

Effect of Meteorological Conditions and Fertilization on the Gross Physical Tomatoes Product in the Open Field

Kostadin KOSTADINOV¹ (✉)

Stoyan FILIPOV¹

Nadezhda SHOPOVA²

Radoslav CHIPILSKI³

Summary

In recent years, climate change has negatively affected open field tomato production. Extremely high temperatures and changes in moisture conditions lead to an increase in the proportion of below the quality standard production and to economic losses. Despite these concerns, the impact of climate change on the three main production directions open field tomato cultivation in southern and central Bulgaria has not been well studied. This study aims to analyse the effects of unfavorable weather conditions on the early and total (standard and non-standard) yield of tomatoes under three fertilization options. The quantity and ratio of yields were studied for three different periods of planting on polyethene mulch in the Plovdiv region during the period 2019-2021. Mineral and organic fertilizations resulted in higher early and total yields compared to unfertilized plants. The tomatoes fertilized with Arcobaleno had a total yield 9% lower compared to NPK. The reported yield below the quality standard in early harvest was highest in the control (37.0%) and lowest (27.8%) in mineral fertilization during the first planting period. The days with an adverse effect on tomatoes during the study period were between 31 and 38, about 30% of their growing season. The results also show that fertilization mitigates the impact of adverse weather conditions and increases the ratio of standard to quality fruits in favor of the standard ones. The correlation between weather indices and yield weakens significantly with mineral fertilization. During the three years of the study, the best results were reported for the first, earliest planting date.

Key words

Solanum lycopersicum L., climate change, planting dates, fertilization, yield

¹ Agricultural University – Plovdiv, AU, 12 Mendeleev Blvd, 4000 Plovdiv, Bulgaria

² Climate, Atmosphere and Water Research Institute at Bulgarian Academy of Sciences (CAWRI-BAS), 66, Blvd Tzarigradsko chaussee, 1784 Sofia, Bulgaria

³ Institute of Plant Genetic Resources, 2 Drouzhba Str., 4122 Sadovo, Plovdiv district, Bulgaria, Agricultural Academy, Sofia, Bulgaria

✉ Corresponding author: kostadinov8888@gmail.com

Received: June 24, 2024 | Accepted: August 27, 2025 | Online first version published: October 27, 2025

Introduction

Tomatoes are one of the most widely consumed vegetable crops in the world. According to statistics from the Food and Agriculture Organization (FAO), around 340 billion pounds (170 million tons) of fresh and processed tomatoes were produced globally in 2014 (FAO 2017). The growth, development, productivity and quality of plants are highly temperature dependent, and each particular species has its own temperature range and optimum temperature for each of the mentioned processes (Hatfield et al., 2014; Hatfield and Prueger, 2015). Therefore, climate change, especially high and low temperatures, lead to major challenges to agriculture (Meena et al., 2018). Tomato (*Solanum lycopersicum* L.) is commonly used as a model crop for various physiological, cellular, biochemical, molecular and genetic studies, as it is easy to grow, has a short life cycle, and is easy to manipulate (Kinet and Peet, 1997). The projected environmental changes show that the main regions of tomato processing may change in the forthcoming decades (Cammarano et al., 2022). Air temperature affects the development, growth, photosynthesis, respiration and physiological development of tomatoes. The optimum daily temperature for tomato production is from 21 to 27 °C. However, the heat stress (HS) refers to the condition that the temperature of the environment is by 10–15 °C higher than the optimum temperature for crop growth (Wahid et al., 2007). HS disrupts the cellular, physiological and molecular functions of the plants, thus leading to membrane dysfunction, protein denaturation, DNA damage, and large-scale changes in gene expression (Mittler et al., 2012; Hu et al., 2020). The tomato is one of the most important vegetables in the world and is very sensitive to heat stress. The temperature range for tomato growth is between 13 and 33 °C, and most varieties cannot grow well at temperatures above 38 °C (Zhang et al., 2018). HS causes wilting, leaf senescence, slow growth and unusual development of the tomato plants (Wahid et al., 2007; Shaheen et al., 2016). It can seriously damage the reproductive organs of the tomato plants, especially pollen vitality female fertility, thus leading to a sharp drop or even complete loss of fruit setting (Müller and Rieu, 2016; Hoshikawa et al., 2021). It also affects the development and ripeness and ultimately reduces both the yield and the quality of the fruits. Environmental changes can cause a significant change in the levels of phenolic and flavonoid content in tomatoes (Ilahy et al., 2016)., the optimum temperatures vary somewhat depending on the stage of development of the plant. At temperatures above 30 °C, lycopene, the red colorant in tomatoes, does not form, and the fruits do not color properly. Daily and night temperatures, close to 25 °C, stimulate the vegetative growth, while the maximum fruit production is observed at night temperatures of 18 °C and daily temperatures of 20 °C (Cholakov, 2009). High temperatures above 42 °C during the tomato growing season cause damage related to vegetative and reproductive growth and fruit set (Wahid et al., 2007). The optimum relative humidity for pollination is 70%. The young seedlings (transplants) usually need about 50 ml of water per plant per day, while the mature plants need 2 L of water per day (Langenhoven, 2018). On average, 90% of the water, taken up by a plant, is used for transpiration (cooling), and the remaining 10% are used for growth (Snyder, 2010). The average daily air temperature in the summer period in the region of Plovdiv exceeds 25 °C, the maximum being over 40 °C. In recent years scientific papers have shown a considerable increase in the average temperature and the number of tropical days and nights in the

country and the region of the Upper Thracian Lowland (Slavcheva et al., 2020; Georgieva et al. 2021; Malcheva et al., 2021; Malcheva et al., 2023).

High temperatures are usually observed throughout the tomato growing season, especially during the critical phenophases in July and August. These high temperatures may be the cause of the abiotic stress for tomato production in the district of Plovdiv, for both the current and the future climatic conditions. Although it has been established that the effect of the high temperatures on the outdoor grown tomatoes is the reason for the growing concern among many producers, no review has yet addressed these concerns. Therefore, the present study was conducted with the aim to determine the effect of the increased environmental temperature and of the unfavorable climatic conditions both during vegetation and fruit giving, and on the early and total (standard and non-standard) yield of outdoor grown tomatoes. The quantity and quality of the yield were analyzed with respect to the different dates of planting on polyethylene in the open field in the region of Plovdiv.

