COMPARISON OF MORPHOLOGICAL CHARACTERISTICS OF TWELVE CULTIVARS OF TOMATO DETERMATE PLANTS AND THEIR IMPACT ON YIELD AND ITS STRUCTURE

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Summary

Experiment took place in the open field in the Vegetable Experimental Station of Agricultural University near Cracow in the years 2008-2010. In the experiment twelve, polish-bred determinate tomato cultivars: Sokal F₁, Batory F₁, Rejtan F₁, Hetman F₁, Babinicz, Luban, Mieszko F₁, III A F₁, Awizo F₁, Ondraszek, Talon and Hubal were used. In the end of growing season, morphological features of plant were measured, concerning: height of plant, number of lateral shoots, length and thickness of the internode and the number of inflorescences per plant. Harvesting was performed once, at the stage of maturity of individual cultivars. The yield and its structure was calculated. The results were statistically analyzed using NIR Fisher’s test, with p=0.05. The dependences of the marketable yield and total yield of tomato plants from morphological characteristics that may affect the yield were analyzed, using multiple regression.

The amount of total and marketable yield was negatively correlated with an extensive vegetative growth of tomato plants. Among all the tested cultivars Ondraszek was characterized by the most preferred morphological features and creates one of the highest yields. Cultivars Ondraszek, Sokal F₁ and Batory F₁ were characterized higher marketable yield, than ‘Hetman F₁’. Total and marketable yield depended about 40% on tomato plant morphological features.

key words: tomato, morphological factors, crop, open field cultivation, weather

INTRODUCTION

Poland is the furthest north country in Europe, where tomato is grown in an open field on a production scale. Tomato, as a thermophilic and susceptible to diseases vegetable, needs the right weather conditions for proper growth and development in the open field. Yield stability in our climate,
especially in the cool and rainy summer, is variable and depends on many factors. Tomato’s requirements vary with the plants phase of growth. Due to the large variation in yield of open-field tomatoes, it is necessary to seek for genotypes more resistant to climatic conditions. A well chosen cultivar and application of modern cultivation technologies are helpful in obtaining high-quality yield and favourably affect the profitability of production (Legąńska & Balcerzak 2000, Elkner et al. 2004, Jędrszczyk 2010, Olaïya 2011). Cultivar is a genetic factor that determines the characteristics of morphological, physical, chemical, uniform ripening, suitability for mechanical harvesting, fertility and susceptibility to diseases and pests (Bąkowski 1999). Currently, a majority of tomato cultivars are addressed to producers of field tomatoes appearing on the market. Among the large amount of cultivars it is hard to make the right decision to choose one that would meet the growing demands of the fruit processing.

The aim of this investigations was to assess the quality of twelve determinate tomato cultivars, in terms of their suitability for processing. In this experiment the polish-bred tomato cultivars: Sokal F₁, Batory F₁, Rejtan F₁, Hetman F₁, Babinicz, Luban, Mieszko F₁, III A F₁, Awizo F₁, Ondraszek, Talon and Hubal were used. In order to compare the morphological characteristics of plants and to find links between morphological features and yielding of plants, multiple regression has been carried on.

MATERIAL AND METHODS

Experiment took place in the open field in the Vegetable Experimental Station of Agricultural University of Mydlniki near Cracow in the years 2008-2010 on the brown soil. Twelve polish-bred tomato cultivars were chosen, as they are adapted to polish climatic conditions. A completely randomized block design with four replicates and 40 plants for plot was used. Dates of sowing and seedlings planting in years were following: 2008 - April 8 sowing, planting 16 May, 2009 - April 16 sowing, planting 21 May, 2010 - March 31 sowing, planting 26 May. Plants spacing was 80 x 60 cm. During the growing season typical treatments, as weeding and chemical diseases protection, were carried out according to current recommendations.

In the end of growing season morphological features of plants were measured concerning: height of plant of each cultivar, number of lateral shoots, length and thickness of the internode and the number of inflorescences per plant. Harvesting was performed once, at the stage of maturity of individual cultivar, while about 75% fruits were matured. In 2009 and 2010 years some cultivars must have been harvested earlier (~55-60% mature fruits), because the weather conditions (especially precipitation) were unfavorable to extend the vegetation. The yield (kg/per plant) and its structure were calculated. Marketable yield consist of fruits fully matured, healthy, with diameter above 3.5 cm. Immature fruits were unripe once, healthy, with diameter above 3.5 cm. Damaged fruits were those diseased
and cracked and also those overriped. Small fruits were characterized by diameter below 3.5 cm. The results were statistically analyzed using NIR Fisher’s test, with p = 0.05.

