Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 23, Issue 1, 2023
PRINT ISSN 2284-7995, E-ISSN 2285-3952

ELEMENTS OF PRODUCTIVITY AND PRODUCTION QUALITY IN PEPPERS IN RELATION TO THE VARIETY AND APPLIED FERTILIZATION

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Abstract

The variation of some parameters of flowering, fruiting, and pepper production, in relation to the fertilization system, was evaluated. The study took place in the area of Cuied Locality, Arad County, Romania. The experiment was in a protected system, modular solar, the summer-autumn crop cycle, year 2020, with a specific technology. Two long pepper varieties of the Kapia type were cultivated (Dumbo 34 - D 34; Elephant's Ear - EE). Three products were used for fertilization, BioHumusSol (BHS), Cropmax (CroM) and Bionat (BioN), together with a control variant (C). The number of pollinated and fertilized flowers per plant (pff) varied between 5.00±0.35 (EE C) and 8.60±0.41 (D34 CroM), and the number of fruits per plant (FruNP) varied between 5.00±0.32 (EE C) and 8.00±0.49 (D34 CroM). The average fruit weight (FaW) varied between 83±13.30 g (D34 C) and 274±22.7 g (EE CroM). The average fruit production per plant (ApP) varied between 0.580±0.13 kg plant^{-1} (D34 C) and 1.920±0.20 g plant^{-1} (EE CroM). Quality I production (YQ1, %) varied between 10.20% (S34 C) and 76.00% (EE CroM), and quality II production (YQ2, %) varied between 24.00% (EE CroM) and 89.80% (D34 C). According to PCA, PC1 explained 68.383% of variance, and PC2 explained 28.917% of variance in relation to flowering and fruiting parameters; PC1 explained 65.489% of variance, and PC2 explained 34.28% of variance in relation to productivity and production parameters, respectively PC1 explained 61.09% of variance, and PC2 explained 38.91% of variance in relation to production quality. The regression analysis facilitated to describe the variation of production by quality classes (YQ1) in relation to productivity parameters.

Key words: *fertilizers, modeling, PCA, peppers, production quality*

INTRODUCTION

Within the vegetable plants, pepper (*Capsicum* spp. L.) is of particular interest due to the great diversity of genotypes, with high ecological plasticity, which makes it possible to cultivate it in different areas around the globe, in different culture conditions (open field, protected areas, pots, etc.) [10].
Pepper (*Capsicum* spp. L.) is one of the oldest plants cultivated by humans, and it originates in the tropical and subtropical areas of Central and South America [27, 41]. There are mentioned approx. 43 species within the genus Capsicum, and a diverse group of types (sweet peppers, hot peppers, etc.), used in food since ancient times, and today they show high importance from a commercial and food perspective, but also phytopharmaceutical or other purposes, etc. [5, 15, 22, 26].
Pepper has been studied from a food resource perspective [14, 25], or different active principles with use in pharmacy and medicine, but also as an ornamental plant or other uses [7, 35, 38].
From the perspective of pepper cultivation for food purposes, the relationships of plants have been studied with climatic conditions, especially with temperatures [1, 16, 23], with the soil, and soil-related factors [4, 18, 24], with fertilizer resources [17, 20, 40], with water regime [13, 31], with different biotic and abiotic stress factors [2, 3, 26]. For the quick and non-destructive evaluation of some symptoms at leaf level, regarding pathogens, imaging analysis is an accessible and easy-to-use method [8, 12].
Pepper has high ecological and technological plasticity and has been studied both under classic culture conditions, on soil, as well as

on substrates and artificial growth media, in hydroponic systems, for which growth system appropriate technologies are developed [34].

Different quality indices have been studied in relation to the growing conditions and the destination of pepper production [9, 19].

The present study analyzed the variation of indices and parameters of flowering, fruiting, productivity, production and quality in two long pepper varieties of the Kapia type, in relation to the fertilization system applied.

MATERIALS AND METHODS

The study evaluated fruit quality variation in pepper (*Capsicum annuum* L.). The study took place in the area of Cuied Locality, Arad County, Romania.

