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Original Research

The Effects of Hydrothermal Conditions during Vegetation Period on Fruit Quality of Processing Tomatoes

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Abstract

Our experiment was carried out in experimental plots of the Vegetable Experimental Station of the Agricultural University in Mydlniki near Kraków, Poland in 2008-10.

The year 2008 was characterized by the driest season of all three years, whereas in the other years of the study the vegetation season seemed moderately humid. Based on the analyses of regression, we found a significant influence of pluvial and thermal conditions on the fruit quality features of tomatoes. A directly proportional relationship between the hydrothermal index (K) and the number of seed chambers, dry matter, and content of lycopene, magnesium, and calcium of the tomato fruit was observed. However, the relationship between the hydrothermal index (K) and fruit weight, potassium content, and total acidity turned out to be inversely proportional. The impact of the hydrothermal conditions on the thickness of the pericarp, the shape coefficient, phosphorus; L-ascorbic acid content, and the reducing sugars of the fruits was not observed. The value distribution of the tested tomato features in all of the years of the experiment points to the different sensitivities of individual tomato cultivars to thermal and precipitation conditions.

The aim of this study was to determine the influence of hydrothermal conditions represented by the hydrothermal index (K) on the morphological features of tomato fruits and their chemical composition.

Keywords: tomato, hydrothermal index, fruit features, chemical composition

Introduction

Climatic conditions, mainly air temperature and precipitation, have a decisive impact on vegetable yield and its quality [1-4]. Many researchers emphasize that extreme weather conditions can disturb the development of fruits and influence their chemical composition [3, 5]. In order to determine quality features and plant yield, Sielianinov's hydrothermal index (K) is frequently used in many studies [6, 7]. This index, which is a quotient of the sum of the pre-

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cipitation and the sum of the temperature, is known in the literature as the coefficient of the hydration needs of plants. Both of these are the main weather factors determining the size and the quality of vegetable yields.

The tomato has adapted to varying climatic and soil conditions. They have been planted in the equatorial zone as well as in higher latitudes. In Poland there is a northern border for planting tomato in open fields. Tomato, as a warm-season vegetable, requires relatively high temperatures for the proper development of its fruits. In the stage of fruit development, the temperature should not be lower than 16ºC and not higher than 25ºC so as to yield fully colored fruit with a flavor typical for that particular cultivar with the right chemical composition. The fastest ripening of fruits can be observed when the temperature is between 20-24ºC. The main tomato carotenoid, lycopene, is not formed in temperatures below 12ºC and above 32ºC [8].

In spite of the temperature's direct influence on plant metabolism, tomato fruit development, and nutritional value, low air humidity and moderate humidity of soil also significantly influence the tomato's features [9, 10]. In experiments carried out by Jędrszczyk et al. [4] in the climatic conditions of southern Poland, the highest tomato yield was observed in moderately dry and warm years. An optimal distribution of precipitation, especially in the period of fruit setting (July and August), influences not only higher yield, but the physical and chemical properties of fruits as well [11]. A deficiency of precipitation at that time was the reason why fruits turned out smaller, with softened peels and a reduced amount of dry matter [12, 13]. Mitchell et al. [11] indicate that a shortage of water increases the amount of sugar, potassium, and organic acid in the tomato's fruit. The beginning of low temperatures in the final growing season, falling throughout September, decreases the tomato's water needs, which are the lowest at harvest time [14].

The aim of our study was to determine the influence of hydrothermal conditions represented by the hydrothermal index (K) on morphological features of tomato fruits and their chemical composition.

Material and Methods

The experiment was carried out on brown soil in an open field on experimental plots at Vegetable Experimental Station of the Agricultural University in Mydlniki near Kraków in years 2008-10.

Twelve processing tomato cultivars were used: 'Sokal F1,' 'Batory F1,' 'Rejtan F1,' 'Hetman,' 'Luban,' 'Babinicz,' 'Awizo F1,' 'Mieszko F1,' 'III A F1,' 'Ondraszek,' 'Hubal,' and 'Talon.' A completely randomized block design with four replicates and 40 plants per plot was used. The dates of sowing and planting of seedlings produced in multi-cell trays were as follows: 2008 – sowing 8 April, planting 16 May; 2009 – sowing 16 April, planting 21 May; 2010 – sowing 31 March, planting 26 May. Plant spacing was 80×60 cm.

