DOI: 10.22620/agrisci.2024.41.003

EFFECTS OF THE DROUGHT INDUCED STRESS ON THE FLOWERING AND THE FRUIT SET STAGES IN TOMATO COLLECTION

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Abstract

In the current study, a collection of forty-seven tomato accessions divided into five groups and the sensitive control MoneyMaker were evaluated based on their performance under the condition of reduced irrigation. The tomato accessions were exposed to water stress (50% reduced irrigation). The reproductive traits (flower and fruit number, fruit set) and fruit weights were used in assessing the drought tolerance. A decrease in the flower number, fruit number, the fruit set and fruit weight from 2nd to 5th inflorescence was observed in scarcity. Among the studied tomato groups, the indeterminate, the large fruited ones were the most strongly affected by the stress: reductions of 41.5% in the number of fruits and 40.0% of the average fruit weight were observed. The studied "Cherry" tomato and the accessions from *Solanum pimpinellifolium* L. have had a better drought tolerance compared to other groups. The cluster analysis showed that the individual accessions belonging to sensitive groups also possessed a better tolerance to water deficit.

Keywords: reproductive traits, fruit weight, water stress, tomato

INTRODUCTION

Globally, water is becoming an insufficient resource due to climate change and increasing demand for food production for feeding a growing human population. Tomatoes are an irrigated crop and as such they are highly sensitive to insufficient water (Dong et al., 2020; Liu et al., 2021). The drought induced stress not only affects the growth and development of tomato plants but also leads to a significant decrease in tomato fruit yield. The formation of a smaller number of flowers, enhancing the processes of flowers and buds abscission, as well as the formation of smaller fruits are among the morphological manifestations of drought that lead to a significant yield reduction (Patanè et al., 2011; Sibomana et al., 2013; Lovelli et al., 2017). Depending on the genotype, the duration, intensity of the stress, and the developmental stage of plants and fruits, yield loss can reach over 70% (Ripoll et al., 2016; Giuliani et al., 2018; Conti et al., 2023).

Various approaches (physiological, morphological, agronomical, and molecular) have been used to evaluate the drought sensitivity/tolerance. However, there is no optimal single method for evaluation of drought tolerance. It must be selected based on the plant material and environmental conditions (Flores-Saavedra et al., 2023; Conti et al., 2023). When working with a large set of accessions, the choice of the traits on which the assessment will be made is especially important. The flower-fruit set ratio was found to be a reliable trait for discriminating between tolerant and sensitive genotypes (Lamin-Samu et al., 2021). Agronomic attributes such as yield and yield-related traits are also used as dependable criteria for drought tolerance because the screening and selection are done during the vegetative and fruit stages of plants (Foold, 2005; EL-Saka, 2016). The irrigation at a reduced rate of up to

50% was found to result in a significant reduction in plant height, stem diameter, leaf area, pollen fertility (Conti et al., 2019; Lamin-Samu et al., 2021). In addition, drought stress has many adverse effects on photosynthesis and chlorophyll fluorescence (Zhou et al., 2017; Sousareai et al., 2021). In many cases, the studies were conducted at the seedling stage, and information on the effects of drought during the flowering and fruiting stages was not recorded (Sousareai et al., 2021; Makhadmeh et al., 2022; Chiwina et al., 2024).

Among the abiotic stress factors, drought was found to have the most adverse impact on yield (Placide et al., 2014; Cui et al., 2020). Therefore, the development of tolerant tomato varieties is a key factor in mitigating the effects of drought (Seleiman et al., 2021). In recent years, new sources of resistance are sought by paying attention to both wild relatives and local landraces in order to establish resistant genes, but also to incorporate the desirable traits into the germplasm (Solankey et al., 2015; Athinodorou et al., 2021).

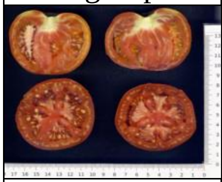
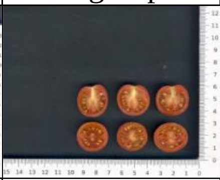
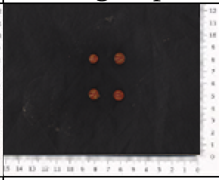
In this regard, the aim of the present study was to apply an agronomical assessment of a tomato collection and identify a potential drought tolerance in the accessions.

