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UTILITY AND BIOLOGICAL VALUE OF HOT PEPPER FRUITS FROM A SINGLE HARVEST

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Abstract. Due to the unique taste features and pro-health values of fruits, hot pepper is cultivated in Poland on the commercial scale, most frequently with the use of single harvest which results in fruits at various maturity stage: green fruits, fruits turning colour and physiologically mature fruits (red). This paper, based on the results of 3-year experiments, evaluates utility and biological value of fruits of four Polish cvs.: 'Bronowicka Ostra', 'Orkan', 'Cyklon' and 'Rokita'. Agricultural study was conducted for three years, during the period 2009–2011. Fruits of various maturity stage consisted of the marketable yield of the and hot pepper from a single harvest. The evaluated cultivars differed in utility and biological value of fruits, quantity and fruit yield structure. The greatest yield was obtained from 'Orkan' and 'Rokita' cvs. (2.17 kg·m^{-2}), yet the greatest yield of physiologically mature fruits (1.16 kg·m^{-2}) from 'Bronowicka Ostra' cv. whose share in marketable yield was 65.0%. Biological value of fruits depended on maturity stage and cultivar genotype. Physiologically mature fruits contained most dry mass (13.18%), soluble solids (4.4%), L-ascorbic acid (199.9 mg·100 g^{-1} f.m.), total sugars (2.92%). Yet more capsaicinoids were proved in green fruits and fruits turning colour. Least dry mass (%) and total sugars (%) were noted in 'Orkan' cv., whereas least L-ascorbic acid in 'Bronowicka Ostra' cv., in which fruits at every stage of maturity accumulated most capsaicinoids.

Key words: *Capsicum annuum* L., cultivar, fruits maturity stage, yield structure, capsaicinoids

INTRODUCTION

Interest in large scale cultivation of hot peppers has increased in Poland in the last few years. Available cultivars are characterized by good adaptation to cultivation in less favourable weather conditions. Hot pepper fruits are characterized by little unit mass, because successive harvests are very laborious [Buczkowska 2001b, Orłowski et al.

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2004, Nowaczyk et al. 2006]. It has been shown that in the case of hot pepper the number of harvests had no effect on marketable fruit yield but only on the number of physiologically mature fruits [Buczkowska 2001a]. In commercial cultivation of hot pepper a limited number of harvests is applied, including single harvest, which leads to yield of fruit at different maturity stages [Buczkowska 2001a, b, Orłowski et al. 2004, Buczkowska et al. 2013].

Unique culinary and pro-health properties of hot peppers are determined by the content of several biologically active substances. The most important among them is vitamin C as pepper fruits accumulate much of it [Daood et al.1996, Howard et al. 2000, Gnaayfeed et al. 2001, Buczkowska and Najda 2002, Perucka and Materska 2003, Orłowski at al. 2004]. Mature pepper fruits are rich in sugars and carotenoids pigments [Topuz and Ozdemir 2007, Ayuso et al. 2008, Iqbal and Amjad 2013]. Spicy hot and burning taste of hot pepper is determined by the presence of capsaicinoids, a group of capsaicin compounds characteristic only of *Capsicum* genus plants. Capsaicin and dihydrocapsaicin appear in capsaicinoids complex in the greatest amounts, whereas nordihydrocapsaicin, homocapsaicin, homodihydrocapsaicin and others appear in lesser amounts. Quantitative relations of particular capsaicinoids in hot pepper fruits depend on genotype of cultivar [Zewide and Bosland 2000, Cisneros-Pineda et al. 2007, Meckelmann et al. 2013]. Biosynthesis of capsaicinoids takes place in the fruits, in placenta epidermal cells, from which they are distributed to seeds and the pericarp, and also in small quantities to vegetative parts of plants [Contreras-Padilla and Yahia 1998, Estrada et al.2002, Pandhair and Sharma 2008, Ben Mansour-Gueddes et al. 2012].

The aim of the present study was to determine useful and biological value of hot pepper fruits of several Polish cultivars obtained from cultivation with application of single fruit harvest.