Harvesting was performed once, at the stage of maturity of the individual cultivar when about 75% fruits were matured. After harvest, the anatomical features of fruits, such as mean fruit weight, thickness of peripheral walls, and number of seed chambers were measured and the shape coefficient was calculated. The assessment of the chemical composition of the fruits included: dry matter (desiccation method at 105ºC to a constant weight), calcium, potassium, and magnesium (atomic absorption method in a Varian Spectr AA-20 and air/acetylene flame under standard operating conditions), phosphorus (colorimetric method – Specol spectrophotometer), lycopene (HPLC method), L-ascorbic acid (Tillman method using indophenol), reducing sugar content (anthrone method), and the level of acidity (Pijanowski method using caustic soda).

During the growing season, typical treatments such as weeding and chemical disease protection were carried out according to current recommendations. The air temperature and precipitation were measured at the Vegetable Experimental Station. In order to analyze meteorological conditions on tomato developmental stages, Sielianinov's hydrothermal index (K) was used. *K* is known as the coefficient of the provision of water in plants. The index was computed as follows [6]:

$$K = P / 0.1 \sum t$$

...where: P is sum of monthly mean precipitation in mm, $\sum t$ is the sum of daily mean air temperatures > 0ºC.

The average weekly air temperature, the sum of precipitation and the number of days with precipitation in the experimental years were calculated on the basis of meteorological measurements.

The sum (P> 0.1 mm) and number of days (L) of precipitation and the sum of the temperature ($\sum$t >0ºC) in particular stages were calculated.

The dependences of the morphological and chemical features of fruits (Y) from the hydrothermal index (K) were analyzed using the linear regression method:

$$Y = b_0 + b_1 \cdot K$$

...where: b_0 is intercept, b_1 is slope (regression coefficient).

Statistical Analysis

For each of the tomato cultivars, statistical analyses were done using the analysis of variance and the LSD Fisher test. Statistical conclusions were carried out at a significance level of α=0.05. The calculations were made with the help of Statistica 10 software.

Only the distribution graphs of a given factor where the regression analysis showed a statistically significant influence of the hydrothermal index are included.

Results and Discussion

During the vegetation period in 2008-10, a largely diversified distribution of meteorological conditions was observed. Varying thermal conditions were recorded, especially at the beginning of plant vegetation (Fig. 1). Weekly precipitation was compared to tomato water needs elaborated upon by Dzieżyc et al. [14] for the Upper Vistula River Basin. The sum of precipitation clearly diverged from the 10-day tomato water needs during the entire vegetation period (Fig. 2). These features are typical of the Polish climate. The hydrothermal index (K) calculated for the years of the experiment shows the diversified thermal and precipitation conditions. The calculated values of the K index for each cultivar were diversified as far as the length of the growing season was concerned. The vegetation season of 2008 was characterized by the K index values from 1.0 to 1.4, which means that the weather conditions were moderately dry and optimal to the growth of the tomato plant. However, the precipitation distribution was diversified and differed greatly from tomato water needs. At the beginning of the vegetation period (May and June), significant shortages in comparison to water needs were observed, but in July the precipitation was much too high. In 2009 and 2010 the value of the K index fluctuated from 1.7 to 1.9 and from 1.8 to 2.0, which suggests that the vegetation seasons of these years were moderately humid. As far as precipitation distribution was concerned, 2009 was the most adequate to tomato water needs. The most unfavorable precipitation distribution occurred in 2010. We also observed excessive precipitation in comparison to tomato water needs from the first to the third 10-day period of May and from the third 10-day period of July to the end of the vegetation period.