The dependences of the marketable yield and total yield of tomato plants from morphological characteristics that may affect the yield were analyzed. Taking into account the characteristics of plants, a general model for the multiple regression (forward selection) predicted total and commercial yield were proposed. **Total yield** = b0 + b1 height of plant + b2 x number of lateral shoots + b3 length of internodes (cm) + b4 number of clusters per plant. **Marketable yield** = b0 + b1 height of plant + b2 x number of lateral shoots + b3 length of internodes (cm) + b4 number of clusters per plant.

In the first step, the variable with the highest impact on tomato yield (the highest squared correlation) was added to the regression equation. Next, the partial F statistic for each possible remaining variable was computed and if the variable with the highest F statistic passed a criterion (α=0.05), it was added to the regression equation. Then, it was checked whether the variable in the regression equation passed the criterion for significance. If so, they remained in the equation, otherwise, they were removed from the equation. The procedure went on until no variable, that passed the criterion for significance, could be found. The calculation were made in the Statistica 10.

**RESULTS AND DISCUSSION**

In the experiment the cultivars of field tomato determinated were used. This type of plant characterizes terminated lateral growth. Also the flowering and fruiting are more concentrated than in the cultivars of indeterminate tomatoes. These cultivars are cultivated with a view to food industry, which is growing rapidly in the recent years (Bąkowski 1999, Kmiecik & Lisiewska 2000, Jabłońska-Ryś & Zalewska-Korona 2009). There is also observed a greater interest in cultivars useful for mechanical harvesting.

The tested cultivars characterized by a similar length of shoots - 82.5-112.1 cm (Table 1). Cultivar Luban was significantly higher than ‘Ondraszek’, ‘Batory F1’ and ‘Mieszko F1’. Others did not differ significantly from each other in the shoot length. The amount of lateral shoots generated by the plants ranged from 2.4 to 4.8. ‘Batory’ was less vegetatively developed in comparison to ‘Hubal’. The differences in the amount of lateral shoots formed were not statistically confirmed. One of the shortest and thickest internodes was observed in Rejtan, Luban and Batory cultivars and that is the reason why they seem to be adequate for mechanical harvesting. The longest (3.8 cm) and thinnest (13.1 mm) internodes were found in the Sokal cultivar, what indicate a pliable-stalk type. A number of clusters in some cultivars ranged from 21.7 to 34.1, however, the differences between them were not statistically significant.

Crop production of tomato plants is closely related to the cultivar, and this in turn with the number of fruits produced per plant and their weight. These features are dependent on the environmental conditions and cultivation. Yielding cannot be considered
solely on the basis of total yield. The most reliable value is the marketable yield dependent on susceptibility to cracking and creating small fruits and their health.

Table 1. The value of some biometric parameters registered for tested tomato cultivars

| Cultivar     | Height of plant (cm) | Number of lateral shoots per plant | Length of internode (cm) | Thickness of internode (mm) | Number of clusters per plant |
|--------------|----------------------|------------------------------------|--------------------------|-----------------------------|-----------------------------|
| Sokal F1     | 104.0 ab             | 4.0 ab                             | 3.8 b                    | 13.1 ab                     | 27.7 a                      |
| Batory F1    | 84.2 a               | 2.4 a                              | 2.0 a                    | 14.2 a-c                    | 25.2 a                      |
| Rejtan F1    | 92.5 ab              | 3.9 ab                             | 2.1 a                    | 15.7 c                      | 30.4 a                      |
| Hetman       | 86.5 ab              | 4.3 ab                             | 2.4 ab                   | 14.8 a-c                    | 26.5 a                      |
| Luban        | 112.1 b              | 2.9 ab                             | 2.0 a                    | 15.0 bc                     | 27.8 a                      |
| Babinicz     | 85.3 ab              | 2.8 ab                             | 3.0 ab                   | 13.7 a-c                    | 21.7 a                      |
| Awizo F1     | 94.5 ab              | 3.6 ab                             | 2.4 ab                   | 13.1 ab                     | 31.6 a                      |
| Mieszko F1   | 84.6 a               | 4.5 ab                             | 2.7 ab                   | 12.3 a                      | 29.4 a                      |
| III A F1     | 95.9 ab              | 2.9 ab                             | 2.7 ab                   | 15.4 bc                     | 34.1 a                      |
| Ondraszek    | 82.5 ab              | 3.0 ab                             | 2.5 ab                   | 14.7 a-c                    | 27.3 a                      |
| Hubal        | 85.4 ab              | 4.8 b                              | 3.8 b                    | 14.1 a-c                    | 23.3 a                      |
| Talon        | 101.9 ab             | 4.3 ab                             | 2.4 ab                   | 14.9 a-c                    | 26.5 a                      |

