# IMPACT OF WATER DEFICIT ON SENSORY PROFILE OF TOMATO (*Solanum lycopersicon* L.) GROWN UNDER HOT SUMMER CONDITIONS IN BULGARIA

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**Abstract**

*The effect of water deficit on sensory characteristics of tomato (Solanum lycopersicon L.) was investigated. A field experiment was carried out during 2016-2017 period under the hot summer conditions in Bulgaria. Twenty four Bulgarian tomato accessions representing three types - indeterminate, determinate for processing and determinate for fresh consumption - were harvested. Optimum and 50% reduced watering regimes were applied using a drip irrigation system. Temperatures over 35ºC during the vegetation were recorded in 26% of the days of the first experimental year and 40% of the days of the second one. The sensory analysis of the tomato fruits was performed by trained panelists on the traits: appearance, shape, external colour, internal colour, aroma, peel tenderness, visible fibre, sourness, sweetness, texture and overall taste. Negative effects of the deficit irrigation were observed on the appearance, shape and total sensory evaluation of tomato fruits regardless of the tomato type. Negative effects were also recorded on the texture of determinate tomato for processing and peel tenderness of determinate tomato for fresh consumption. The sweetness was better expressed in tomatoes grown under water deficit in all studied genotypes. Reduced irrigation did not result in aroma, external colour and visible fibre. Two-way analysis of variance revealed a significant influence of genotype on the sensory traits in the range of 39.56-74.79% in indeterminate tomato accessions, 33.49 - 56.05% in determinate tomato for processing, 14.96 - 62.93% in determinate tomato for fresh consumption. Slight influence of the applied watering regime was established except for appearance, shape and sweetness. Indeterminate tomato accessions Rozovo sartse and BG 21 β, determinate accession for processing BG 2086 and determinate accession for fresh consumption Marti and BG 252 demonstrated the best sensory profile in both treatments of irrigation.*

**Key words:** *tomato accessions, reduced irrigation, organoleptic characteristics*

## 1. INTRODUCTION

Tomato is a traditional vegetable crop for Bulgaria. The specific climatic conditions including a lot of sunshine and enough water for irrigation give the desired flavour of the tomato fruits which meets the high requirements of the local consumers. Tomatoes are highly sensitive to environmental factors such as temperature, light and changes in irrigation throughout the growth of the plant (Dumas et al. 2003; Murshed, Lopez-Lauri & Sallanon 2013).

Forecasts of water withdrawals on a global scale predict sharp increases in future demand to meet the needs of the urban, industrial and environmental sectors (Fereres & Soriano 2007). Given that the single biggest water problem worldwide is scarcity there is significant uncertainty about what the level of water supply will be for future generations (Jury & Vaux 2005). Recent and potential increases in global temperatures are likely to be associated with impacts on the hydrologic cycle including changes to precipitation and increases in extreme events such as droughts (Sheffield & Wood 2008).

Drought occurrence will increase despite future emission reductions and this will be exacerbated by the thermal inertia of the oceans (Wigley 2005). The scientific publications show that by the late 19$^{th}$ century until now the global air temperature has increased and the first decade of the 21$^{st}$ century was the warmest period of instrumental observations (Hartmann 2013).

Summer in Bulgaria also manifests propensity to be warmer from the beginning of the 1980's (Alexandrov et al. 2004). The scientific works on regime and many years of changes in precipitation showed a decreasing trend of rainfall amounts and drought in many regions of the country (Vekilska &

Rathcev 2000). This tendency will be kept in the future. The regional climate models (MPI and ETHZ) show a considerable increase of number of years with extreme hot months for the period 2051-2080 in comparison to 2021-2050 (Chenkova & Nikolova 2015).

In respect of the global warming, in the last years tomato breeders have directed their efforts to develop heat tolerant varieties. A lot of investigations concerning tomato yield were conducted. Now it is well known that the deficit irrigation and the elevated temperatures decrease fruit water accumulation and fresh fruit yield (Mitchell et al. 1991; Patanè & Cosentino 2010; Sibomana, Aguyoh & Opiyo 2013). During reproductive development of tomato high temperature causes significant increment in flower drop (Hanna & Hernandez 1982) and in fruit set (Berry & Rafique-Uddin 1988). The combined effect of both heat and drought on the yield is stronger than the effects of each stress alone (Dreesen et al. 2012; Rollins et al. 2013).

Many studies indicate that tomato yield is reduced but the biological value of the fruits is improved under certain degree of water deficit (Veit-Köhler, Krumbein & Kosegarten 1999; Mingchi et al. 2010; Favati et al. 2009). Reduced irrigation may benefit tomato fruit quality due to the increased levels of total soluble solids (sugars, amino acids, and organic acids) which are major compounds accumulated in the fruits (Nuruddin, Madramootoo & Dodds 2003; Shinohara et al. 1995).

Very limited investigations about the influence of high temperatures and water deficit on the sensory properties of tomato have been reported. According to Stevens et al. (1977) tomato breeders have to constantly try not only to increase the yield potential of their hybrids or varieties but also have to retain and improve the flavour components of the fruits under drought conditions.

