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[1] Experimental Station for Cultivar Assessment of Central Crop Research Centre
Uhnin, 21-211 Dębowa Kłoda, Poland
e-mail: P.Pszczolkowski.inspektor@coboru.pl
[2] Department of Plant Production Technology and Commodities, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland
[3] Institute of Agriculture and Food Sciences, Vytautas Magnus University Agriculture Academy, Studentu 11, Kaunas Akademija, LT, 53361, Lithuania

PIOTR PSZCZÓŁKOWSKI [1], BARBARA SAWICKA [2],
ELVYRA JARIENE [3], ANNA KIEŁTYKA-DADASIEWICZ [2]

Phenotypic yield and its structure variability of moderately late and late potato cultivars

Fenotypowa zmienność plonu i jego struktury średnio późnych i późnych odmian ziemniaka

Summary. The breeding of new potato cultivars of a given earliness group is closely related to the knowledge of the range of variability and interdependence of traits in a given year and between years. The research results were based on the field experience conducted in 2010–2012, in Central-Eastern Poland (51°34'N, 23°02'E), on lessive, slightly acidic soil. The experiment was carried out in a randomized block design in triplicate. Seventeen medium late and late potato cultivars were tested. Agronomic and plant protection treatments were carried out following the principles of good agricultural practice. The variability of potato economic characteristics was assessed through variance analysis, variance component analysis, cluster analysis, and principal component analysis (PCA). The years of research (52.5–94.6%) have played a dominant role in the phenotypic variability of general yield, commercial and seed yield, and their structure. The genetic factor was from 1.3 to 24.1%, and the interaction of the cultivar × years – from 3.1 to 61.7% of the variance share in the total variance. The analysis of the main components has identified four groups of cultivars with specific properties. They can be used in the decision-making system of breeding the new potato creations.

Keywords: cultivars, fertility, tuber fractions, number of shoots, trait fluctuation

INTRODUCTION

The size and stability of potato cultivars yielding is closely related to their genotype, phenological and morphological characteristics. The interaction between cultivars (G) and environment (E), referred to as G × E, is influenced by these values. It is necessary to conduct a wide system of cultivar experiments in different climatic and soil regions, taking into account the above interactions. Due to this procedure, cultivars can be more precisely selected for cultivation under different conditions [Cooper et al. 2006, Balzarini et al. 2011, Arvanitoyannis et al. 2012, Sawicka et al. 2015, Pszczółkowski and Sawicka 2017, Patel et al. 2018]. The choice of cropping regions for a given cultivar depends on the variance proportion of interaction effects: genotype × environment, and major genotypic effects. The environment chosen for testing cultivars, according to Pszczółkowski and Sawicka [2017], should be characterized by high soil and climate variability and the occurrence of biotic and abiotic stresses. Under conditions of climate change and the appearance of strong biotic and abiotic stresses, at a large diversity of climatic and soil environments, in which potato crops are grown, there is a modification of internal regulation processes, both within the plant and among plants in the field, related to the years and localizations [Rymuza et al. 2012, Sawicka et al. 2015, Bhandari et al. 2017, Rahajeng and Rahayuningsih 2017, Wang et al. 2019].

The basic carriers of biological progress are newly produced cultivars. Potato fertility is conditioned by many features resulting from a complex polygenic inheritance and the large impact of environmental factors [Kamiński 2015, Bhandari et al. 2017, Stefańczyk et al. 2017]. The tetrasomic inheritance of traits and low potato reproduction ratio make it very difficult to make rapid progress in improving this feature [Annicchiarico 2002, Flis et al. 2014, Kamiński 2015, Rahajeng and Rahayuningsih 2017, Patel et al. 2018].

In order to maintain the appropriate size and stability of the yield of a given cultivar or group of potato cultivars, it is necessary to integrate and harmonize research and breeding efforts to understand the range of variability and interdependence of features, both in a given year and between years. Therefore, the purpose of this study was to learn the structure of variability of selected quantitative traits of moderately late and late potato cultivars. This will allow in the future to facilitate the typing of cultivars with the highest stability of desirable traits in different climatic and soil regions.