The experiment was organized in protected conditions, modular solar system, the summer -autumn crop cycle year 2020. An appropriate technology was provided for the long pepper culture, in a protected space conditions.

Two long pepper varieties of the Kapia type were studied, respectively Dumbo 34 (D 34) and Elephant's Ear (EE). Three products were used for fertilization, BioHumusSol (BHS), Cropmax (CroM) and Bionat (BioN), along with a control variant (C). The experiment was organized in three repetitions. Eight experimental variants resulted from the combination of the varieties and the fertilizers used (Table 1).

Table 1. Experimental variants of long pepper, Kapia type

Experimental variants		
Treatment	Cultivar	Variant Code
Control	Elephant's Ear	EE C
	Dumbo 34	D34 C
BioHumusSol	Elephant's Ear	EE BHS
	Dumbo 34	D34 BHS
Cropmax	Elephant's Ear	EE CroM
	Dumbo 34	D34 CroM
Bionat	Elephant's Ear	EE BioN
	Dumbo 34	D34 BioN

Source: Original data.

Parameters were analyzed: Flowering and fruiting parameters – Ffp (flowers number on the plant – FloNP; pollinated and fertilized flowers – pff; aborted flowers – af; fruits number on plant - FruNP), and Productivity, production and quality parameters – Ppqp (Fruit average weight – FaW; Average production on plant – ApP; production per surface unit – Y; production by quality classes I and II – YQ1, YQ2). For the comparative analysis of the results, average values per variety (Average by variety) and per experiment (Experiment average) were calculated.

The fruits were harvested at maturity for consumption and use (Photo 1), from the beginning of September to the end of October - beginning of November.

Photo 1. Kapia long pepper from the experiment, at the time of harvest
Source: Original image.

The experimental data regarding the parameters proposed in the study were recorded and processed appropriately, under a mathematical and statistical aspect.

In order to quantify the differentiated response of the pepper varieties studied, in relation to fertilization, based on the determined parameters; PCA analysis, Cluster analysis and Regression analysis were performed.

The ANOVA test was used to evaluate the reliability of the data and the presence of variance in the data set. Adequate statistical safety parameters were considered for the safety of the results of the analysis made [11].

RESULTS AND DISCUSSIONS

The two pepper varieties, Elephant's Ear (EE) and Dumbo 34 (D 34), responded differently to the applied fertilization, and the values of the flowering parameters, of the fruiting parameters and of the recorded production, by quality classes (Q1, Q2), are presented in Tables 1 and 2.

Table 1. Flowering and fruiting parameters in peppers under the influence of experimental variants

Experimental variants			FloNP			FruNP
Treatment	Cultivar	Variant Code	TFN	pff	af	
Control	Elephant's Ear	EE C	9.50±0.19	5.00±0.35	4.50±0.49	5.00±0.32
	Dumbo 34	D34 C	10.50±0.31	8.30±0.41	2.20±0.19	7.00±0.49
BioHumusSol	Elephant's Ear	EE BHS	9.00±0.19	6.80±0.35	2.20±0.49	6.00±0.32
	Dumbo 34	D34 BHS	9.20±0.31	7.00±0.41	2.20±0.19	7.00±0.49
Cropmax	Elephant's Ear	EE CroM	9.00±0.19	7.00±0.35	2.00±0.49	7.00±0.32
	Dumbo 34	D34 CroM	9.40±0.31	8.60±0.41	1.20±0.19	8.00±0.49
Bionat	Elephant's Ear	EE BioN	10.00±0.19	6.00±0.35	4.00±0.49	6.00±0.32
	Dumbo 34	D34 BioN	8.60±0.31	6.40±0.41	2.20±0.19	6.00±0.49
Average by variety	Elephant's Ear		9.38±0.19	6.20±0.35	3.18±0.49	6.00±0.32
	Dumbo 34		9.43±0.31	7.58±0.41	1.95±0.19	7.00±0.49
Experiment average			9.40±0.15	6.89±0.31	2.56±0.29	6.50±0.31

Sources: Original data from the experiment.

