combinations, on quality indices in maize grains such as protein, starch, fat, fiber, ash and moisture.

MATERIALS AND METHODS

The study evaluated the influence of silicon and nitrogen, on some corn quality indexes. The research was carried out at SD Timişoara of USAMVB Timişoara, between 2017-2018.

Experimental variants

The biological material was represented by the Lovrin 400 maize hybrid.

Nitrogen, in the form of ammonium nitrate, was applied in the spring in doses ranging from 0 to 200 kg ha^{-1} with a graduation of 40 kg and resulted in the variants N0, N40, N80, N120, N160 and N200, respectively.

At each level of nitrogen fertilization, silicon (silicic acid) was applied in the concentrations: 0, 0.5%, 1.0%, 1.5% and 2%, respectively. The Si treatments have been applied foliar, in the main growth stage I: Leaf development BBCH Code (Maier, 2001); treatment I at 4 leaves, treatment II at 6-8 leaves and treatment III at 10 leaves respectively. The experience had 30 variants in three rehearsals.

Quality indices determined

Corn grain quality indices have been evaluated, such as starch (ST), protein (PRO), fat (FAT), and fiber (FIB). Moisture (MSTR) and ash (ASH) were also determined.

The determinations were made using non-destructive methods with the InfraXact, a high-performance analyzer working in the NIR, with the scanning range between 570 and 1850 nm.

Statistical analysis of the results

The relationship between the qualitative elements pursued as dependent variables and the production factors, as independent variables (Si and N), analyzed the efficiency of a model given by the relation (1).

$$f(N,Si) = a \cdot N^2 + b \cdot Si^2 + c \cdot N + d \cdot Si + e \qquad (1)$$

where: f represents, in turn, the dependent variables ASH/ST/PRO/FAT/FIB/MSTR; N - the independent variable defined by the nitrogen doses; Si - the independent variable defined by the amount of silicon.

Statistical determination of function coefficients was performed using the Past3_21 application (Hammer et al., 2001).

RESULTS AND DISCUSSIONS

The two nutrients N and Si, applied to maize, the Lovrin 400 hybrid, by ground fertilization (ammonium nitrate) and foliar fertilization (silicic acid), influenced the formation of grain quality indices, the values obtained are shown in Table 1.

The starch content (ST) ranged from 55.17 to 59.92% (V20), protein content (PRO) between 4.41% and 8.64% (V23), fat content (FAT) between 2.52% and 3.82 (V14), fiber (FIB) between 1.25% and 2.35 (V14, V19), ash (ASH) between 1.69% and 2.26% (V14), and humidity (MSTR) between 12.51% and 17.42% (V24).

Expression of protein content (PRO), as the dependent variable under the influence of nitrogen and silicon, by a model as type $f = (N,Si)$ indicated the strongest correlation (R^2 = 0.800) with $p < 0.001$. The expression of the function is given by the relation (2).

$$PRO = -0.00012 \cdot N^2 - 1.0786 \cdot Si^2 + 0.03465 \cdot N + 2.7175 \cdot Si + 3.6313 \qquad (2)$$

The values of the coefficients of the function (2) are statistically significant, each having $p < 0.001$. Were determined the N and Si values leading to a maximum of the PRO function, as extremes of the function of two variables, the relation (3).

$$\begin{cases} \partial PRO(N,Si)/\partial N = -0.00024 \times N + 0.0346 = 0 \\ \partial PRO(N,Si)/\partial Si = -2.1572 \times Si + 2.7175 = 0 \end{cases} \qquad (3)$$

Optimum values for independent variables were obtained, ie N = 144.4 kg ha^{-1} and Si = 1.26%, respectively. Graphical distributions of protein values in relation to Si and N are shown in Figure 1, respectively in Figure 2.

Figure 3 represents the optimal values for Si and N, through which the maximum values for protein content were obtained, under the experimental conditions.

Expression of fat content (FAT) estimated by the model $f = (N,Si)$ correlates strongly, R^2 = 0.763, with p<0.001.
However, in this relation the N factor (fertilizer) has a negligible contribution, the values of the coefficients a and c being very low, and not statistically assured. Thus, the expression of the function is given by the relation (4).

$$FAT = -1.79 \cdot 10^{-7} \cdot N^2 - 0.38619 \cdot Si^2 + 5.57 \cdot 10^{-5} \cdot N + 1.1294 \cdot Si + 2.6502 \quad (4)$$

The value of the silicon dose that led to a maximum of the FAT function (4) is given by the relation (5) and has the value of Si = 1.46%.

$$\delta FAT(N,Si) / \delta Si = -0.77238 \cdot Si + 1.1294 = 0 \quad (5)$$

No reference has been made to the optimal value of N due to the reduced contribution of this element for this index (FAT). In the case of the ST, ASH and FIB variables, the correlations were of medium intensity (0.4<R2 <0.5) and the MSTR correlation had a low intensity with respect to N and Si.