Materials and Methods

The climate of the Plovdiv region lies in the Upper Thracian lowland. The region is characterized by a transition from continental to continental-Mediterranean precipitation with a total annual amount of about 500 mm. The minimum precipitation is in autumn and winter, and the major maximum is in the summer – June (77.18 mm). Spring comes early in the region and is very short, while summer is hot and often accompanied by draughts. The temperature sum during the growing seasons exceeds 3900 °C. A limiting factor for the spring crops, including early outdoor tomatoes, are the last spring ground frosts (Shopova et al., 2019). Once in every two-years frost falls in the region of Sadovo and Plovdiv around the 14th and 17th of April (Georgieva et al., 2017).

Meteorological data. The experimental field work was conducted in the period 2019-2021 in the Learning Experience Base of the Department of Vegetable Farming at the Faculty of Viticulture and Horticulture of the Agricultural University – Plovdiv. The meteorological parameters were measured for each day of the growing season using the meteorological station installed for this purpose, which contains sensors for the following values: air temperature (average, maximum, minimum) in °C; relative humidity in %; precipitation in mm; solar radiation in W·m⁻².

The Bulgarian variety “Rugby F1” was used for the experiment. The production of seeds is Bulgarian company “Geosem”. This indeterminate tomato with a balanced, harmonious taste is used in Bulgaria, Romania, and Serbia for fresh consumption. It is successfully grown under controlled conditions and in the open field for early and mid-early production. The variety is characterised by good growth and forms between 4 and 6 flowerheads. The fruits are about 180-200 g in weight, smooth, heart-shaped, with a delicate consistency and balanced pink colour. An advantage of the variety 'Rugby F1' is the fine skin, which can be easily removed, while, at the same time, the variety is distinguished by its good durability. Another quality of the variety is its high yield. The vegetative period of the variety is between 100 and 115 days.

Methodology. Seedlings 40-45 days old, with 5-6 leaves, were used in this experiment. The plants were planted in the field on three dates: April 25-27; May 5-7, and May 15-17. The experiment was carried out in three variants and four replications. In each replication, 20 plants were planted. The following variants were tested: 1st – unfertilized = control; 2nd – mineral fertilisation (NPK); 3rd – organic fertilisation. For the mineral fertilisation, the recommended norms for mid-early tomatoes were used: triple superphosphate (50% P₂O₅) - 16 kg ha⁻¹, potassium sulphate (35% K₂O) - 60 kg ha⁻¹, ammonium nitrate (33,5% N) 63 kg ha⁻¹. In the variant with an organic fertiliser was used “Arkobaleno”. This fertiliser is produced by the company “Agrofert”. It is used in a dose of 100 kg ha⁻¹. The raised flat beds were mulched with foil by means of a drip irrigation system. The irrigation norm was adapted to the meteorological conditions and more specifically to the amount of rainfall in the region in mm. The tomatoes were planted in a single-row scheme, 160 between rows and 50 cm between plants within a row.

For each of the monitored years in the period 2019-2021, early and total standard and non-standard yields were reported. Harvesting is carried out from the phenophase of the beginning of fruiting until the end of August. Picking was carried out every week, and the early yield for the three planting dates was reported from the harvests for the first weeks until mid-July. The results are statistically processed using ANOVA. Similar to other studies (Iliev et al., 2020), an LSD test was performed for statistical significance of differences, for standard deviation, and for coefficient of variation. Using multiple linear regression, a correlation between meteorological indicators and yield was sought.

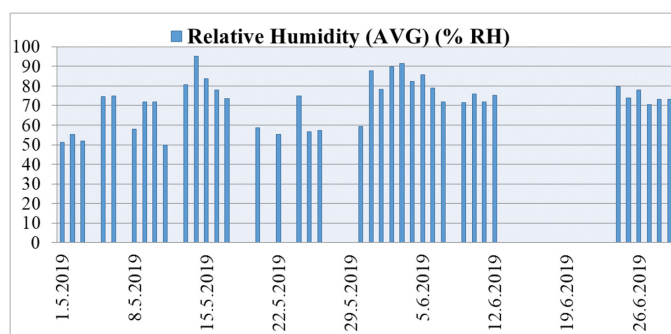
Results and Discussion

Meteorological conditions

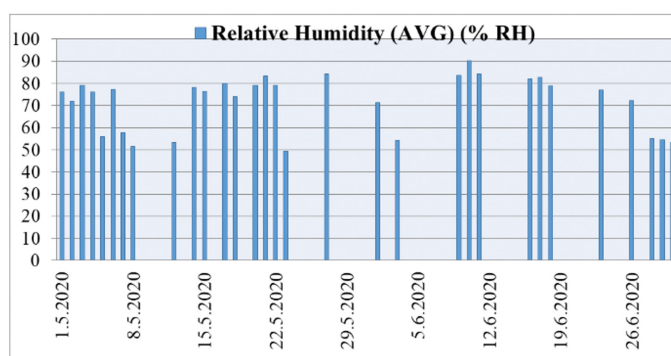
Three critical periods can be distinguished when growing tomatoes in the open air: 1 - planting and adaptation; 2 - flowering, pollination and fertilization; 3 - ripening and harvesting. The good adaptation and development of the young tomato plants depends on the meteorological conditions during the period of their planting and rooting, before entering the less favorable conditions of the summer period.

The vegetative stage of the plants is usually more resistant to high temperatures than the stage of reproduction (Ruan et al., 2010; Zinn et al., 2010). In June, at the beginning of the reproductive period, the total precipitation for 2019 was 197 mm or 364% of the monthly norm (<http://bulletins.cfd.meteo.bg/>) (Figs. 1_a, 1_b, 1_c, 1_d).

