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QUALITY AND STRUCTURE OF SINGLE HARVEST TOMATO FRUIT YIELD

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Abstract. Tomato fruit, constituting raw material for processing industry, can be harvested manually or mechanically, with the use of a harvester. Such features of new cultivars, as almost simultaneous fruit setting, high fruit durability and slow overripening of fruit, make it possible to give up the traditional, multiple harvesting. Limiting the number of harvests and introducing mechanical harvest, express aiming at decreasing the harvest costs. During studies conducted in the years 2009–2010 the quantity and structure of fruit yield in several tomato cultivars recommended for processing industry. Fruit came from single harvest, conducted in the second half of September. The highest fruit yield and the best fruit yield were these of Dyno F_1 and Benito F_1 cultivars. The cultivars Asterix F_1 and Tenorio F_1 yielded at a similar level and the unfavourable feature in their yield structures was high share of small fruits (of the diameter from 4.0 to 3.5 cm) and very small ones (below 3.5 cm). The yield of tomato fruit in the subsequent years was significantly differentiated and depended upon weather conditions. It was demonstrated that in the case of cultivars with longer vegetation periods, including cultivars recommended for processing industry, the harvest of the whole yield is not always possible. In the first study year ripe fruits constituted 94.9%, in the second year – 80.7%. A large number of unripe fruits significantly hinders conducting mechanical tomato harvest.

Key words: *Lycopersicon esculentum*, single harvest, industrial tomato cultivars, marketable fruit

INTRODUCTION

Tomato is in Poland the most important species grown under covers and takes the 6th place in the structure of vegetables grown in the field. In the year 2009 it was grown on the surface of 12.9 thousand ha, and the fruit harvest was 265.3 thousand tons [GUS 2010]. Tomato fruit is a valuable raw material for processing industry – main processing directions are: producing concentrate, juice, sauce, ketchup, as well as increasingly

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popular frozen, tinned and dried tomatoes. More than half of field-grown fruit is processed. The yearly consumption of fresh tomato fruit in the year 2009 in Poland was 10.09 kg per person, whereas the consumption of tomato concentrate, ketchup and tomato sauce – 3.0 kg.

The main element of costs borne on field tomato growing is very labour consuming, multiple manual fruit harvest. The cost of harvesting tomatoes grown for industry can be lowered by giving up the traditional multiple fruit harvest, replacing it by single or double manual harvest, or applying mechanical harvest. The mechanical tomato harvest predominates in such countries, as the USA, Spain or Portugal [Gonzales 1999, Machado et al. 1999, Macua et al. 1999, 2001, Murray 2001, Macua-Gonzales et al. 2003]. In Poland, in certain regions of commodity tomato growing for industry also mechanical harvesting is applied for a small scale, but it is more often that single or double manual harvesting is conducted. The growers owning large plantations are especially interested in mechanical harvesting. It is a problem for growers to select appropriate cultivars and to meet the fruit quality requirements of processing industry, because decreasing the frequency of harvests leads to changes in the chemical composition and technological properties of fruit.

In Poland the date of single harvest is determined by the course of weather conditions and the date when the first autumn ground freezes occur. In most regions where commodity tomatoes are grown, due to the frosts, fruit must be picked in the second decade of September at the latest. The studies conducted before [Rożek 2007] demonstrated that by that time, depending on the years, there have been from 75.3–80.6% to 94.5% of ripe fruits at the plantation. A significant divergence in the obtained results indicates how much tomato yielding in Poland depends on the weather conditions during vegetation.

The aim of the present study was to estimate the quality and structure of single harvest tomato fruit yield.

MATERIAL AND METHODS

The studies were conducted in the years 2009–2010 at a commodity plantation near Lublin (51º18' N, 22º45' E). The experiment material consisted of industrial tomato cultivars: Asterix F_1, Benito F_1, Chibli F_1, Dyno F_1, Tenorio F_1. All the cultivars had elongated fruits. The experiment was established on loamy soil. The abundance of the soil in nutrients was supplemented every year on the basis of the chemical analyses of the soil to the level of N – 150 mg·dm^{-3}, P – 80 mg·dm^{-3}, K – 250 mg·dm^{-3}. Ammonium saltpeter, triple superphosphate and potassium sulphate were applied. The production of tomato seedlings was conducted in a heated tunnel. The seeds were sown in the first week of April. After the proper leaves had appeared, the seedlings were thinned into seeding pallets of the dimensions of a single pot – 6 × 6 cm (54 pots in a pallet of the dimensions: 40 × 60 cm).