Jędrszczyk et al. [4] emphasized the unfavorable distribution of meteorological conditions for tomato yielding in the years when the experiment was carried out. The researchers concluded that the impact of the sum and distribution of precipitation on tomato yield was decisive. High precipitation decreased yield, whereas frequent and lower precipitation had a favourable influence. The authors observed the strongly diversified value of the hydrothermal index (K) in each developmental stage of the tomato cultivars.

Based on the analyses of regression, the significant impact of the hydrothermal index (K) on mean fruit weight

-fruits growing and harvesting period 2008
2009
2010

Fig. 1. Ten-day average air temperature (ºC) during the vegetation period.

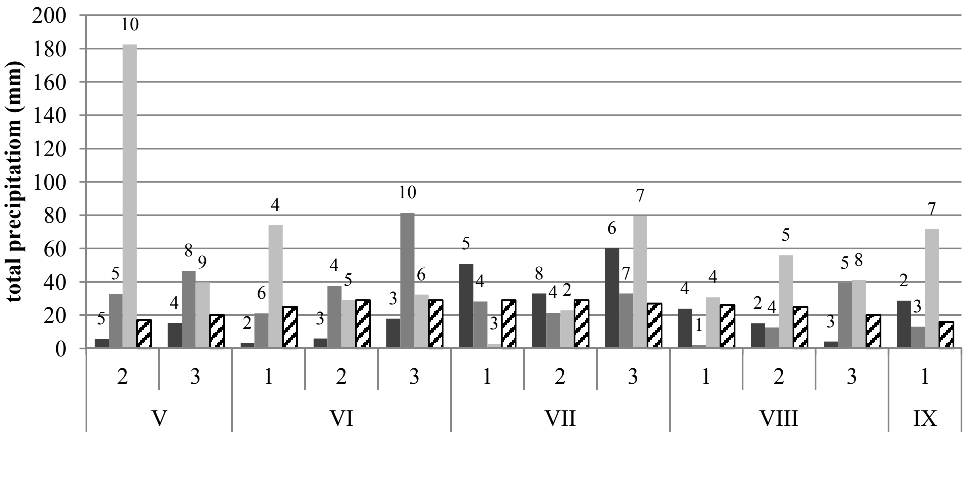

Fig. 2. Ten-day sum (bars) and number of days with precipitation (numbers over the bars) according to tomato water needs during the vegetation period.

was confirmed. This influence between the K index and tomato fruit weight is inversely proportional, which means that the more water the tomato plant received the smaller the fruits that were developed. This can be clearly noticed in Fig. 3a, where in the most humid year, 2010 (K oscillated from 1.8 to 2.0), the fruits weighed from 74 to 145 g (100 g on average for the cultivars), and in 2008, the most dry year (K oscillated from 1.1 to 1.4), mass of fruits fluctuated from 84 to 176 g (130 g on average for the cultivars). The results achieved in this study are consistent with the results obtained by Heuvelink and Dorais [10]. Those authors pointed out the influence of optimal thermal and humidity conditions on the size of tomato fruits.

The thickness of the pericarp did not differ much in each year of the experiment and oscillated from 0.64 to 0.67 mm. The K index impact on the thickness of the pericarp was not statistically significant (Table 2).

The number of seed chambers in the tested cultivars ranged from 2.14 (2008) to 3.81 (2009) and varied in the years of the experiment (Fig. 3b). A great majority of the tested cultivars created the largest number of seed chambers in 2009 (2.3-5.3), and the smallest number of seed chambers occurred in 2008 (2.0-2.7). The Hetman cultivar was characterized by the smallest number of seed chambers in each year of the study. A strong, statistically significant, directly proportional relationship between the number of seed chambers and the hydrothermal index (K) was found with the help of analyses of variances (Table 2).

The shape coefficient fluctuated between 0.94-1.00 in each year of research. The hydrothermal index's (K) impact on tomato shape was tested with the help of the analyses of regression. However, this relationship did not turn out to be statistically significant (Table 2). It suggests that the shape of the fruits is strongly genetically conditioned [15].