MATERIAL AND METHODS

The field trials were conducted in 2010–2012 at the Experimental Station of Variety Assessment in Uhnin (51°34'N, 23°02'E, H = 155 m.a.s.l.), belonging to the Central Plant Variety Research Center. Field studies were carried out on lessive soils developed from light loamy sands on the complex of agricultural soil suitability – very good rye. The accumulation of humus in these soils is low due to the fast mineralization process [Marcinek i Komisarek 2011, WRB 2014]. The experiment was performed on a randomized, triplicate block. The object of the study consisted of 17 medium late and late potato cultivars, including 4 edible ones (‘Soplica’, ‘Syrena’, ‘Ursus’ and ‘Zeus’) and 13 starch ones (‘Bosman’, ‘Danuta’, ‘Hinga’, ‘Ikar’, ‘Inwestor’, ‘Jasia’, ‘Kuras’, ‘Meduza’, ‘Neptun’, ‘Pasja Pomorska’, ‘Pokusa’, ‘Rudawa’ and ‘Skawa’).

Field research

The organic and mineral fertilization under the potato was applied on uniform level (90 kg N, 39.3 kg P, 112.0 kg K·ha^{-1}), moreover, white mustard post-crop was plowed in autumn (20 t·ha^{-1}). Winter triticale was the potato forecrop. Tubers were planted in the third decade of April in ditches with spacing of 67.5 × 37 cm. The seed material consisted of tubers in the C/A class. The plot area for harvesting was 15 m^2 (60 plants in the harvesting plot). Agronomic treatments and plant protection against potato beetle as well as potato blight and alternaria were carried out in accordance with the principles of Good Agricultural Practice. In the vegetation period, 2–3 sprays against potato blight were made, while potato beetles were controlled at the time of occurrence applying available preparations. Plateen 41.5 WG herbicide was used to combat weed infestation – in a dose of 2.0 kg·ha^{-1} immediately after planting the tubers and carefully ridging. The potato blight was fought with the use of the following preparations: Infinito 687.5 SC in the dose of 1.6 dm^3·ha^{-1}; Ridomil Gold MZ 67.8 WG in the amount of 2.5 kg·ha^{-1} and Acrobat MZ 69 WG – 2 kg·ha^{-1}. The following preparations were used to control the Colorado potato beetle: Actara 25 WG at the dose of 0.08 kg·ha^{-1} and Proteus 110 OD at the amount of 0.4 dm^3·ha^{-1}. Potato tubers were harvested at physiological maturity (phase BBCH 97) [Bleinholder et al. 2005] at the end of September.

Collection and determination of soil samples and its physicochemical properties

Every year, before the experiment was established, 20 primary soil samples were collected, constituting one total sample, weighing approximately 0.5 kg [PN-R-04031:1997]. The samples collected in this way were determined: soil granulometry, pH in 1 mole of KCl·dm^{-3} and organic carbon content (C_{org}) – using the Tiurin method and the soil humus content in soil was determined [Mocek 2015]. Samples for testing the physicochemical properties of the soil were taken from 20 randomly selected places, from the arable layer (0–25 cm), after harvesting the crop. The content of available phosphorus, potassium and magnesium in soil samples [Mocek and Drzymała 2010].

Tuber sampling

Each year prior to harvest, tubers of ten plants selected at random from each plot were dug to determine the following: to determine the number and weight of tubers <40, 40–50, 50–60, >60 mm in diameter. During the harvest, representative samples of tubers were collected from each plot to assess the potato yielding. Total tuber yield consisted of the weight of tubers harvested from the whole plot area and the weight of previously taken samples, both converted to t ha^{-1} [Roztropowicz 1999]. Marketable yield included tubers with the diameter of over 40 mm without external and internal defects [Regulation of the Minister of Agriculture 2003]. The yield of fractions 40 to over 60 mm in diameter was considered the marketable yield, excluding mechanically damaged tubers and those damaged by pests and greenish. The yield of potato seedlings included tubers of 40–60 mm, excluding those damaged by pests and mechanically damaged to a high degree.