Table 2. Productivity, production and quality parameters in peppers under the influence of experimental variants

Experimental variants			FaW	ApP	Y	YQ1		YQ2	
Treatment	Cultivar	Variant Code	g piece^{-1}	kg plant^{-1}	kg ha^{-1}	kg ha^{-1}	%	kg ha^{-1}	%
Control	Elephant's Ear	EE C	141±22.7	0.705±0.20	31725	4631	14.60	27094	85.40
	Dumbo 34	D34 C	83±13.30	0.580±0.13	26100	2662	10.20	23438	89.80
BioHumusSol	Elephant's Ear	EE BHS	181±22.7	1.140±0.20	51300	26317	51.30	24983	48.70
	Dumbo 34	D34 BHS	125±13.30	0.880±0.13	39600	25186	63.60	14414	36.40
Cropmax	Elephant's Ear	EE CroM	274±22.7	1.920±0.20	86400	65664	76.00	20736	24.00
	Dumbo 34	D34 CroM	157±13.30	1.405±0.13	63225	36544	57.80	26681	42.20
Bionat	Elephant's Ear	EE BioN	227±22.7	1.360±0.20	61200	39352	64.30	21848	35.70
	Dumbo 34	D34 BioN	154±13.30	0.925±0.13	41625	22436	53.90	19189	46.10
Average by variery	Elephant's Ear		205.75±22.7	1.280±0.20	57656.25	33991	51.55	23665.25	48.45
	Dumbo 34		129.75±13.30	0.948±0.13	42637.5	21707	46.38	20930.5	53.62
Experiment average			167.75±17.60	1.114±0.12	50146.88	27849	48.96	22297.88	51.04

Sources: Original data from the experiment.

The total number of flowers per plant (TFN) varied between 8.60±0.31 (D34 BioN) and 10.50±0.31 (D34 C). The number of pollinated and fertilized flowers per plant (pff) varied between 5.00±0.35 (EE C) and 8.60±0.41 (D34 CroM). The number of aborted flowers per plant (af) varied between 1.20±0.19 (D34 CroM) and 4.50±0.49 (EE C). The number of fruits per plant (FruNP) varied between 5.00±0.32 (EE C) and 8.00±0.49 (D34 CroM).

In the case of productivity and production elements, the average fruit weight (FaW) varied between 83±13.30 g (D34 C) and 274±22.7 g (EE CroM). The average fruit production per plant (ApP) varied between 0.580±0.13 kg plant^{-1} (D34 C) and 1.920±0.20 g plant^{-1} (EE CroM). Quality I production (YQ1, %) varied between 10.20% (S34 C) and 76.00% (EE CroM), and quality II production (YQ2, %) varied between 24.00% (EE CroM) and 89.80% (D34 C).

The ANOVA test confirmed the reliability of the experimental data and the presence of variance in the data set, on the two evaluated parameter categories, Flowering and fruiting parameters (Ffp), Productivity, production and quality parameters (Ppqp), Table 3 (Alpha=0.001).

Table 3. ANOVA test

Source of Variation	SS	df	MS	F	P-value	F crit
	Flowering and fruiting parameters (Ffp)					
Between Groups	264.1186	3	88.03953	106.7126	3.97E-19	6.59454
Within Groups	33.00063	40	0.825016			
Total	297.1192	43				
	Productivity, production and quality parameters (Ppqp)					
Between Groups	2.58E+10	6	4.3E+09	51.15377	1.15E-23	4.27529
Within Groups	5.88E+09	70	83965601			
Total	3.16E+10	76				

Source: Original data.

In order to find out the distribution and association of variants (variety and fertilization) with determined parameters, PCA analysis was used.

In relation to flowering and fruiting parameters (Ffp), the PCA analysis led to the diagram in Figure 1, in which the association of some variants with studied parameters was observed (eg D34 C variant with the FloNP parameter, D34 CroM variant with pff and FruNP parameters; the variants EE BioN and EE C with the af parameter - in the case of the two variants, the highest number of aborted flowers was recorded). PC1 explained 68.383% of variance, and PC2 explained 28.917% of variance.