In the year 2009 the tomato seedlings were transplanted in the field on May 22nd, and in the year 2010, due to unfavorable weather conditions, as late as on May 27th. The plants grew in the spacing of 70 × 65 cm, in the stocking of 21.97 thousand plants·ha^{-1}.

The experiment was established as one-factor, in the randomized block system in four repetitions. The size of a single plot was 9.1 m^2. The protection of plants against weeds, diseases and pests was conducted in accordance with „Vegetable Plant Protection Program". In order to accelerate and equalize the ripening of fruits in the year 2009 at the beginning, and in the year 2010 at the end of the third decade of August Ethrel was applied in the amount of 2.5 $l \cdot ha^{-1}$. The earlier application of Ethrel in the year 2010 was impossible, initially due to a small quantity of fully grown and dye-penetrated fruit and then because of too low temperature.

A single fruit harvest was conducted in the year 2009 on September 18^{th} and in the year 2010 on September 24^{th}.

The following features was assessed in the experiment:

– size of industrial yield, which consisted of fully dyed, healthy fruit of the diameter above 3.5 cm,

– size of non-marketable yield, which included very tiny fruits, of the diameter below 3.5 cm, diseased (also broken) fruits and unripe ones,

– share of ripe fruits in the yield of healthy fruit. The yield of healthy fruit consisted of ripe and unripe (inflamed, green) fruits. No overripe fruits (very soft, with wrinkled skin) were observed in the yield.

The assessment of anatomical features of fruits (4 × 20 fruits of each cultivar) included:

– number of seed chambers (pc.),

– thickness of external fruit walls (mm),

– fruit shape coefficient as the ratio of fruit length to its diameter measured half of the fruit length).

The obtained results were elaborated with the use of variance analysis for single classification. The significance of differences was assessed by means of Tukey's confidence intervals at the significance level of $\alpha = 0.05$.

RESULTS

The weather conditions in the study years exerted a significant effect upon the quantity and structure of the yield of examined tomato cultivars. In the year 2009 the temperatures were favorable for the growth and ripening of tomato fruit. Mean monthly temperatures in the period from May to September significantly exceeded the multiannual means. Intense precipitations in June accelerated the growth of plants, and thanks to small amount of rain in August and September, the plants remained healthier. In the year 2010 the weather conditions were very untypical. At the beginning of the season, in May, intense precipitations delayed the planting date and at the end of vegetation the temperatures were much lower than multiannual means, which inhibited fruit dyeing.

The industrial fruit yield of five tomato cultivars obtained as a result of single harvest ranged from 47.14 to 103.02 $t \cdot ha^{-1}$ and was significantly differentiated between the years (tab. 1). On average, for the examined cultivars a significantly higher yield (89.36 $t \cdot ha^{-1}$) was obtained in the year 2009 compared to the yield in the year 2010 (61.97 $t \cdot ha^{-1}$). Every year Dyno F_1 was the highest-yielding cultivar (on average, from

Table 1. Yielding characterization of 5 tomato cultivars (t·ha^{-1})
Tabela 1. Charakterystyka plonowania 5 odmian pomidora (t·ha^{-1})