The purpose of the present study was to characterize the sensory profile of three tomato genotypes grown in reduced irrigation and under elevated temperatures of the hot summer conditions in Bulgaria in order to find appropriate accessions to include them in a breeding program aiming to develop heat and drought tolerant tomato varieties.

## 2. MATERIALS AND METHODS

### *2.1. Field design*

The field experiment was carried out during 2016-2017 period at the Maritsa Vegetable Crops Research Institute in Plovdiv, Bulgaria. The seeds of the tomato genotypes were sown at the beginning of April in an unheated greenhouse. The seedlings were transplanted into an open field at the beginning of May. The experiment was conducted with 10 plants of each genotype on an area of 2.4 $m^2$ in two replications. Optimum (well-watered) and 50% reduced watering regimes were applied using a drip irrigation system. The reduced irrigation was applied 20 days after transplanting when the plants were well adapted in the field. Standard agronomic practices such as fertilization and plant protection were applied during the crop period.

### *2.2. Plant material*

Twenty four Bulgarian tomato accessions were grown. They were separated in three groups - indeterminate for fresh consumption (Aleno sartse, Ideal, Plovdivska karotina, Rozovo sartse, BG 21 β, BG 24/13, BG 720, BG 735, BG 785, BG 822 and BG 2066); determinate for processing (Kapri, Neven, Pautalia - semi-determinate, Venera, BG 160, BG 985, BG 1527 and BG 2086); determinate for fresh consumption (Marti, Milyana, Solaris, Spectar and BG 252). According to the fruit colour four groups were formed: orange - BG 21 β, Neven; light yellow - BG 2066; pink – Rozovo sartse, BG 1527; red - all the other accessions.

### *2.3. Sample preparation*

After harvesting the fruits from each genotype were selected on the base of minimum variation in shape, colour, size and firmness. The tomato fruits were cooled until they were adapted to the room temperature at 22° C before being evaluated by the panelists. Then they were washed with tap water, dried with a paper towel and placed in white dishes.

*2.4. Sensory analysis*

The sensory analysis was performed in the Laboratory for Vegetable Quality Control of the Maritsa Vegetable Crops Research Institute. Randomized samples of 7 tomato fruits were assessed on the following sensory traits and criteria:

- appearance: 5 - unexceptionable, total lack of cracks and defects on the tomato surface; 1 - serious defects with deep and wide cracks on the tomato surface;
- shape: 5 - typical for the genotype; 1 - misshapen, non-aesthetic shape;
- colour: 5 - typical for the genotype, saturated, homogeneous; 1 - non-homogeneous colouring, fruits with spots and shades of colour predominate;
- aroma: 5 - well expressed, typical; 1 - poorly expressed;
- peel tenderness: 5 - fine, melting peel; 1 - thick and tough peel;
- visible fibre: 5 - total lack of visible fibre; 1 - well formed, thick and rough
- sourness: 5 - well expressed; 1 - poorly expressed;
- sweetness: 5 - well expressed; 1 - poorly expressed;
- texture: 5 - tender and palatable; 1 - very firm and rough or very soft and watery;
- overall taste: 5 - excellent perception; 1 - poor perception

A five-point panel test with 0.25-step was used. A four-member panel trained for fresh and processed tomato conducted sensory analyses during the two experimental years.

*2.5. Data analysis*

Significant differences in sensory traits among tomato accessions were determined by Duncan's multiple range test ($p<0.05$). A two-way analysis of variance with twenty four cultivars and two watering regimes was applied to evaluate the effect of genotype, irrigation and their interaction on the studied sensory traits. The coefficient of variability (CV) was also calculated. All data analyses were performed using SPSS software.