MARERIALS AND METHODS

The study presented results of agrotechnical research conducted for three years on a private farm near Lublin (51.35º N, 22.85º E). Every year winter wheat was the forecrop for the hot pepper. Organic fertilization was applied in autumn with the use of manure at the rate of 30 $t \cdot ha^{-1}$. Depending on a year, mineral nutrients content in the soil was as follows: $N\text{-}NO_3$ 15–45, P 60–125, K 100–140, Ca 700–1150, Mg 70–115 $mg \cdot dm^{-3}$, and soil pH of 6.2–6.6. Mineral fertilization was applied two weeks prior to the planned seedling transplantation in the amounts of: 90–100 kg N (ammonium nitrate), 50–60 kg P (triple superphosphate), 110–130 kg K (potassium sulfate) per 1 ha. During the cultivation period pepper was foliar-treated twice with calcium nitrate (1%) and twice with Florovit (0.5%). Potted pepper seedling was prepared in the greenhouse of the University of Life Sciences in Lublin, at the Experimental Station, Lublin-Felin, in accordance with commonly accepted rules for that plant. The hot pepper seedlings were planted in the field between May 24th and 30th, at the spacing of 0.67 × 0.35 m. 4.26 plants were cultivated per 1 m^2. Four Polish cultivars of the hot pepper were used: 'Orkan', 'Cyklon', 'Rokita', 'Bronowicka Ostra'. The experiment was designed as one-factor, in the randomized system blocks, in 4 repetitions, 40 plants per plot of 9.4 m^2 surface. During

plant vegetation period necessary maintenance was conducted, in case of water shortage plants were watered. In the present investigation we decided in favour out a single harvest prior the appearance of autumn ground frosts. Usually the first ground frosts in this pepper cultivation region begin in the third decade of September. A single fruit harvest was conducted in the period between September 27th and 30th. In every year of the research all fruits were harvested one-time, separately in each replication. The following features were assessed in the experiment: total yield, marketable yield and number of total fruits and marketable fruits. Fruits in the typical size for the particular cultivar and without visible disease symptoms were determined as marketable fruits. Marketable fruits from each replication were sorted according to maturity stages into: green fruits, fruits turning colour and red fruits. Their number, yield and structure including maturity stage were assessed. One hundred randomly selected fruits at each maturity stage were subject to evaluation of selected parameters of their biological value. Laboratory analyses were performed in 3 repetitions: dry matter of fruits was determined by means of dryer method in temperature of + 105ºC, L-ascorbic acid by means of Roe method with Ewelin's modification (mg·100 g^{-1} f.m.) [Korenman 1973], total sugars (%) by means of Schoorl-Luff method [Kasperek et al. 1977], soluble solids (%) refractometrically – using Brix Tester. The content of capsaicinoids (capsaicin and dihydrocapsaicin) was determined by HPLC, according to the procedure described by Collins et al. [1995]. Fifty selected fruits of the four hot pepper cultivars, at three maturity stages, were dried in a special microprocessor-controlled drying oven at the temperature of 60ºC. The fruit drying period lasted 3 days. Directly before carotenoid extraction the dried fruits were ground. Then samples of 1.5 g were transferred quantitatively to 50 ml round-bottom flasks and immersed in 15 ml of acetonitrile (ACN). The extraction was carried out in a heated bath at 80ºC for 4 hours, shaking it by hand every hour. The obtained supernatant was filtered through 0.45 µm Waters-Millex filters. The qualitative and quantitative analysis of capsaicinoids was performed using a liquid chromatograph with a Li Chrom C_{18} column (250 × 4.6 mm) filled with silica gel. HPLC methanol was used as an eluent. The standards: 8-methyl-N-vanillyl-6-nonenamide (capsaicin) and N-vanillylnonenamide (dihydrocapsaicin), were manufactured by Sigma-Aldrich. The determinations were performed in 3 replications.