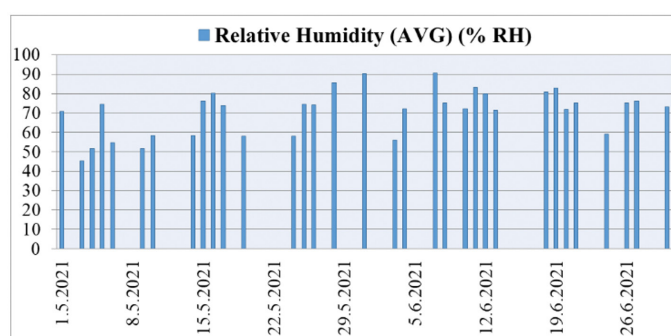
The trend in 2019 continued in July, when precipitation amounted 135% of the norm. These extreme conditions are a prerequisite for overwetting of the soil, development of diseases, weeds and insects, having a negative effect on the early, standard and non-standard yields in the first extremely humid year. In 2020 and 2021, the total amount of precipitation in June was slightly above the monthly norm. During the same period, flowering starts under conditions of unfavorable values of relative air humidity. At levels of relative humidity (RH) above 80%, pollen grains start conglutinating, which leads to a reduction in their dispersal and lower pollination rate. The stickiness of pollen decreases as humidity levels drop. At a relative humidity below 60%, the stigma



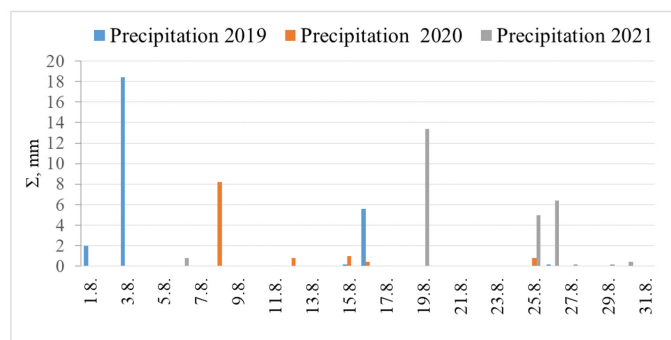
(a)



(b)



(c)



(d)

Figure 1. Mean values of relative air humidity % (a) 2019; (b) 2020; (c) 2021 and (d) total precipitation in the harvesting periods

(the female part of the flower that receives the pollen) can dry out, which also reduces the pollination rates (Langenhoven, 2018).

The days with values below 60% and over 70%, which have the strongest influence on the vitality and functionality of the pollens, have been tracked out (Figs. 1_a, 1_b, 1_c).

In 2019, at the beginning and the end of the first 10 days of May, there was a series of at least three consecutive days with unfavorable conditions according to this indicator. Periods of 5 and more consecutive days with unfavorable air humidity were recorded in mid-May, at the beginning and the end of June, when the plants were flowering intensively. The months May-June 2019 contained an extended period of 38 days with unfavorable conditions for flowering (10 days below 60% and 28 above 70% relative humidity). The most favorable relative humidity was registered in the period 15-25 May. In 2020 the days with unfavorable humidity are a total of 31 (9 days below 50% and 22 above 70%), and in 2021 - 33 days (10 days below 60% and 23 days above 70%). As it was mentioned above, the most unfavorable days were the days with humidity above 80%, which for the corresponding years are respectively: 7 days in 2019 and 2020 and 5 days in 2021, compared to the climatic norms (<http://bulletins.cfd.meteo.bg/>) and in the three experimental years, the last spring month with temperature values above the average ones, with the largest deviation from the climatic norm (1.4 °C) in 2021, and the lowest (0.5 °C) in 2020 (Fig. 2). According to de Villiers (2017), stress early in a plant's life can inhibit its ability to continue both its vegetative growth (growth of roots, stems and leaves) and its generative growth (growth of flowers and fruits), which reduces its yield. The critical air temperatures during flowering in 2019 were recorded in the beginning of June, and in 2020 and 2021 they were shifted towards the end of the month, but with a higher frequency. In accordance with the positive trend in the summer air temperature in the region of Plovdiv in the recent decades (Slavcheva et al., 2020; Georgieva et al., 2022), anomalous average values were reported in all three experimental years in July and August, while in 2021, the deviation for the last month even exceeded 3.5 °C. The experimental years 2020 and 2021 are defined as two of the warmest years since 1935 (<http://bulletins.cfd.meteo.bg/>). Average and maximum air temperatures are directly related to yield. The optimum temperature for vegetative growth of tomato plants has been found to be 25 °C (Van Der Ploeg. & Heuvelink, 2005). Tomato vegetative development can be considered as leaf formation and emergence of flower heads, as this type of plant is sympodial, having approximately one flower head for every three leaves (Heuvelink, 2005). Tomato vegetative development needs an optimum temperature between 22 °C and 26 °C, according to Adams et al., 2001. The most favorable periods by this criterion are presented in Figure 2. In 2019, consecutive unfavorable days were observed during the ripening period in August, with greater intensity in the second and third ten days of the month (two series of 7 consecutive days), combined with relative air humidity below 60%. In 2020, the stress periods occurred at the beginning and end of July and the beginning and end of August. Since the mid-1980s, the hot periods with threshold values of 34 °C, 36 °C, 38 °C and 40 °C and corresponding durations of at least 6, 5, 4, 3 and 2 consecutive days (Malcheva et. al., 2021) have sharply increased. The analysis of the maximum temperatures during the studied period shows sequences of 3 or more days with maximum temperatures around and above 33 °C.