Table 1. Values of quality indices in maize, Lovrin 400 hybrid, influenced by N and Si

Trial	N (kg ha^{-1})	Si (%)	Ash (%)	ST (%)	PRO (%)	FAT (%)	FIB (%)	MSTR (%)
V1	0	0	1.69	57.31	4.41	2.87	1.25	15.24
V2	0	0.5	1.6	56.8	4.78	3.32	1.38	14.27
V3	0	1	1.73	56.13	4.84	3.39	1.42	14.35
V4	0	1.5	1.62	55.18	4.98	3.38	1.49	14.94
V5	0	2	1.77	56.81	4.72	3.25	1.47	14.51
V6	40	0	1.77	55.17	4.68	2.52	1.23	15.56
V7	40	0.5	1.91	57.27	6.49	3.05	1.62	14.23
V8	40	1	1.93	58	6.68	3.21	1.77	14.57
V9	40	1.5	2.04	59.21	6.74	3.61	1.94	14.72
V10	40	2	1.82	58.17	6.12	3.28	1.71	14.17
V11	80	0	1.54	55.29	4.81	2.58	1.14	13.4
V12	80	0.5	2.02	57.05	6.4	2.76	1.35	15.89
V13	80	1	2.11	58.12	6.51	3.19	1.6	15.49
V14	80	1.5	2.26	59.47	7.35	3.82	2.35	15.28
V15	80	2	2.14	59.37	6.36	3.41	1.72	14.75
V16	120	0	1.32	56.33	5.76	2.68	1.06	12.51
V17	120	0.5	2.03	56.74	6.21	3.22	1.54	16.42
V18	120	1	2.15	58.76	7.6	3.49	1.71	16.39
V19	120	1.5	2.24	59.41	8.05	3.58	2.35	17.06
V20	120	2	1.94	59.92	6.74	3.53	1.63	15.37
V21	160	0	1.38	56.47	6.74	2.77	1.65	13.98
V22	160	0.5	1.67	56.65	7.91	2.86	1.67	14.8
V23	160	1	1.66	57.15	8.64	3.26	1.69	14.44
V24	160	1.5	1.92	57.6	8.27	3.77	1.88	17.42
V25	160	2	1.42	57.43	7.66	3.2	1.3	13.81
V26	200	0	1.79	57.28	5.55	2.64	1.44	14.48
V27	200	0.5	1.77	57.38	5.93	3.29	1.5	15.28
V28	200	1	1.75	58.23	6.73	3.32	1.55	14.16
V29	200	1.5	1.63	58.55	7.24	3.51	1.7	13.72
V30	200	2	1.56	57.36	6.3	3.16	1.39	14.31
SE	-	-	± 0.045	± 0.232	± 0.213	± 0.064	± 0.053	± 0.193

