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ELEMENTS OF PRODUCTIVITY IN TOMATO PLANTS IN RELATION TO FOLIAR FERTILIZATION

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Abstract

The study evaluated productivity elements in tomato plants in relation to foliar fertilization. 'Beldine F1', 'Sandoline F1', 'Ciciu F1' and 'Izmir F1' tomato hybrids were grown. Foliar fertilization was done with the Bionat product. In relation to the specifics of each hybrid and the applied fertilization, the variation of some physiological and productivity parameters was recorded: plants height, Ph=179.80-203.60 ± 2.73 cm; inflorescence number, In=7.50-8.50 ± 0.12; flower number, Fn = 5.20-6.70 ± 0.17; fecundated flower, Ff = 4.60-6.20 ± 0.20; fruit number in bunches, Fnb = 4.60-6.20 ± 0.20; average bunch weight, Abw = 0.53-0.90 ± 0.05 kg; fruits number on plant, Fnp = 35.50-50.80 ± 2.12; average fruit weight, Afw = 0.12-0.16 ± 0.01 kg; average plant production, App = 4.17-7.33 ± 0.42 kg. Based on the coefficient of variation, high variability was recorded in the case of the App parameter (CV = 20.79140) and low variability in the case of the Ph parameter (CV = 3.95331). According to PCA, the distribution diagrams of variants were generated in relation to flowering parameters (PC1 explained 80.696% of variance, and PC2 explained 18.566% of variance) and in relation to fruiting parameters (PC1 explained 83.685% of variance, and PC2 explained 15.523% of variance).

Key words: *fecundated flowers, inflorescence number, multicriteria analysis, Pearson's correlation, prediction models.*

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) represent one of the most important horticultural species in the whole world, both in the production sector and in the agri-food and service chain (Tagiakas et al., 2022; Wako and Muleta, 2023). Tomatoes are cultivated plants, in the category of vegetables, cultivated both in protected spaces (greenhouses and solariums) and in the open field, with a major role in human nutrition (Bihon et al., 2022).

Tomatoes are characterized by a wide range of genotypes, among which F1 hybrids (commercial hybrids) predominate for crop, as a result of the advantages they offer (Hoza et al., 2022; Tagiakas et al., 2022). However, local germplasm (traditional plant populations) is also of interest as a result of some qualitative advantages of the fruits and some traditional cultivation systems, with socio-economic and ecological values. Tagiakas et al. (2022) compared several local tomato breeds (Greek) with commercial hybrids, and reported comparable results of the productivity indices and especially of the quality indices with the values recorded in the commercial hybrids. Although there are many cultivated genotypes, improving the yield and quality of the fruits is a permanent concern (Bihon et al., 2022).

Tomatoes have high specific nutritional requirements, and in order to optimize fertilization, different studies were done with mineral and organic mineral and biostimulant resources, with soil application, through fertigation, or foliar. Suchithara et al. (2022) reported favorable results for the use of microalgae in tomatoes, with variations in efficiency in relation to the application method. The authors of the study communicated the increase in the content of mineral elements in the fruits, and highlighted the option of fertilization with micoalge associated with manure.

The effects of mineral fertilization were analyzed in relation to the advantages on crops and yields in food production, and the side effects on the environment (Chaudhary et al., 2022). Vermicompost has been tested as an alternative to chemical fertilizers for adding nutrition to tomatoes (Qasim et al., 2023). Mixed fertilization, vercompost and mineral fertilizers, facilitated the reduction of the dose of chemical fertilizers. The authors of the study recorded better values for biometric parameters and physiological indices in plants, also for productivity elements, and fruit quality indices. The physical and chemical properties of the soil also registered a significant improvement, according to the authors.

Tomato production, fruit quality and tomato cultivation performance were studied in relation to the use of vermicompost in the plant culture system (Wako and Muleta, 2023). In the conditions of the study, the authors found variable profitability, often reduced in tomato crop as a result of limitations given by fertilizer resources, the level of training of growers and access to inputs. Analyzing the influence of vermicompost, the authors of the study highlighted positive aspects on the properties of the soil and in tomato crop, in terms of yield, fruit quality, with benefits for sustainable agriculture.