Due to similar results of the studied parameters obtained in the years 2009–2011 of agricultural and laboratory experiments, average values of three years were presented in this study. Statistically, research results were determined as a two-factor experiment of 4 × 3 type (4 cultivars × 3 stages of fruit maturity) by means of variance analysis. The significance of differences was evaluated with Tukey's multiple confidence intervals at a significance level of 5%.

RESULTS AND DISSCUSSION

During a three-year experiment on cultivation of hot pepper in the field in Polish climate, a satisfactory marketable yield of fruits was obtained (1.927 kg·m^{-2}). Its share in total yield equaled 80.3% (tab. 1, fig. 1). Differences among the researched cultivars were observed in the marketable yield. Significantly greater yield was obtained from

'Rokita' and 'Orkan' cvs. The marketable yield of the hot pepper harvested one-time consisted of fruits of various maturity stage. The yield of red fruit was the greatest. Its share in the total marketable yield was on average 45.8%. The greatest yield of mature fruits was obtained from 'Bronowicka Ostra' cv.

Table 1. Marketable yield and number of marketable fruits of the hot pepper depending on the fruit maturity stage (mean for years 2009–2011)

Factor		Marketable yield (kg·m^{-2})				Number of marketable fruits (No·m^{-2})			
		green	turning colour	red	total	green	turning colour	red	total
Cultivar (A)	Bronowicka Ostra	0.451	0.171	1.157	1.779	19.4	9.4	72.3	101.1
	Orkan	0.526	0.571	1.072	2.169	19.5	15.4	36.6	71.5
	Cyklon	0.540	0.272	0.783	1.595	11.9	8.4	49.2	69.5
	Rokita	0.772	0.874	0.519	2.165	23.8	24.2	16.6	64.6
Fruit maturity stage (B)		0.572	0.472	0.883	1.927	18.6	14.4	43.7	76.7
$LSD_{at\ p = 0.05}$									
Cultivar (A)					0.2715				16.69
Fruit maturity stage (B)					0.2240				13.08
Interaction (A × B)					0.6145				37.80

Number of fruits obtained in marketable yield equaled on average 76.7 pieces per 1 m^2. Their share in total number accounted for 73.3% (tab. 1, fig. 2). The evaluated cultivars differed significantly in number of marketable fruits harvested from 1 m^2 . By far, the most mature fruits were collected from 'Bronowicka Ostra' and 'Cyklon' cvs. compared to 'Rokita' cultivars whose fruits turned colour and matured more slowly, which indicates that the evaluated cultivars differed in terms of vegetation period duration.

The marketable yield of the hot pepper (1.59–2.16 kg·m^{-2}) that was obtained in the area of Lublin was similar to the yield from these cultivars in previous studies [Buczkowska 2001a, b, Buczkowska et al. 2001] and to the yield harvested in other regions of Poland [Orłowski et al. 2004, Golcz and Kujawski 2005]. It was also comparable to the yield obtained in a warmer climate of Spain and Turkey [Ayuso et al. 2008, Yaldiz et al. 2010].

Dry matter in the fruits of hot pepper equaled on average 13.18% (tab. 2) and was comparable to values noted for these cultivars in other studies [Buczkowska et al. 2001, Buczkowska and Najda 2002, Orłowski et al. 2004, Golcz and Kujawski 2005, Buczkowska et al. 2013]. More dry matter was determined in the fruits of 'Cyklon' and 'Bronowicka Ostra' cvs. An increase of dry matter content (%) was shown in fruits of all cultivars when fruit maturity increased with the exception of 'Cyklon' cv. Soluble solids content, however, depended only on fruit maturity stage (tab. 2). Mature fruits contained significantly more extract compared to green fruits. This confirms results reached by other authors who proved that dry matter and soluble solids content in the

pepper fruits mainly depend on cultivar genotype and fruit maturity stage [Buczkowska et al. 2001, Buczkowska and Najda 2002, Orłowski et al. 2004, Martínez et al. 2007, Lannes et al. 2007, Ayuso et al. 2008].