MATERIALS AND METHODS

The experimental work was carried out during the two summer seasons of 2021 and 2022 at the field of the Maritsa Vegetable Crops Research Institute in Plovdiv. A total of 47 accessions and the sensitive control variety Moneymaker were included in the study. The tomato accessions were divided into five groups: I group - indeterminate, large fruited (11 accessions); II group - “Cherry” type (12 accessions); III group - *Solanum pimpinellifolium* L. (3 accessions); IV group - determinate, large fruited (8 accessions); V group - determinate, for processing (13 accessions) (Table 1). The seeds were sown at the beginning of April in an unheated greenhouse. The tomato seedlings were transplanted into the field at the beginning of May at the stage of 3rd-4th true leaf using a technology for a mid-season production with a two-rowed planting scheme 120+40/30 cm for indeterminate and 120+40/25 cm for determinate ones (Ganeva et al., 2014). The plants were grown under two watering regimes - optimum and 50% reduced, with a buffer zone of 160 cm. The reduced irrigation was applied 20 days after transplanting when the plants were well adapted in the field. The experiment was carried out in a randomized complete block design with three replications for each of the irrigation regimes (6 plots). Each plot was comprised of 48 accessions and each accession was presented by 10 plants. The size of the experimental area for 10 plants was 0.24 m^2 for indeterminate and 0.20 m^2 for determinate accessions. The microflow drip irrigation method was used with dripping wings and distributors giving 1.6 L h^{-1}, spaced 10 cm apart and placed along the row. The tomato plants were grown in accordance with standard agronomic practices, equal for all genotypes.

Weather data were collected from June to August. Air minimum and maximum temperature (°C), air humidity (%), rainfalls (l/m^2) and soil moisture at 15 and 30 cm depth (kPa) were recorded by the weather station Caipos Wave (Caipos GmbH, Austria). The daily mean temperature from June to August ranged from 15.2 to 32.1ºC in 2021 and from 18.3 to 29.8ºC in 2022. The highest value of air temperature was recorded in the last decade of July and the beginning of August in 2021 and with picks in the second decade in July and August in 2022. The total rainfalls were 118 l/m^2 and 42.5 l/m^2 respectively. The rainfalls were distributed as follows: June – 35.0 l/m^2, July - 58.0 l/m^2 and August – 25.0 l/m^2 in 2021 and June – 14.5 l/m^2, July - 5.5 l/m^2 and August – 22.5 l/m2 in 2022. (Fig. 1).

Table 1. Tomato accessions included in the study.

I group	II group	III group	IV group	V group	MoneyMaker
					
1-11 accessions	12-23 accessions	24-26 accessions	27-34 accessions	35-47 accessions	48 accession
1 - Ideal 2 - A. sartse 3 - R. sartse 4 - 176 5 - 1040 6 - 1560 7 - Dara 8 - Slantse 9 - 1201 10 - 1300 11 -1423	12 - 1441 13 - 1447 14 - Mini miss 15 - Salzitsa 16 - 320 17 -139 18 - 140 19 -1597 20 -1560 21 - 24a 22 - Alia 23 – 1923	24 - 122 25 - 178 26 - 268	27 - 412 28 - 418 29 -1320 30 - 1321 31 - 1360 32 - 188 33 - 133 34 – 355	35 - Prometey 36 - Zhaklin 37 - 1944 38 - 1468 39 - 337 40 - 340 41 - 342 42 - 367 43 - 394 44 - 403 45 - 495 46 - 511 47 - 610	

