ACTA SCIENTIARUM POLONORUM

Acta Sci. Pol. Hortorum Cultus, 16(2) 2017, 11–19

www.acta.media.pl ISSN 1644-0692

ORIGINAL PAPER

Accepted: 4.10.2016

EVALUATING ECONOMIC VALUE OF 23 STRAWBERRY CULTIVARS IN THE CLIMATIC CONDITIONS OF CENTRAL EUROPE

Justyna Wójcik-Seliga[1], Marcin Studnicki[2], Elżbieta Wójcik-Gront[2]✉

[1] Research Institute of Horticulture, Skierniewice, Poland

[2] Department of Experimental Design and Bioinformatics, Warsaw University of Life Sciences – SGGW, Warsaw, Poland

ABSTRACT

Aim of the project was to test 23 strawberry cultivars in the climate of Poland and evaluate their economic value. 13 of discussed cultivars were newly bread in Poland and 10 are of foreign origin including cultivars that were never tested in East–Central Europe. All of these cultivars were evaluated in comparison to the 4 standard cultivars used in Poland. The experiment was conducted between 2004 and 2011 in central Poland in the Research Institute of Horticulture in Skierniewice. The data were analyzed using linear mixed model. The results shows that cultivar 'Paladyn' performed exceptionally well regarding yield and fruit size. Thus, it is one of the best cultivars for including into canon strawberry cultivars, not only in Poland. The rest of tested cultivars, especially those with foreign origin, may need specific treatment or more investigation to accomplish more in the climatic conditions of this geographical region.

Key words: strawberry yield, fruit size, harvest, adaptive response, linear mixed model

INTRODUCTION

Strawberries are known for their taste and excellent source of vitamin C, antioxidants, fiber and a lot other health benefits [Ames et al. 1993, Heinonen et al. 1998]. Strawberry is one of the most important fruit crop cultivated in Poland. Its cultivation is very extensive and fragmented. Almost all of the berry plantation are individual farms. The yield of strawberry in highly specialized farms in Poland can be up to 15 t ha^{-1} and on average it is 4 t ha^{-1} in private farms [GUS 2013]. Poland is an important frozen strawberry exporter and main supplier to the European Union. In the last couple of years number of strawberry plantations decreased but the size of an average plantation become larger, which results in modernized management and equipment. Recently, a continuous increase in number of cultivars for fresh markets in Polish production is observed. Now consumers are attracted mostly by large, well shaped fruits of very good quality [Roudeillac and Trajkowski 2004]. Strawberry producers are interested in delivering fruit to the market for as long as possible, so techniques to obtain early and late yields become more popular. The producers are also interested in cultivars, which fruit susceptibility to decay is low. This geographical region's weather with cold, sometimes severe winters (the temperature can drop below -30°C) and springs with frequent showers and ground frost even in May is the main obstacle for routine strawberry farming. Many of interesting strawberry cultivars come from countries with more favorable

✉ewojcik.gront@gmail.com

climate and may not perform as well in Poland as in the country of origin.

One of the centers where the cultivar evaluation is conducted is the Research Institute of Horticulture in Skierniewice. There were many types of fruits evaluated in Skierniewice [Rozpara 2008, Pluta et al. 2012, 2014, Wójcik-Seliga and Wójcik-Gront 2013]. There were also several experiments conducted regarding fruiting of strawberries with origins in regions with different climatic and soil conditions [Żurawicz and Masny 2002, Masny and Żurawicz 2010, Masny et al. 2014]. These experiments provided information for Polish producers. The other obstacle in strawberry farming is Verticillium dahliae, a fungal plant pathogen. This fungus infects over 300 cultivated plants, including strawberry. The severity of the plant decay depends on susceptibility of it s genotype [Harris and Yang 1996] and suitable environmental conditions, it is high humidity and temperature of 23 to 25°C. Verticillium dahliae is very difficult to fight against because it can continue to live in soil even for 14 years [Wilhelm 1955].