Meteorological conditions

Meteorological conditions in the years of research were varied. During the potato vegetation period, values of the hydrothermal Sielianinov coefficient were determined; which is a measure of the effectiveness of precipitation in a given month. Based on them, years 2010 and 2011 can be counted as wet, while 2012 as average (Tab. 1). The best distribution of precipitation was recorded in 2010, which was characterized by higher air temperatures than the long-term average. The year 2011 was characterized by an excess of precipitation in the first half of vegetation period, and in August and September drought or extreme drought, whereas 2012 was characterized by high air temperatures and droughts in May, July and September, with wet conditions in June and average in April and August (Tab. 1).

Table 1. Rainfall, air temperature and the hydrothermal coefficient of Sielianinov, during the growing season of potato, according to the meteorological station in Uhnin in 2010–2012

Year	Month	Monthly rainfall (mm)	Average monthly air temperature (°C)	Hydrothermal coefficient of Sielianinov*
2010	April	17.1	9.2	0.6
	May	93.0	14.9	2.0
	June	63.8	18.2	1.2
	July	63.1	21.9	0.9
	August	141.1	20.0	2.3
	September	77.3	12.2	2.1
	Total/Mean	455.4	16.1	1.5
2011	April	39.9	9.6	1.4
	May	46.2	14.0	1.1
	June	117.2	18.4	2.1
	July	169.7	18.7	2.9
	August	42.9	18.1	0.8
	September	8.9	14.3	0.2
	Total/Mean	424.8	15.5	1.4
2012	April	30	9.4	1.1
	May	38	15.0	0.8
	June	100.8	17.5	1.9
	July	53.1	21.8	0.8
	August	70.1	18.7	1.2
	September	34	14.3	0.8
	Total	326	16.1	1.1

* Coefficient was calculated according to the formula:

$$k = \frac{10P}{\sum t}$$ [Skowera et al. 2014]

where: P – the sum of the monthly precipitation in mm, Σ*t* – monthly total air temperature > 0°C
Ranges of values of this index were classified as follows: extremely dry – 0.0 ≤ k < 0.4; very dry – 0.7 ≤ k < 0.4; dry – 1.0 ≤ k < 0.7; rather dry – 1.3 ≤ k < 1.0; optimal − 1.6 ≤ k < 1.3; rather humid – 2.0 ≤ k < 1.6; wet − 2.5 ≤ k < 2.0; very humid − 3.0 ≤ k < 2.5; extremely humid − k < 3.0

Soil characterization before establishing the experiment

The results of soil granulometric analysis and some physicochemical properties of soil are presented in Table 2. The experiment was carried out on sandy loam soil type. According to percentage content of sand, silt and loam fraction, this is a granulometric subgroup – clay sand (medium soil). Soil granulometric composition was determined by means of the aerometric method by Prószyński [Ryzak et al. 2009]. The fraction of sand was 67.22%, the dust fraction was 30.33% and the loam was 2.45% (Tab. 2). This proportion of individual fractions corresponds to the composition of clayey dust. In terms of agricultural suitability, these soils belong to slightly acidic good rye complex. This soil is classified to agronomic category as light mineral [PTG 2008, Mocek 2015].

Table 2. The granulometric composition of soil; content of soil fractions in %

Year	Sand	Silt	Loam	Soil classification
	2.0–0.05 mm	0.05–0.002 mm	<0.002 mm	
2010	67.14	30.29	2.57	sandy loam
2011	67.04	30.24	2.72	sandy loam
2012	67.47	30.45	2.08	sandy loam
Average	67.22	30.33	2.46	–

Source: own experiment results, which made in the Chemical and Agricultural Station in Lublin

Table 3. The content of assimilable minerals in the studied soil (mg·kg^{-1} in dry mass of soil) and its pH (1M KCl) in 2010–2012

Years	P	K	Mg	pH
2010	94.2	97.1	43.0	5.7
2011	98.8	105.4	81.0	6.3
2012	73.8	110.4	74.0	6.1
Mean	88.9	104.6	66.0	6.0

Source: own experiment results, which made in the Chemical and Agricultural Station in Lublin