Biofertilizers find more and more use in horticultural practices, as a result of supporting crop productivity and a more environmentally friendly effect (Ammar et al., 2023). The use of biofertilizers is increasingly promoted within innovative, environmentally friendly technologies, increasingly promoted in the context of sustainable agriculture (Kumar et al., 2021).

In relation to tomato irrigation, as a component of culture technologies, the watering regime was studied to optimize the volume of water and the way the plants grow (Ahmad et al., 2023). Based on the data recorded regarding plant parameters, production and certain quality indices, the authors of the study identified the growth system and the watering regime in the appropriate variants for the tomato culture, in the specific study conditions.

Elements of productivity, yield and quality in tomatoes were studied in relation to the technique and watering regime, in order to optimize the use of water in arid and semi-arid areas (Mukherjee et al., 2023). The productivity of tomato crops was analyzed in relation to different categories of factors in order to optimize the production process and the profitability of farmers (Asfaw, 2021). The author used different sources of data collected from growers through appropriate sampling and statistical processing techniques, and the results provided information on the categories of factors and how they affected the productivity of the tomato crop. The productivity of the tomato crop was also analyzed in relation to the category of small farmers in relation to culture and marketing practices, in order to identify the constraints that affect farmers and formulate solutions (Nyalugwe et al., 2022). The study was based on the collection of data and information by questioning a significant number of respondents (farmers and input suppliers). The study provided results that led to the identification of some main categories of constraints that affected the productivity of the tomato crop under the study conditions, and facilitated the formulation of support solutions.

Productivity, fruit quality and profitability in tomatoes was studied in relation to fertilizer resources and crop variants with mulching and without mulching (Velza et al., 2023). The authors of the study recorded the variation of plant biometrics, the number of fruits and the quality of the fruits and the yield in relation to the type of fertilizer and culture technology.

The appropriate sources and elements were analyzed to optimize the tomato production process, especially for small farmers, in relation to tomato processors for the purpose of technical efficiency in the production chain, with efficiency for both components, producers - processors (Čechura et al., 2021).

In order to optimize tomato cultivation technologies, reduce the impact on the environment and sustainable production of food resources, comparative studies were made between tomato cultivation in the greenhouse and in the open field (Maureira et al., 2022). The authors of the study used simulation procedures and identified the impact of the two culture variants (greenhouse, open field) on some categories of inputs and environmental elements, with recommendations for reducing energy consumption and the use of clean energy resources.

Tomato cultivation technology was studied based on elements specific to intelligent agriculture (IoT elements) and precision agriculture, in order to monitor the water regime and optimize the watering regime of plants (Singh et al., 2023). The profitability of tomato cultivation was studied in relation to the efficiency of the use of some categories of resources (Ajibare et al., 2022). Based on sampling techniques in stages, on representative categories of tomato growers, the study highlighted a series of factors that contribute to the profitability of tomato cultivation, in relation to the conditions of the study area. The authors of the study formulated practical recommendations for capitalizing on resources and increasing the level of profitability, under the specific conditions of the sampled growers.

A recent study analyzed productivity in tomato cultivation, in relation to different practices based on energy efficiency (Jerca and Smedescu, 2023). The authors of the study analyzed the evolution of greenhouse tomato production in Europe, the dynamics of surfaces and productivity.

To a significant extent, tomatoes are exploited through industrial processing, and in this sense some studies have analyzed the optimization of water and energy flows in the processing of tomatoes to optimize resources and reduce the impact on the environment (Eslami et al., 2023).

The present study analyzed the variation of some biometric parameters, physiological indices and productivity elements in four tomato hybrids (F1 hybrids) under the influence of treatments with the Bionat fertilizer product.

MATERIALS AND METHODS

The study took place in the area of Jimbolia, Timis County, Romania. The experiment was located in an unheated greenhouse, belonging to a family vegetable association (Figure 1).

Figure 1. Overview of the solariums where the tomato hybrid experiment was carried out

Four tomato hybrids were cultivated: Beldine F1; Sandolin F1; Ciciu F1; Izmir F1.

The tomato seedlings were 60 days old when planted. The culture was established in the solar soil, in rows in strips (40+80+80+80+40), with a density of 28,000 plants ha^{-1}.