Years Lata	Cultivar Odmiana	Marketable yield Plon handlowy (t·ha^{-1})	Non-marketable yield Plon niehandlowy (t·ha^{-1})	Total yield Plon ogółem (t·ha^{-1})	Share of unripe fruits in healthy fruit yield Udział owoców niedojrzałych w plonie owoców zdrowych (%)
2009	Asterix F_1	87.92 bc *	14.51 ab	102.43b	2.3
	Benito F_1	92.60 b	7.50 c	100.10 b	3.1
	Chibli F_1	79.26 c	17.72 a	96.98 b	7.5
	Dyno F_1	103.02 a	12.11 b	115.13 a	8.0
	Tenorio F_1	84.01 bc	16.46 ab	100.47 b	4.4
	mean średnio	89.36 A	13.66 B	103.02 A	5.1
2010	Asterix F_1	47.14 c	40.32 a	87.46 b	21.6
	Benito F_1	59.48 b	33.13 b	92.61 b	21.4
	Chibli F_1	58.88 b	36.84 ab	95.72 b	21.0
	Dyno F_1	88.48 a	23.86 c	112.34 a	11.8
	Tenorio F_1	55.89 bc	36.87 ab	92.76 b	20.6
	mean średnio	61.97 B	34.20 A	96.17 A	19.3
Mean Średnio	Asterix F_1	67.53 c	29.92 a	97.45 b	12.0
	Benito F_1	76.04 b	20.33 b	96.36 b	12.3
	Chibli F_1	69.07 bc	27.28 a	96.35 b	14.3
	Dyno F_1	95.75 a	18.00 b	113.75 a	9.9
	Tenorio F_1	69.95 bc	26.67 a	96.62 b	12.5
	mean średnio	75.67	24.44	100.11	12.2

* Means followed by the same letter do not differ significantly at $\alpha = 0.05$
Średnie oznaczone tą samą literą nie różnią się istotnie przy $\alpha = 0,05$

study years: 95.75 t·ha^{-1}) and a significantly lower yield was obtained from Benito F_1 cultivar (76.04 t·ha^{-1}). The cultivars Asterix F_1, Chibli F_1 and Tenorio F_1 yielded on a similar level (from 67.53 t·ha^{-1} to 69.95 t·ha^{-1}). In both study years the decision on the harvest date was affected by the forecasts concerning the occurrence of first autumn frosts. On average, for cultivars, in the first year of studies the fruit harvest was conducted when 94.9% of fruits on plants were ripe, and in the second – 80.7%.

A significant differentiation was demonstrated between years, as to the quantity of non-marketable yield and the total tomato yield. A significantly higher total yield (on average: 103.02 t·ha^{-1}) and a lower non-marketable yield (13.66 t·ha^{-1}) was obtained in the year 2009. In the year 2010 weather conditions contributed to a significant increase of non-marketable yield (including diseased and unripe fruits, fig. 1). A large share of diseased fruits (from 10.74 to 16.68 t·ha^{-1}) resulted from hindered chemical conservation of plants during long- lasting rainfalls, and a large share of unripe fruits (11.81–16.24 t·ha^{-1}) was caused by low temperatures in August and September, during fruit-dyeing period.

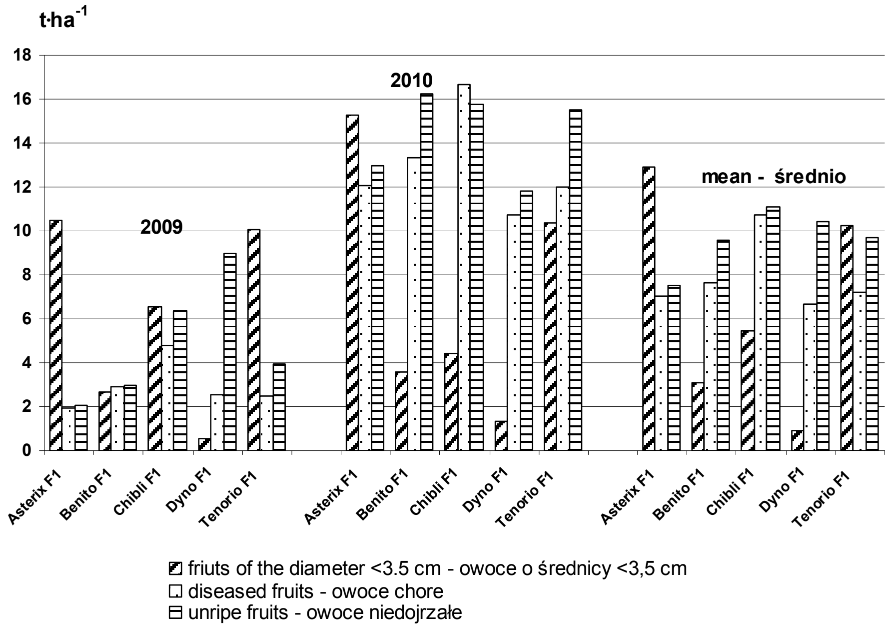

Fig. 1. Non-marketable yield structure of 5 tomato cultivars (2009–2010, t·ha^{-1})
Ryc. 1. Struktura plonu niehandlowego 5 odmian pomidora (2009–2010, t·ha^{-1})