The content of assimilable components in soil was as follows: phosphorus high and very high (73.8–98.8 mg P·kg^{-1} soil), low and medium in potassium (97.1–110.4 mg K·kg^{-1} soil), magnesium low to high (43.0–81.0 mg Mg·kg^{-1} soil) (Tab. 3). The average acidity of the soil (pH), in a solution of KCl, in 2010 was 5.7 (pH), in 2011 – 6.3 (pH) and in 2012 – 6.1 (pH); these values allowed the classification of the experimental soil as slightly acidic soil. The humus content in the arable layer was low and formed at 0.94–1.06%. The accumulation of organic carbon in mineral soils is undoubtedly favored by periods of high and low activity of microorganisms. Because in moderate zone soils, humidity and temperature generally stimulate the annual activity of microorganisms, mineralization processes prevail over humification processes and, as a result, humus content is generally low (Tab. 3).

Statistical analyses

Statistical analysis of results was performed by means of two-factor analysis of variance (ANOVA) [SAS 9.2 2008]. Significance of variation sources was tested with Fisher-Snedecor "F" test. In order to determine the share of individual sources of variability and their interactions in total variability, variance components were evaluated using the following notation:

– σ^2_e assessment of environmental variability, associated with repetition of observation or measurement over time;

– σ^2_G assessment of genotypic variability (varietal);

– σ^2_P assessment of phenotypic variability (total).

The empirical values of the mean squares obtained from the analysis of variance were compared with their expected values. Solving the equation systems in this way yields an estimate of the variance components corresponding to the individual variation sources. Mutual relationships of the evaluated variance components and their percentage structure were the basis for assessing the effects of cultivars and years on crop yield variability and yield characteristics. In order to group similar cultivars, cluster analysis was performed. For analysis of multi-trait diversification of objects, analysis of main components (PCA) was applied [Arvanitoyannis et al. 2012]. The main components analysis and the UPGMA clustering analysis were based on Euclid's square distance. For several groups of cultivars, a multiple canonical discriminative analysis was carried out to identify the most discriminating features in differentiation of varietal groups [Rymuza 2015]. Variance analysis, main component analysis, cluster analysis and discriminant analysis were performed in the SAS® statistical package [SAS 9.2 2008].

RESULTS

Yield variability and its structure

Condition during the study period played predominant role in variability of the total yield, seedling tubers yield, participation of tubers with <40, 40–50 and 50–60 mm diameter, and marketable tubers and seedlings, which was from 52.5 to 94.6% of the variance share in the total variance (Tab. 4). Genetic properties of tested cultivars affected in 1.3–7.4% the phenotypic variability of tuber yield and its structure. Genetic traits exerted the largest impact on shoot number (24.1%). Interaction of cultivars with habitat conditions determined the phenotypic variability of studied potato traits from 3.1 to 65.4% in the total variance. The lowest dependence on the interaction of year × cultivar was shown by the share of marketable tubers and seed potatoes, which constituted only 3.1–3.6% of variance in total variance, and the highest – number of shoots per plant (65.4%) (Tab. 4).

Table 4. The influence of cultivars and years on the yield of tubers, its structure and their percentage of share in total variation

Trait	Significance of the influence			Percentage of variance share in the total variance (phenotypical one)		
	cultivars	years	cultivars × years	cultivars	years	cultivars × years
Number of shoots per plant	**	**	**	24.1	11.2	65.4
Tuber's yield ($t \cdot ha^{-1}$)	*	**	**	4.9	65.8	29.3
Tuber's weight of diameter < 40 mm (%)	*	**	**	5.6	52.5	41.8
Tuber's weight of diameter 40–50 mm (%)	*	**	**	6.7	54.3	38.9
Tuber's weight of diameter 50–60 mm (%)	*	**	**	7.4	57.1	35.2
Tuber's weight of diameter > 60 mm (%)	*	**	**	5.9	32.4	61.7
Share of comercial yield (%)	***	**	***	1.9	94.6	3.1
Comercial yield ($t \cdot ha^{-1}$)	*	**	**	5.6	55.8	38.3
Share of seed potato (%)	***	**	***	1.3	93.9	3.6
The yield of seed potato ($t \cdot ha^{-1}$)	*	**	**	4.8	37.1	58.1