Table 2. Yielding and it structure (kg·plant⁻¹)

| Cultivar     | Total yield | Marketable yield | Yield of immature fruits | Yield of damaged fruits | Yield of small fruits |
|--------------|-------------|------------------|--------------------------|------------------------|----------------------|
| Sokal F1     | 5.54 ab     | 2.53 bc          | 1.45 a                   | 1.34 a                 | 0.21 a               |
| Batory F1    | 6.03 ab     | 2.63 bc          | 1.59 a                   | 1.33 a                 | 0.49 ab              |
| Rejtan F1    | 7.56 b      | 2.39 a-c         | 3.25 a                   | 1.41 a                 | 0.51 ab              |
| Hetman       | 4.24 a      | 0.70 a           | 1.44 a                   | 2.02 a                 | 0.08 a               |
| Luban        | 6.29 ab     | 2.22 a-c         | 1.96 a                   | 1.27 a                 | 0.83 b               |
| Babinicz     | 4.43 a      | 1.70 ab          | 2.23 a                   | 1.20 a                 | 0.31 a               |
| Awizo F1     | 6.36 ab     | 2.25 a-c         | 2.90 a                   | 0.86 a                 | 0.38 ab              |
| Mieszko F1   | 5.14 ab     | 1.81 ab          | 1.93 a                   | 1.16 a                 | 0.23 a               |
| III A F1     | 5.86 ab     | 1.63 ab          | 2.06 a                   | 1.72 a                 | 0.46 ab              |
| Ondraszek    | 7.43 b      | 3.65 c           | 1.57 a                   | 1.74 a                 | 0.47 ab              |
| Hubal        | 4.02 a      | 1.17 ab          | 1.46 a                   | 1.32 a                 | 0.07 a               |
| Talon        | 5.19 ab     | 2.46 a-c         | 1.22 a                   | 1.24 a                 | 0.27 a               |

In many studies concerning the evaluation of field yielding tomato the differences in yield between the cultivars of tomatoes were demonstrated (Borowy et al. 1996, Osinska et al. 1998, Gajc-Wolska et al. 2010). In this experiment the total yield ranged from 4.02 to 7.56 kg per plant. Cultivars Ondraszek and Rejtan F1 were characterized by significantly higher total yield (7.43 and 7.56 kg per plant) in comparison to the cultivars Hubal, Hetman F1 and Babinicz (respectively: 4.02, 4.24, 4.43 kg per plant). The lowest marketable yield was obtained by ‘Hetman F1’ (0.70 kg per plant), whereas significantly higher yield were obtained by: ‘Ondraszek’, ‘Bato-
ry F₁ and ‘Sokal F₁’ (3.65, 2.63, 2.53 kg per plant). It suggests that these cultivars are more resistant to adverse weather conditions during the growing season. Numerous studies confirm the impact of weather on yielding and its quality (Heuweling & Dorais 2005, Skowera et al. 2007, Sadowska et al. 2011). The most important factor which determined the yield, was the amount and distribution of rainfall during the growing season (Table 3).

Table 3. Mean of meteorological characteristics during vegetation period in the years of research 2008-2010