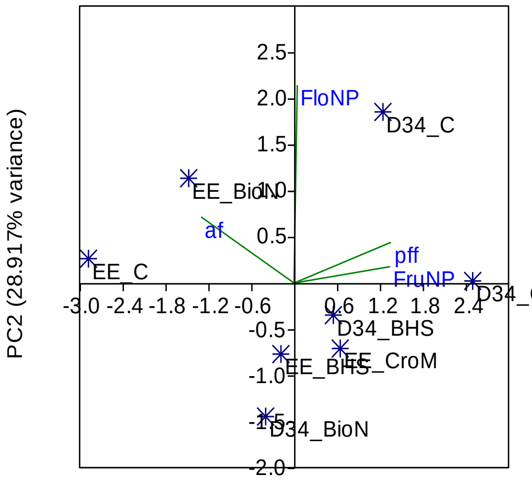

Fig. 1. PCA diagram in relation to flowering and fruiting parameters (Ffp)
Source: Original figure

The cluster analysis in relation to flowering and fruiting parameters (Ffp) led to the dendrogram in Figure 2, in which the variants were grouped on the basis of similarity in relation to the determination of the values of the considered parameters, under conditions of statistical safety (Coph.corr.= 0.810).

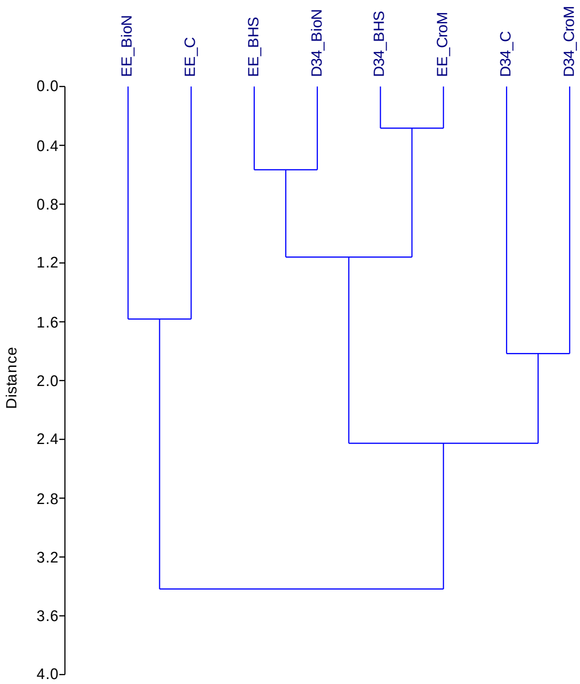

Fig. 2. Dendrogram generated by cluster analysis in relation to flowering and fruiting parameters (Ffp)
Source: Original figure.

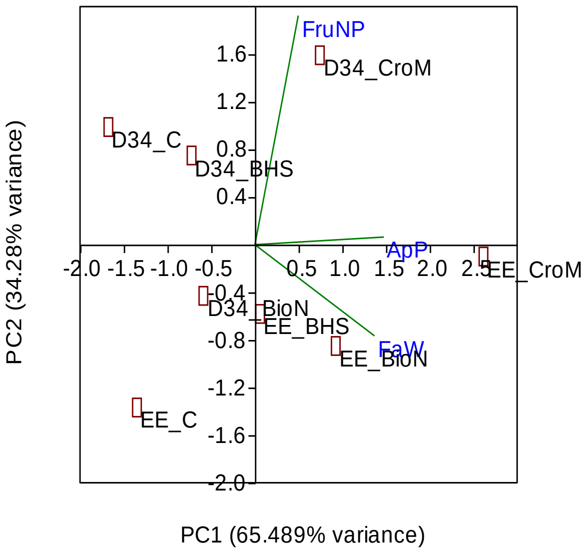

Fig. 3. PCA diagram in relation to productivity, production per plant parameters
Source: Original figure.

The formation of two distinct clusters was found. A C1 cluster that includes the variants EE C and EE BioN, with a high number of aborted flowers (af). Cluster C2 included the other variants, grouped into two sub-clusters.

The highest level of similarity was recorded between the D34 BHS and EE CroM variants (SDI=0.2828).

According to PCA, in relation to productivity and production per plant parameters, the diagram in Figure 3 was generated, in which PC1 explained 65.489% of variance, and PC2 explained 34.28% of variance.