In the present research, the amount of dry matter in fruits strongly depended on the year of the study (Fig. 3c). The amount of dry matter in the fruits of all tomato cultivars was the largest in 2009 and fluctuated between 4.7 and 5.4%. The analysis of regression showed the statistically significant, directly proportional relationship between dry

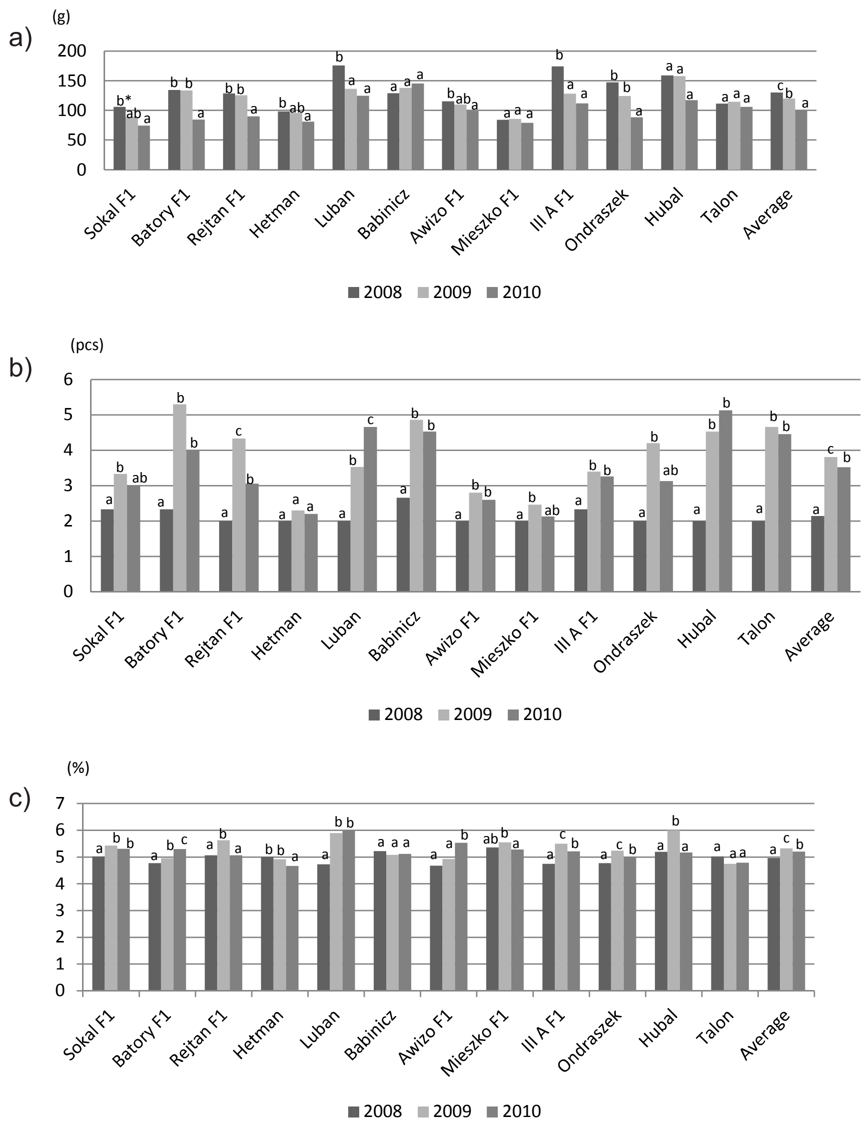

Fig. 3. a) Mean fruit weight in particular years of the experiment, b) number of seed chambers (pcs) in particular years of the experiment, c) dry matter of tomato fruit in particular years of the experiment.
*Differences in years were calculated for each cultivar separately. Values followed by the same letter are not significantly different.

Table 1. The hydrothermal index (*K*) during the vegetation period of 12 processing tomato cultivars.