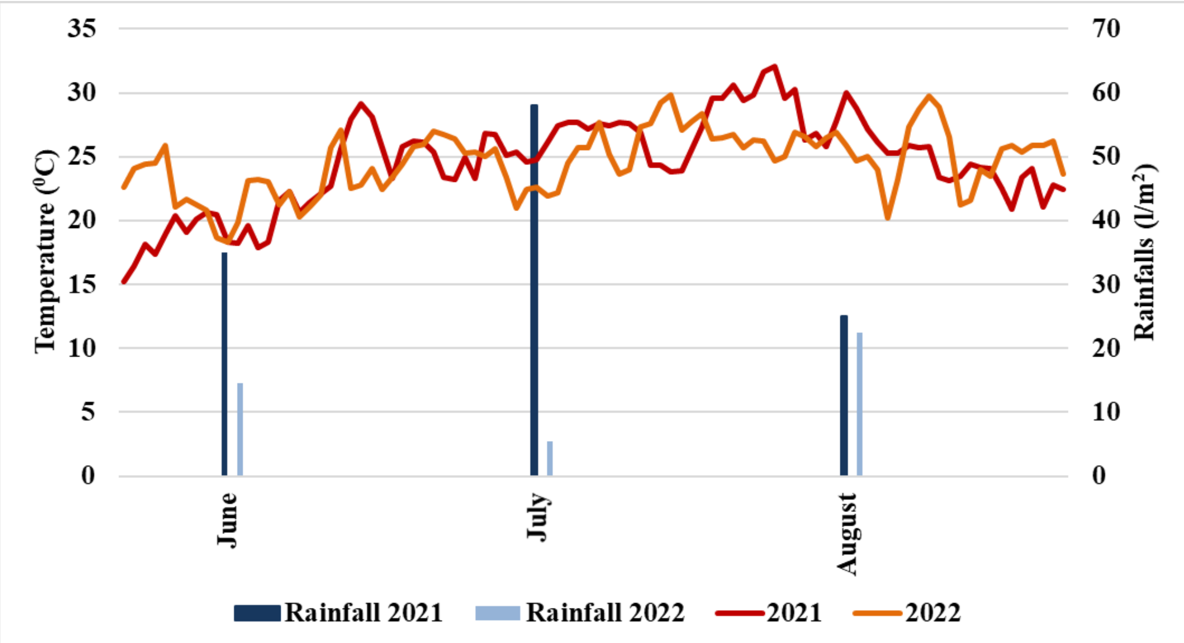


Fig 1. Daily mean temperature and rainfalls in 2021 and 2022.

The drought tolerance response was determined by evaluating the reproductive traits such as the number of flowers and fruits produced per inflorescence and the fruit set percentage. The fruit weight (g) and productivity per plant (g) were also measured. All these characters were recorded from 2 to 5 inflorescences in three replications, three plants per replication of each genotype and irrigation regime.

To identify differences in response to stress among the tomato groups and individual accessions the hierarchical cluster analysis using the Ward method in the *jamovi* program (Version 2.2.2) was performed.

RESULTS AND DISCUSSION

The reproductive traits (the numbers of flower and fruit, and the fruit set) were used to define the drought tolerance in the studied tomato accessions. The data presented in Fig. 2 shows that significant differences in the number of formed flowers for both irrigation regimes in the studied tomato groups were not observed. However, with an increase in the duration of exposure to stress (4th and 5th inflorescence), the number of flowers decreased, with this trait being most strongly expressed in the group of the indeterminate, large fruited tomato (33.7%) followed by the "Cherry" type (20.0%). In the groups of the determinate tomato (IV and V) the differences in the number of formed flowers among trusses were not so clearly expressed, which is due to the fact that they flowered together and they were exposed to stress for a short period. In the indeterminate tomato, flowering was continuous and the effect of water stress in flowering could not be avoided (Pulupol et al., 1996; Ganeva et al., 2019).