The resulting diagram showed the association of the D34 CroM variant with the FruNP parameter, the association of the EE CroM variant with the ApP parameter, and the association of the EE BioN variant with the FaW parameter. It was also found the independent positioning of some variants in relation to the considered parameters (eg. variant D34 C, variant D34 BHS).

The cluster analysis, in relation to productivity and production per plant parameters, led to the dendrogram in Figure 4, under statistical safety conditions (Coph.corr. =0.817).

Within a cluster (C1) the variants EE CroM and EE BioN were associated with high values for the FaW parameter (average fruit weight, g). The highest level of similarity was recorded between the variants D34 CroM and D34 BioN (SDI=3.6374).

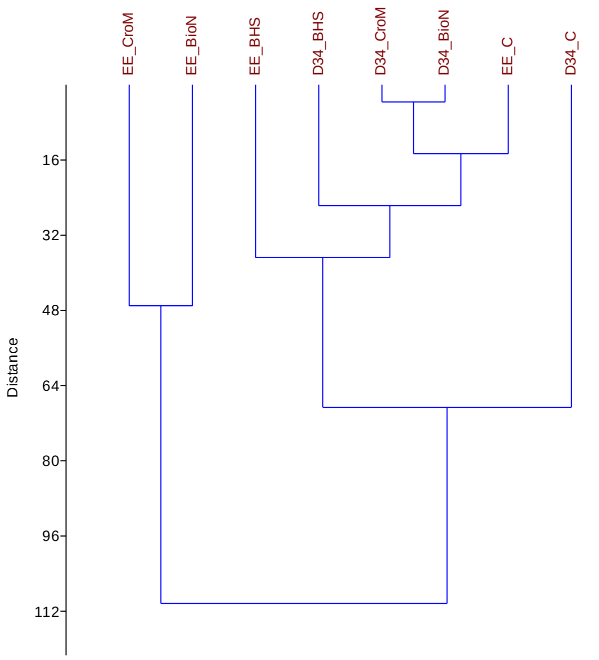

Fig. 4. Dendrogram generated by Cluster analysis in relation to productivity and production per plant parameters
Source: Original figure.

In relation to production quality (Q1 and Q2, physical values), the PCA analysis generated the diagram in Figure 5, in which PC1 explained 61.09% of variance, and PC2 explained 38.91% of variance. In the resulting diagram, the distinctive association with the Q1 quality (as biplot) of the EE CroM variant was found. The EE BHS variants of the D34 CroM were associated with the Q2 quality (as biplot).

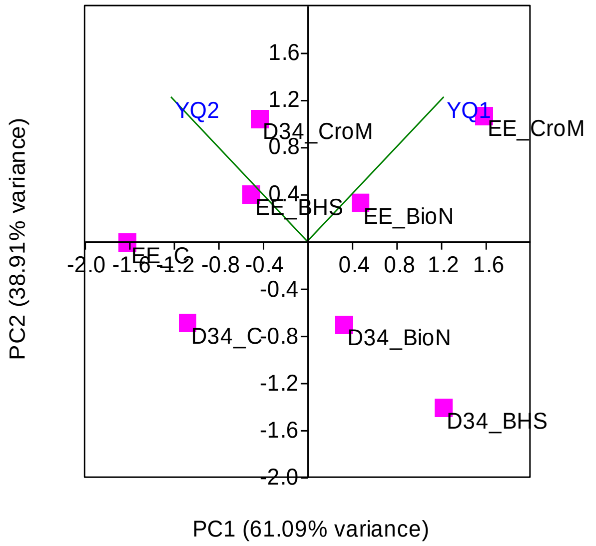

Fig. 5. PCA diagram in relation to the quality of pepper production, given by the experimental variants
Source: Original figure.