The crop technology was specific to tomato culture, in unheated solariums. Within each hybrid, a control variant and a variant treated with the Bionat product were considered: control variants: Beldine F1 – V1; Sandolin F1 – V3; Ciciu F1 – V5; Izmir F1 – V7; variants treated with Bionat: Beldine F1 + Bionat – V2; Sandoline F1 + Bionat – V3; Ciciu F1 + Bionat – V5; Izmir F1 + Bionat – V7. The Bionat product was applied in four treatments, concentration 0.5%, at intervals of 14 days between treatments; the first treatment was applied after planting the seedlings.

In order to evaluate the influence of Bionat treatments, and the response of each hybrid, certain plant parameters were determined within each variant.

In relation to the specifics of tomato plants, the following parameters were determined: plant height (Ph, cm); inflorescence number (In, no.); flowers number in inflorescence (Fn, no.); fecundated flowers (Ff, no.); number of fruits in bunches (Fnb, no.); average bunch weight (Abw, kg b^{-1}, b - bunch); fruits number on plant (Fnp, no.); average fruit weight (Afw, kg f^{-1}, f -

fruit); average plant production (App, kg plt^{-1}, plt – plant).

The recorded experimental data were processed and analyzed mathematically and statistically appropriately (Hammer et al., 2001; Statistica, 2020; JASP, 2022).

RESULTS AND DISCUSSIONS

The determinations made during the vegetation period for tomato hybrids in relation to the applied treatments, led to the results presented in Table 1. The height of the plants varied between Ph = 179.80-203.60 ± 2.73 cm. The number of inflorescences was between In = 7.50-8.50 ± 0.12. The number of flowers in the inflorescence varied between Fn = 5.20-6.70 ± 0.17. The number of fertilized flowers (in the inflorescence) varied between Ff = 4.60- 6.20 ± 0.20. The number of fruits per bunch varied according to Fnb = 4.60-6.20 ± 0.20. It was found that there was no loss of fruits, the number of fruits at harvest per bunch was the same as the number of fecundated flowers. The average weight of the bunch varied between Abw = 0.53-0.90 ± 0.05 kg b^{-1}. The number of fruits per plant varied between Fnp = 35.50-50.80 ± 2.12. The average weight of a fruit was between Afw = 0.12 = 0.16 ± 0.01 kg f^{-1}. The average production per plant varied between App = 4.17-7.33 ± 0.42 kg plt^{-1}. The experimental data recorded showed heterogeneity and statistical reliability, according to ANOVA Test (Alpha = 0.001) (Table 2).

Table 1. The values of the parameters studied in tomatoes

Experimental Variants	Parameters determined in tomato plants								
	Ph	In	Fn	Ff	Fnb	Abw	Fnp	Afw	App
	(cm)	(no)	(no)	(no)	(no)	(kg b^{-1})	(no)	(kg f^{-1})	(kg plt^{-1})
V1	187.70	7.80	5.50	4.60	4.60	0.541	35.5	0.118	4.170
V2	196.40	8.40	5.90	5.50	5.50	0.705	46.3	0.128	5.925
V3	179.80	7.50	5.40	4.80	4.80	0.712	35.7	0.148	5.290
V4	198.30	8.10	6.20	5.70	5.70	0.900	46.5	0.158	7.330
V5	199.70	7.70	5.90	5.30	5.30	0.673	40.5	0.127	5.139
V6	203.60	8.20	6.70	6.20	6.20	0.863	50.8	0.139	7.074
V7	195.40	7.90	5.20	4.60	4.60	0.532	36.6	0.116	4.237
V8	199.80	8.50	5.90	5.50	5.50	0.709	46.9	0.129	6.057

Table 2. ANOVA Test

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	256312.8	8	32039.1	2943.579	5.24E-78	3.833807
Within Groups	685.7175	63	10.88441			
Total	256998.6	71				

Based on the correlation analysis, the values from Table 3 resulted. The height of the plants (Ph) and the number of inflorescences (In) showed lower correlations in intensity with the other determined parameters, as the productivity elements of the tomato plants. Very strong and strong correlations, statistically assured, were registered at the level of the parameters Fn, Ff, Fnb, Abw, Fnp.