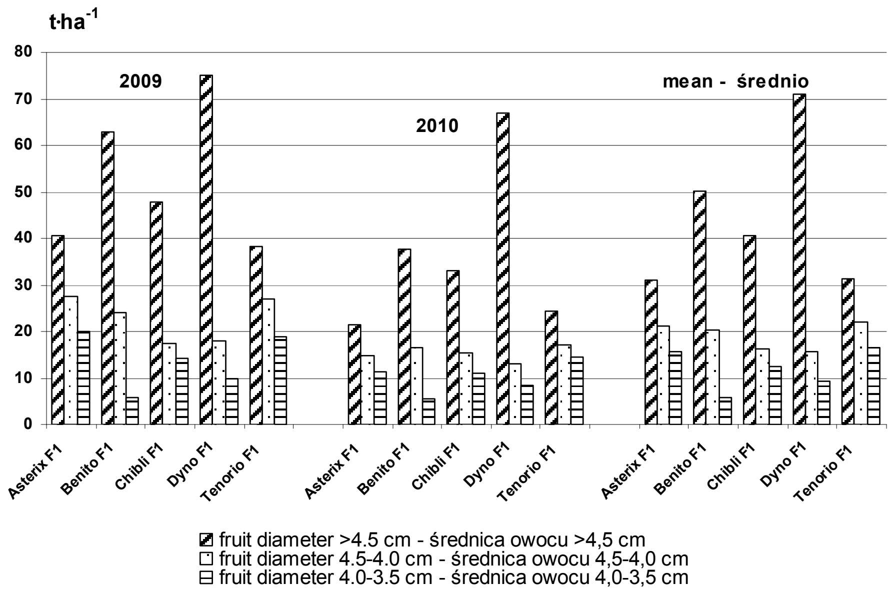

Fig. 2. Marketable yield structure of 5 tomato cultivars, considering fruit diameter (2009–2010, t·ha^{-1})
Ryc. 2. Struktura plonu przemysłowego 5 odmian pomidora uwzględniająca średnicę owoców, (2009–2010, t·ha^{-1})

Phot. 1. The fruits of studied tomato cultivars
Fot. 1. Owoce badanych odmian pomidora

The fruits of the assessed cultivars were presented in photo 1 and the yield structure, considering fruit diameter – in figure 2. The most favourable yield structure was found in Dyno F_1 and Benito F_1 cultivars. The yield of large fruits, of the diameter above 4.5 cm in these cultivars equaled, respectively: 70.97 t·ha^{-1} and 50.21 t·ha^{-1}. The cultivars Asterix F_1 and Tenorio F_1 had similar yield structures – small share of large fruit yield and higher yield of small and average fruits than in the remaining cultivars. In these cultivars the share of fruits of the diameter below 3.5 cm was also very large, respectively: 13.39 and 10.22 t·ha^{-1}), and these fruits were included in non-marketable yield (fig. 1). In the remaining cultivars the yield of very small fruits (of the diameter below 3.5 cm) ranged from 0.93 to 5.49 t·ha^{-1}.

Table 2. Mean marketable fruit weight of 5 tomato cultivars, considering their diameter (g)
Tabela 2. Średnia masa owoców handlowych 5 odmian pomidora uwzględniająca ich średnicę (g)