* significant at $p_{0.05}$ ** significant at $p_{0.01}$ *** not significant at $p_{0.05}$

The number of shoots on the potato plant ranged from 4.3 to 8.1, depending on the cultivar. The late, high-starch 'Hinga' cv. produced their greatest number, while 'Jasia' cv. appeared to be homogenous in this respect. Cultivar with the lowest average shoot number was 'Soplica', whereas the following cultivars were homogeneous because of this feature: 'Syrena', 'Bosman', 'Danuta', 'Ikar', 'Inwestor', 'Kuras', 'Meduza', 'Neptun', 'Pasja Pomorska' and 'Skawa' (Tab. 5). Variability coefficient for the number of shoots was about 21%. The smallest variation in shoot formation was revealed by the 'Ursus', while the largest was 'Jasia' (Tab. 5). This feature has been the most dependent on the interaction of cultivars and vegetation conditions (65.4%), less than the genetic traits of cultivars (24.1%) and in the smallest – from the conditions during the study years (11.2%) (Tab. 4).

Of the cultivars tested, the highest yield of tubers was produced by edible, medium late 'Syrena' (52.3 $t \cdot ha^{-1}$), while cultivars: 'Inwestor', 'Ursus', 'Danuta', 'Pasja Pomorska' and 'Zeus' turned to be homogenous in this view. The most reproducible in yielding was the late, starchy 'Skawa' (V = 15.4%), while the most variable was moderately late edible 'Zeus' (V = 40.9%) (Tab. 5). The overall yield of tubers was most dependent on conditions during the study years (65.8%). The interaction of cultivars and years determined it in 29.3%, and the varietal traits the least affected the yields (4.9%) (Tab. 4).

Table 5. Number of shoots per plant and total yield of tubers and their coefficients of variation V (%) in 2010–2012

Group of earliness	Cultivars	Number of shoots per plant		Total tuber yield ($t \cdot ha^{-1}$)	
		Mean	V	Mean	V
Middle late	'Bosman'	5.9	29.3	42.2	25.2
	'Danuta'	5.4	19.5	44.2	24.3
	'Ikar'	5.4	20.4	37.5	23.6
	'Pasja Pomorska'	5.2	17.9	43.5	35.0
	'Syrena'	4.4	17.5	52.3	30.5
	'Zeus'	6.1	29.7	43.3	40.9
Late	'Hinga'	8.1	14.6	38.2	25.7
	'Inwestor'	4.5	23.8	45.3	20.8
	'Jasia'	7.8	30.6	37.9	30.2
	'Kuras'	5.6	15.6	38.2	22.4
	'Meduza'	5.5	20.1	38.2	27.1
	'Neptun'	5.4	23.7	35.5	34.6
	'Pokusa'	6.8	19.8	33.3	28.7
	'Rudawa'	6.3	25.1	37.6	31.3
	'Skawa'	5.3	14.5	31.4	15.4
	'Soplica'	4.3	21.8	36.4	32.0
	'Ursus'	6.6	12.0	44.4	25.5
Mean		5.8	20.9	40.0	27.8
$HSD_{0.05}$		1.7	–	12.0	–

V – coefficient of variation (%)

The tubers weight structure in the total yield was significantly different across all studied fractions (Tab. 6). The highest share in yields was shown by tubers with a diameter of 40–50 mm (64.8%), while the smallest – tubers with a size > 60 mm (2.2%). 'Skawa' and 'Jasia' produced the largest weight of small tubers with diameter of < 40 mm, and at the same time, they were characterized by the smallest weight of tubers in the crop, with size > 60 mm. 'Inwestor' produced the lowest weight of fine tubers, while the highest – largest tubers in the yield. At the same time, this cultivar proved to be the least variable in formation of tubers with a diameter of 50–60 mm. The most variable in the tuber production of this fraction were 'Neptun' and 'Pokusa'. Cultivars tested were characterized by the highest variability in the largest tubers production (V = 141%) (Tab. 6).