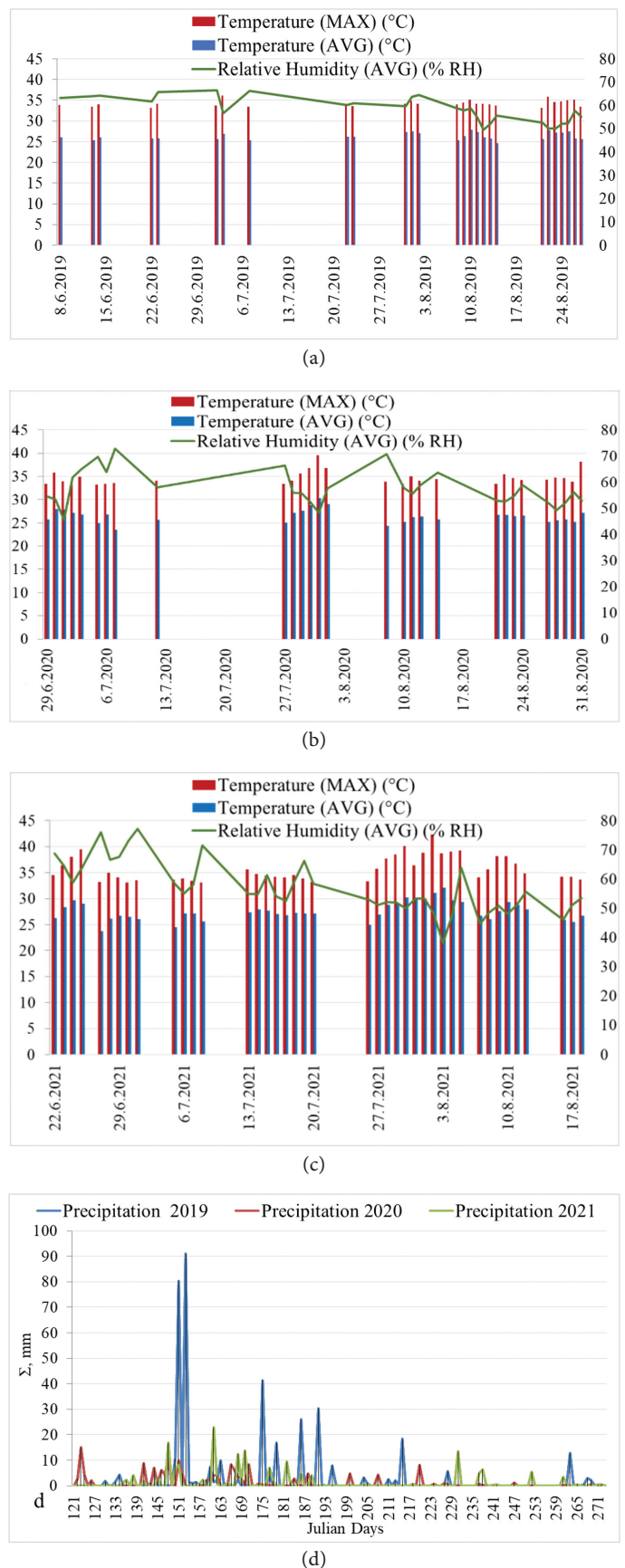


Figure 2. Periods with unfavorable hydrothermal conditions and amount of precipitation during the growing season (a) 2019; (b) 2020; (c) 2021; (d) precipitation, \sum_{mm}

In 2021 the hot periods started as early as the third ten days of June and continued through July and August. Maximum values of above 40 °C were recorded both in July and until the end of August in 2021. Lower values (around and slightly above 35 °C) were registered in 2019. The unfavorable periods were observed after the period of flowering and during the period of mass fruiting (the second and third ten days of August). The precipitations in August are also of importance for the quality of the harvested produce (Fig. 2d). All three years are relatively favorable according to this indicator, with rainfall below the normal amounts.

The analysis of the meteorological conditions demonstrates that the most unfavorable in terms of the temperature factor was 2021, and conditions of overwetting and deviation from the optimal relative humidity in % during flowering were observed at the beginning of the reproductive phase in 2019. Irrigation is an active measure, taken to increase yields, but the adverse effect of extreme rainfall on the total (non-standard and standard) yields cannot be avoided. The days with an adverse effect on the tomatoes during the study period were between 31 and 38, which is about 30% of their entire season of growth. Extremely high rainfall during the period of flowering and fruiting significantly lowers yields. Yet, the use of mineral and organic fertilizers has shown a mitigating effect and a positive influence on the yield and the quality of the final product even in the first extremely wet year.

Gross physical early and total product (standard quality yield and yield below the quality standard)

Effect of the planting date and type of fertilization on the early yield

A well-expressed trend was observed (Table 1) in the three experimental years, related to the moment of planting and its influence on the early yield average amount.

The highest values of the early yield were recorded for the first date of planting, respectively (1805.6; 1771.3 and 2628.2 kg ha⁻¹). On the second date, the yield was lower by 400 - 900 kg ha⁻¹. When planting on the third date, the early yield is the lowest, decreasing by 60% and 29% respectively compared to the first and second dates.

When evaluating the method of cultivation and the type of the used fertilizer on the amount of the early yield, a well-defined trend is also outlined. The highest early yield in all three experimental years, regardless of the planting period, was obtained in the variant with mineral fertilization, as follows: in 2019 year it was 1452.4 kg ha⁻¹, in 2020 year it was 1388.0 kg ha⁻¹, and in 2021 year it was 2192.1 kg ha⁻¹. Close values were reported when fertilizing with Arkobaleno organic fertilizer. The best interaction between the planting date and the type of fertilization was observed for the 1st date and for mineral fertilization (MF) with average values by years respectively: 1981; 2046 and 3176.5 kg ha⁻¹.

Influence of the date and the type of fertilization on the total yield

The total yield shows similar regularities, well expressed with the type of fertilization (Table 1). The highest total yield, regardless of the planting date, for the research period 2019/2021, was obtained with MF (mineral fertilization), with the following average values by years: 4928.7; 6793 and 6981.4 kg/ha⁻¹. Organic fertilization (OF) gave a yield below the MF by 9% and 11% for

2019 and 2020, while in 2021 it exceeded the MF by 2.4%. The fertilization factor at average values for the study period 6234.4 kg/ha⁻¹ for the MF and 5893.8 kg/ha⁻¹ for the OF, has a well-pronounced stimulating effect and proven statistical differences at 5% and 1%. With respect to the control group, after evaluating 769 datasets from 107 scientific papers, Gao et al., 2023 have established that organic fertilizers can increase tomato yield by 42.18%, compared to the control group, and increased content of soluble solids, soluble sugars, lycopene and vitamin C has also been found. Other scientist as Direkvandi et al., 2008 and Rusu et al., 2023 report similar results for mineral and organic fertilization of tomato varieties.