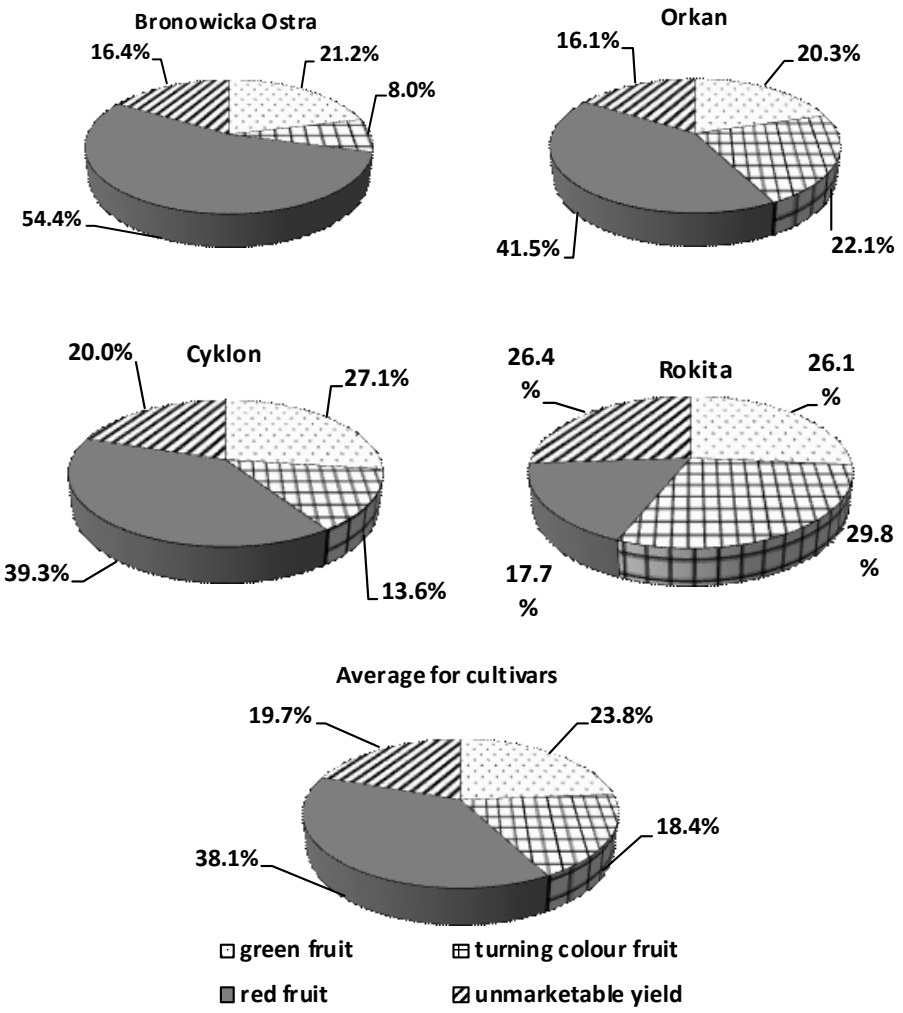

Fig. 1. Structure of total yield of hot pepper depending on fruit maturity stage

High content of L-ascorbic acid was marked in the evaluated cultivars – the highest in completely mature fruits (tab. 3). Fruits of the evaluated cultivars differed statistically in the content of this compound. More L-ascorbic acid was accumulated in fruits of 'Rokita' and 'Orkan' cvs. These values are comparable to those obtained for the same cultivars in previous studies [Buczkowska et al. 2001, Buczkowska and Najda 2002,

Perucka and Materska 2003, Orłowski et al. 2004] and similar to those marked by other authors in hot and sweet pepper [Martínez et al. 2007, Iqbal and Amjad 2013, Meckelmann et al. 2013]. Vitamin C content in pepper fruits is determined mainly by genetic features of the cultivar and depends also on fruit maturity stage [Daood et al. 1996, Howard et al. 2000, Gnaayfeed et al. 2001, Martínez et al. 2007, Iqbal and Amjad 2013, Meckelmann et al. 2013]. Martínez et al. [2007] achieved that the total ascorbic acid in red fruits was 27% higher in the than of green pepper.