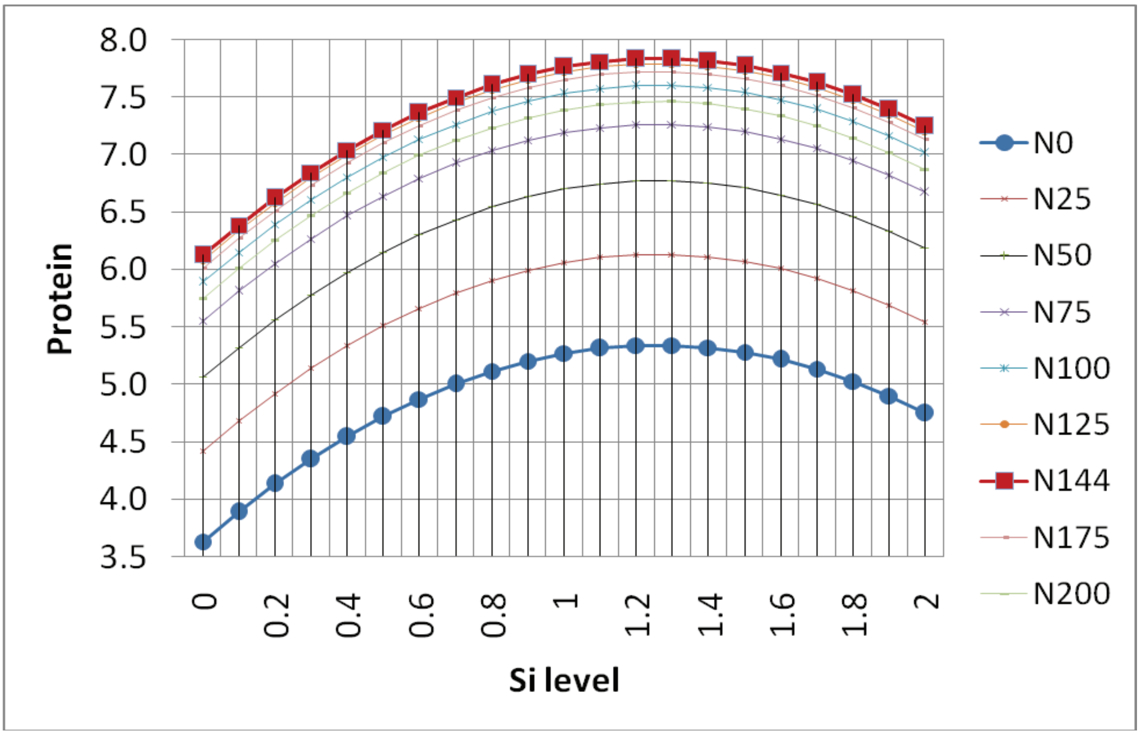

Figure 1. Graphic distribution of protein content (PRO) depending on Si concentration variation

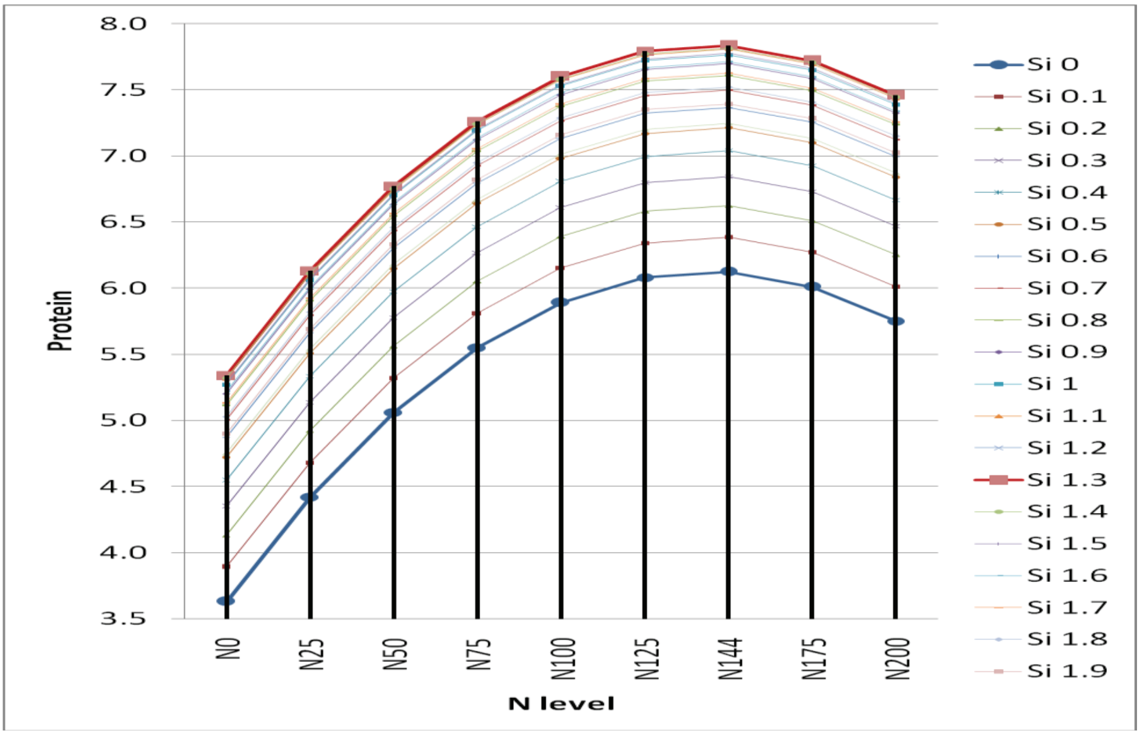

Figure 2. Graphical distribution of protein content (PRO) based on dose variation of N

The function (6) describing the variation of the ASH index by Si and N, and the function (7) describing the change in fiber content (FIB) in relation to the independent variables (N and Si) were obtained.