Starting from the identified correlations, regression analysis was used to find out the variation of the Fnp (number of fruits per plant) and App (average fruit production per plant) parameters, as the main productivity parameters. The variation of the considered parameters (Fnp, App) in relation to the number of inflorescences (In) and the number of fecundated flowers (Ff) was described by the general equation (1), with the presentation of the values of the coefficients of the equation in Table 4. The graphic distribution of the values of Fnp and App in relation to In and Ff is presented in Figures 2 and 3.

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

where: Y - Fnp, or App (presented in Table 4);
x - inflorescence number (In);
y - fecunded flowers (Ff);
a, b, c, d, e, f - coefficients of the equation (1) (Table 4);

Table 3. The table of correlations between parameters studied in tomatoes

	Ph	In	Fn	Ff	Fnb	Abw	Fnp	Afw	App
Ph									
In	0.671								
Fn	0.704	0.512							
Ff	0.739^{*}	0.621	0.969^{***}						
Fnb	0.739^{*}	0.621	0.969^{***}	$.999^{***}$					
Abw	0.408	0.342	0.837^{**}	0.864^{**}	0.864^{**}				
Fnp	0.783^{*}	0.805^{*}	0.901^{**}	0.964^{***}	0.964^{***}	0.777^{*}			
Afw	-0.059	-0.036	0.468	0.494	0.494	0.862^{**}	0.376		
App	0.527	0.536	0.866^{**}	0.916^{**}	0.916^{**}	0.976^{***}	0.881^{**}	0.766^{*}	

Table 4. Statistical values related to equation (1)

Coefficient	Y = Fnp (according to Eq. 1)				Y = App (according to Eq 1)			
	Coefficient values	R^2	F	RMSE	Coefficient values	R^2	F	RMSE
a	-1.6971501	0.999	408.021	0.1758	-8.9477960	0.935	5.7636	0.2801
b	-0.4133510				-3.6046885			
c	23.0813388				76.0047572			
d	-2.8035737				-61.9891430			
e	1.8897685				12.7655628			
f	-87.1202972				-140.5404017			

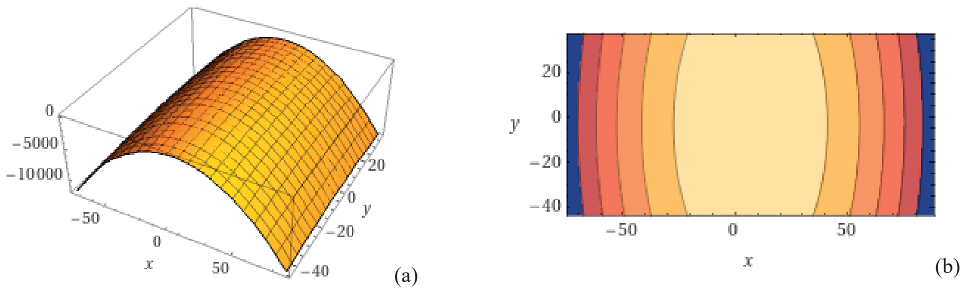

Figure 2. The graphic distribution of the parameter Fnp in relation to In and Ff in tomatoes

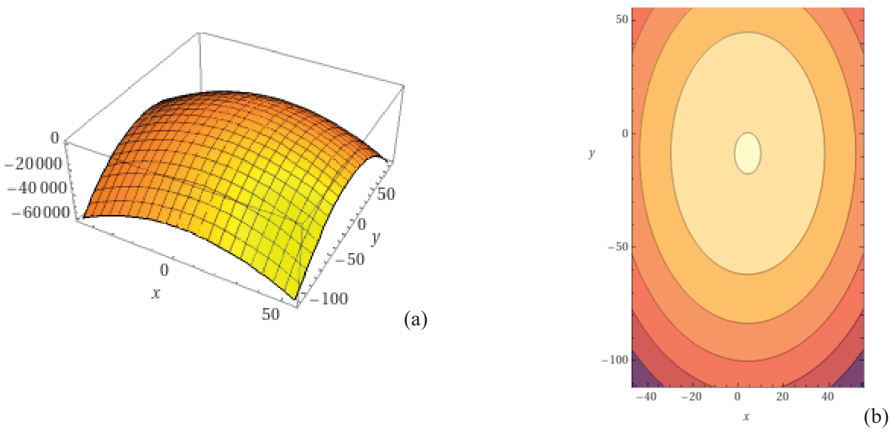

Figure 3. The graphic distribution of the App parameter in relation to In and Ff in tomatoes