To deliver essential information of new strawberry cultivars, they have to be evaluated under different ecosystems (locations) and years (growing seasons). The system of evaluation is called Pre-registration Variety Testing System. One of location, where the horticultural evaluation takes place is the Research Institute of Horticulture in Skierniewice in central Poland. After tests many of the cultivars will be enrolled to Polish National List of Fruit Plant Varieties. The cultivars were also included into *Fragaria* collection conducted in the Research Institute of Horticulture in Skierniewice. The cultivars tested in the trial came from different breeding programs from many countries. In the evaluation described in this paper there were 13 new polish strawberry cultivars tested including: 'Alfa Centauri', 'Alioth', 'Alkor', 'Dominika', 'Feriusz', 'Filut', 'Hokent', 'Marduk', 'Markat', 'Paladyn', 'Pegat', 'Recoda', 'Selvik' and 10 foreign, where most of them were never tested in Poland: 'Camino Real', 'Elianny', 'Emily', 'Eros', 'Kimberly', 'Placartfre', 'Plahuelfre', 'Plarocifre', 'Rosie' and 'Ventana'. These cultivars were evaluated in comparison to 4 standard cultivars used in Poland: 'Elsanta', 'Honeoye', 'Kama' and 'Senga Sengana'. The summation of cultivars characteristic contains Table 1.

MATERIALS AND METHODS

The project took place in the Pomological Orchard in Skierniewice, central Poland, between years 2004–2011. The orchard is owned by the Research Institute of Horticulture. The main goal of the experiment was to evaluate economic value of new promising cultivars and identify cultivars that are less prone to freeze injury and pests. There were 23 mostly new to Polish environment conditions strawberry cultivars tested (tab. 1). These cultivars were evaluated in comparison to Poland's standard cultivars, 'Kama' and 'Senga Sengana'– cultivars popular for processing and 'Elsanta' and 'Honeoye' – typical dessert cultivars. The whole 2004–2011 experiment consisted of several trials. Each trial took 3 years. There were different cultivar sets tested during each trial. There were up to 8 cultivars tested in one trial including at least 2 standards.

The plants were planted always in the autumn a year before the trails started. The strawberries were planted in a randomized block design in four replications. One plot area was around 5 m^2 and there were 20 strawberries planted in a distance of 0.25 × 1 m. In the vegetation season of each experiment there was chemical protection applied to the plants according to valid recommendations elaborated in the Research Institute of Horticulture.

Maintenance and fertilization to the plants were done according to rules used for strawberry mass production. The plants were fertilized and irrigated during hot summers. Straw was applied before the flowering season to keep ripen berries clean and healthy. It was removed after picking. The strawberry runners were cut down in the autumn. In the late fall plants were covered with straw to reduce winter injury. The experiments were conducted according to tips from the Community Plant Variety Office (CPVO) protocol on strawberry [CPVO 2012].

For studied strawberry cultivars their ripening period, fruit yield and weight of 100 fruits were recorded in the years 2004–2011. The crop picked a year after planting is not that representative of a crops

Table 1. Description of strawberries used in the Skierniewice trials in 2004–2011

Cultivar	Breeding name	Origin	Pedigree	Time of fruit ripening
Alfa Centauri	DM 97211	Poland	'Pandora' × 'Onebor'	late
Alioth	DM 01501	Poland	'Camarosa' × 'Pandora' × 'Selva'	late
Alkor	DO 02752	Poland	unknown	medium
Camino Real	C213	USA	Cal 89.230–7 × Cal 90.253–3	early
Dominika	5B	Poland	unknown	medium
Elianny	Elianny	Netherlands	restricted	early
Elsanta	Elsanta	Poland	'Gorella' × 'Holiday'	medium
Emily	Emily	U.K	'Honeoye' × 'Gea'	medium
Eros	Eros	U.K	'Allstar' × 'Elsanta'	early
Feriusz	K–1605	Poland	'Ferrara' × 'Syriusz'	late
Filut	K–9409–02	Poland	'Syriusz' × 'Vicoda'	late
Hokent	K–9536–11	Poland	'Kent' × 'Honeoye'	early
Honeoye	Honeoye	USA	'Vibrant' × 'Holiday'	early
Kama	SIN 72	Poland	'Senga Sengana' × 'Cavlier'	early
Kimberly	93/94	Netherlands	'Elsanta' × 'Parker'	medium
Marduk	K–9620–12	Poland	'Onebor' × 'Dukat'	medium
Markat	K–97076–01	Poland	'Onebor' × 'Dukat'	medium
Paladyn	K–98054–01	Poland	'Pandora' × 'Onebor'	late
Pegat	K–99076–01	Poland	'Pegasus' × 'Elkat'	medium
Placartfre	97.10.030	Spain	Sel. 92–38 × Sel. 86–032	early
Plahuelfre	96.09.014	Spain	Sel. 92–44 × Sel. 86–032	early
Plarocifre	97.06.522	Spain	Sel. 92–61 × Sel. 86–032	early
Recoda	K–1580	Poland	'Real' × 'Vicoda'	late
Rosie	Rosie	U.K.	'Honeoye' × Italian seedling	early
Selvik	K–9404–16	Poland	'Selva' × 'Vicoda'	late
Senga Sengana	Senga Sengana	Germany	'Markee' × 'Sieger'	medium
Ventana	C216	USA	Sel. Cal. 93.170–606 × Sel. Cal. 92.35–601	early