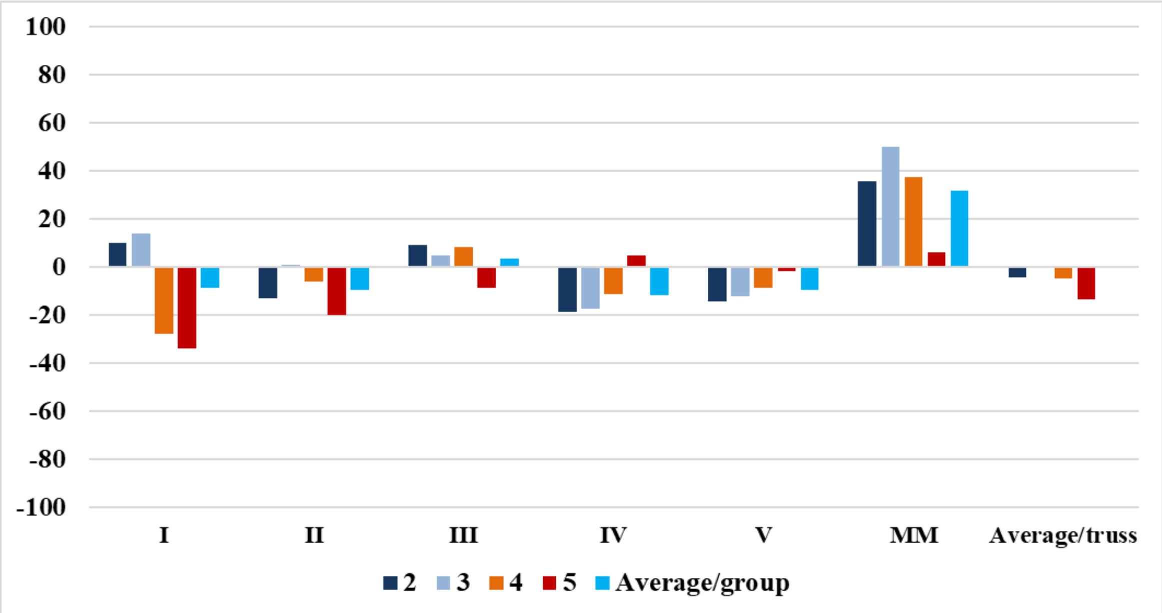


Fig. 2. Percentage of change in the flower number from 2nd to 5th inflorescences in 47 tomato genotypes divided into five group and control under 50% reduced irrigation compared to the optimum irrigated plants.

The result confirmed significant differences in the fruit set between tomato groups as well as between inflorescences. The highest values for a fruit set were observed in 2nd inflorescence: from 54.1% to 86.8% of flowers in the plants grown under reduced irrigation and from 75.8% to 95.3% of flowers under optimum one developed into fruits (Fig. 3). In both irrigation regimes, the highest fruit set was registered in *Solanum pimpinellifolium* L. group followed by the "Cherry" type. In 3th and 4th inflorescences a high variability in the fruit set under water stress was observed, ranging from 40.2% in the group of the indeterminate, large fruited tomato to 80.3% in the „Cherry" type. Mostly affected by the applied stress was 5th inflorescence where there was a decreased fruit set for almost all genotypes. The only exception was the genotypes from the group of the "Cherry" tomato, which retained fruit sets close to those under optimal irrigation.

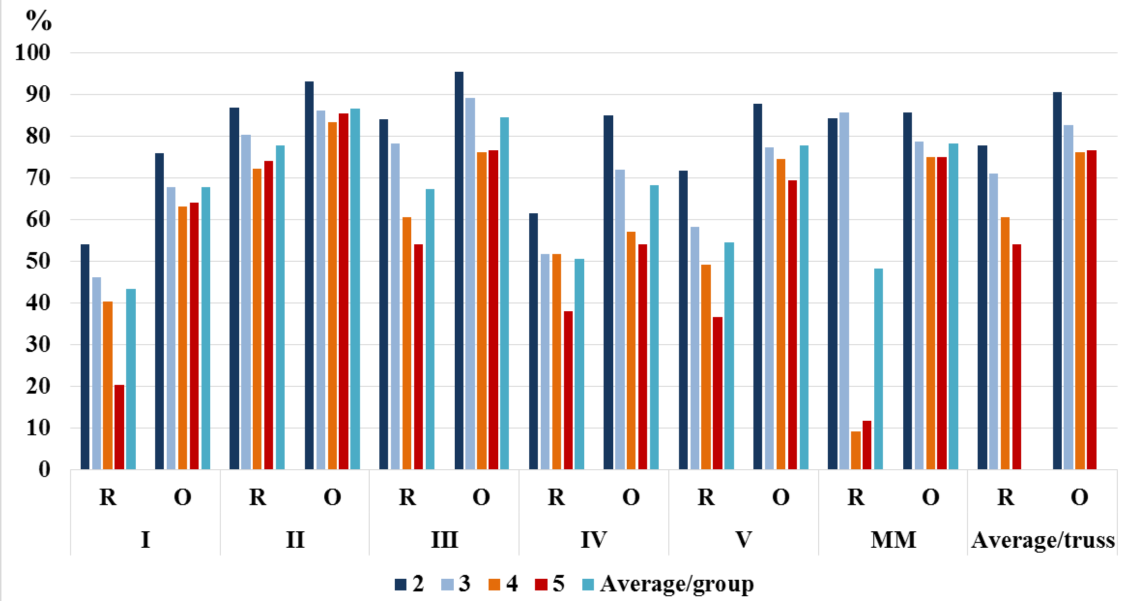


Fig. 3. Effects of water stress on the fruit set from 2nd to 5th inflorescences in 47 tomato genotypes divided into five groups and sensitive control MonayMaker (MM).