| Cultivar   | Vegetation period (days) | Mean temperature (°C) | Total of precipitation (mm) | Number of days of precipitation |
|------------|--------------------------|-----------------------|----------------------------|---------------------------------|
| Sokal F₁   | 156                      | 18.5                  | 281.9                      | 45.3                            |
| Batory F₁  | 140                      | 17.9                  | 267.0                      | 43.3                            |
| Rejtan F₁  | 142                      | 18.3                  | 287.1                      | 44.7                            |
| Hetman     | 134                      | 18.2                  | 296.4                      | 46.0                            |
| Luban      | 143                      | 18.4                  | 287.7                      | 44.3                            |
| Babiničz   | 128                      | 18.4                  | 281.5                      | 43.3                            |
| Avizo F₁   | 131                      | 18.4                  | 282.3                      | 44.0                            |
| Mieszko F₁ | 156                      | 18.3                  | 292.7                      | 45.7                            |
| III A F₁   | 144                      | 18.4                  | 289.7                      | 45.0                            |
| Ondraszek  | 128                      | 17.4                  | 276.3                      | 41.7                            |
| Hubal      | 140                      | 18.4                  | 279.2                      | 43.0                            |
| Talon      | 130                      | 18.7                  | 282.4                      | 43.0                            |
| Mean       | 139                      | 18.3                  | 283.7                      | 44.1                            |

An important problem in the cultivation of tomatoes for mechanical harvest is unevenness ripening of fruits. At the time of harvest some of the fruits are mature, meeting the requirements of the processing industry, and some fruits are fully developed but mature green. These fruits, after a suitable period of storage, will obtain an optimum color. In our experiment, yield of mature green fruits ranged from 1.22 to 3.25 kg per plant. There was also no statistically significant differences among the tested tomato cultivars. The problem of proper ripening was touched by Bąkowski (1999), who stressed that the color of the fruits would then decide about the color of juices and tomato paste. It also affects the quality of the products (Saltveit 2005).

Susceptibility of different cultivars to the diseases was variable, however, the differences among them was not statistically significant. The amount of damaged fruits obtained from 1 plant, ranged from 0.86 at the Avizo F₁ cultivar, to 2.02 kg. at the ‘Hetman F₁’, which constitutes 14-48% of damaged fruits in the total yield (Fig. 1).

During the once-over harvest the small, undeveloped fruits were also measured. The cultivar Luban was characterized by the greatest number of such fruits (0.83 kg per plant). It means that this variety is most sensitive to adverse growing conditions, giving small fruits in response.
Rożek et al. (2011) showed that tomato fruit yield was dependent on the length of the growing season. The authors pointed out that the once-over harvest of tomato later cultivars was not always possible and a large number of immature fruits excluded mechanical harvesting. In our experiment the analyzes of the percentage of yield structure (Fig. 1) showed that a cultivar Hetman, IIIA F₁ and Hubal were characterized by the lowest marketable yield. It leads to the conclusion that these tomato cultivars are late genotypes and in our climatic conditions their fruits were not ripe enough on the harvest time. The largest share of marketable yield in total yield were observed in the cultivar Ondraszek (49%), Talon (47%), Sokal F₁ (46%) and Batory F₁ (44%). Zalewska-Korona and Jabłonska-Ryś (2009), while analyzing 17 new tomato breeding determinate lines in terms of their concentrated maturation, and evaluation of yielding and its quality, stated that apart from the genetic factor, the weather conditions, strongly varied between years of studies, had the significant impact on tomatoes characteristics.

Fig. 1. Structure of total yield (%)

Apart from analyzing a number of morphological characteristics of 12 cultivars of tomato plants the relationship among them and the total and commercial yield was tested by multiple regression (forward selection). To apply this method the necessary assumptions were checked.

1. The residuals (predicted minus observed values) are distributed normally. It was checked using the Shapiro-Wilk normality test.

2. Variables in the regression equation cannot be correlated with each other. Durbin-Watson statistic was used.

At the significance level $\alpha=0.05$, these assumptions were met in each of the cases.

Finally, the model of relationship between the total yield and the mor-
phological features of plants was obtained

**Total yield** = 8.921013 − 0.517472 **number of lateral shoots** − 0.402799 **length of internode** (cm).

Multiple correlation coefficient (R) is 0.64.

The Fisher test was used to checked the significance of the proposed model. The value of probability p was smaller than the assumed level of significance α=0.05, so the regression equation was well defined.

Similarly, the dependence of the marketable yield and his morphological features of plants was obtained.

**Marketable yield** = 5.145697 − 0.0121880 **height of plant** − 0.343299 **number of lateral shoots**. Multiple correlation coefficient (R) is about 0.62.

The Fisher test confirmed the significance of the proposed model.