long term productivity so the data were not taken into account during statistical analysis. Fruits were picked three times a week, almost every other day not including weekends and all fruits from each plant were weighed and counted. The data on 100 berries were collected based on yield in 3, 5, 7. Harvest which is at least once a week. First and last harvest dates were determined based on 5 and 95% harvest.

Regarding the experiments design we had to be very careful with statistical analysis. The two way combination: 23 cultivars × 8 years creates an unbalanced dataset, because during the entire experiment period, different sets of cultivars were tested in separate trials. The yield and fruit size of strawberries can be influenced by weather, especially temperatures and amount of water fall during flowering and ripening each year. They also can be influenced by soil type although the trails were not far away from each other. In the analysis we wanted to eliminate these effects by applying the best model possible and this way evaluate cultivars adaptive response to Polish climate.

The comparisons among cultivars from unbalanced datasets can be done based on selected balanced data subsets [So and Edwards 2009]. This approach allows using classic statistical methods at the expense of loosing part of the data and important information. Instead, we decided to use linear mixed model (LMM), which is now a method often used for analyzing unbalanced data from cultivar evaluation [Smith et al. 2001, 2005, Crossa et al. 2006, Piepho and Möhring 2006].

Table 2. Strawberry cultivars ripening periods in the Skierniewice trials in 2004–2011

Cultivar	2004	2005
Recoda	21.06–23.07	20.06–8.07
Feriusz	14.06–12.07	13.06–8.07
Kama	5.06–5.07	7.06–8.07
Elsanta	7.06–12.07	7.06–8.07
Senga Sengana	11.06–16.07	10.06–8.07
Plahuelfre	7.06–5.07	7.06–8.07
Placartfre	11.06–12.07	10.06–8.07
Plarocifre	7.06–12.07	7.06–6.07
	2005	2006
Kama	7.06–12.07	9.06–30.06
Elsanta	10.06–12.07	9.06–5.07
Senga Sengana	10.06–12.07	14.06–5.07
Selvik	15.06–12.07	16.06–5.07
Filut	13.06–12.07	14.06–7.07
Honeoye	7.06–12.07	7.06–30.06
Camino Real	7.06–12.07	7.06–30.06
Ventana	7.06–12.07	9.06–5.07
	2007	2008
Kama	28.05–18.06	6.06–27.06
Elsanta	30.05–3.07	4.06–1.07
Marduk	1.06–28.06	9.06–7.07
Hokent	4.06–22.06	4.06–4.07
Alfa	8.06–5.07	16.06–11.07
Emily	1.06–28.06	9.06–4.07
Rosie	28.05–25.06	2.06–23.06
Eros	28.05–25.06	4.06–27.06
	2008	2009
Kama	4.06–25.06	28.05–25.06
Elsanta	4.06–4.07	28.05–2.07
Senga Sengana	9.06–4.07	3.06–2.07
Markat	9.06–4.07	5.06–2.07
Kimberly	4.06–4.07	1.06–2.07
	2009	2010
Honeoye	25.05–2.07	2.06–2.07
Elsanta	28.05–6.07	9.06–2.07
Senga Sengana	3.06–6.07	9.06–29.06
Paladyn	10.06–13.07	11.06–2.07
Elianny	28.05–6.07	7.06–29.06
Dominika	8.06–6.07	9.06–2.07
	2010	2011
Honeoye	4.06–2.07	31.05–15.06
Elsanta	7.06–2.07	2.06–15.06
Senga Sengana	11.06–2.07	2.06–17.06
Pegat	7.06–29.06	2.06–17.06
Alioth	11.06–29.06	6.06–17.06
Alkor	4.06–2.07	2.06–15.06