Table 2. Dry matter and soluble solids in the hot pepper depending on the fruit maturity stage (mean for years 2009–2011)

Factor		Dry matter (%)				Soluble solids (%)			
		green	turning colour	red	mean	green	turning colour	red	mean
Cultivar (A)	Bronowicka Ostra	12.63	15.07	14.21	13.97	2.9	3.7	5.2	3.9
	Orkan	9.92	12.73	13.26	11.97	3.1	4.2	4.7	4.0
	Cyklon	11.40	15.76	14.93	14.03	3.3	4.4	5.2	4.3
	Rokita	9.95	14.07	14.16	12.73	3.7	4.5	5.0	4.4
Fruit maturity stage (B)		10.98	14.41	14.14	13.18	3.3	4.2	5.0	4.2
$LSD_{at\ p=0.05}$									
Cultivar (A)					1.424				n.s.
Fruit maturity stage (B)					1.116				0.92
Interaction (A × B)					3.226				n.s.

explanation: fruits: g – green, t – turning colour, r – red

Table 3. Content of L-ascorbic acid and total sugars in the hot pepper depending on the fruit maturity stage (mean for years 2009–2011)

Factor		L-ascorbic acid ($mg \cdot 100\ g^{-1}$ f.m.)				Total sugars (%)			
		green	turning colour	red	mean	green	turning colour	red	mean
Cultivar (A)	Bronowicka Ostra	123.5	167.3	208.7	166.5	2.05	2.92	3.28	2.75
	Orkan	194.3	203.2	277.9	225.1	1.89	2.44	2.96	2.43
	Cyklon	145.6	182.9	222.9	183.8	2.35	3.45	3.79	3.20
	Rokita	194.9	218.6	258.6	224.0	2.41	3.56	3.91	3.29
Fruit maturity stage (B)		164.6	193.0	242.0	199.9	2.17	3.09	3.49	2.92
$LSD_{at\ p=0.05}$									
Cultivar (A)					38.65				n.s.
Fruit maturity stage (B)					30.30				0.717
Interaction (A × B)					87.54				n.s.