The coefficients of the function (6) are statistically safe but the contribution N to the ash content was negligible.

$$ASH = -2.67 \cdot 10^{-5} \cdot N^2 - 0.24238 \cdot Si^2 + 0.004744 \cdot N + 0.58576 \cdot Si + 1.5013 \quad (6)$$

For this reason the optimal value of this element (N) was not calculated and only the optimum value of the silicon level was determined, Si = 1.208%.

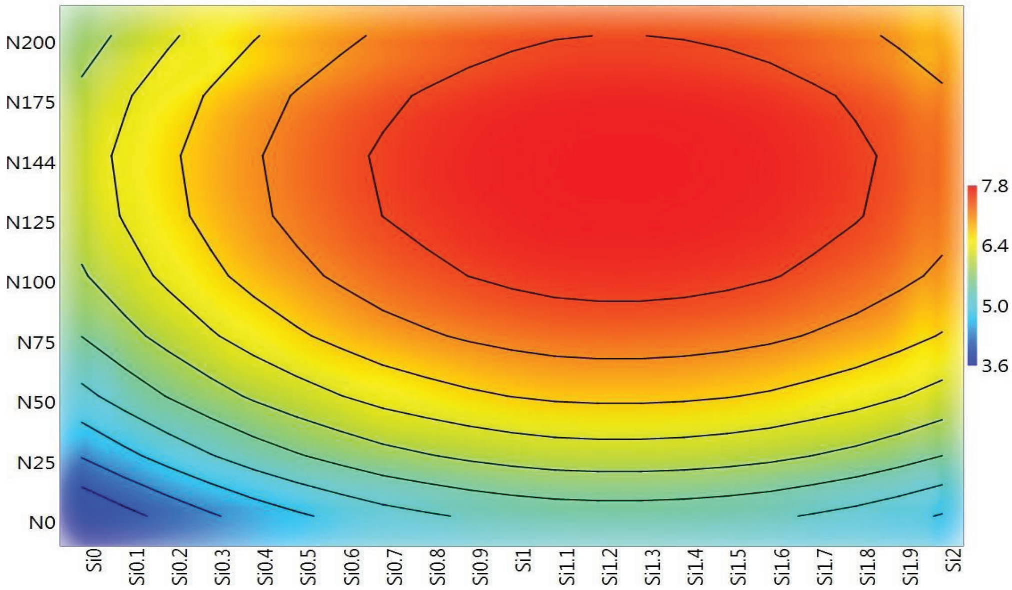

Figure 3. Graphical representation in the form of isoquants indicating the optimal values for Si and N to ensure protein content (PRO)

$$FIB = -2.08 \cdot 10^{-5} \cdot N^2 - 0.29857 \cdot Si^2 + 0.004548 \cdot N + 0.78214 \cdot Si + 1.0991 \quad (7)$$

The coefficients of the variable N in function (7) had negligible values and did not present statistical safety. The optimum value of silicon was obtained, Si = 1.309%.

The coefficient of variation (CV) indicated low values for ST (CV_{ST} = 2.2118), middle values for MSTR (CV_{MSTR} = 7.1332) and FAT (CV_{FAT} = 10.9137), and higher values for ASH (CV_{ASH} = 13.7839), PRO (CV_{PRO} = 18.3138) and, respectively, FIB (CV_{FIB} = 18.6018).

PCA analysis of experimental data against three higher quality indices (ST, PRO and FAT) led to the representation in Figure 4.

The association of V22, V23, V24, V25, V18 and v19 variants with the PRO index, and of V8, V9, V10, V13, V14, V15, V20, V28 and V29 variants with ST and FAT indices was found. PC1 (ST) explained 76.136% of variance, and PC2 (PRO) explained 21.798% of the variance.

Clustering analysis led to the dendrogram in Figure 5, which grouped the experimental variants (V1-V30) into three distinct clusters based on similarities expressed by Euclidean Distances, depending on the values of the PRO index.