In terms of planting dates, the highest total yield for the three years was the one, related to the first planting date, respectively: 4726.4; 6529.2 and 6871.1 kg/ha⁻¹ and the average was 6042.4 kg/ha⁻¹. This defines the first date as the best planting moment in terms of the total yield. The second date falls under the most unfavorable weather conditions and gives by about 11% lower yield. The third date is close in value to the first one with 5945.3 kg/ha⁻¹.

Effect of the weather and the type of fertilizer on below the quality standard yield

The percentage ratios of the yield below the quality standard to the gross physical early yield (Early yield) and the total gross physical product for the entire harvest period (Total yield) with respect to the factors planting date and type of fertilization shows some regularities (Figs. 3 and 4).

The analysis of the results of the early yield below the quality standard, compared to the total yield by years, shows a sustained trend of highest values in the case of no fertilization. The average early yield below the standard reported for the three years was highest for the control group - 37.0%, while for the cases of NPK and Arkobaleno fertilization, the value was 31.3% and 31.4%, respectively. Regarding the planting date factor, the results for the ratio of the yield below the quality standard to the total yield showed the highest values of non-standard production obtained for the second date of planting - 36.0%, and on the third date - 35.5%. The lowest ratio of non-standard yield to total yield was recorded for the first planting period - 27.8%. At a total physical gross yield below the quality standard, the trend, concerning the percentage of the yield below the quality standard with respect to the total yield, found in the gross physical early yield for the factor fertilization type, stays the same. The control is with a percentage value of 34.2%, and the difference, compared to the NPK fertilization, is almost 10%. This trend concerns all the three years, with the best expressed values in 2020, which shows the stability of the variety behavior under the applied different types of fertilization. Regarding the other factor, planting date, no clear trend has been identified. The differences between the planting dates are smaller. The first planting moment relates to the lowest percent of non-standard total yield, both by years and on average for the period - 27.9%. The second date has the highest non-standard total return rate for 2019 and 2020, with the lowest value in 2021. For the third date, the percentage of the non-standard total yield is comparable to that, for the first date. The lowest % of non-standard total yield is obtained for the first planting moment with mineral fertilization.

Table 1. ANOVA: two factors with replication of Gross physical product (kg·ha⁻¹)

		Gross physical product									
Year	Date of planting	Yearly yield					Total yield				
		Control	NPK	AB	Mean	Mean of factor date	Control	NPK	AB	Mean	Mean of factor date
2019	1	1370.1	1981.0	2065.6	1805.6	2068.4	4652.7	4850.3	4676.2	4726.4	6042.4
	2	1166.0	1504.9	1384.1	1351.7	1484.2***	3515.1	4132.8	3752.8	3800.2	5491.7^{n.s.}
	3	678.3	871.4	768.5	772.7	813.8***	3999.7	5803.0	5013.1	4938.6	5945.3^{n.s.}
	Mean	1071.5	1452.4	1406.1			4055.8	4928.7	4480.7		
2020	1	1091.2	2046.0	2176.8	1771.3		6288.2	7003.4	6296.1	6529.2	
	2	1213.9	1337.6	1585.6	1379.0		5193.4	5931.3	5508.5	5544.4	
	3	680.7	780.4	859.1	773.4		5572.6	7444.3	6349.5	6455.5	
	Mean	995.3	1388.0	1540.5			5684.7	6793.0	6051.4		
2021	1	2160.4	3176.5	2547.8	2628.2		6505.3	6509.4	7598.5	6871.1	
	2	1317.7	2237.7	1610.7	1722.0		6574.5	7281.1	7536.2	7130.6	
	3	654.1	1162.1	869.7	895.3		5858.5	7153.8	6313.4	6441.9	
	Mean	1377.4	2192.1	1676.1			6312.8	6981.4	7149.4		
Mean of the factor fertilizer		1148.0	1677.5***	1540.9***			5351.1	6234.4**	5893.8'		
		LSD fertilizer/data				LSD interaction					
		5% =	166.2	5% =	287.9			5% =	613.5	5% =	1062.6
		1% =	220.6	1% =	382.1			1% =	814.3	1% =	1410.4
		0.1% =	286.0	0.1% =	495.4			0.1% =	1055.9	0.1% =	1828.9

Note: AB – Arkobaleno; * - significant at $P < 0.05$, 0.01 and 0.001, respectively