Cultivar	2008	2009	2010
Sokal F1	1.1	1.7	1.9
Batory F1	1.2	1.8	1.8
Rejtan F1	1.2	1.8	1.9
Hetman	1.3	1.9	1.9
Lubań	1.1	1.8	2.0
Babinicz	1.2	1.8	2.0
Awizo F1	1.2	1.8	1.9
Mieszko F1	1.1	1.9	1.9
III A F1	1.1	1.7	2.0
Ondraszek	1.4	1.8	2.0
Hubal	1.1	1.8	1.9
Talon	1.2	1.8	1.9
Mean	1.2	1.8	1.9

* Hydrothermal index value:
$K \leq 0.4$ extremely dry,
$0.4 < K \leq 0.7$ very dry,
$0.7 < K \leq 1.0$ dry,
$1.0 < K \leq 1.3$ relatively dry,
$1.3 < K \leq 1.6$ optimal,
$1.6 < K \leq 2.0$ relatively humid,
$2.0 < K \leq 2.5$ humid,
$2.5 < K \leq 3.0$ very humid,
$K > 3.0$ extremely humid.

matter content and the hydrothermal index (K) (Table 3). Many researchers have observed the strong impact of environmental factors on the dry matter of the fruit. The observed amount of dry matter of tomato fruits in Poland was lower than in the countries of Southern Europe, where the climatic conditions are favorable to tomato growth, development, and yield. In conditions with a moderate, warm climate (i.e. Romania), the amount of dry matter was much higher and fluctuated from 5.25 to 8.25% [16].

The content of macroelements in the fruits of each tomato cultivar was strongly diversified in the years of the study. In 2008 the potassium content was the highest and varied from 207.0 to 273.6 mg·100^{-1} g f.m., whereas the content of calcium, phosphorus, and magnesium were the lowest. In 2009 tomato fruits had the highest calcium content (13.1-19.3 mg·100^{-1} g f.m.). In 2010, however, the content of phosphorus and magnesium in fruits was the highest (16.7-23.4 and 8.2-12.1 mg·100^{-1} g f.m., respectively) (Fig. 4a-4c). The influence of hydrothermal conditions on the content of macroelements of the fruits was calculated. A statistically significant influence of the hydrothermal conditions on the content of calcium, magnesium and potassium was found. The relationship between the K index and the calcium and magnesium content was directly proportional, whereas the content of potassium and the K index were inversely proportional (Table 3). This fact suggests that the weather conditions have a varied impact on the accumulation of macroelements in tomato fruits in the examined years. This directly proportional influence of humidity on the accumulation of macroelements in tomato fruits was also confirmed by the research of Heuvellink and Dorais [10].

The lycopene content in tomato fruits differed in each year of the experiment. The tomato fruits contained the highest content in 2010 (281.5 mg·100^{-1} g f.m.), which was the most humid of all of the years of the experiment (K varied from 1.8 to 2.0), and was a little lower in 2009 (236.5 mg·100^{-1} g f.m.) (K varied between 1.7 and 1.9), and a clearly low content of lycopene appeared in 2008 (120.0 mg·100^{-1} g f.m.), which was the driest year in the experimental period (K varied between 1.1 and 1.4) (Table 1, Fig. 4d). The significant impact of weather conditions on the amount of lycopene in tomato fruits was confirmed by an analysis of regression. The regression equation showed the directly proportional relationship between the hydrothermal index (K) and the lycopene amount in tomato fruits. The favorable temperature and unfavorable heavy precipitation impact on the lycopene level was confirmed by other researchers [3, 17, 18]. Kuti and Konuru [19] demonstrated in their research that tomato cultivars planted in a greenhouse in 20ºC in controlled conditions that are optimal for tomato development were characterized by a higher content of lycopene than ones cultivated in an open field with less favorable weather conditions.

The acidity of the tomato juice of the tested cultivars diversified in each year of the study (Fig. 4d). The fruits were characterized by the highest acidity (0.45-0.55% f.m.) in 2008, whereas the fruits from 2010 had the lowest (0.31-0.45% f.m.). However, in each year when optimal temperatures and moderate precipitation occurred, meteorological factors negatively impacted the acidity of tomato juice. This

Table 2. The dependences between the hydrothermal index (K) and anatomical features of fruits.