Table 6. The percentage of share in the yield of tubers mass with diameter < 40, 40–50, 50–60 > 60 mm and variability coefficients V (%) in 2010–2012

Group of earliness	Cultivars	Diameter of tubers (mm)							
		<40		40–50		50–60		>60	
		Mean	V	Mean	V	Mean	V	Mean	V
Middle late	'Bosman'	7.4	47.3	64.3	12.9	25.9	41.4	2.4	92.6
	'Danuta'	7.0	37.6	58.4	16.4	32.4	29.5	2.2	116.3
	'Ikar'	7.1	38.9	65.1	3.6	25.5	40.2	2.2	81.8
	'Pasja Pomorska'	6.0	31.0	64.3	12.6	27.3	28.4	2.4	78.6
	'Syrena'	5.8	61.7	48.1	20.5	39.8	27.9	5.7	100.9
	'Zeus'	5.5	53.8	71.6	5.4	22.1	26.0	0.7	128.4
Late	'Hinga'	8.7	32.8	78.6	5.6	12.6	46.0	0.1	300.0
	'Inwestor'	3.3	24.2	48.6	13.0	40.7	7.9	6.7	76.9
	'Jasia'	10.1	18.0	74.5	15.5	15.3	32.4	0.1	300.0
	'Kuras'	5.8	19.0	60.1	13.4	31.4	20.4	2.3	100.7
	'Meduza'	6.2	12.5	47.4	20.1	42.2	19.5	3.8	68.3
	'Neptun'	6.0	18.9	76.8	10.5	16.7	54.1	0.4	158.5
	'Pokusa'	7.9	59.0	75.5	6.4	16.4	53.6	0.2	172.0
	'Rudawa'	7.5	47.1	60.7	14.5	28.0	37.8	3.8	107.5
	'Skawa'	12.7	16.0	76.2	5.1	11.1	27.3	0.1	300.0
	'Soplica'	7.5	64.7	62.2	10.3	28.2	30.9	2.2	114.5
	'Ursus'	4.6	23.1	68.6	12.0	24.9	28.0	1.9	94.2
Mean		7.0	35.6	64.8	11.6	25.9	32.4	2.2	140.7
$HSD_{0.05}$		2.1	–	19.5	–	7.8	–	0.7	–

V – coefficient of variation (%)

The tubers yield was highly variable. This was due to the different course of meteorological conditions, and in particular the uneven distribution of precipitation in May–August deciding on the number and size of tubers of particular fractions. Dominant role in the variability of tubers with diameter < 40, 40–50 and 50–60 mm was played by the habitat conditions during the years of research (52.5–57.1%). Interaction of cultivars and years determined the size of tubers to a much lesser extent (35.2–41.8%). The interaction of cultivars × years mostly determined the phenotypic variation of tubers with a diameter of > 60 mm (61.7%), while the habitat conditions in the study years made up 32.4% of the variance share in the total variance. Genetic properties of the cultivars tested determined only in 5.6–7.4% of phenotypic variability of tuber yield structure (Tab. 4).

The share of marketable tubers in the total yield was high (93% on average), but not significantly related to the genetic traits of the cultivars tested. This feature was only slightly variable (V = 2.7%) (Tab. 7). On the other hand, 94.6% of the variance in total variance was remarkably influenced by the study years. The marketable tuber yields were also most dependent on habitat conditions during the study years (55.8%), while the interactions of cultivars × years determined in 38.3 and 5.6% the phenotypic variation of the trait (Tab. 4).