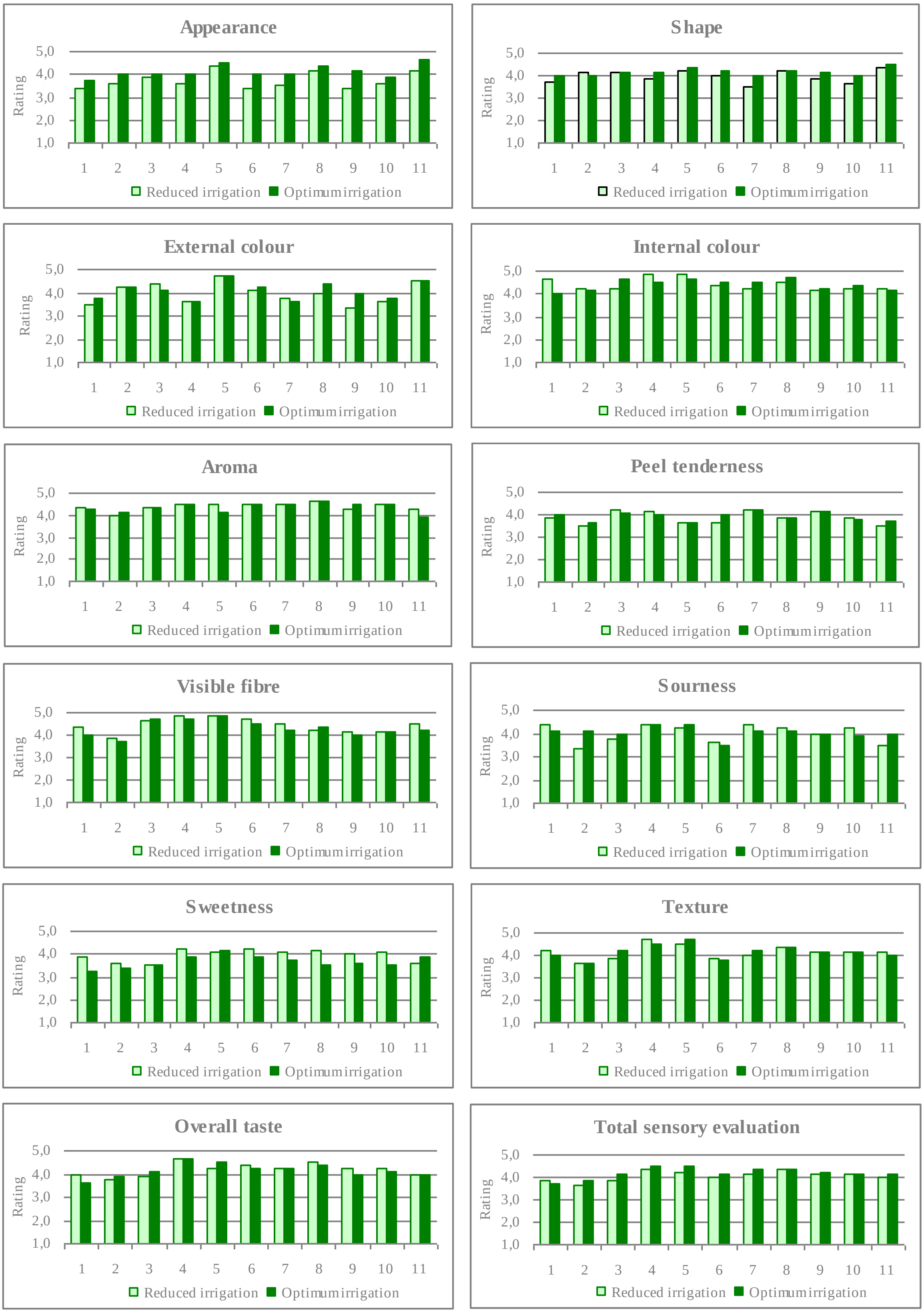
## 3. RESULTS

The summers in Bulgaria were hot and dry during the experimental years. For the period June-August temperatures over 35ºC were recorded in 26% of the days in 2016 and 40% of the days in 2017. The total rainfalls were 134 $l/m^2$ and 76.5 $l/m^2$ respectively. Under these climatic conditions the applied reduced irrigation was a good basis for revealing the sensory profile of tomato with different level of heat and drought tolerance.

The most negative effect of the deficit irrigation was observed on the appearance of the indeterminate tomatoes (Figure 1). Higher evaluations were given to all accessions grown in optimum irrigation. Duncan's test showed that the differences among the accessions grown in both watering regimes kept almost identical (Table 1). Similar negative effect was recorded concerning the tomato shape and the total sensory evaluation. Sweetness was the fourth sensory trait affected by the water scarcity. In contrast, the evaluations for tomatoes grown in 50% reduced irrigation were higher for the predominant part of the accessions.

Two-way analysis of variance confirmed the influence of the water deficit on the sensory evaluations for the above mentioned traits (Table 2). Water deficit did not result in external colour, aroma, peel tenderness, visible fibre, texture and overall taste. Comparatively high (over 20%) was the effect of the interaction genotype x irrigation on the sensory assessments for internal colour and sourness. A significant influence of genotype on sensory traits in the range of 39.56 - 74.79% was established. The differences between investigated accessions grown in water deficit were better expressed in appearance, shape, external colour, internal colour, sourness and total sensory evaluation (Table 1).

Variety Rozovo sartse grown in reduced irrigation obtained the best total sensory rating (Figure 1, 2). The fruits kept the pink external colour, improved internal colour, saturated aroma, tender peel, no visible fibre, succulent and fleshy texture, no change in the sourness perception but much better expressed sweetness.



**1** - Aleno sartse; **2** – Ideal; **3** - Plovdivska karotina; **4** - Rozovo sartse; **5** - BG 21 β; **6** - BG 24/13; **7** - BG 720; **8** - BG 735; **9** - BG 785; **10** - BG 822; **11** - BG 2066

**Figure 1.** Sensory characteristics of the indeterminate tomato accessions

Among the tomato accessions with red fruits BG 735 was the leader. It obtained a total sensory evaluation of 4.4 like as Rozovo sartse. Its peel tenderness and the texture were only the sensory traits evaluated a little bit low. The sensory profile of BG 21 β with orange coloured fruits was very close to both accessions. Variety Ideal possessed the most unacceptable sensory profile because of a negative change in the taste caused by decreased sourness perception.