Water stress significantly affected the number of formed fruits per trusses (Fig. 4). The highest percentage of decrease in a fruit number was registered in 4th and 5th clusters (24% and 39%, respectively). Among the studied groups the decrease of the fruit number was highest in the group of the indeterminate, large fruited tomato and the determinate, for processing (41.5% and 36.7%, respectively). In the group of the indeterminate, large fruited tomato the fruit development was not found on 5th truss in five of the studied 11 accessions. According to Dariva et al., (2021) yield losses resulting from fewer and smaller fruits are due not only to the degree of stress but also to the fact that the plants have passed their entire flowering and fruiting stages under deficit irrigation conditions.

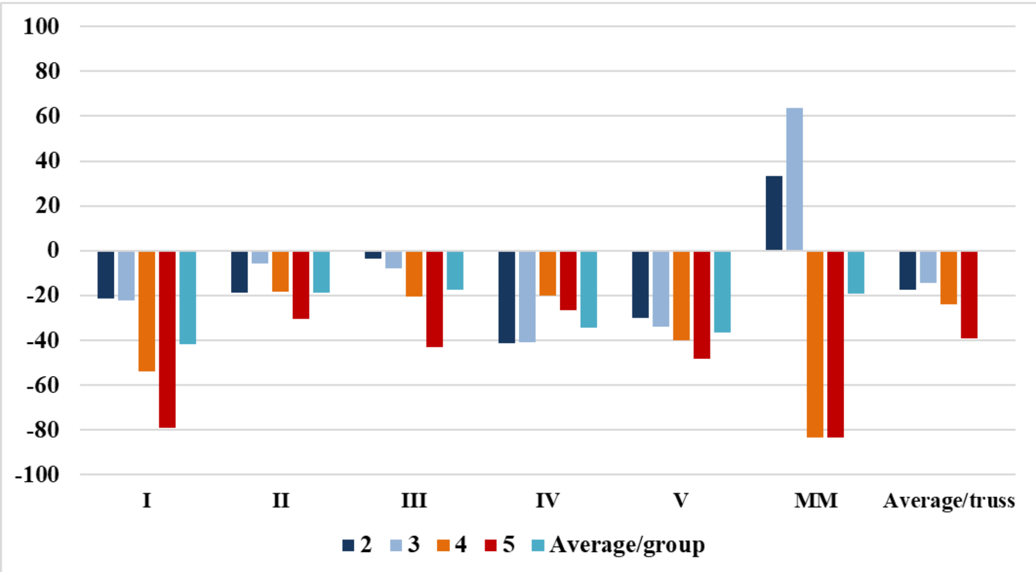


Fig. 4. Percentage of change in the fruit number from 2nd to 5th inflorescences in 47 tomato genotypes divided into five group and control under 50% reduced irrigation compared to the optimum irrigated plants.

Fruit weight is an important trait that determines yield and is negatively affected by the water deficit (Dariva et al., 2021; Huang et al., 2023). The experimental results showed that there were differences in the reduction of the average fruit weight depending on the genotype, the irrigation regime and the truss, but the effect of the genotype was the strongest (Fig. 5). The average fruit weight was reduced by 21.1% and by 48.7% from 2nd to 5th cluster respectively. The loss of fruit weight was higher in *Solanum pimpinellifolium* L. group (66%). In the other studied tomato groups, the decrease in the average weight was between 16.7% and 40.0% and 35.5% in the control MoneyMaker. The results were very close to those reported by Sivakumar and Srividhya (2016) who established a less than 30% decrease of the average fruit weight in the conditions of water deficit. On the other hand, Huang et al., (2023) observed 78.19% and 52.60% reductions of tomato fruit yield and single fruit weight respectively under the condition of drought stress.