The Cl cluster, with several sub-clusters, contains the variants with the lowest values for the PRO index (V1-V6, V11). Within this cluster, there were found similarities for PRO in variants [(V2-V11, V3)], (V5-V6), and V4 and V1 variants were placed on independent positions. The CII cluster, also with several sub-clusters, comprises 8 variants (V14, V18, V22-V25, V29). Within this cluster, a high degree of similarity was found in variants [(V14-V29), (V18-V25)], [(V19-V22), V24], and V23 was placed in the independent position. The CIII cluster comprises 15 variants grouped into three distinct sub-clusters: CIII-1 subgroup with variants [(V16-V27), V26]; subgroup CIII-2 with variants [((V9-V20-V21) V28), V8]; subgroup CIII-3 with variants [(V7-V13), ((V12-V15), V30)), (V10-V17)].

The clusterial classification based on the Euclidean distances showed a high degree of statistical safety, Coph. coef. = 0.780. The favorable influence of Si on certain physiological and quality indices in maize was also communicated by Abdel Latef and Tran (2016). Regarding the favorable influence of Si on the protein content, Soundararajan et al. (2014) have appreciated that Si plays an important role in the formation of specific proteins, by essentially contributing to the binding of amino acids. The favorable influence of Si on the leaf protein content of maize has been also reported by Moussa (2006).

Xu et al. (2016) have reported the favorable influence of silicon on sugar and starch content in maize, with statistical safety ($p<0.05$).

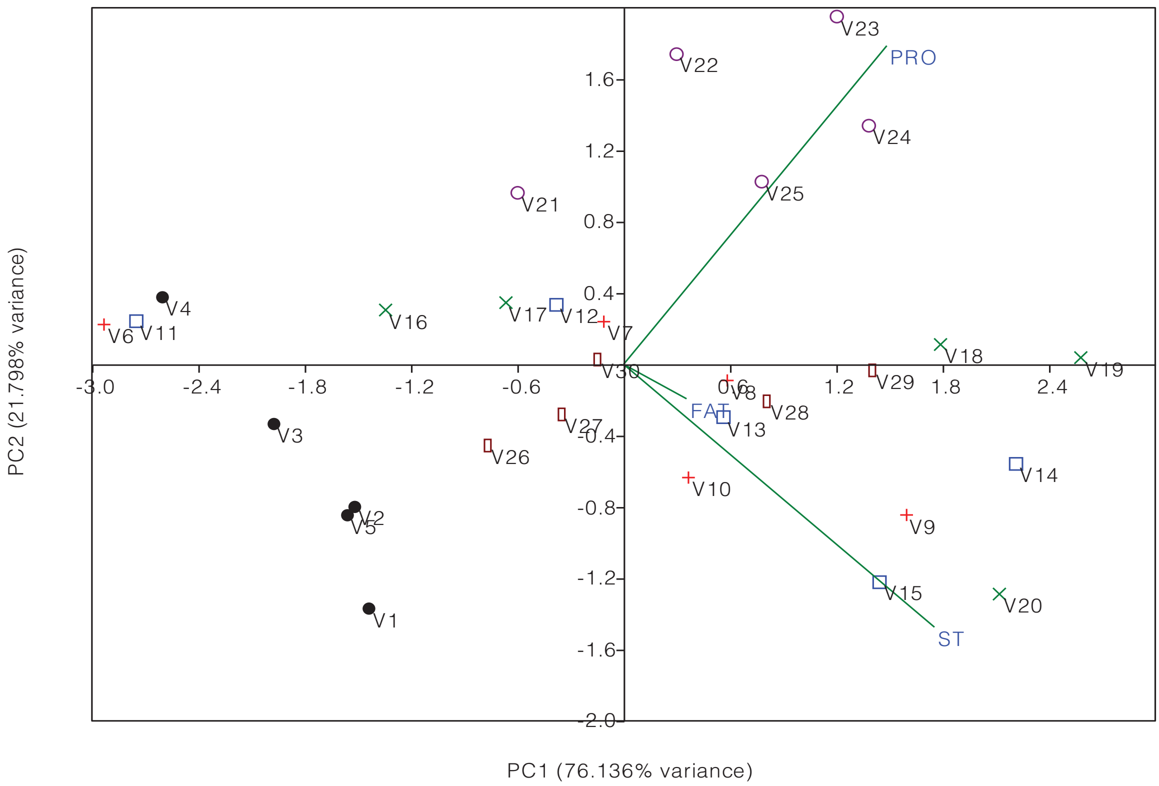

Figure 4. The PCA distribution of the cases studied (biplot PRO, FAT, ST) under the influence of independent variables (N, Si)