Anatomical features of fruits	Regression equation	Coefficient of correlation R	F statistic (1.34)*	Probability p
Mean fruit weight	$Y = -0.55 \cdot K + 166.67$	0.37	5.53	0.025
Thickness of pericarp	No significant relationships			
Number of seed chambers	$Y = 2.13 \cdot K$	0.64	24.037	0.00002
Shape coefficient	No significant relationships			

* degree of freedom

was confirmed by a high correlation coefficient and statistically significant regression. In 2010, when K ranged from 1.8 to 2.0, precipitation was much higher than the tomato's water needs, whereas tomato acidity was at the lowest level (Table 4, Fig. 4d). The same conclusions were obtained by Mitchel et al. [11]. They proved that there exists a significant negative relationship between optimal tomato water needs and its acidity.

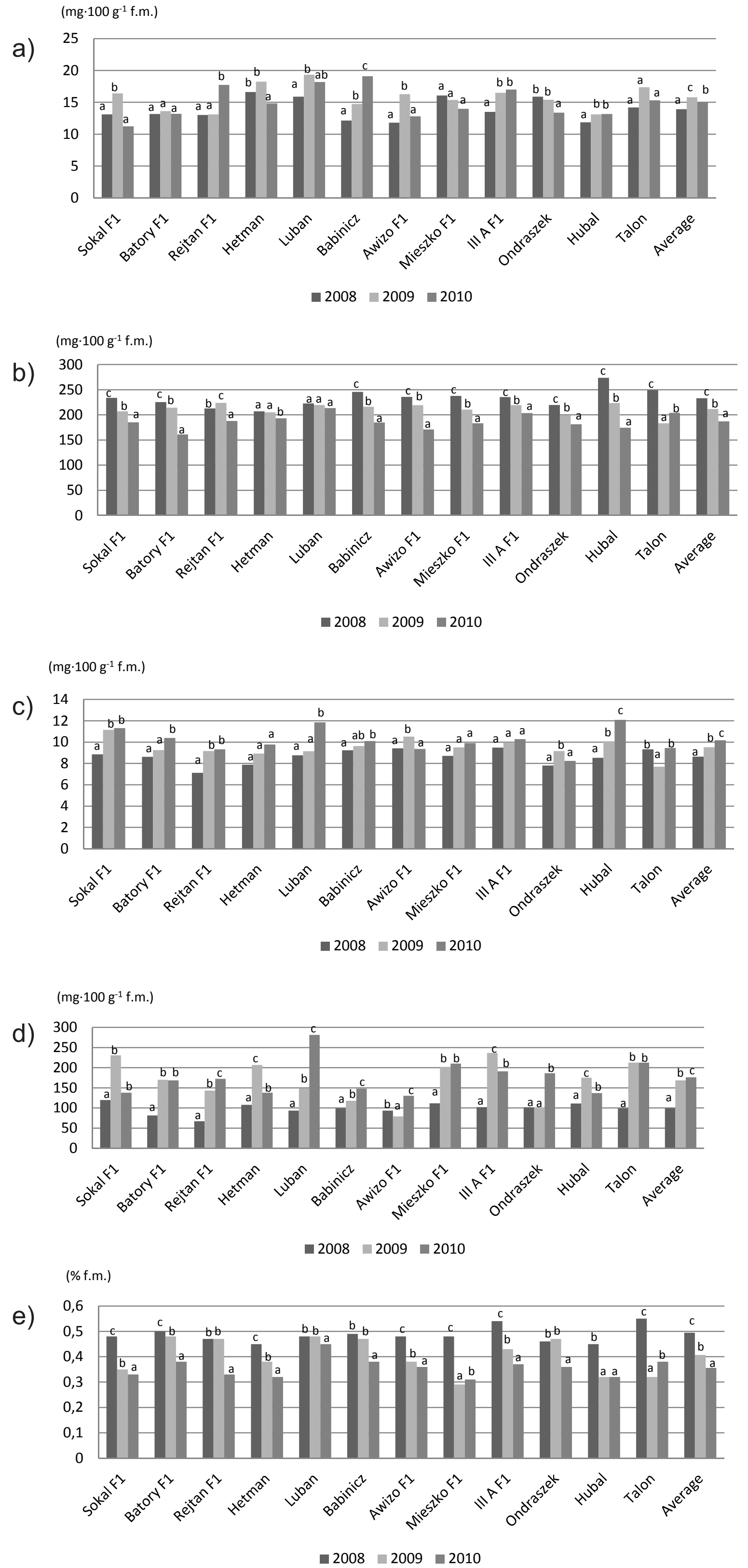

Fig. 4. a) Calcium content of tomato fruit in particular years of the experiment, b) potassium content of tomato fruit in particular years of the experiment, c) magnesium content of tomato fruit in particular years of the experiment, d) lycopene content of tomato fruit in particular years of the experiment, e) acidity of tomato fruit in particular years of the experiment.

Table 3. The dependences between the hydrothermal index (K) and the dry matter and macroelement content.

Dry matter and macroelements content	Regression equation	Coefficient of correlation R	F statistic (1.34) *	Probability p
Dry matter	$Y = 0.38 \cdot K + 4.55$	0.35	4.69	0.037
Calcium	$Y = 2.30 \cdot K + 11.15$	0.35	4.71	0.037
Potassium	$Y = -51.91 \cdot K + 295.50$	0.71	34.13	0.00000
Phosphorus	No significant relationships			
Magnesium	$Y = 1.68 \cdot K + 6.71$	0.50	11.62	0.00169

* degree of freedom

Table 4. The dependences between the hydrothermal index (K) and fruit chemical components.

Fruit chemical components	Regression equation	Coefficient of correlation R	F statistic (1.34) *	Probability p
Lycopene	$Y = 106.75 \cdot K - 26.66$	0.67	27.84	0.00001
Acidity	$Y = -0.15 \cdot K + 0.67$	0.70	32.15	0.00000
L-ascorbic acid	No significant relationships			
Reducing sugars	No significant relationships			

* degree of freedom