The observed values of cultivar fruit mass and yield were analysed using a two stage combined analysis. That kind of approach is recommended and practiced in cereal cultivars evaluation [Smith et al. 2005]. It also can be successfully used in horticulture for fruit cultivars evaluation. In the first stage of the analysis we used the data separately for each trial (two year experiment) and applied a mixed model ANOVA for randomized block design treating cultivars and blocks (possible differences in soil) as random effects and years as a fixed one:

$$x_{ijk} = \mu + y_i + b_{j(i)} + g_k + gy_{ki} + e_{ijk} \quad (1)$$

where x_{ijk} is the response of the *k*–th cultivar in the *j*–th block within the *i*–th year; μ is the overall mean; y_i is the fixed effect of the *i*–th year; $b_{j(i)}$ is the random effect of the *j*–th block within the *i*–th year; g_k is the random effect of the *k*–th cultivar; gy_{ki} is the random effect of the interaction effect between the *k*–th cultivar and the *i*–th year; e_{ijk} is the residual random effect $\sim NID(0,\sigma^2_e)$. This way we calculated least squares (LS) means for all cultivars, which then were used to create an unbalanced two–way cultivar (G – genotype) × trial (T) table. Then we used linear mixed model (LMM) to estimate the effect of cultivar and trial on the results:

$$x_{kl} = \mu + g_k + t_l + e_{kl} \quad (2)$$

where x_{kl} is the response of the *k*–th cultivar in the *l*–th trial; μ is the overall mean; g_k is the random effect of the *k*–th cultivar; t_l is the fixed effect of the trial; e_{kl} is the residual random effect $\sim NID(0,\sigma^2_e)$. This procedure is analogue to the augmented design [Federer 1956, Federer et al. 2001]. The estimates of the genotypic effects (g_k) from the equation 2 were obtained using the Best Linear Unbiased Predictor (BLUP) with the Residual Maximum Likelihood (REML) method. To eliminate potential influence of weather and soil on yield and fruit size of strawberries they are assessed by the model and the results are expressed as estimated adjusted means calculated from the formula: $m_k^{est} = \mu^{est} + g_k^{est}$, where m_k^{est} is the estimate of cultivar mean for the *k*–th cultivar, μ^{est} is the estimate of overall mean, and g_k^{est} is the BLUP

estimate of the *k*–th cultivar. Thus, obtained cultivar means m_k^{est} for fruit mass and yield were unbiased regarding years and trials effects [You et al. 2013]. Therefore, the cultivars can by evaluated jointly, although they were assessed in various trial series.

Decision, if adjusted means differed significantly (pairwise comparisons), was based on the criterion calculated as two times the standard error of the means [Piepho 2000, Emrich et al. 2008]. The latter abbreviations of pairwise comparisons are assigned on the algorithm by Piepho [2004].

All LLM calculation were performed via the ASReml 3.0 software [Gilmour et al. 2009], implemented in R package – ASReml-R. The analysis gives separate evaluation for weight of 100 fruits in grams and fruit yield in kg per plot. For selecting cultivars which group together, regarding mass and yield at the same time, the Ward's cluster analysis was performed assuming seven clusters. The results of cluster analysis were generated using procedure PROC CLUSTER in the SAS 9.3 software (Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

In the experiment there were also ripening time saved (tab. 2 and fig. 1). While there were slight differences from year to year with harvest date, on average the cultivars fell into couple groups. First to bore a ripen crop in the end of May was 'Elsanta', 'Eros', 'Kama' and 'Rosie' in 2007, 'Elianny', 'Elsanta', 'Honeoye' and 'Kama' in 2009 'Honeoye' in 2011. Besides Elsanta these cultivars are known as early ripening. The one cultivar that bore a ripen crop the latest, around 20th June in 2004 and 2005, was 'Recoda', that is a late cultivar. All the rest cultivars felt into two groups with ripening period in the very first days of June or a week later, at the end of the first half of June.

The results of the LLM analysis are shown in Table 3. There are estimates of the cultivar mean weight of 100 fruits and fruit yield shown. Mean values followed by the same letter are not significantly different. The results are also plotted in Figure 2.