PCA analysis was used to find out the distribution of variants in relation to parameters associated with flowers and fruits. In relation to flower parameters (In, Fn, Ff), the diagram in

Figure 4 resulted, in which PC1 explained 80.696% of variance, and PC2 explained 18.566% of variance. In relation to fruit parameters, the diagram in Figure 5 resulted, and PC1 explained 83.685% of variance, and PC2 explained 15.523% of variance.

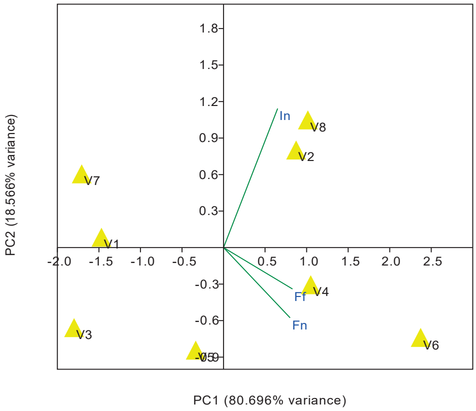

Figure 4. PCA diagram in relation to representative parameters for tomato flowers

The increase generated by Bionat treatments was analyzed for each analyzed parameter. For this, the significance of the differences between the mean of the control variants (Ct; V1, V3, V5, and V7), and the values of the variants treated with Bionat (V2, V4, V6, and V8) was analyzed. The results obtained (One-sample test) are presented in Table 5.

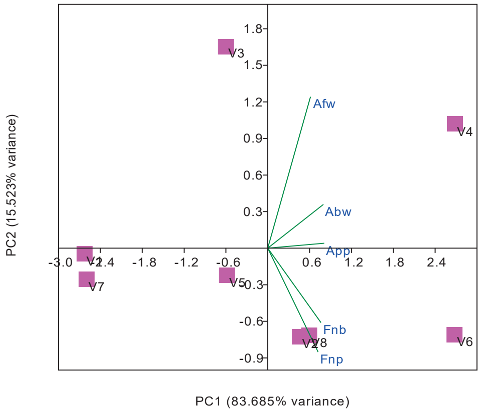

Figure 5. PCA diagram in relation to representative parameters for tomato fruits

The differences between the mean of the control variant (Ct) and the sample mean showed statistical reliability in the case of parameters Ph, In, Ff, Fnb, Fnp and App ($p < 0.05$). In the case of the Fn, Abw and Afw parameters, the differences did not show statistical certainty.

Table 5. The significance of the differences for the parameters studied in tomatoes

Statistical parameters	Parameters determined in tomato plants								
	Ph	In	Fn	Ff	Fnb	Abw	Fnp	Afw	App
Given mean:	190.65	7.725	5.50	4.825	4.825	0.614	37.075	0.127	4.709
Sample mean:	197.75	8.185	6.04	5.545	5.545	0.7582	45.515	0.1362	6.219
95% conf. interval:	(191.83 203.67)	(7.8102 8.5598)	(5.4875 6.5925)	(4.9318 6.1582)	(4.9318 6.1582)	(0.6098 0.9066)	(39.224 51.806)	(0.11993 0.15247)	(4.9229 7.5151)
Difference:	7.10	0.46	0.54	0.72	0.72	0.1442	8.440	0.0092	1.510
95% conf. interval:	(1.1789 13.021)	(0.08518 0.83482)	(-0.012506 1.0925)	(0.10682 1.3332)	(0.10682 1.3332)	(-0.0041968 0.2926)	(2.1494 14.731)	(-0.0070701 0.02547)	(0.21394 2.8061)
t :	3.3293	3.4074	2.7136	3.2601	3.2601	2.6979	3.7251	1.57	3.2348
p (same mean):	0.029126	0.027092	0.053338	0.031077	0.031077	0.054211	0.020384	0.19151	0.031832
Significance	*	*	ns	*	*	ns	*	ns	*

The height of the plants (Ph) in the case of the treated variants showed significant differences compared to the control variant (Ct), average values. The height of the plants was positively correlated with the parameters Ff, Fnb and Fnp (*, $p<0.05$) (Table 3). Through the positive variation of the height of the plants, with a positive impact on the three productivity parameters, the treatment with Bionat was justified. The number of inflorescences (In) showed significant differences in the treated varieties, compared to the average of the control varieties, and showed a positive correlation with Fnp ($r = 0.805$*).