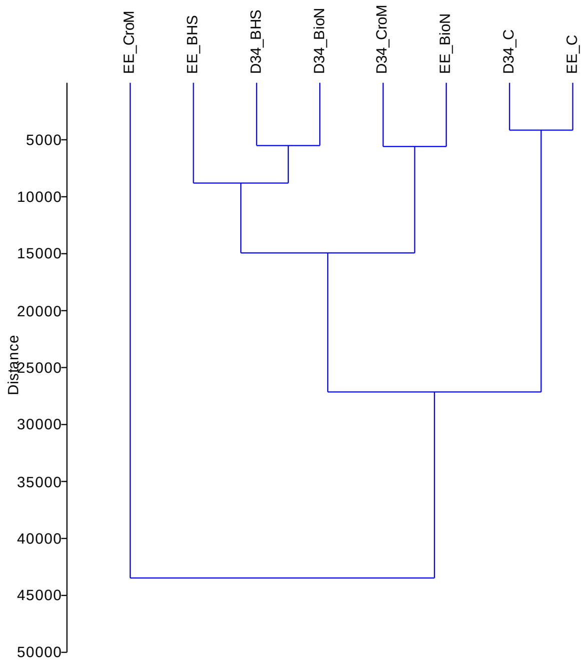

Fig. 6. Dendrogram generated by Cluster analysis in relation to the quality of pepper production (YQ1, YQ2, physical values)
Source: Original figure.

The clus The other experimental variants presented a lower affinity, or were positioned independently compared to the two parametric quality ones (Q1 and Q2, as biplot).

The cluster analysis of the data in relation to the production quality (YQ1 and YQ2, physical values) led to the dendrogram in Figure 6 (Coph. corr.=0.862). The independent positioning of the EE CroM variant with a high value for the physical production of pepper was found, and the other variants were associated within a separate cluster, with several sub-clusters.

ter analysis in relation to the quality of YQ1 pepper production (percentage values) led to the dendrogram in Figure 7 (Coph. corr. = 0.955). The positioning of the variants was found in relation to the degree of similarity for the generation of YQ1 quality fruit (% of total fruit production). Within a C1 cluster, the D34 C and EE C variants were positioned with a low percentage level in the formation of Q1 quality fruits.

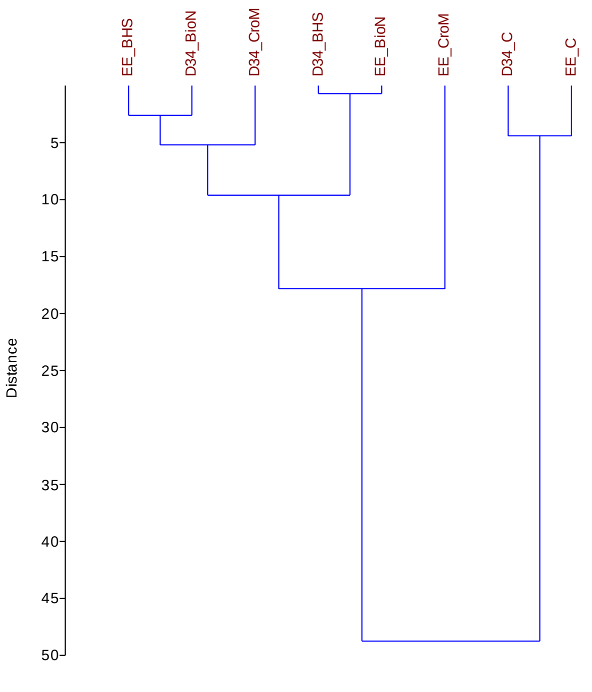

Fig. 7. Dendrogram generated by Cluster analysis in relation to the quality of pepper production (YQ1, percentage values)
Source: Original figure.

The other variants were positioned in a C2 cluster, in several sub-clusters. Meanwhile, the EE CroM variant with the highest percentage of YQ1 quality fruits from the total production (76%) was positioned in the C2 cluster, and the other variants were positioned according to the degree of similarity. The highest level of similarity was recorded between the D34 BHS and EE BioN variants (SDI=0.7).

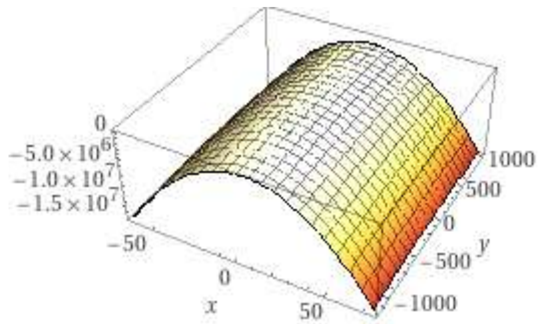

Fig. 8. 3D representation of the variation of pepper production, quality I (YQ1), in relation to FruNP (x-axis) and FaW (y-axis) parameters
Source: Original figure.