The results of statistical analyses indicated that there were significant differences ($\alpha = 0.01$) in yield and fruit weight due to cultivar and year, and there were significant cultivar x year interactions. Mean

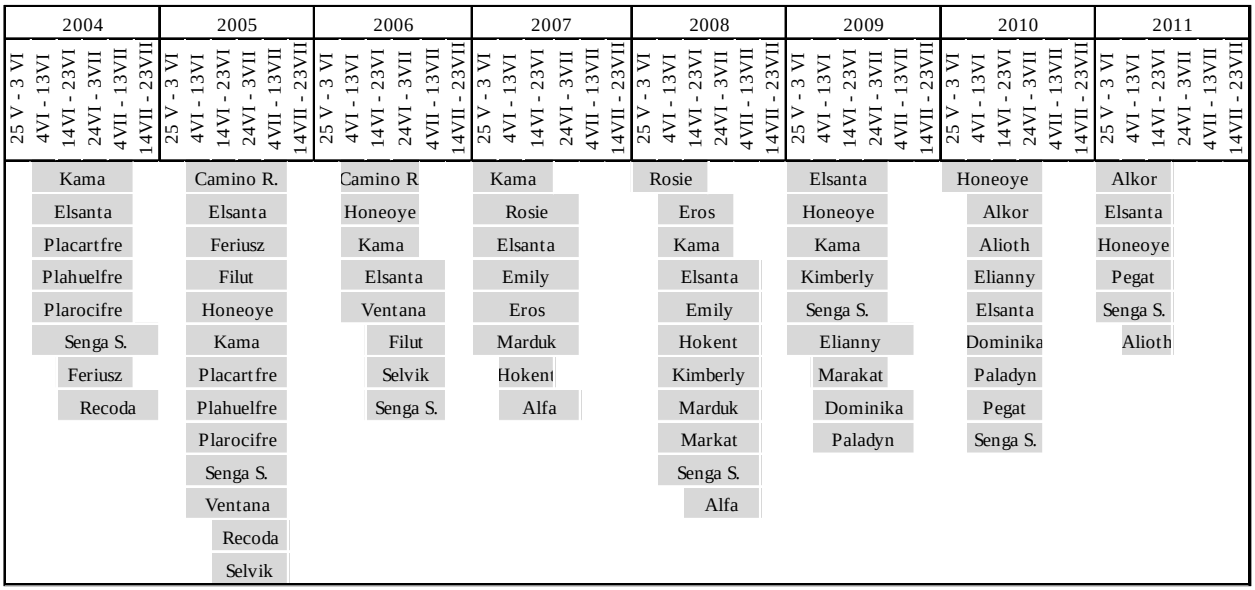

Fig. 1. Strawberry cultivars ripening periods in the Skierniewice trials in 2004–2011

Table 3. Estimated yield and berry weight for 27 strawberry cultivars grown in Skierniewice and harvested in 2004–2011. Mean values followed by the same letter are not significantly different

Cultivar	Weight of 100 fruits (g)		Fruit yield (kg/plot)	
Alfa Centauri	1326	bc	11.6	d
Alioth	1287	bc	5.7	cfghi
Alkor	1324	bc	5.0	bcfgh
Camino Real	1201	abc	4.4	abcfgh
Dominika	1112	ab	5.7	cfghi
Elianny	1234	abc	5.9	fghi
Elsanta	1096	ab	5.7	cfghi
Emily	1319	bc	1.9	abc
Eros	982	ab	6.4	fghij
Feriusz	1067	ab	5.3	cfghi
Filut	1200	abc	7.4	ehij
Hokent	1111	ab	4.4	abcfgh
Honeoye	1152	abc	6.4	fghij
Kama	810	a	3.8	abcfgh
Kimberly	1034	ab	3.1	abcfg
Marduk	1153	abc	10.0	dej
Markat	938	ab	2.6	abcf
Paladyn	1579	c	10.7	de
Pegat	1175	abc	5.4	cfghi
Placartfre	1252	abc	2.0	abc
Plahuelfre	1236	abc	0.9	a
Plarocifre	1142	abc	1.0	a
Recoda	1045	ab	6.8	ghij
Rosie	1111	ab	1.1	ab
Selvik	1142	abc	8.9	deij
Senga Sengana	898	ab	7.0	ehij
Ventana	1176	abc	4.1	abcfgh