### Table 4. Relationship between total yield and the morphological features of plant

|            | R= 0.63734755 | R² = 0.406211990 | Modified. R² = 0.37022475 |
|------------|----------------|------------------|---------------------------|
|            |                | F(2,33)=11.288 p<0.00018 |
| B*         | Standard       | Standard         |
|            | deviation of b*| deviation of b   |
| Intercept  | 8.921013       | 0.733413         | 12.16370                  |
| Height of plant (cm) | -0.377655 0.157952 | -0.517472 0.216430 | -2.39094 0.022666 |
| Number of lateral shoots | -0.351371 0.157952 | -0.402799 0.181071 | -2.22454 0.033066 |

### Table 5. Relationship between marketable yield and the morphological features of plant

|            | R=0.61592234 | R² = 0.37936033 | Modified. R² = 0.34174580 |
|------------|--------------|-----------------|---------------------------|
|            | F(2,33)=10.085 p<0.0038 |
| b*         | Standard       | Standard         |
|            | deviation of b*| deviation of b   |
| Intercept  | 5.145697       | 0.708527         | 7.26253                   |
| Height of plant (cm) | -0.398124 0.141838 | -0.021880 0.007795 | -2.80688 0.008331 |
| Number of lateral shoots | -0.379191 0.141838 | -0.343299 0.128413 | -2.67340 0.011582 |

On the basis of the calculated coefficients in the regression equation (the coefficients b₁, b₂) it can be stated that the more complex vegetative developed (higher and more shoots) tomato plant is, the lower yield, both total and marketable can be obtained.

A similar dependence of yielding reductions in response to the intense vegetative development of tomato plants was observed by Abukhovich et al. (2009). The authors explain this phenomenon of increased competition between fruits and vegetative organs...
by the distribution of assimilates and the weak access of the light for fruits. Also, the results of Stephen et al. (2003) on the yield of 23 cultivars and breeding lines of tomato indicates that cultivars which were characterized by having the highest length of shoots gave the lower yield.

CONCLUSIONS

1. The amount of total and marketable yield was negatively correlated with an extensive vegetative growth of tomato plants.
2. Among all the tested cultivars Ondraszek was characterized by the most preferred morphological features and creates one of the highest yields.
3. Cultivars Ondraszek, Sokal F₁ and Batory F₁ were characterized higher marketable yield, than ‘Hetman F₁’.
4. Total and marketable yield depended about 40% on tomato plant morphological features.

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PORÓWNANIE CECH MORFOLOGICZNYCH ROŚLINY
12 ODMIAN POMIDORA KARŁOWEGO
I ICH WPŁYW NA WIELKOŚĆ I STRUKTURĘ PLONU

Streszczenie
Doświadczenie prowadzono na terenie Warzywniczej Stacji Doświadczalnej Uniwersytetu Rolniczego w Mydlinach koło Krakowa w latach 2008–2010. W badaniach wykorzystano 12 odmian pomidora samokończącego polskiej hodowli: ‘Sokal F1’, ‘Batory F1’, ‘Rejtan F1’, ‘Hetman F1’, ‘Babinicz’, ‘Lubań’, ‘Mieszko F1’, ‘III A F1’, ‘Awizo F1’, ‘Ondraszek’, ‘Talon’ oraz ‘Hubal’. W trakcie wegetacji przeprowadzono pomiary morfologiczne roślin, które dotyczyły: wysokości roślin poszczególnych odmian, ilości wytwarzanych rozgałęzień I rzędu, długości i grubości międzywęźla oraz liczby gron na roślinie. Zbiór owoców przeprowadzono jednorazowo, w fazie dojrzałości zbiorczej poszczególnych odmian, oceniano wielkość i strukturę plonu. Uzyskane wyniki poddano analizie statystycznej testem NIR Fishera, przy p=0,05. Zbadano zależność plonu handlowego i plonu ogółem pomidora od cech morfologicznych roślin, mogących mieć wpływ na wielkość plonu, przeprowadzając analizę regresji wielorakiej. Stwierdzono, iż wysokość plonu ogółem i handlowego była ujemnie skorelowana z rozbudowaną częścią wegetatywną rośliny pomidora. Sposób badanych odmian najkorzystniejszymi cechami morfologicznymi rośliny i jednym z najwyższych plonów odznaczał się Ondraszek. Odmiany Ondraszek, Sokal F1 i Batory F1 plonowały istotnie lepiej niż odmiana Hetman F1. Plon ogółem i handlowy w około 40% zależał od cech morfologicznych rośliny pomidora.

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