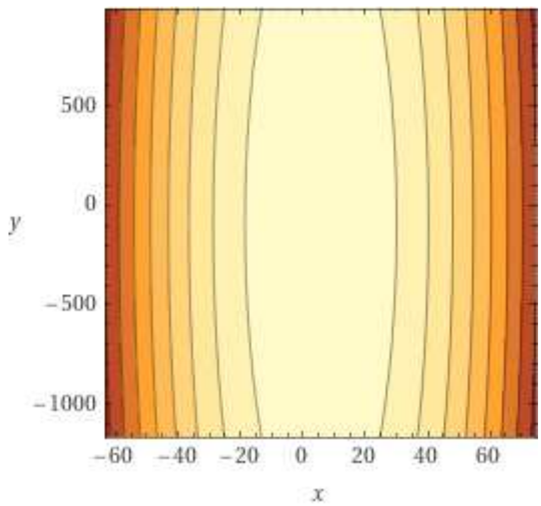

Fig. 9. Representation in the form of isoquants of the variation of pepper production, quality I (YQ1), in relation to FruNP (x-axis) and FaW (y-axis) parameters
Source: Original figure.

Through the regression analysis, it was analyzed how determined parameters and productivity elements contributed to the formation of pepper production (quality I, YQ1 was considered in the analysis).

The variation of pepper production, YQ1, in relation to FruNP and FaW was described by equation (1), under conditions of R^2=0.991, p=0.0215, Ftest=45.6614. The graphic distribution in 3D form and in the form of isoquants of YQ1 production in relation to FruNP (x-axis) and FaW (y-axis) is presented in Figure 8 and 9.

$$YQ1 = ax^2 + by^2 + cx + dy + exy + f \quad (1)$$

where: YQ1 – pepper production, quality I (YQ1);
x – fruits number on the plant (FruNP);
y – fruit average weight (FaW);
a, b, c, d, e, f – coefficients of the equation (2);
a= -3342.78077776;
b= -0.66500979;
c= 38387.90471968;
d= -119.63518237;
e= 97.11309785;
f= -142767.44321

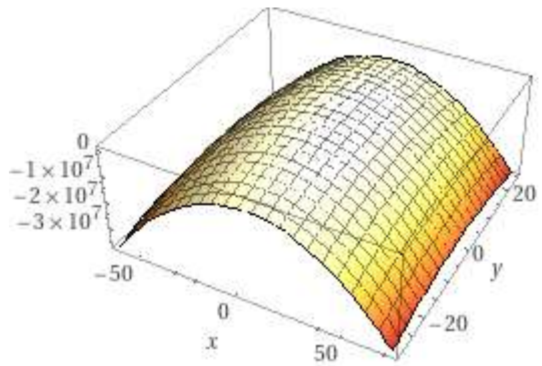

Fig. 10. 3D representation of the variation of pepper production, quality I (YQ1), in relation to FruNP (x-axis) and ApP (y-axis) parameters
Source: Original figure.

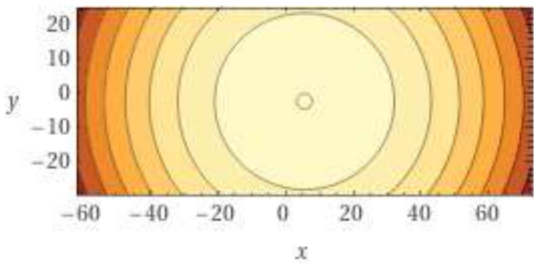

Fig. 11. Representation in the form of isoquants of the variation of pepper production, quality I (YQ1), in relation to FruNP (x-axis) and ApP (y-axis) parameters
Source: Original figure.