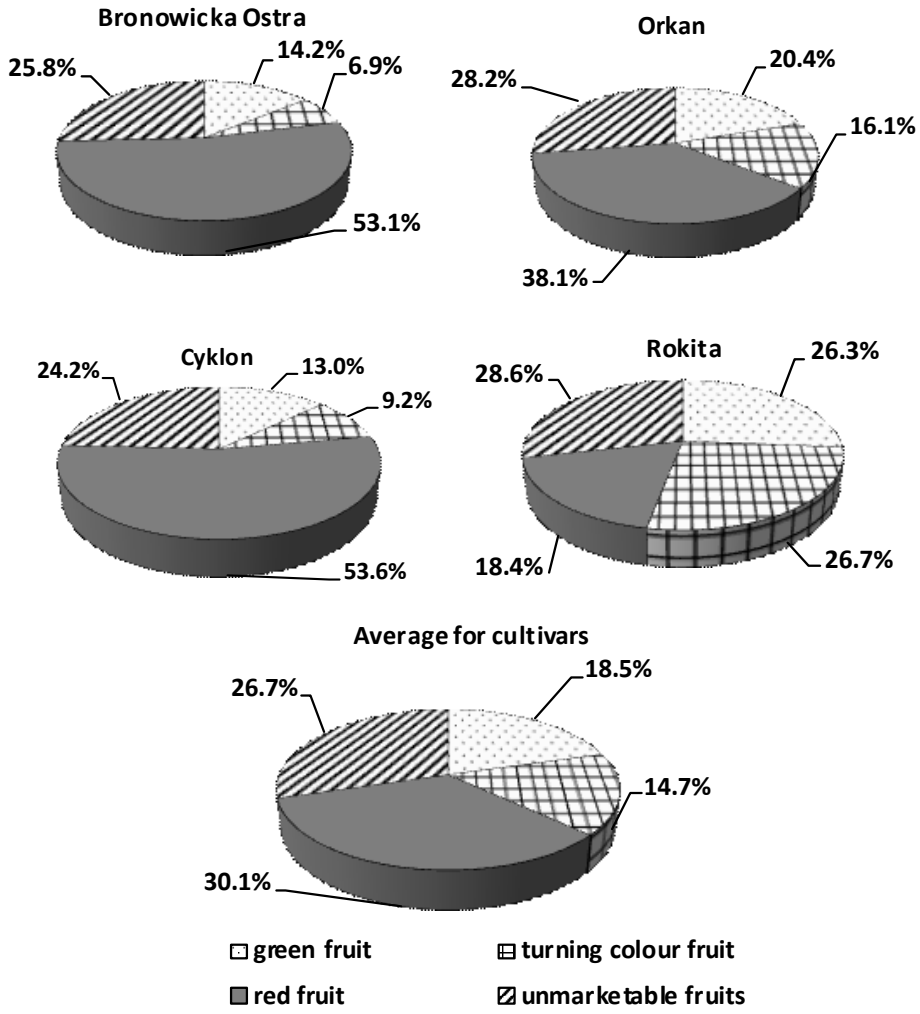

Fig. 2. Structure of total number fruits of hot pepper depending on fruit maturity stage

The total content of sugars in the fruits of evaluated cultivars ranged between 2.43% and 3.29% (tab. 3), and was significantly lower than that marked in the fruits of the same cultivars from other studies [Buczkowska et al. 2001, Buczkowska and Najda 2002, Orłowski et al. 2004]. Mature fruits of the hot pepper contained more total sugars than fruits turning colour or green, which indicates significant influence of fruit maturity on sugars accumulation. Serrano et al. [2010] noted that the greatest growth of total sugars content took place in hot pepper after 60–70 days from flowering. Orłowski et al. [2004] and Martínez et al. [2007] showed twice higher content of total sugars (%) in mature fruits of pepper compared to green fruits.

Table 4. Content of capsaicin and dihydrocapsaicin in the hot pepper depending on the fruit maturity stage (mean for years 2009–2011)

Factor		Capsaicin (mg·kg^{-1})				Dihydrocapsaicin (mg·kg^{-1})			
		green	turning colour	red	mean	green	turning colour	red	mean
Cultivar (A)	Bronowicka Ostra	347	312	285	315	31	27	25	28
	Orkan	202	184	170	185	18	15	14	16
	Cyklon	216	205	184	202	17	16	14	16
	Rokita	274	257	233	255	22	23	18	21
Fruit maturity stage (B)		260	239	218	239	22	20	18	20
$LSD_{at\ p = 0.05}$									
Cultivar (A)					61.1				4.4
Fruit maturity stage (B)					37.9				3.4
Interaction (A × B)					138.4				9.9

Capsaicinoids content (capsaicin and dihydrocapsaicin) in hot pepper equaled on average 239 and 20 mg·kg^{-1} (tab. 4). Dihydrocapsaicin content was over 11 times lower than main capsaicinoid content. Quantitative relation of capsaicin to dihydrocapsaicin indicates that capsaicin in capsaicinoids complex appears in the greatest amounts, whereas quantitative relation among other elements of this complex are determined by cultivar features [Zewide and Bosland 2000, Gibbs and O'Garro 2004, Ayuso et al. 2008, Ben Mansour-Gueddes et al. 2012]. Fruits of the evaluated cultivars differed significantly in the content of those elements. Most capsaicin and dihydrocapsaicin (315 and 28 mg·kg^{-1}) was marked in the fruits of 'Bronowicka Ostra' cv. Capsaicinoids content marked in this research was similar to the values marked for the same cultivars in other studies [Buczkowska et al. 2001, Materska and Perucka 2003, Golcz and Kujawski 2005, Buczkowska et al. 2013] and also similar to those determined in fruits of hot pepper cultivars belonging to *Capsicum annuum* L. species [Topuz and Ozdemir 2007, Ayuso et al. 2008, Ben Mansour-Gueddes et al. 2012, Iqbal and Amjad 2013]. Significantly greater capsaicinoid content is accumulated in the fruits of plants belonging to *Capsicum frutescens* L. and *Capsicum chinense* Jacq. species [Gibbs and O'Garro 2004, Cisneros-Pineda et al. 2007, Lannes et al. 2007, Meckelmann et al. 2013]. In this study most capsaicinoids were marked in green fruits. These results are compliant with those presented in other studies, where authors identified most of these metabolites also in the fruits in early maturity stages, usually after 40–60 days from flowering [Contreras-Pandila and Yahia 1998, Gnaayfeeld et al. 2001, Pandhair and Sharma 2008, Ben Mansour-Gueddes et al. 2012, Iqbal and Amjad 2013].