yields of cultivars were statistically different and varied from 0.9 kg per plot in case of cultivar 'Plahuelfre' to 11.6 kg per plot for 'Alfa Centauri', which is more than 10-fold higher. 'Plahuelfre' is the cultivar with origin in Spain, where is much warmer so it can perform worse in Polish environment. In Table 3 can be seen that there are couple of groups with similar performance regarding fruit yield. The worst performing are: 'Plahuelfre', 'Plarocifre', 'Rosie', 'Emily', 'Placartfre', 'Markat', 'Kimberly', 'Kama', 'Ventana', 'Hokent' and 'Camino Real' with the yield from 0.9 to 4.4 kg per plot. Then there is 'Alkor' with 5.0 kg fruits per plot. Next is group with: 'Feriusz', 'Pegat', 'Alioth', 'Dominika', 'Elsanta' with the yield from 5.3 to 5.7 kg per plot. 'Elianny', 'Honeoye' and 'Eros' come into next group with the yield 5.9–6.4 kg per plot. Then Recoda – 6.8 kg per plot. Then Senga Sengana and Filut with the yield from 7.0 to 7.4 kg per plot. And the last one with highest yield is the group with: Selvik, Marduk, Paladyn and Alfa Centauri 8.9–11.6 kg per plot. Mean masses of 100 fruits were also influenced by cultivar and vary from 810 g for 'Kama' to 1579 g, almost twice as high, for 'Paladyn' (tab. 3, fig. 2). There can be several group extracted with cultivars having fruits of similar size/mass. The smallest fruits belong to: 'Kama', 'Senga Sengana', 'Markat', 'Eros', 'Kimberly', 'Recoda', 'Feriusz', 'Elsanta', 'Rosie', 'Hokent', 'Dominika', 'Plarocifre', 'Selvik', 'Honeoye', 'Marduk', 'Pegat', 'Ventana', 'Filut', 'Camino Real', 'Elianny', 'Plahuelfre', 'Placartfre' and 100 of them measure from 810 to 1252 g. Next group: 'Alioth', 'Emily', 'Alkor', 'Alfa Centauri' has fruits with weight of 100 from 1287 to 1326. The biggest fruits belonged to 'Paladyn'.

In the cluster analysis there were 7 groups appointed with cultivars having similar together yield and fruit mass. The dendrogram is showed in Figure 3. First group with the highest yield and heaviest fruits consists of only one cultivar: 'Paladyn'. Then there is a second group with 'Alfa Centauri', 'Selvik' and 'Marduk'. Third group contains three cultivars: 'Marakat', 'Kimberly' and 'Kama'. Next are 'Eros', 'Recoda' and 'Senga Sengana'. Then the group with 'Rosie', 'Placartfre', 'Plahuelfre', 'Plarocifre' and 'Emily'. Sixth group comprise 'Alioth', 'Alkor', 'Eliany', 'Honeoye', 'Pegat' and 'Filut'. And the last one is made of 'Dominika', 'Elsanta', 'Feriusz', 'Hokent', 'Camino Real' and 'Ventana'.

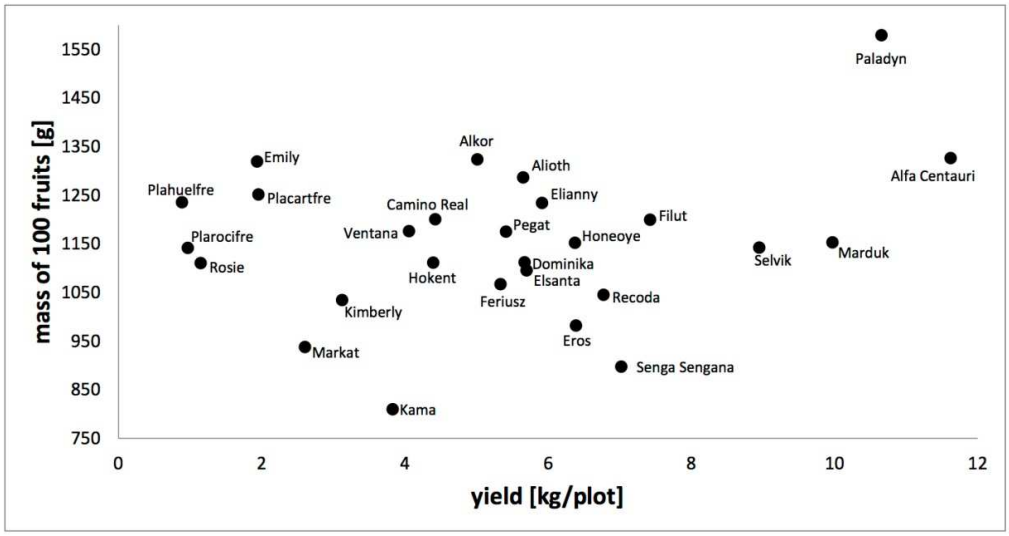

Fig. 2. Estimated yield and berry weight for 27 strawberry cultivars grown in Skierniewice and harvested in 2004–2011