Years Lata	Cultivar Odmiana	Fruit diameter – Średnica owoców		
		>4.5 cm	4.5–4.0 cm	4.0–3.5 cm
2009	Asterix F_1	63.2 e	43.7 d	37.3 a
	Benito F_1	76.7 d	51.0 c	39.4 a
	Chibli F_1	82.9 b	51.9 c	38.2 a
	Dyno F_1	109.2 a	60.8 a	42.8 a
	Tenorio F_1	71.2 c	55.6 bc	41.2 a
	mean – średnio	80.6 A	52.6 A	39.8 A
2010	Asterix F_1	66.1 d	44.7 c	40.0 a
	Benito F_1	77.3 c	50.9 b	41.7 a
	Chibli F_1	94.8 b	56.4 a	39.9 a
	Dyno F_1	104.8 a	60.4 a	47.3 a
	Tenorio F_1	74.1 c	56.7 a	46.4 a
	mean – średnio	83.4 A	53.8 A	43.1 A
Mean Średnio	Asterix F_1	64.7 d	44.2 c	38.7 a
	Benito F_1	77.0 c	51.0 b	40.6 a
	Chibli F_1	88.9 b	54.2 b	39.9 a
	Dyno F_1	107.0 a	60.6 a	45.1 a
	Tenorio F_1	72.7 c	56.2 ab	43.8 a
	mean – średnio	82.0	53.2	41.5

Explanations see table 1 – Oznaczenia jak w tabeli 1

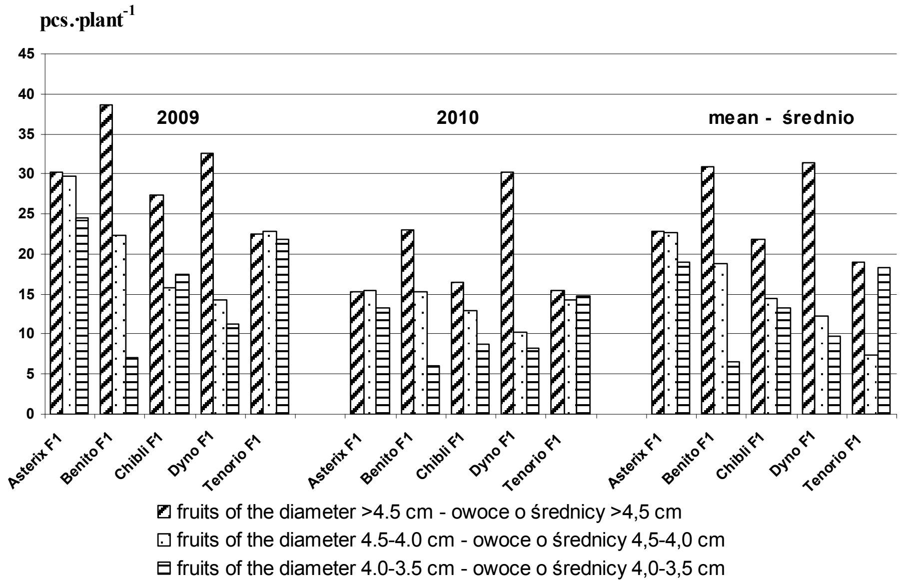

Fig. 3. Tomato fruit structure in pieces from 1 plant, considering their diameter (2009–2010)
Ryc. 3. Struktura owoców pomidora w szt. z 1 rośliny, uwzględniająca ich średnicę (2009–2010)

Table 3. Selected fruit features of 5 tomato cultivars
Tabela 3. Wybrane cechy owoców 5 odmian pomidora

Years Lata	Cultivar Odmiana	Fruit lenght Długość owocu (cm)	Fruit diameter Średnica owocu (cm)	Thickness of peripheral walls Grubość ścian obwodowych (mm)	Number of seed chambers (pc.) Liczba komór nasiennych (szt.)	Shape coefficient Współczynnik kształtu
2009	Asterix F_1	4.95 b	4.64	6.39 d	2.50 b	1.07
	Benito F_1	5.75 ab	4.83	8.52 a	2.50 b	1.19
	Chibli F_1	6.21 ab	5.24	6.50 d	3.31 a	1.18
	Dyno F_1	6.63 a	4.89	7.96 b	3.16 a	1.35
	Tenorio F_1	5.54 ab	4.56	7.51 c	2.73 b	1.21
	mean – średnio	5.82 A	4.83 A	7.38 A	2.84 A	1.20
2010	Asterix F_1	5.22 b	4.73 a	7.11 c	2.53 b	1.10
	Benito F_1	5.93 ab	4.81 a	8.47 a	2.36 b	1.23
	Chibli F_1	6.17 ab	5.12 a	7.28 c	3.48 a	1.18
	Dyno F_1	6.54 a	4.91 a	8.26 a	3.24 a	1.33
	Tenorio F_1	5.48 ab	4.67 a	7.98 b	2.43 b	1.17
	mean – średnio	5.87 A	4.85 A	7.82 B	2.81 A	1.20
Mean Średnio	Asterix F_1	5.09 b	4.69 a	6.75 d	2.52 b	1.09
	Benito F_1	5.84 ab	4.82 a	8.50 a	2.43 b	1.21
	Chibli F_1	6.19 ab	5.18 a	6.89 d	3.40 a	1.18
	Dyno F_1	6,59 a	4.90 a	8.11 b	3.20 a	1.34
	Tenorio F_1	5.51 ab	4.62 a	7.75 c	2.58 b	1.19
	mean – średnio	5.84	4.84	7.60	2.83	1.20