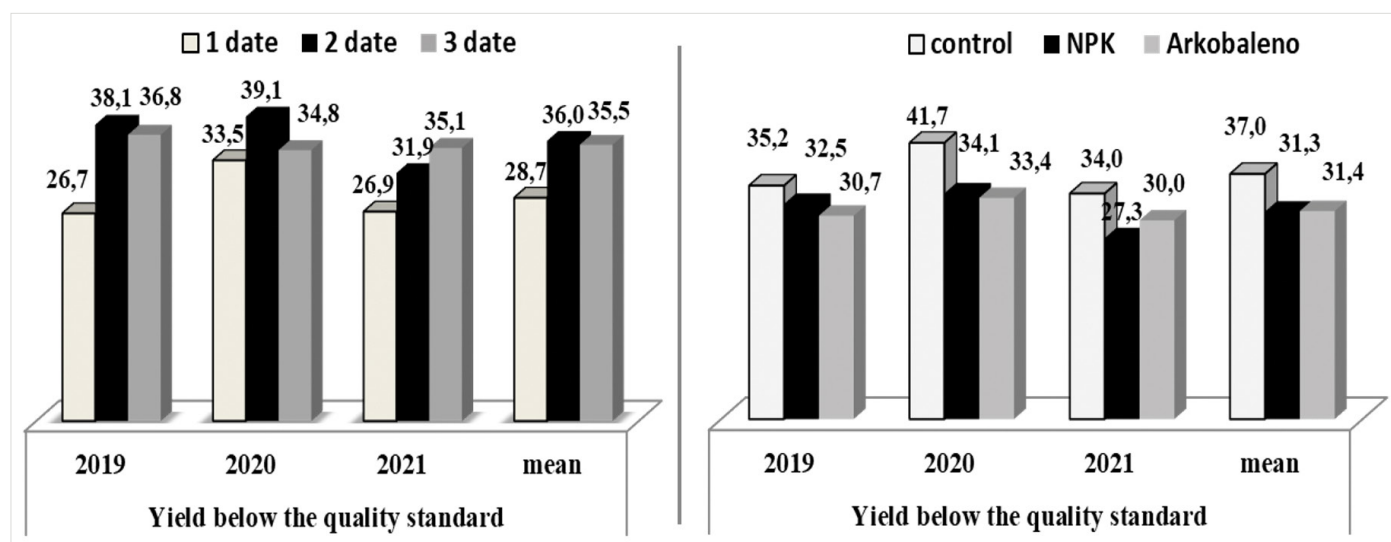


Figure 3. Percentage ratio of the yield below the quality standard to the gross physical early yield for the factors planting date and type of fertilization

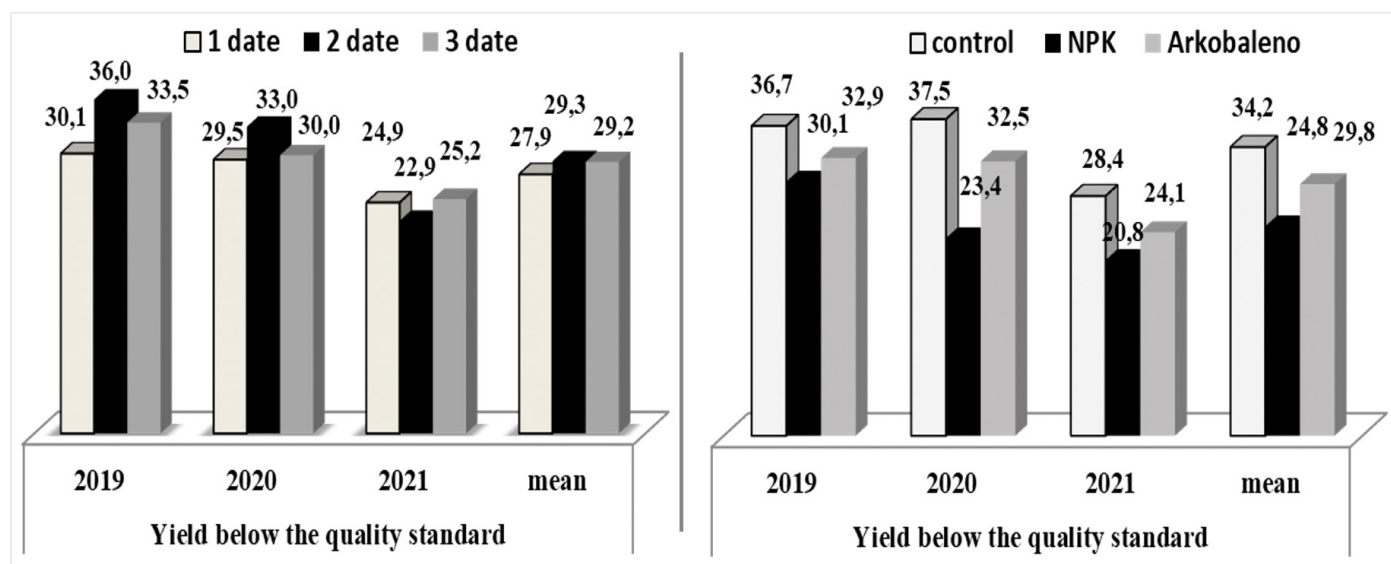


Figure 4. Percentage ratio of the yield below the quality standard to the gross physical total yield for the factors planting date and type of fertilization

Multiple Regression Analysis

The correlation between the meteorological elements is used in many studies related to biological and mineral fertilization of plants (Iliev et al., 2020). Under the observed meteorological conditions, a relationship between air temperature, relative air humidity and solar radiation, and the non-standard tomato yield (Table 2) was sought.

Statistically significant multiple regressions have been obtained at a 99% confidence level. With the introduction of the synthetic NPK, the relationship between the maximum temperature and humidity, on the one hand, and the average air temperature and

the solar radiation, on the other hand, strongly decreases, while the biologically fertilized plants maintain a strong relationship in the third decade of August. Yet, reduction in the R-squared is observed with Arkobaleno fertilizing. It can be said that the fertilizing process reduces the adverse impact of the extreme weather events on the yield. In the course of the experimental work, it has been established that these dependencies continue to be valid during the remaining ten-day periods of the growing season. The early dependencies (May, June) can be used to make a preliminary forecast for obtaining non-standard and standard yields.

Table 2. Multiple Regression Analysis (Yield below the quality standard)

Meteorological indices/ten days periods	Regression equations Between non standart Yield (Y) and main meteo indices (X)	P-Value Constant	P-Value Model	R-Squared
Av Max T °C August 3 rd ten days period	Control = -14903,2 + 348,18* Av Max °C August 3 rd ten day +	0,0001	0,0000	92,80 percent
Av HR% August 3 rd ten days period	92,269 * RH August 3 rd ten day	0,0001		
Av Max T °C August 3 rd ten days period	Arcobaleno = -17421,9 + 399,151* Av Max °C August 3 rd ten	0,0000	0,0000	82,89 percent
Av HR% August 3 rd ten days period	day +105,776 * RH August 3 rd ten day	0,0000		
Av Max T °C August 3 rd ten days period	NPK = -1807,27 + 76,1333* Av Max °C August 3 rd ten day +	0,0450	0,0822	18,80 percent
Av HR% August 3 rd ten days period	14,3858 * RH August 3 rd ten day	0,1312		
Av T °C August 3 rd ten days period	Control = -794,516 - 706,85* Av SolarR August 3 rd ten days	0,0000	0,0002	92,80 percent
Av Solar R August 3 rd ten days period	period + 4021,73 * Av T °C August 3 rd ten days period	0,0000		
Av T °C August 3 rd ten days period	Arcobaleno = -1247,87 - 810,33* Av Solar August 3 rd ten days	0,0380	0,000	82,89 percent
Av Solar R August 3 rd ten days period	period + 4610,47 * Av T °C August 3 rd ten days period	0,0000		
Av T °C August 3 rd ten days period	NPK = 321,202 - 128,622* Av SolarR August 3 rd ten days period	0,0790	0,0822	18,79 percent
Av Solar R August 3 rd ten days period	+ 760,544 * Av T °C August 3 rd ten days period	0,0054		