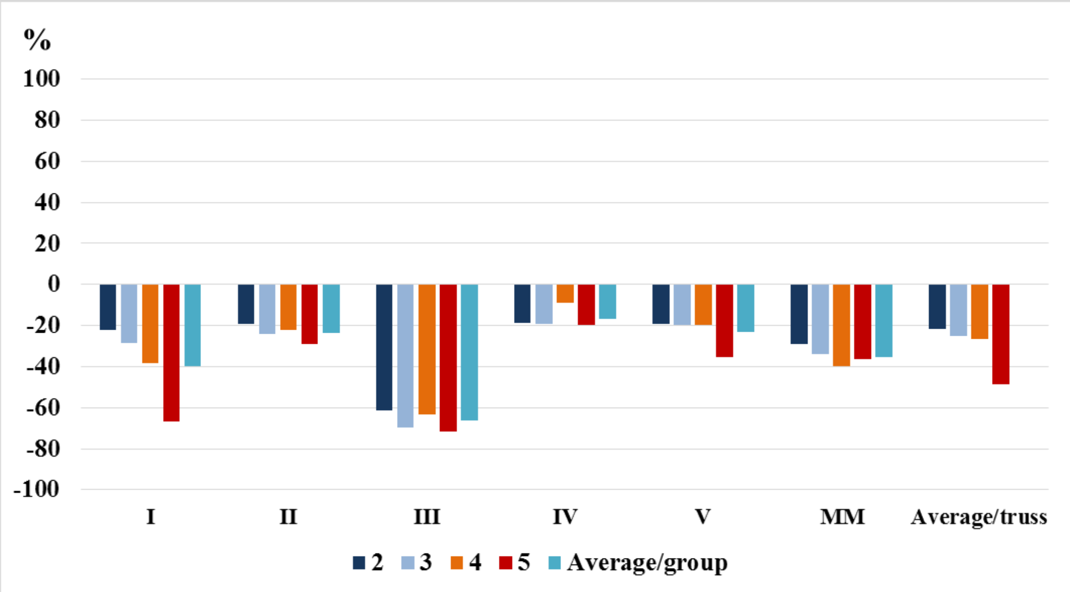
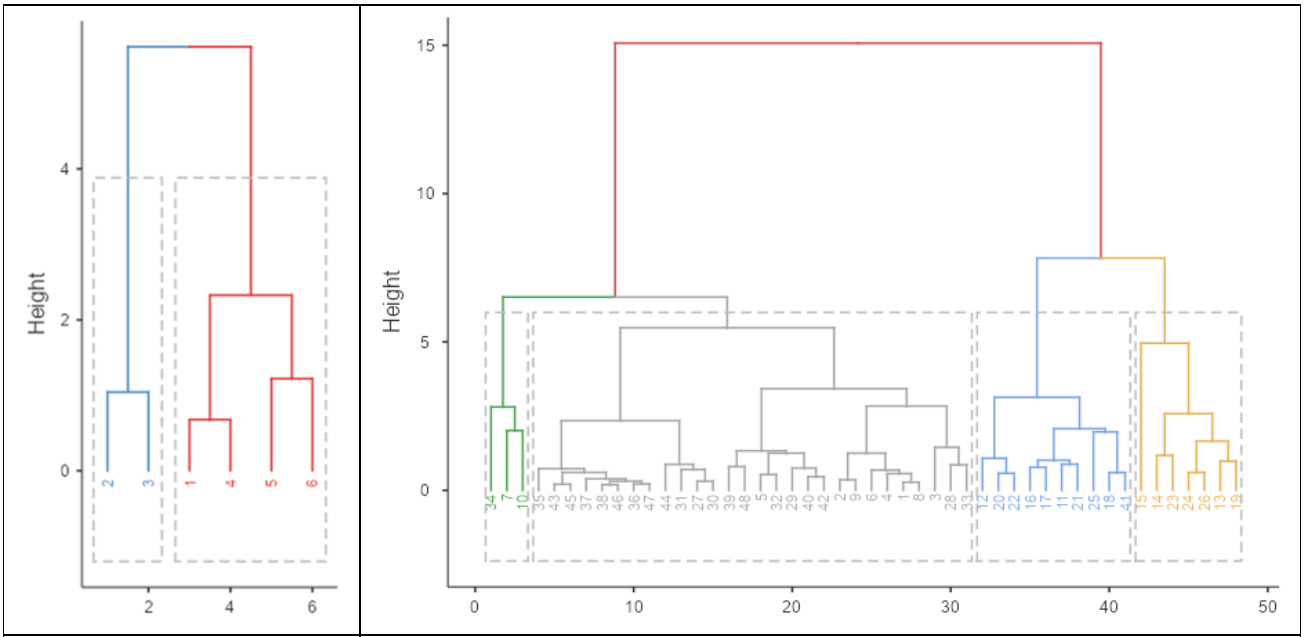


Fig. 5. Percentage of change in the average fruit weight under reduced irrigation from 2nd to 5th inflorescences.