**Table 1.** Duncan's multiple range test and coefficient of variability for the sensory assessments of the indeterminate tomatoes

| **Accessions** | **Appearance** | | **Shape** | | **External colour** | | **Internal colour** | | **Aroma** | | **Peel tenderness** | | **Visible fibre** | | **Sourness** | | **Sweetness** | | **Texture** | | **Overall taste** | | **Toral sensory evaluation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** |
| **Al.sartse** | d | d | cde | b | ef | de | ab | b | ab | abc | abc | ab | ab | ab | a | a | abc | c | abc | bcd | abc | e | ab | d |
| **Ideal** | cd | cd | abc | b | abcd | bc | ab | ab | b | bc | c | b | b | b | c | a | bc | bc | c | d | c | de | b | cd |
| **Pl.karotina** | bc | cd | abc | ab | abc | bcd | ab | ab | ab | ab | a | ab | ab | a | abc | ab | c | bc | bc | abcd | bc | bcd | ab | bc |
| **Roz.sartse** | cd | cd | bcde | ab | def | e | a | ab | a | ab | ab | ab | a | a | a | a | a | ab | a | ab | a | a | a | a |
| **BG 21 β** | a | ab | ab | ab | a | a | a | ab | a | bc | bc | b | a | a | ab | a | ab | a | ab | a | abc | ab | a | a |
| **BG 24/13** | d | cd | abcd | ab | abcd | bc | ab | ab | a | bc | bc | ab | a | ab | bc | b | a | ab | bc | cd | abc | abcd | ab | bc |
| **BG 720** | cd | cd | e | b | cdef | e | ab | ab | a | bc | a | a | ab | ab | a | a | ab | abc | bc | abcd | abc | abcd | ab | ab |
| **BG 735** | ab | abc | ab | ab | bcdef | abc | ab | a | a | a | abc | ab | ab | ab | ab | a | ab | bc | bc | abc | ab | abc | a | ab |
| **BG 785** | d | bcd | bcde | ab | f | bcd | b | ab | ab | ab | ab | ab | ab | ab | abc | a | abc | abc | abc | abcd | abc | cde | ab | ab |
| **BG 822** | cd | d | de | b | df | de | ab | ab | a | ab | abc | ab | ab | ab | ab | ab | ab | bc | abc | abcd | abc | bcd | ab | bc |
| **BG 2066** | ab | a | a | a | ab | a | ab | ab | ab | c | c | ab | ab | ab | c | ab | bc | ab | abc | bcd | abc | bcd | ab | bc |
| **CV (%)** | 9.91 | 7.20 | 7.49 | 5.09 | 12.31 | 9.53 | 7.28 | 6.94 | 4.85 | 6.05 | 8.15 | 6.93 | 9.01 | 10.14 | 10.62 | 7.10 | 7.85 | 8.31 | 8.66 | 8.81 | 7.57 | 7.54 | 6.89 | 6.08 |

a, b, c… - Duncan's multiple range test ($p<0.05$); **R**-reduced irrigation, **O**-optimum irrigation

**Table 2.** Two-way analysis of variance of the indeterminate tomatoes

| Sensory traits | Factor A (genotype) | Factor B (irrigation) | A x B | Residue |
|---|---|---|---|---|
| **Appearance** | 55.19*** | 25.87*** | 6.13 | 12.80 |
| **Shape** | 56.63*** | 11.47** | 10.22 | 21.68 |
| **External colour** | 74.79*** | 1.37 | 7.03 | 16.81 |
| **Internal colour** | 39.56* | 0.14 | 22.53* | 37.77 |
| **Aroma** | 53.85** | 0.93 | 14.45 | 30.77 |
| **Peel tenderness** | 61.63** | 0.62 | 7.05 | 30.70 |
| **Visible fibre** | 59.06** | 1.88 | 3.50 | 35.56 |
| **Sourness** | 51.78** | 0.41 | 20.90* | 26.91 |
| **Sweetness** | 39.88** | 20.65*** | 16.43 | 23.05 |
| **Texture** | 65.79*** | 0.03 | 7.61 | 26.57 |
| **Overall taste** | 63.15*** | 0.30 | 9.00 | 27.55 |
| **Total sensory evaluation** | 63.22*** | 5.39* | 4.90 | 26.48 |

Stronger unfavourable effect of the reduced irrigation in determinate tomatoes for processing was recorded on the appearance, followed by the shape, texture, aroma and total sensory evaluation (Table 3, Figure 3). By analogy with indeterminate tomatoes, the evaluations for sweetness were higher for the fruits grown in water deficit than the fruits grown in optimum watering regime. Reduced irrigation did not result in external and internal colour, peel tenderness, sourness and overall taste. The influence of reduced irrigation as a single factor on these sensory traits was insignificant.