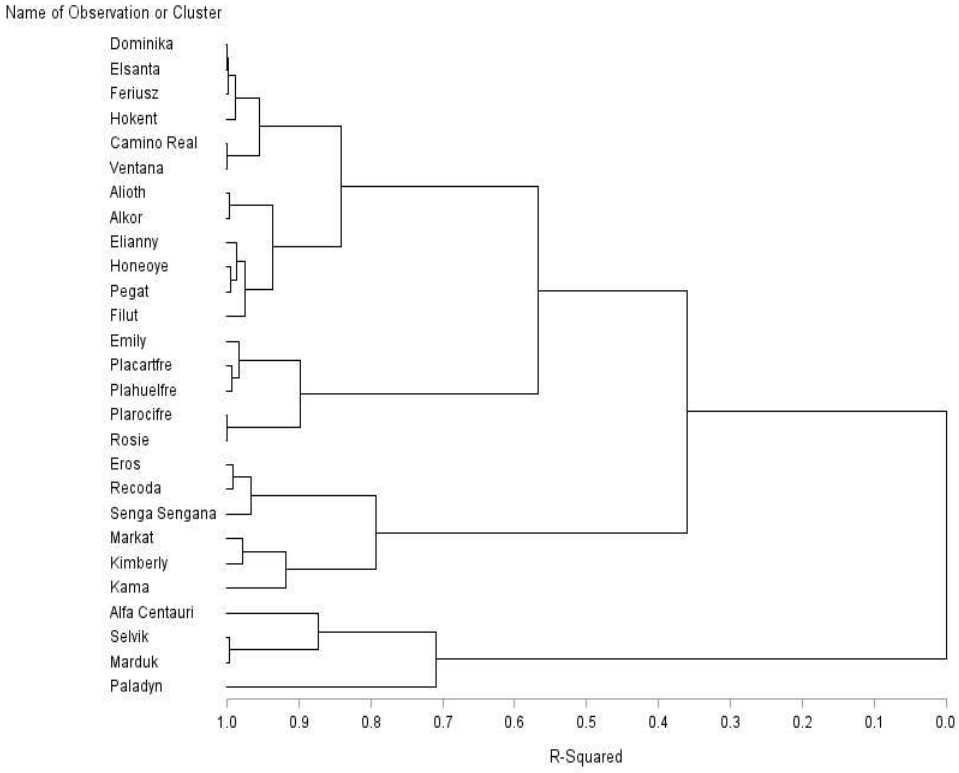

Fig. 3. Dendrogram of cultivars clusters regarding yield and berry weight for 27 strawberry cultivars grown in Skierniewice and harvested in 2004–2011

CONCLUSIONS

The experiment showed that there are many very interesting new cultivars which perform better than the commonly used cultivars in Poland. There are also many cultivars which origin is in more favorable weather conditions ('Placartfre', 'Plahuelfre' and 'Plarocifre') and they may perform not as well as in the country of origin. Many cultivars had low yield but can be very attractive for the appearance of their fruits for example 'Emily' and 'Alkor'. Cultivars with origin in Poland has very high resistance against very typical there adverse weather during flowering and ripening. The experiment showed that best performing are Polish cultivars 'Paladyn', 'Alfa Centauri', 'Selvik' and 'Marduk' and they might be the first choice to include in strawberry production in climatic conditions of Central Europe.

ACKNOWLEDGEMENT

This work was performed in the frame of multi-annual programme on preservation of gene bank resources financed by the Polish Ministry of Agriculture and Rural Development: Task 1.7.

REFERENCES

Ames, B.M., Shigena, M.K., Hagen, T.M. (1993). Oxidants, antioxidants, and the degenerative diseases of aging. P. Natl. Acad. Sci. USA, 90, 7915–7922.

CPVO (2012). The Community Plant Variety Office. Protocol for distinctness, uniformity and stability tests *Fragaria* L. Strawberry 2012.

Crossa, J., Burgueño, J., Cornelius, P.L., McLaren, G., Trethowan, R., Krishnamachari, A. (2006). Modeling genotype × environment interaction using additive genetic covariances of relatives for predicting breeding values of wheat genotypes. Crop Sci., 46, 1722–1733.