Conclusions

The tomato variety "Rugby" proved to be resistant to the conditions of the transitional continental climate of Plovdiv under extreme meteorological conditions and climate change. Better results are obtained with drip irrigation in dry and hot weather than with extreme precipitation and relative humidity above 80 during the flowering period. The best ratio between planting date and type of fertilizer for early yield is observed when planting in the 1st term and using MF (mineral fertilization with NPK) with average values by year: in 2020 it is 2046 kg·ha⁻¹, and in 2021 it is 3176.5 kg·ha⁻¹. The first date shows the best total yield, and the second date falls under the most unfavorable climatic conditions and gives a lower yield by 11%. The first planting date has the lowest percentage of substandard total yield, both by year and on average for the period (27.9%).

Acknowledgements

The research was carried out with the funding of the Center for Scientific Research, Intellectual Property Protection and Technology Transfer at the Agricultural University - Plovdiv.

CRedit authorship contribution statement

Stoyan Filipov, Kostadin Kostadinov: Conceived the project and supervised the work, conceptualization, Investigation, performed most of the experiments, analyzed the data and drafted the manuscript. **Radoslav Chipilski, Nadezhda Shopova:** Performed some of the experiments, analyzed some of the data and drafted part of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Adams S. R., Valdez V. M. (2002). The effect of periods of high temperature and manipulating fruit load on the pattern of tomato yields. *J. Hortic Sci. Biotechnol* 77: 461-466.
- Adams S. R., Cockshull K. E., Cave C. R. J. (2001). Effect of temperature on the growth and development of tomato fruits. *Ann Bot* 88: 869-877.
- Cammarano D., Jamshidi S., Hoogenboom G., Ruane A. C., Niyogi D., Ronga D. (2022). Processing tomato production is expected to decrease by 2050 due to the projected increase in temperature. *Nat Food* 3 (6): 437-444. doi: 10.1038/s43016-022-00521-y
- Cho W., Kim S., Na M., Na I. (2021). Forecasting of Tomato Yields Using Attention-Based LSTM Network and ARMA Model. *Electronics* 10: 1576. doi: 10.3390/electronics10131576
- Cholakov D. (2009). *Zelenchukoproizvodstvo*. Akademichno izdatelstvo na AU – Plovdiv, p. 282.
- de Villiers M. (2017). Predicting tomato crop yield from weather data using statistical learning techniques, Thesis Department of Statistics and Actuarial Sciences, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa
- Direkvandi S. Najafvand N. Alemzadeh A., Sedighie Dehcordie F. (2008). Effect of Different Levels of Nitrogen Fertilizer with Two Types of Bio-Fertilizers on Growth and Yield of Two Cultivars of Tomato (*Lycopersicon esculentum* Mill.). *Asian J Plant Sci* 7: 757-761
- Food and Agriculture Organization of the United Nations (FAO). (2017). FAOSTAT Database. Available at: <https://www.fao.org/faostat/en/#home>
- Gao F, Li H, Mu X, Gao H, Zhang Y, Li R, Cao K, Ye L. (2023). Effects of Organic Fertilizer Application on Tomato Yield and Quality: A Meta-Analysis. *Appl Sci* 13 (4): 2184. doi: 10.3390/app13042184
- Georgieva V. Kazandjiev V. Bozhanova V. Mihova G. Ivanova D. Todorovska E. Uhr Z. Ilchovska M. Sotirov D., Malasheva P. (2022). Climatic Changes—A Challenge for the Bulgarian Farmers. *Agriculture* 12: 2090. doi:10.3390/agriculture12122090
- Georgieva V., Kazandjiev V., Stoycheva A. (2017). Assessment of agroclimatic conditions in Plovdiv district. International Conference, 135 Years Agricultural Science in Sadovo and 40 Years Institute of Plant Genetic Resources – Sadovo 1-2: 547-563 (*in Bulgarian*)
- Hatfield G. Takle R. Grotjahn P. Holden R. C. Izaurralde T. Mader E. Marshall D., Liverman J. M. (2014). Agriculture. In: *Climate Change Impacts in the United States: the Third National Climate Assessment*, U.S. Global Change Research Program, U.S. Global Change Research Program (Melillo J. M., Richmond T. C., Yohe, G. W, eds.), Washington, pp. 150-174. doi: 10.7930/J02Z13FR
- Hatfield J. L., Prueger J. H. (2015). Temperature Extremes: Effect on Plant Growth and Development. *Weather Clim Extrem* 10: 4-10. doi: 10.1016/j.wace.2015.08.001
- Heuvelink E., Dorais M. (2005). Crop growth and yield, In: *Crop production science in horticulture, tomatoes* (Heuvelink E., ed.), CABI, Cambridge, UK, pp. 85-144.
- Heuvelink, E. (2005). Developmental processes, In: *Crop production science in horticulture, tomatoes* (Heuvelink E., ed.), CABI, Cambridge, UK, pp 53-83.
- Hu S., Liang Y., Liu T., Li F., Lu Y., Shi Z. (2020). Kinetics of As (V) and carbon sequestration during Fe(II)-induced transformation of ferrihydrite-As (V)-fulvic acid coprecipitates. (2020). *Geochim Cosmochim Acta* Vol 272: 160-176. doi: 10.1016/j.gca.2020.01.002
- Ilahy R., Siddiqui M. W. Piro G. Lenucci M. S., Hdidier C. (2016). Year-to-year variations in antioxidant components of high-lycopene tomato (*Solanum lycopersicum* L.) breeding lines. *Turkish Journal of Agriculture-Food Science and Technology* 4 (6): 486-492.
- Iliev M, Bozhanska T, Petkova M. (2020). Impact of Mineral and Organic Foliar Fertilizing on Some Productivity Factors of a Natural Grassland of *Chrysopogon gryllus* L. Type and a Natural Pasture of *Nardus stricta* L., *Ecologia Balkanica* 12 (2): 65-75.
- Kinet J. M., Peet M. M. (1997). Tomato. In: *The Physiology of Vegetable Crops* (Wien H.C., ed.), Commonwealth Agricultural Bureau (CAB) International, Wallingford, UK, pp. 207-258.
- Langenhoven P. (2018). Hydroponic tomato production in soilless culture. Indiana horticultural congress, February 13, 2018., Technical report, Department of Horticulture and Landscape Architecture, Purdue University, USA
- Malcheva K, Bocheva L, Chervenkov H. (2021). Climatology of extremely hot spells in Bulgaria (1961-2019). *Proceedings from 21st International Multidisciplinary Scientific GeoConference SGEM 2021*, 16 - 22 August, 2021, doi: 10.5593/sgem2021/4.1/s19.40
- Malcheva K, Chervenkov, K., Bocheva, L. (2023). The importance of seasonal climate assessments in the analysis of the contemporary climate of Bulgaria. *Bulgarian. Bulg.J. Meteorol. Hydrol* 27(1): 1-51.
- Malcheva K, Bocheva L, Chervenkov H. (2022). Spatio-Temporal Variation of Extreme Heat Events in Southeastern Europe, *Atmosphere* 13 (8): 1186. doi: 10.3390/atmos13081186
- Meena Y., Khurana D., Kaur N., Singh K. (2018). Towards enhanced low temperature stress tolerance in tomato: an approach. *J Environ Biol* 39: 529-535.
- Mittler R., Finka A., Goloubinoff P. (2012). How do plants feel the heat? *Trends Biochem Sci* 37(3): 118-125. doi: 10.1016/j.tibs.2011.11.007
- Mittler R., Vanderauwera S., Suzuki N., Miller G., Tognetti V. B., Vandepoele K., Gollery M. Shulaev V., Van Breusegem F. (2011). ROS signaling: the new wave? *Trends Biochem Sci* 16 (6): 300-309. doi: 10.1016/j.tplants.2011.03.007.