The amount of L-ascorbic acid in tomato fruits was significantly different from each level achieved in the years of the study and ranged from 16.01 to 16.51 mg% f.m. However, analyses of regression did not confirm significant dependences between L-ascorbic acid content and the K index (Table 4). Michalska [15] pointed out that the amount of L-ascorbic acid in the tomato's fruits was strictly connected with the plant cultivar. Dependences between the level of L-ascorbic acid and the hydrothermal index was not observed, which might be caused by much lower temperatures in Poland compared to countries with more favorable thermal conditions. Lee and Kader [2] found a negative correlation between the level of L-ascorbic and high temperatures in citruses cultivated in California. According to Dorais et al. [3], lower temperatures reduce respiration, which results in a higher level of L-ascorbic acid in tomato fruits.

The fruit sugar content varied from 1.79 up to 2.02% f.m. An influence of the weather conditions represented by the hydrothermal index (K) was not observed (Table 4). Sugars are produced mainly in leaves during photosynthesis and are transported to other plant organs and tissues. Light is the main environmental factor influencing photosynthesis in plant leaves [20]. This is why a relationship between the K index and sugar concentration in fruits was not noted. Teng et al. [21] have published an accurate model where fruit-soluble sugar content and temperature as well as PAR has good conformity. The influence of solar radiation and temperature on sugar content in cherry tomatoes also has been reported [22].

Conclusions

Based on the analyses of regression, a significant influence of hydrothermal conditions on the fruit quality features of tomato was found. A directly proportional relationship between the hydrothermal index (K) and the number of seed chambers, dry matter, lycopene, magnesium, and calcium in tomato fruits was observed. However, the relationships between the hydrothermal index (K) and fruit weight, and potassium and total acidity turned out to be inversely proportional. The impact of the hydrothermal conditions on the thickness of the pericarp, the shape coefficient, the phosphorus and L-ascorbic acid content, and the reducing sugars of the fruits was not observed. The value distribution of the tested tomatoes' features in all of the years of the study points to the different sensitivities of individual tomato cultivars to thermal and precipitation conditions.

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