The variation of pepper production, YQ1, in relation to FruNP and ApP was described by equation (2), under conditions of R^2=0.983, p=0.0421, F test = 23.0799. The graphic distribution in 3D form and in the form of isoquants of YQ1 production in relation to FruNP (x-axis) and ApP (y-axis) is presented in Figure 10 and 11.

$$YQ1 = ax^2 + by^2 + cx + dy + exy + f \quad (2)$$

where: YQ1 – pepper production, quality I (YQ1);
x – fruits number on the plant (FruNP);
y – average production on plant (ApP)
a, b, c, d, e, f – coefficients of the equation (2);
a= -7171.59275;
b= -7491.81907;
c= 80016.74802;
d= -34453.02839;
e= 14079.11056;
f= -238720.24343

Fertilizers represent important inputs for plant production, and the properties of fertilizers make the effect of fertilization on plant production (quantitative and qualitative) to be different [30, 39].

At the same time, crop plants, and especially vegetables, due to the great diversity of cultivated species and genotypes, the different growth systems and technologies, as well as in relation to the vegetation stages, have different requirements for nutrients, in direct relation to the quantity and production quality [6, 21, 28, 30, 32].

Therefore, studies and experiments with fertilizers are always up-to-date in order to find the balance between genotype (through its specificity), fertilization (an important component of culture technology), the level and quality of production (the product of the agricultural technological process), but also the impact on the environment [6, 21, 29, 32].

The quality of pepper production in relation to the fertilization system (different fertilizers, nutrients, application techniques) was communicated in some studies. Lu et al. (2021) [20] reported in their study the significant improvement of the yield, but the reduction of the nutritional quality of pepper fruits by magnesium fertilization.

The share of pepper production by quality classes in relation to fertilization (vermicompost, solarized manure, and inorganic NPK) was reported by Valenzuela-Garcia et al., 2019 [36], and the authors reported a share of 60% in Second-Class Quality , and 25% in First-Class Quality.

The efficiency of the use of nutrients (especially N) was also studied in pepper culture, in relation to different fertilizing resources, genotypes, conditions and culture technologies. Silva et al. (2020) [33] reported a decrease in NUE (nitrogen use efficiency) and an increase in the concentration of nitrates in the substrate with an increase in the rate of

N from fertilizers under the study conditions (N rates: 0, 1.5, 3.0, 4.5, 6.0 and 7.5 g plant^{-1}). The efficiency of N use (four doses) in relation to the watering regime (four levels of irrigation) was studied in greenhouse conditions, and the authors reported the decrease of partial factor productivity of nitrogen (PFPN) in relation to the increase of nitrogen application rate, as well as the initial increase followed by the decrease when it was also associated with the watering regime [37].
The results communicated through the present study fall within the interest for the optimization of pepper culture technology through fertilization in relation to the cultivated genotypes, in order to obtain productions in higher classes of quality and economic efficiency.

CONCLUSIONS

The two long pepper varieties, of the Kapia type (Elephant's Ear and Dumbo 34), utilized the applied fertilizer resources differently.
This was quantified by Flowering and fruiting parameters (Ffp), respectively by Productivity, production and quality parameters (Ppqp).
PCA analysis and cluster analysis (CA) facilitated the distribution, association and grouping of the variants given by the 'genotype x fertilizer' combination in relation to the response quantified by the values of each analyzed parameter. Thus, within the PCA, PC1 explained 68.383% of variance, and PC2 explained 28.917% of variance in relation to flowering and fruiting parameters; PC1 explained 65.489% of variance, and PC2 explained 34.28% of variance in relation to productivity and production parameters, respectively PC1 explained 61.09% of variance, and PC2 explained 38.91% of variance in relation to quality parameters. Within the CA, the variants were grouped into clusters based on similarity in the generation of the values of the analyzed parameters, under conditions of statistical safety.
The regression analysis facilitated the obtaining of models in the form of equations, as well as graphic models (3D and in the form of isoquants) that described the variation of the production of quality I (YQ1) in relation to the productivity parameter at the plant level.
The obtained results are of scientific interest but also for horticultural practice, as they facilitate the highlighting of the 'variety × fertilizer' combinations that have led to significant results, under conditions of statistical certainty.

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