Table 7. Share and tuber yield of commercial and seed potato and their coefficients of variation V (%) in 2010–2012

Group of earliness	Cultivar	The share of commer-cial tubers (%)		Commercial yield of tubers (t·ha⁻¹)		Participation seed (%)		Yield of seed potato (t·ha⁻¹)	
		mean	V	mean	V	mean	V	mean	V
Middle late	‘Bosman’	92.6	3.8	39.4	28.7	90.1	3.3	38.1	27.1
	‘Danuta’	93.0	2.8	41.2	25.0	90.8	0.9	40.2	24.6
	‘Ikar’	92.9	4.4	34.8	26.7	90.7	4.4	33.9	26.6
	‘Pasja Pomorska’	94.0	2.0	40.9	35.1	91.6	1.5	39.7	34.1
	‘Syrena’	94.2	3.9	49.6	31.8	87.9	0.7	46.0	30.6
	‘Zeus’	94.5	3.2	41.2	42.6	93.8	2.7	40.9	42.9
Late	‘Hinga’	91.3	3.2	35.0	27.5	91.2	3.4	35.0	27.5
	‘Inwestor’	96.7	0.8	43.8	20.6	89.3	4.8	40.1	17.4
	‘Jasia’	89.9	1.4	34.3	30.1	89.8	2.6	34.3	25.0
	‘Kuras’	94.2	1.2	36.1	23.3	91.5	2.1	34.9	21.5
	‘Meduza’	93.8	0.8	35.9	27.7	89.5	1.7	34.1	25.8
	‘Neptun’	94.0	1.2	33.5	35.1	93.6	1.4	33.3	34.6
	‘Pokusa’	92.1	5.0	31.0	32.3	91.9	4.9	30.9	32.0
	‘Rudawa’	92.5	3.9	35.2	33.6	88.7	1.9	33.5	32.3
	‘Skawa’	87.3	2.3	27.5	17.4	87.2	2.5	27.5	17.5
	‘Soplica’	92.5	5.2	34.1	35.2	90.4	4.2	33.1	33.3
	‘Ursus’	95.4	1.1	42.4	25.4	93.5	2.2	41.4	23.9
Mean		93.0	2.7	37.4	29.3	90.7	2.7	36.3	28.0
$HSD_{0.05}$		ns	–	11.2	–	ns	–	10.9	–

V – coefficient of variation (%); ns – non significante differences at $p_{0.05}$

The highest marketable yield of tubers and the yield of seed potatoes was produced by middle late edible ‘Syrena’, whereas the lowest yielding by late starchy ‘Skawa’. This cultivar proved to be the least variable in crop yield (V = 17.4%). The highest variability in the yield of tubers and yield of seed potatoes was shown by moderately late edible ‘Zeus’ (about V = 43%) (Tab. 7).

Percentage of potato seed tubers in the crop was high (90.7%). Varietal traits did not differentiate the seed fraction, which resulted from its low variability coefficient (V = 2.7%). This proves the high stability of that trait (Tab. 7).

The largest influence on the weight of seed tubers was exerted by conditions during the study period (93.9%), while on seed tubers yield – interaction: cultivar × years (58.1%). Much lower share of variance in the total variance for this trait was shown by conditions in the test years (37.1%), while the lowest – cultivars (4.8%) (Tab. 4).

Difference between the maximum and the minimum value of the trait is the scope of the data and is a measure of empirical area of variation of a given feature, but it did not give any information about different values of that trait in the set. This information is shown by the coefficient of variation that informs about the stability of a given feature. Value of this parameter ranged from a very low – for the percentage of seed potatoes weight – to a high – for the weight of tubers > 60 mm diameter (Tab. 8).

Table 8. Descriptive statistics for the number of shoots and the yield and its structure of middle late cultivars

Specification	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
Mean	5.8	40.0	7.0	64.8	25.9	2.2	93.0	37.4	90.7	36.3
Minimum	2.0	18.0	1.6	36.8	4.1	0.0	84.7	16.4	81.3	16.4
Maksimum	11.0	76.7	15.3	86.5	50.8	14.9	98.4	71.6	96.8	69.6
Coefficient of variation (%)	27.1	30.1	48.8	18.8	45.9	136.4	3.7	31.9	3.5	30.3

x_1 – the number of shoots, x_2 – yield of tubers ($t \cdot ha^{-1}$), x_3 – share of tuber mass of diameter < 40 mm (%), x_4 – share of tuber mass of diameter 40–50 mm (%), x_5 – share of tuber mass of diameter 50–60 mm (%), x_6 – share of tuber mass of diameter > 60 mm (%), x_7 – share of commercial tubers (%), x_8 – commercial yield of tubers ($t \cdot ha^{-1}$), x_9 – share od seed potatoes (%), x_{10} – yield of seed potatoes ($t \cdot ha^{-1}$)