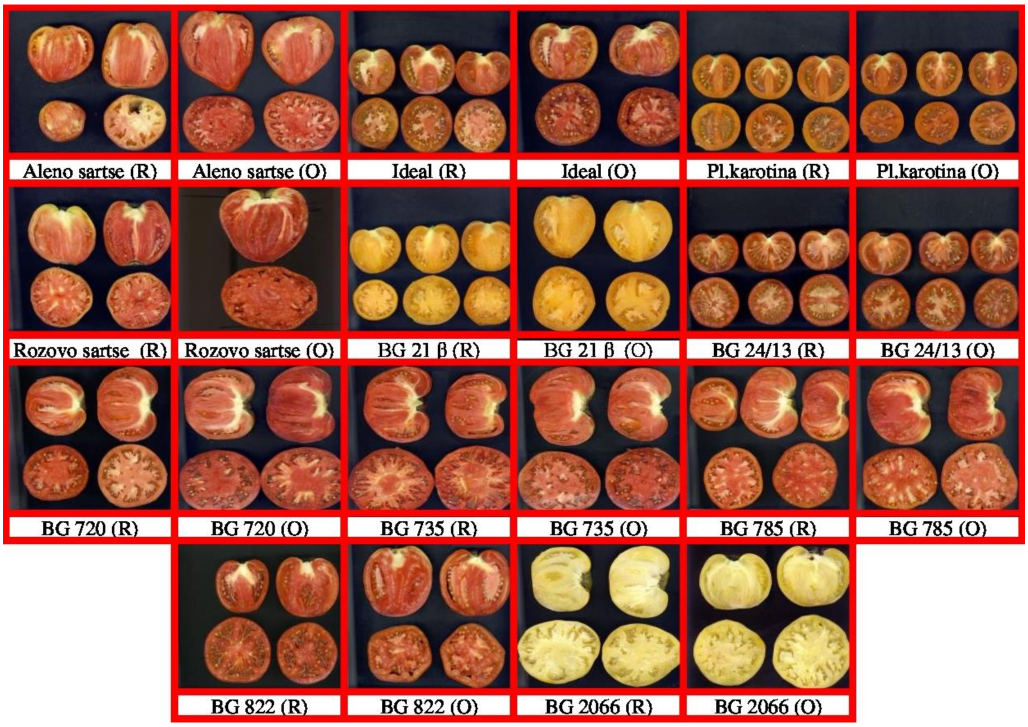



**Figure 2.** Scanned fruits of the studied indeterminate tomatoes grown under reduced irrigation (R) and optimum irrigation (O)

Significant effect (over 25%) of the interaction genotype x irrigation on the sensory evaluations for external colour, internal colour and texture was proved by two-way analysis of variance (Table 3). The genotype effect on the sensory properties ranged from 33.49% to 56.05%. Except the shape the studied accessions grown in 50% reduced irrigation differed more strongly than the well-watered ones. It was confirmed by the higher coefficients of variability (Table 4). The tomato accessions were not significantly different in the fruit sensory traits internal colour, aroma, visible fibre and sourness when they had been grown in optimum watering regime while in the reduced watering regime the differences were statistically proved.

**Table 3.** Two-way analysis of variance of the determinate tomatoes for processing

| Sensory traits | Factor A (genotype) | Factor B (irrigation) | A x B | Residue |
|---|---|---|---|---|
| **Appearance** | 43.63* | 25.37** | 4.85 | 26.16 |
| **Shape** | 40.46* | 10.57* | 17.95 | 31.02 |
| **External colour** | 44.76** | 0.31 | 37.89** | 17.04 |
| **Internal colour** | 49.72** | 3.49 | 25.56* | 21.23 |
| **Aroma** | 51.39** | 8.68* | 12.15 | 27.78 |
| **Peel tenderness** | 56.05** | 1.79 | 13.45 | 28.70 |
| **Visible fibre** | 42.49** | 2.63 | 28.84 | 26.05 |
| **Sourness** | 53.89** | 0.15 | 22.01 | 23.95 |
| **Sweetness** | 44.86* | 16.04** | 11.03 | 28.07 |
| **Texture** | 39.91** | 9.08** | 33.07** | 17.94 |
| **Overall taste** | 51.36** | 0.78 | 19.43 | 28.44 |
| **Total sensory evaluation** | 46.94** | 6.25* | 23.34 | 23.47 |

Toward the sensory profile BG 2086 was the best adapted to water deficit tomato accession for processing. With the exception of the appearance and shape all the other traits were given higher assessments for the fruits grown in reduced irrigation (Figure 3). The better taste was determined predominantly by the increased awareness of sourness and sweetness.


**For processing: 1** - Kapri; **2** - Neven; **3** - Pautalia; **4** - Venera; **5** - BG 160; **6** - BG 985; **7** - BG 1527; **8** - 2086 **For fresh consumption: 9** - Marti; **10** - Milyana; **11** - Solaris; **12** - Spektar; **13** - BG 252

**Figure 3.** Sensory characteristics of the determinate tomato accessions

**Table 4.** Duncan's multiple range test and coefficient of variability for the sensory assessments of the determinate tomatoes