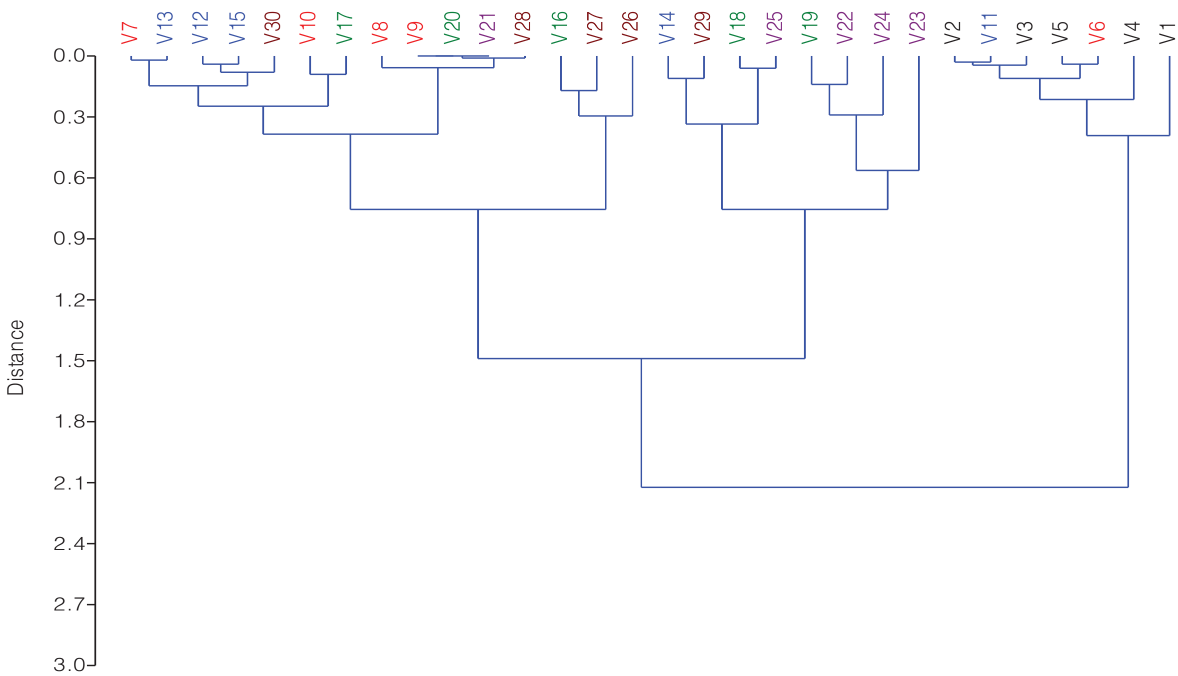

Figure 5. Clustering of variants based on Euclidean distances, depending on the values of the PRO index

An important role of Si on the absorption and phosphorus regime in maize was communicated by Meena and Malav (2016). The influence of Si in relation to calcium and potassium regime in plants, and in relation of wheat growth processes was communicated by Mali and Aery (2007), and an extensive study on the influence of Si on the absorption of nutrients in rice was reported by Chen et al. (2011).

Silicon has an active role in DNA formation and RNA functionality (Abbas et al., 2015).

Various benefits of silicon for agricultural crops have been communicated by Guntzer et

al. (2012), Habibi (2015), Karmollachaab and Gharineh (2015), Malčovská et al. (2014a; 2014b). In the context of climate change, and water stress times associated with high temperature, the favorable influence of silicon on maize was recorded by Amin et al. (2018).
The results communicated by this study are in line with recent research on the influence of silicon on crop plants and on quality indices.

CONCLUSIONS

Nitrogen and silicon have influenced favorably PRO, FAT, FIB in maize grains, the Lovrin 400 hybrid, in safe statistical conditions. Also, variations in Ash and Moisture (MSTR) were recorded in maize grains, but in low correlation conditions.
The statistical analysis facilitated finding the optimum N dose at 144.4 kg ha^{-1} and the optimal Si concentration at 1.16% for the PRO index at the Lovrin 400 hybrid.
The PCA analysis identified the association of fertilization variants (N×Si type) with the PRO index and other variants (N×Si type) with the ST and FAT quality indices. PC1 (ST index) explained 76.136% of the variance, and PC2 (PRO index) explained 21.798% of the variance.
Clusterial analysis has led to the formation of affinity-based variation groups, based to the PRO index values determined by N and Si treatments, which are of practical importance in the management of maize fertilization.

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