CONCLUSIONS

The evaluated Polish cultivars of the hot pepper differed in utility and biological value of fruits. The greatest yield of marketable fruits was obtained from 'Orkan' and

'Rokita' cvs. (2.17 kg.·m^{-2}). 'Bronowicka Ostra' cv. produced the greatest yield of fruits red, whose share in total yield equaled 54.4% and in total number of fruits 53.1%. Influence of fruit maturity stage on useful and biological value of hot pepper fruits was noted. Fruits in physiological maturity stage contained most dry matter, soluble solids, L-ascorbic acid and total sugars. Whereas more capsaicin and dihydrocapsaicin was marked in green fruits and fruits turning colour. Least dry matter (%) and total sugars (%) were marked in fruits of 'Orkan' cv. The least L-ascorbic acid was accumulated in fruits of 'Bronowicka Ostra' cv. Fruits of this cultivar in each maturity stage contained most capsaicin and dihydrocapsaicin.

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STRUKTURA PLONU I WARTOŚĆ BIOLOGICZNA OWOCÓW PAPRYKI OSTREJ Z JEDNORAZOWEGO ZBIORU

Streszczenie. Niepowtarzalne właściwości smakowe i wartości prozdrowotne owoców papryki ostrej sprawiają, że w Polsce prowadzi się już uprawy towarowe papryki ostrej, najczęściej z zastosowaniem zbioru jednorazowego, z którego uzyskuje się owoce w różnych fazach dojrzałości: owoce zielone, przebarwiające się oraz dojrzałe fizjologicznie (czerwone). W niniejszej pracy na podstawie wyników z trzyletnich doświadczeń oceniono wartość użytkową oraz biologiczną owoców czterech polskich odmian: Bronowicka Ostra, Orkan, Cyklon oraz Rokita. Odmiany te różniły się pod względem wielkości i struktury plonu owoców w zależności od ich fazy dojrzałości. Największy plon otrzymano z odmian Orkan i Rokita (2,17 kg·m^{-2}), natomiast największy plon owoców dojrzałych fizjologicznie (1,16 kg·m^{-2}) z odmiany Bronowicka Ostra, którego udział w plonie handlowym stanowił 65,0%. Wartość biologiczna owoców uzależniona była od fazy dojrzałości oraz genotypu odmiany. Najwięcej suchej masy (13,18%), ekstraktu (4,4%), kwasu L-askorbinowego (199,9 mg·100 g^{-1} s.m.) i cukrów ogółem (2,92%) zawierały owoce dojrzałe fizjologicznie, natomiast więcej kapsaicynoidów wykazano w owocach zielonych i przebarwiających się. Najmniej suchej masy (%) oraz cukrów ogółem (%) oznaczono u odmiany Orkan, zaś kwasu L-askorbinowego u odmiany Bronowicka Ostra, której owoce w każdej fazie dojrzałości akumulowały najwięcej kapsaicynoidów.

Słowa kluczowe: *Capsicum annuum* L., odmiana, dojrzałość owoców, struktura plonu, kapsaicynoidy

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