The cluster analysis of the studied 47 tomato genotypes divided into five groups and a control identified two clusters based on their response to drought stress (Fig. 6a). Cluster I included two groups (the "Cherry" type and *Solanum pimpinellifolium* L.), tolerant to drought stress. Cluster II combined accessions from other three tomato groups (indeterminate, large fruited, determinate, large fruited, and determinate, for processing) and the sensitive control MoneyMaker. The cluster analysis based on the individual response of the accessions divided them into four district clusters (Fig. 6b). Among all 4 clusters, cluster II was populated with the largest number of accessions 28, sensitive to drought stress. This cluster included 92% of the accessions from group V (determinate, for processing), 88% of the accessions from group IV (determinate, large fruited), 73% from I group (indeterminate, large fruited), and the variety MoneyMaker. Cluster III consisted of 10 accessions distinguished as moderately tolerant to water stress, to which in addition to the members of the groups of the "Cherry" type and *Solanum pimpinellifolium* L., one accession from the group of the determinate tomato, for processing and one - from the indeterminate, large fruited was included. In Cluster IV, the accessions were from the "Cherry" type group (5 accessions) and from *Solanum pimpinellifolium* L. group (2 accessions), tolerant to drought stress. Three accessions from the groups of the large fruited tomato with indeterminate and determinate growth habit were united in a separate cluster (Cluster I) characterized by yield stability under stress conditions. The data indicated that from the large fruited tomato accessions 1 (Ideal), 2 (R. sartse) and 3 (A. sartse) belonged to the group of the sensitive to drought stress, while 7 (Dara), 10 (1300) and 34 (355) were tolerant to water deficit. The resistant accessions also included 13 (147), 14 (Mini miss), 15 (Slantse), 19 (1597) and 23 (1623), as well as two accessions from *Solanum pimpinellifolium* L. – 24 (123) and 26 (275). Wild species have been exploited as sources of stress-resistant tomato germplasm and can provide a genetic diversity useful for breeding (Solankey et al., 2015; Egea et al., 2018). On the other hand, the same landraces or breeding lines are also better adapted to inferable environmental conditions as water stress (Ntanasi et al., 2021; Villena et al., 2023). The results obtained in the present study show that the "Cherry" tomatoes and the wild accessions from *S. pimpinellifilium* L. have had a better drought tolerance compared to the accessions in other groups. However, individual accessions belonging to other groups also showed tolerance to water deficit. These accessions could be used as donors to increase the drought resistance in tomato varieties.



a. Among groups | **b. Among accessions**

Fig. 6. Cluster dendrogram based on reproductive traits (numbers of flower and fruit, and fruit set), fruit weight and productivity in reduced irrigation.

CONCLUSION

The water deficit applied to plants in this study reduced the flower and fruit number and the average fruit weight of all tomato genotypes compared to the groups under optimum irrigation conditions. Under the condition of 50 % reduced irrigation, the reductions in the number and weight of fruits were greater compared to the flower number. As more sensitive to applied stress were established 4th and the 5th inflorescences. A wide range of variations in responce to water stress were detected among the accessions. In general, accessions 13 (147), 14 (Mini miss), 15 (Slantse), 19 (1597) and 23 (1623) belonging to the "Cherry" type and 24 (123) and 26 (275) from *Solanum pimpinellifolium* L. formed the group of the tomato with a high tolerance to water stress. Individual accessions from other groups defined as sensitive also possessed a drought tolerance, these accessions were 7 (Dara), 10 (1300) and 34 (355). The identification and selection of more tolerant genotypes provide an opportunity to develop new varieties less sensitive to environmental changes.

ACKNOWLEDGMENTS

This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-27/06.02.2024). MVCRI authors would also like to acknowledge the support provided by the Agricultural academy project No ЗМДКТ 17.

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