Emrich, K., Wilde, F., Miedaner, T., Piepho, H.P. (2008). REML approach for adjusting the Fusarium head blight rating to a phenological date in inoculated selection experiments of wheat. Theor. Appl. Genet., 117, 65–73.

Federer, W.T. (1956). Augmented (or hoonuiaku) designs. Hawai. Plant. Rec., 2, 191–208.

Federer, W.T., Reynolds, M., Crossa, J. (2001). Combining results from augmented designs over sites. Agron. J., 93, 389–395.

Gilmour, A.R., Gogel, B.J., Cullis, B.R., Thompson, R. (2009). ASReml User Guide Release 3.0. VSN International Ltd, Hemel Hempstead, UK.

GUS (2013). Central Statistical Office. Statistical yearbook of agriculture. Warsaw.

Harris, D.C., Yang, J.R. (1996). The relationship between the amount of *Verticillium dahliae* in soil and the incidence of strawberry wilt as a basis for disease risk prediction. Plant Pathol., 45, 106–114.

Heinonen, I.M., Meyer, A.S., Frankel, E.N. (1998). Antioxidant activity of berry phenolics on human low-density lipoprotein and liposome oxidation. J. Agr. Food. Chem., 46, 4107–4112.

Masny, A., Żurawicz, E. (2010). Productive value of new foreign strawberry cultivars evaluated in 2007–2010. J. Fruit Ornam. Plant Res., 18(2), 273–282.

Masny, A., Żurawicz, E., Pruski, K., Mądry, W. (2014). Combining Ability analysis in 10 strawberry genotypes used in breeding cultivars for tolerance to Verticillium Wilt. J. Am. Soc. Hortic. Sci., 139(3), 275–281.

Piepho, H.P. (2000). Multiple treatment comparisons in linear models when the standard error of a difference is not constant. Biometr. J., 42, 823–835.

Piepho, H.P. (2004). An algorithm for a letter-based representation of all-pairwise comparisons. J. Comp. Graph. Stat., 13, 456–466.

Piepho, H.P., Möhring, J. (2006). Selection in cultivar trials: Is it ignorable? Crop Sci., 46, 192–201.

Pluta, S., Mądry, W., Sieczko, L. (2012). Phenotypic diversity for agronomic traits in a collection of blackcurrant (*Ribes nigrum* L.) cultivars evaluated in Poland. Sci. Hort. Amsterdam, 145, 136–144.

Pluta, S., Żurawicz, E., Studnicki, M., Mądry, W. (2014). Combining ability analysis for selected plant traits in gooseberry J. Am. Soc. Hortic. Sci., 139(3), 325–335.

Roudeillac, P., Trajkowski, K. (2004). Breeding for fruit quality and nutrition in strawberries. Acta Hort., 649, 55–60.

Rozpara, E. (2008). Growth and field of eleven sweet cherry cultivars in Central Poland. Acta Hort., 795, 2571.

Smith, A.B., Cullis, B.R., Thompson, R. (2001). Analyzing variety by environment data using multiplicative mixed

models and adjustments for spatial field trend. Biometrics, 57, 1138–1147.

Smith, A.B., Cullis, B.R., Thompson, R. (2005). The analysis of crop cultivar breeding and evaluation trials: an overview of current mixed model approaches. J. Agr. Sci., 143, 1–14.

So, Y., Edwards, J. (2009). A comparison of mixed–model analyses of the Iowa Crop Performance Test for corn. Crop Sci., 49, 1593–1601.

StatSoft, Inc. (2011). STATISTICA data analysis software system, version 10.

Wilhelm, S. (1955). Longevity of the verticillium wilt fungus in the laboratory and field. Phytopathology, 45, 180–181.

Wójcik-Seliga, J., Wójcik-Gront, E. (2013). Evaluation of blackberry and hybrid berry cultivars new to Polish climate – short communication. Hortic. Sci. (Prague), 40, 88–91.

You, F.M., Duguid, S.D., Thambugala, D., Cloutier, S. (2013). Statistical analysis and field evaluation of the type 2 modified augmented design (MAD) in phenotyping of flax (*Linum usitatissimum*) germplasms in multiple environments. Aust. J. Crop Sci., 7, 1789–1800.

Żurawicz, E., Masny, A. (2002). New strawberry cultivars from the breeding project of Research Institute of Pomology and Floriculturae (RIPF) Skierniewice, Poland. Acta Hortic., 567, 179–181.