Explanations see table 1 – Oznaczenia jak w tabeli 1

The largest fruits, of average weight of 107.0 g for fruits of the diameter above 4.5 cm, were formed by the cultivar Dyno F_1 (tab. 2). The fruits of this cultivar were also of the most elongated shape and had quite thick peripheral walls. On average, for the study years, the cultivars Benito F_1 and Tenorio F_1 had fruits of similar weight, the cultivar Chibli F_1 had significantly larger fruits than these, and Asterix F_1 had significantly smaller fruits. The cultivars Dyno F_1 and Benito F_1 were favourably distinguished against the background of the remaining ones, as to the number of large fruits they formed (of the diameter above 4.5 cm), falling on one plant. At the same time these cultivars formed the least of small fruits, of the diameters ranging from 4.0 to 3.5 cm (fig. 3). The thickest peripheral walls were these of the fruits of Benito F_1 cultivar (8.5 mm), and the thinnest – these of Asterix F_1 cultivar (6.75 mm, tab. 3). The fruits of Asterix F_1, Benito F_1 and Tenorio F_1 cultivars had 2–3 chambers (respectively: 2.52, 2.43 and 2.58 pcs.) and those of Chibli F_1 and Dyno F_1 cultivars had 2–5 chamber fruits (on average: 3.40 and 3.20 pcs.).

DISCUSSION

A single tomato fruit harvest is possible thanks to growing cultivars with evenly ripening and slowly overripening fruits. The earliest tomato cultivars, of general designation, yield in Poland from the second decade of July [Dyduch et al. 1988, Rożek 1999], but the cultivars designed for processing industry have longer vegetation periods and their peak yielding falls in September [Rożek 2007]. The basic problem during single harvest, both manual and mechanical, is establishing its optimal date. Most frequently the harvest date is determined by assessing the number of ripe, unripe, overripe and diseased fruits on the plantation. The harvest date determines both the quantity of obtained yield and the technological features of fruits [Nichols et al. 1999, 2001, Helyes et al. 2003, Arozuri et al. 2007]. Each deviation of harvest date from the optimal one, is unfavourable. A too early fruit harvest results in high share of unripe fruits, when it is too late – soft, overripe and diseased [Batilani and Bieche 1994, Nichols et al. 1999, Lopez et al. 2001, Machado et al. 2004]. In the studies by Hartz et al. [2001], as well as by Thorre et al. [2001], a single tomato fruit harvest was conducted when the ripe fruits constituted 85–95%. In the author's own studies, presented in this paper, in subsequent years, at the moment of harvest, ripe fruits constituted 94.9 and 80.7%. In the year 2010 a large number of overripe fruits was caused by temperature course, which was unfavourable for tomato fruits. During the author's own studies, conducted before [Rożek 2007], weather conditions had crucial influence upon tomato yielding, and ripe fruits, that had been collected by the end of the 2^{nd} decade of September (until the first autumn frosts), constituted 75.3–94.5% of healthy fruit yield.

According to the data of FAO [2011], average tomato yield in the year 2009 in Poland was 46.42 $t \cdot ha^{-1}$. Elkner et al. [1995] defined the yield of industrial tomato cultivars between 63.20 and 73.34 $t \cdot ha^{-1}$, whereas Rożek [2000] – from 65.0 to 116.0 $t \cdot ha^{-1}$. Among cultivars assessed in the experiment presented here, definitely the highest yielding turned out to be the cultivar Dyno F_1. The yield obtained in the year 2009, which was favourable for tomato yielding (on average for cultivars 89.36 $t \cdot ha^{-1}$) indicates the potential possibility of obtaining the yield which is comparable to that obtained in a climate which is more advantageous for growing this species.