In the case of the number of flowers (Fn), the treatment with Bionat did not generate statistically significant differences (Table 4). However, the Fn parameter presented positive correlations, very strong with Ff, Fnb and strong with Abw, Fnp and App. This may suggest the physiological balance of tomato plants.

If we still analyze the number of fertilized flowers (Ff), it was found that in the case of the treated variants, the recorded results showed differences compared to the average Ct, under statistically reliable conditions ($p < 0.05$). On the one hand, this shows the bioactive effect of the Bionat product, and on the other hand, it justifies the treatment in the production process.

In the case of the Ff parameter (fecundated flowers), treatments with Bionat generated statistically safe increases, the differences between the mean of the treated variants and the control variants showed statistical reliability ($p < 0.05$). The Ff parameter presented very strong, positive correlations with Fnb and Fnp, and strong, positive correlations with Abw and App. A similar response was recorded in the case of the Fnb parameter.

In the case of the Abw parameter, the differences generated by the treatment with Bionat, in relation to the average of the control variants, did not show statistical certainty. However, Abw presented positive correlations with other determined parameters, under conditions of statistical safety. Similar results were recorded in the case of the Afw parameter.

The values of the Fnp parameter, in the case of the variants treated with Bionat, showed differences compared to the average of the control variants, under statistical safety conditions. The Fnp parameter presented positive correlations, with the other parameters, under statistical safety conditions.

In the case of the App parameter in the treated variants, differences were recorded compared to the control variants, under statistical safety conditions, table 4. The App parameter showed significant correlations with the other studied parameters, except for Ph and In.

Increased yield and better quality indices for vegetable products have been reported in different horticultural species in relation to differentiated fertilization systems (Dobrei et al., 2009; Ofoe et al., 2024). Yu et al. (2023) communicated models for managing the watering and fertilization rate for productivity efficiency in greenhouse tomatoes. The positive variation of the photosynthetic indices and the quality indices, under statistical safety conditions, was recorded in relation to the variable rate of tomato fertilization in greenhouse conditions (Ofoe et al., 2024). Organic fertilization generated favorable results for tomatoes, in terms of the yield and the content of mineral elements in the fruits (Adekiya et al., 2022). Through the recorded results, the present study shows, on the one hand, the differentiated response of the cultivated tomato hybrids, and on the other hand, highlights the favorable bioactive effect of the Bionat fertilizer used, and thus contributes a set of information to the scientific literature in the specific field of the tomato crop.

CONCLUSIONS

The four F1 tomato hybrids have differently valorised the treatments with the applied Bionat fertilizer. The highest value for App was recorded in the Sandoline F1 hybrid, under the influence of Bionat treatment (V4; App = 7.330 kg plt^{-1}). In second place was the hybrid Ciciu F1, under the influence of Bionat treatment (V6; App = 7.074 kg plt^{-1}).

Treatments with Bionat generated increases in the studied parameters, compared to the control variant (average of the untreated variants, V1, V3, V5, V7), under statistical safety conditions ($p < 0.05$) for the parameters Ph, In, Ff, Fnb, Fnp and App. Positive differences were also recorded in the case of the other parameters (Fn, Abw, Afw), but without statistical certainty. A favorable effect of the treatment with Bionat was registered in the case of the parameter Ff (fecundated flowers), even if the parameter Fn (total number of flowers) did not register a positive variation, in statistical safety conditions, under the influence of the applied fertilizer. The results show the importance of the treatment for the growth of fruits number on the plant.

The statistical analysis used, generated results in the form of equations and graphic models, which described the variation of the main parameters of tomato productivity, under the study conditions.

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