| **Accessions** | **Appearance** | | **Shape** | | **External colour** | | **Internal colour** | | **Aroma** | | **Peel tenderness** | | **Visible fibre** | | **Sourness** | | **Sweetness** | | **Texture** | | **Overall taste** | | **Toral sensory evaluation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** | **R** | **O** |
| *Determinate tomato for processing* | | | | | | | | | | | | | | | | | | | | | | | | |
| **Kapri** | bc | b | a | ab | a | b | a | ns | abc | ns | a | ns | a | ns | ab | ns | bc | b | ab | b | ab | b | ab | b |
| **Neven** | bc | ab | ab | b | bc | ab | bc | ns | bcd | ns | a | ns | cde | ns | bc | ns | c | b | ab | a | ab | ab | bc | ab |
| **Pautalia** | a | a | ab | a | ab | a | ab | ns | cd | ns | a | ns | e | ns | c | ns | ab | a | ab | ab | abc | ab | ab | b |
| **Venera** | ab | ab | ab | ab | ab | b | ab | ns | ab | ns | b | ns | de | ns | c | ns | abc | ab | a | ab | abc | ab | ab | ab |
| **BG 160** | c | ab | ab | b | d | ab | d | ns | abc | ns | ab | ns | bcd | ns | c | ns | abc | ab | bc | ab | c | ab | c | ab |
| **BG 985** | abc | ab | b | ab | bc | b | bc | ns | abc | ns | b | ns | ab | ns | c | ns | abc | b | a | b | bc | b | bc | ab |
| **BG 1527** | c | ab | ab | b | cd | b | d | ns | d | ns | ab | ns | abc | ns | bc | ns | abc | ab | c | ab | bc | ab | c | ab |
| **BG 2086** | abc | ab | b | b | abc | b | abc | ns | a | ns | a | ns | abc | ns | a | ns | a | ab | a | a | a | a | a | a |
| **CV (%)** | 11.21 | 10.04 | 7.00 | 7.36 | 11.50 | 8.76 | 11.50 | 8.59 | 7.36 | 5.01 | 15.47 | 12.51 | 11.10 | 10.21 | 15.36 | 8.55 | 10.42 | 7.10 | 16.56 | 8.28 | 14.53 | 11.04 | 14.04 | 10.47 |
| *Determinate tomato for fresh consumption* | | | | | | | | | | | | | | | | | | | | | | | | |
| **Marti** | a | ns | a | ns | ab | ns | ns | a | ab | ns | b | ns | ab | ns | ab | ns | b | b | a | ns | a | ns | a | ns |
| **Milyana** | b | ns | c | ns | b | ns | ns | bc | b | ns | ab | ns | a | ns | b | ns | ab | ab | b | ns | b | ns | b | ns |
| **Solaris** | ab | ns | bc | ns | a | ns | ns | c | ab | ns | ab | ns | ab | ns | ab | ns | ab | ab | ab | ns | ab | ns | a | ns |
| **Spektar** | b | ns | bc | ns | b | ns | ns | ab | ab | ns | ab | ns | ab | ns | a | ns | ab | ab | a | ns | a | ns | a | ns |
| **BG 252** | a | ns | ab | ns | ab | ns | ns | abc | a | ns | a | ns | b | ns | ab | ns | a | a | a | ns | a | ns | a | ns |
| **CV (%)** | 13.80 | 4.32 | 10.42 | 5.55 | 10.74 | 7.27 | 6.67 | 6.73 | 8.32 | 2.97 | 6.80 | 6.20 | 10.84 | 5.48 | 11.16 | 11.73 | 12.43 | 14.14 | 14.13 | 7.38 | 11.15 | 7.01 | 13.68 | 4.70 |

a, b, c… - Duncan's multiple range test ($p<0.05$), ns - not significant; **R**-reduced irrigation, **O**-optimum irrigation

Accession BG 160 suffered lack of water at the highest degree. Almost all sensory properties of the fruits from reduced irrigation treatment were given lower ratings compared to the optimum one (Figure 3, Table 4). The same low total sensory evaluation of 2.9 was given to BG 1527 but the reason for the change of the sensory perception was different. Although the fruits grown in water deficit did not change the external colour and had an improved internal colour (Figure 4) the total assessment was low because of the very poor soft texture.


**Figure 4.** Scanned fruits of the studied determinate tomatoes for processing grown under reduced irrigation (R) and optimum irrigation (O)

The sensory characteristics of determinate tomatoes for fresh consumption were also affected by the water insufficiency during the vegetation period. The increase of sourness and sweetness perception was well expressed (Table 5, Figure 3). The peel of the fruit became rougher in the four tomato varieties. The influence of water deficit on the appearance, shape and total sensory evaluation was also proved. However, its manifestations were dependent on the genotype as well. The genotype effect as a single factor on the sensory evaluations ranged from 14.96% to 62.93%.

**Table 5.** Two-way analysis of variance of the determinate tomatoes for fresh consumption

| Sensory traits | Factor A (genotype) | Factor B (irrigation) | A x B | Residue |
|---|---|---|---|---|
| **Appearance** | 19.93* | 26.47*** | 37.25* | 16.34 |
| **Shape** | 14.96 | 33.20*** | 33.40* | 18.44 |
| **External colour** | 56.86* | 1.77 | 8.19 | 33.19 |
| **Internal colour** | 62.93* | 0.20 | 6.81 | 30.06 |
| **Aroma** | 31.60 | 3.77 | 36.32 | 28.30 |
| **Peel tenderness** | 30.08 | 31.93** | 8.97 | 29.02 |
| **Visible fibre** | 42.60 | 0.51 | 18.62 | 38.27 |
| **Sourness** | 30.95 | 24.08* | 17.61 | 27.35 |
| **Sweetness** | 49.36* | 20.77* | 2.95 | 26.92 |
| **Texture** | 45.77* | 0.77 | 20.15 | 33.30 |
| **Overall taste** | 54.02* | 1.05 | 13.50 | 31.43 |
| **Total sensory evaluation** | 44.05** | 8.09* | 31.59* | 16.28 |

The differences concerning the sensory profile of the studied accessions increased in the treatment of reduced irrigation (Table 4). Except for the internal colour and sweetness the differences were not significant in well-watered tomatoes but they were proved in the scarcity of water.