- Monthly hydrometeorological bulletin. National Institute of Meteorology and Hydrology of Bulgaria, May-August 2019-2021, Sofia, ISSN 1314-894X (print) ISSN 2815-2743 (online), <http://bulletins.cfd.meteo.bg/>
- OECD (2017). Tomato (*Solanum lycopersicum*), In: Safety Assessment of Transgenic Organisms in the Environment, Volume 7: OECD Consensus Documents, OECD Publishing, Paris, doi: 10.1787/9789264279728-6-en.
- Profillidis V. A., Botzoris G. N. (2019). Statistical Methods for Transport Demand Modeling, In: Modeling of Transport Demand, (Profillidis V. A., Botzoris G. N., eds), pp. 163-224.
- Ruan Y. L., Jin Y., Yang Y. J., Li G. J., Boyer J. S. (2010). Sugar input, metabolism, and signaling mediated by invertase: roles in development, yield potential, and response to drought and heat. *Molecular Plant* 3(6): 942-55. doi: 10.1093/mp/ssq044
- Rusu O., Mangalagiu I. Amăriucăi-Mantu D., Teliban G. Cojocaru A., Burducea M., Mihalache G., Roșca M., Caruso G., Sekara A., Stoleru V (2023). Interaction Effects of Cultivars and Nutrition on Quality and Yield of Tomato. *Horticulturae* 9 (5): doi: 10.3390/horticulturae9050541
- Shaheen M. R., Ayyub C. M., Amjad M., Waraich E. A. (2016). Morpho-physiological evaluation of tomato genotypes under high temperature stress conditions. *J Sci Food and Agric* 96 (8): 2698-2704. doi: 10.1002/jsfa.7388
- Shopova N., Georgieva V., Kazandjiev V., Malasheva P. (2020). Regime of soil temperature during the sowing period of spring crops in the some stations of South-Eastern Bulgaria. *Ecologia Balkanica* 11 (1): 137 – 143.
- Slavcheva-Sirakova D., Shopova N., Kostsdinov K., Filipov S., Velichkova K. (2020). Climate Analysis and Effects Of Abiotic Stresson Salad Grounded In Underground Greenhouseand Outdoor And Effects Of Organic Fertilizersin The Fight With Stress Factors. *Scientific Papers. Series B, Horticulture LXIV* (2): 251-260.
- Snyder R. (2010). *Greenhouse tomato handbook*. Mississippi state university extension service. P1828
- Van Der Ploeg, A., Heuvelink E. (2005). Influence of sub-optimal temperature on tomato growth and yield: A review *J Hort Sci Biotechnol* 80: 652 659.
- Vijayakumar A., Shaji S. Beena R., Sarada S., Sajitha Rani T., Stephen R., Manju R. V., Viji M. M. (2021). High temperature induced changes in quality and yield parameters of tomato (*Solanum lycopersicum* L.) and similarity coefficients among genotypes using SSR markers, *Heliyon* 7 (2): e05988. doi: 10.1016/j.heliyon.2021.e05988
- Wahid A., Gelani S. Ashraf M., Foolad M. R. (2007). Heat tolerance in plants: an overview. *Environ Exp Bot* 61: 199–223. doi: 10.1016/j.envexpbot.2007.05.011
- Zhang H., Yuan H., Liu X., Yu J., Jiao Y. (2018). Impact of synoptic weather patterns on 24 h-average PM2.5 concentrations in the North China Plain during 2013–2017. *Sci Total Environ* 627: 200–210. doi: 10.1016/j.scitotenv.2018.01.248
- Zinn K. E., Tunc-Ozdemir M., Harper J. F. (2010). Temperature stress and plant sexual reproduction: uncovering the weakest links. *J Exp Bot* 61 (7): 1959-1968. doi: 10.1093/jxb/erq053