The author's own studies [Rożek 2007] conducted in the years 1998–2005 revealed that in the case of industrial cultivars replacing multiple harvest with a two-tine manual harvest does not contribute to the decrease of fruit yield. During the studies quoted above it was also demonstrated that in the case of Benito F_1 cultivar the two-time manual harvest can be replaced with a single harvest without a significant yield loss.

Most industrial tomato cultivars have medium sized fruits, weighing several tens of grams [Macua-Gonzales et al. 2003]. According to Gruda and Postolski [1999] small and medium sized tomato fruits are suitable for freezing as wholes, and Macua et al. [2001] report that the optimum weight of fruits recommended for skinless tinning should be 60–75 g. Fruit weight is an important usability feature, determining the effectiveness of manual harvest. In this respect the fruits of Dyno F_1 and Chibli F_1 cultivars were most favorably assessed. Thick peripheral walls, high fleshiness of fruit, as well as small number of seed chambers are important technological features of fruit. The author's previous studies [Rożek 2007] revealed a significant negative correlation between the number of seed chambers and fruit wall thickness, as well as the shape coefficient, and the positive correlation between mean fruit weight and the number of fruit chambers. These observations are confirmed by the present results.

CONCLUSIONS

The tomato is sensitive to temperature falling below 0°C, that is why fruit harvest must be conducted before frosts. In the case of the assessed cultivars, whose vegetation periods are quite long, unripe fruits, during a single harvest, constituted on average from 5.1 to 19.3%. No overripe fruits were found in the yield (very soft, wrinkled), which proves the usability of assessed cultivars to decreased harvest frequency. The best yield and the best yield structure was that of Dyno F_1 and Benito F_1 cultivars. In the cultivars Asterix F_1 and Tenorio F_1 a high share of small and very small fruits was observed in the yield, which was an unfavourable feature.

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JAKOŚĆ I STRUKTURA PLONU OWOCÓW POMIDORA POCHODZĄCYCH Z JEDNOKROTNEGO ZBIORU

Streszczenie. Owoce pomidora stanowiące surowiec dla przemysłu przetwórczego mogą być zbierane ręcznie lub mechanicznie, za pomocą kombajnu. Takie cechy nowych odmian, jak prawie jednoczesne wiązanie owoców, duża trwałość owoców oraz powolne ich przejrzewanie umożliwiają rezygnację z tradycyjnego wielokrotnego zbioru. Ograniczenie liczby zbiorów oraz wprowadzenie zbioru mechanicznego to wyraz dążenia do zmniejszenia nakładów ponoszonych na zbiór. Podczas badań przeprowadzonych w latach 2009–2010 oceniono wielkość i strukturę plonu owoców kilku odmian pomidora polecanych dla przemysłu przetwórczego. Owoce pochodziły ze zbioru jednorazowego, przeprowadzonego w drugiej połowie września. Największym plonem owoców i najlepszą strukturą plonu wyróżniały się odmiany Dyno F_1 i Benito F_1. Odmiany Asterix F_1 i Tenorio F_1 plonowały na zbliżonym poziomie, a cechą niekorzystną w ich strukturze plonu był duży udział owoców małych (o średnicy od 4,0 do 3,5 cm) i bardzo małych (poniżej 3,5 cm). Plon owoców pomidora w kolejnych latach był istotnie zróżnicowany i uzależniony od warunków pogodowych. Wykazano, że w przypadku odmian o dłuższym okresie wegetacji, a do takich zaliczane są odmiany polecane do przemysłu przetwórczego, nie zawsze możliwy jest zbiór całego plonu. W pierwszym roku badań owoce dojrzałe stanowiły 94,9%, w drugim roku – 80,7%. Duża liczba owoców niedojrzałych znacznie utrudnia przeprowadzenie zbioru mechanicznego pomidora.

Słowa kluczowe: *Lycopersicon esculentum*, zbiór jednorazowy, przemysłowe odmiany pomidora, owoce handlowe

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