Marti and BG 252 seem to be the most appropriate for growing in water deficit. The plants grown in reduced irrigation formed tasty fruits with increased sourness and sweetness perception reflecting on a better overall taste. Additionally, improved appearance, aroma and texture were established for both accessions (Figure 5).

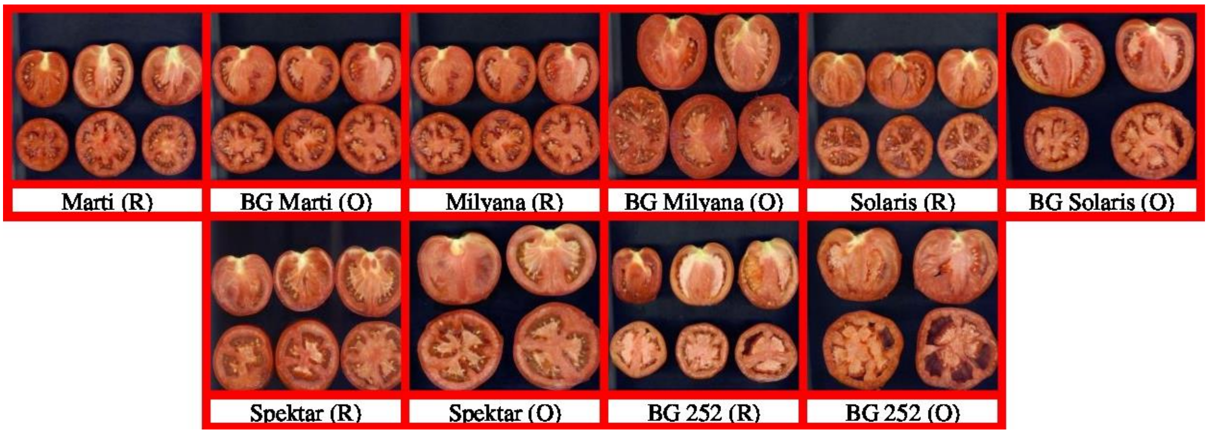



**Figure 5.** Scanned fruits of the studied determinate tomatoes for fresh consumption grown under reduced irrigation (R) and optimum irrigation (O)

Variety Milyana demonstrated the most sensitive reaction to water stress. The fruits developed under conditions of reduced irrigation were given the lowest total sensory evaluation. The main reason was the decreased fruit size and deep and wide cracks on the tomato surface.

## 4. DISCUSSION

Sensory properties of tomato fruits are important for consumer's acceptance and for their decision to buy a distinct variety. Many factors influence the organoleptic characteristics of tomatoes such as genotype (Causse et al. 2002), climatic conditions (Dzakovich, Ferruzzi & Mitchell 2016), soil compounds (Heeb et al. 2006), watering regime (Stevens et al. 1977), harvest time (Johansson et al. 1999), growing method (Thybo et al. 2006) etc.

Hot summer conditions in Bulgaria combined with the applied regime of water deficit for the period of tomato growth during our experiment caused changes in the sensory profiles of the three investigated tomato genotypes (Figure 6). The most negative effect of reduced irrigation was recorded on the appearance. The sensory assessments decreased by 9.4 % for the indeterminate tomatoes and by 10.5% for both types of determinate tomatoes. The shape was the next tomato sensory trait that was influenced by the lack of water at some level. During the panel test these two properties were visually different for the well-watered fruits and for the fruits from the treatment with reduced irrigation. Similar negative trend in response to increasing soil water deficit for fruit size was observed by Patanè & Cosentino (2010), Obreza et al. (1996). In contrast, according to Ripoll et al. (2016) fruit size and fresh weight were not affected by controlled water deficit.

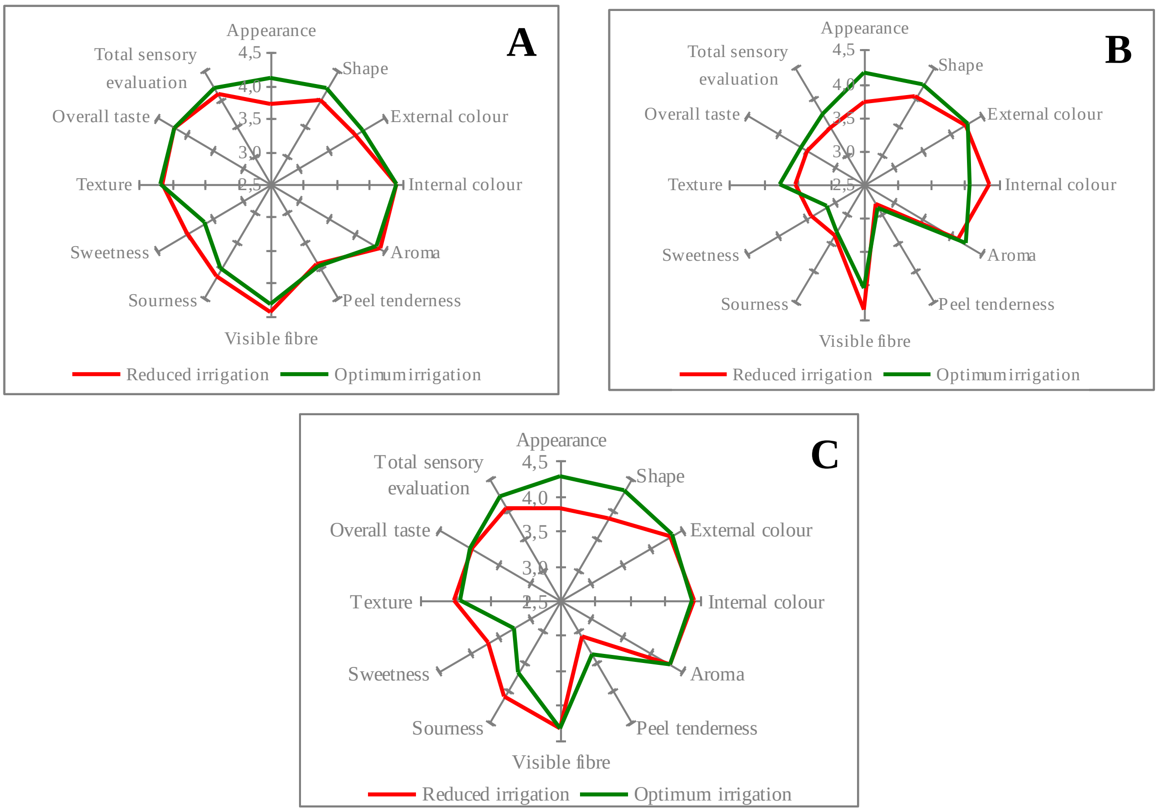



**Figure 6.** Sensory profile of the tomato fruits (A - indeterminate, B - determinate for processing, C - determinate for fresh consumption)

No significant differences were found in external and internal colour of well-watered and water stressed tomato fruits. Having in mind that the color measurements are correlated with the lycopene content (Arias et al. 2000; Molyneux, Lister & Savage 2004), our results did not correspond indirectly to the results of some authors. According to Atkinson et al. (2011) drought stress decreases the lycopene content compared to well-watered plants. Under soil water deficit conditions the carotenoid biosynthetic pathway is more 'β-carotene accumulation' oriented especially at the beginning of the fruit ripening process (Riggi, Patané & Ruberto 2008). In contrast, an increase in lycopene content was observed in tomatoes grown in reduced irrigation (Theobald, Bacon & Davies 2007; Favati et al. 2009; Sánchez-Rodríguez et al. 2012).

The sensory panel was not able to separate well the investigated samples from the different treatments by aroma and visible fibre.

Water stressed fruits compared to well-watered ones showed a higher value of the assessments for sweetness in all investigated genotypes. Sweetness is in relation with contents of sugars and soluble solids in tomato (Malundo, Shewfelt & Scott 1995; Pevicharova & Todorov 2001). Mitchell et al. (1991) established that increases in soluble solids in fruit grown under soil water deficits were related primarily to decreases in fruit water content and to slight increases in soluble sugars. Similar results were obtained by Nahar & Gretzmacher (2002) and Klunklin & Savage (2017).

In our experiment water stress also led to increasing of sourness in all studied determinate tomato for fresh consumption and in some accessions of indeterminate tomatoes and determinate for processing. Sourness positively correlates with titratable acidity and pH (Stevens, Kader & Albright 1979). There are reports of tomato fruit acidity enhance under water deficits (Rudich et al. 1977; Mingchi et al. 2010).

Increasing of sweetness and sourness did not affect unidirectionally on the overall taste and the total sensory evaluation in tomato accessions investigated by us. One part of accessions displayed better flavour in water stressed fruits while the other part manifested deterioration. Taking into account the high correlation found between tomato sensory traits and organoleptic compositions (Causse, Damidaux & Rousselle 2007; Tandon et al. 2003) we could say our results did not fully support the suggestion given by other authors that water deficit improves fruit quality (Guida et al. 2017; Chen et al. 2013). In our investigation under limited water supply the sensory characteristics of tomato fruits mainly depended on the genotype (Tables 2, 3, 5).

## 5. CONCLUSIONS

Negative effects of reduced irrigation were observed in appearance, shape and total sensory evaluation of tomato fruits regardless of the tomato type. Negative effects were also recorded in texture of determinate tomato for processing and peel tenderness of determinate tomato for fresh consumption. The sweetness was better expressed in water stressed tomatoes in all studied genotypes. Limited water supply did not result in aroma, external colour and visible fibre. The influence of genotype on sensory traits was much stronger than the applied watering regime. The established significant differences for some sensory traits found among genotypes grown under water deficit are a good precondition for a successful breeding process. To avoid the negative effects of reduced irrigation combined with the elevated temperatures of the hot summers in Bulgaria on the sensory characteristics of tomato the development of new varieties with heat and drought tolerance is needed. Some of the investigated accessions could be used as parental components for this purpose.

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