Pearson correlation coefficients show that the number of shoots is positively correlated with the weight of tubers of 40–50 mm in diameter and negatively with the weight of tubers 50–60 mm in diameter. The share of tubers with a diameter of < 40 mm was significant, negatively related to general yield, marketable and seed potato yield, as well as marketable tuber weight and seed weight. In turn, the overall yield of tubers was positively correlated with the marketable yield and seed yield and the marketable tuber weight. The marketable yield of tubers was positively correlated with the yield of seed potatoes (Tab. 9).

Analysis of the main components indicated that in the first separated arrangement, following cultivars were grouped: ‘Danuta’, ‘Bosman’, ‘Ursus’, ‘Soplica’, ‘Kuras’. These cultivars were characterized by rather high number of shoots, average yield and average share of particular fractions of tubers in yield. The second arrangement contained ‘Pasja’, ‘Syrena’, ‘Zeus’, with average shoots number, largest overall, marketable and seed yields, resulting from high participation of the largest tubers in the crop, 50–60 and > 60 mm in diameter (Tab. 10). The third group included seven cultivars (‘Pokusa’, ‘Neptun’, ‘Rudawa’, ‘Ikar’, ‘Hinga’, ‘Skawa’, ‘Jasia’), with the largest number of shoots, yet the largest share of the largest tubers in yield (>60 and 50–60 mm), and at the same time, with the highest percentage of the finest and medium tubers (40–50 and <40 mm in diameter) in the crop. Such arrangement of individual fractions of tubers caused that group of cultivars to have the lowest overall, marketable and seed potatoes yields. In the fourth focus, two cultivars were grouped (‘Inwestor’ and ‘Meduza’), with the smallest number of shoots, the highest share of largest tubers, with a size > 60 and 50–60 mm in diameter, and the smallest participation of small and medium tubers (<40 and 40–50 mm) in yield. Cultivars of this group were characterized by high overall yield of tubers, the highest share of marketable tubers and the lowest share of seed potatoes (Tab. 10, Fig. 1).

Table 9. The coefficients of linear correlation Pearson for medium late and late potato cultivars

Variables	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
x_1	1.00									
x_2	–0.07	1.00								
x_3	0.28*	–0.57**	1.00							
x_4	0.39*	–0.15	0.28*	1.00						
x_5	–0.37*	0.16	–0.31*	–0.97**	1.00					
x_6	–0.19	0.10	–0.17	–0.75**	0.69**	1.00				
x_7	–0.28*	0.57**	–0.99**	–0.28	0.31*	0.17	1.00			
x_8	–0.10	0.99**	–0.63**	–0.17	0.18	0.11	0.63**	1.00		
x_9	–0.08	0.12	–0.60**	0.19	–0.12	–0.15	0.60**	0.16	1.00	
x_{10}	–0.09	0.99**	–0.62**	–0.12	0.14	0.07	0.62**	0.99**	0.22*	1.00

* significant at $p_{0.05}$ **significant at $p_{0.01}$

x_1 – the number of shoots, x_2 – yield of tubers ($t \cdot ha^{-1}$), x_3 – share of tuber mass of diameter < 40 mm (%), x_4 – share of tuber mass of diameter 40–50 mm (%), x_5 – share of tuber mass of diameter 50–60 mm (%), x_6 – share of tuber mass of diameter > 60 mm (%), x_7 – share of commercial tubers (%), x_8 – commercial yield of tubers ($t \cdot ha^{-1}$), x_9 – share od seed potatoes (%), x_{10} – yield of seed potatoes ($t \cdot ha^{-1}$)

Table 10. Mean values of the analyzed features for 4 groups of medium late and late potato cultivars determined on the basis of cluster analysis

Feature	Group			
	1	2	3	4
x_5 – the number of shoots	5.6	5.2	6.4	5.0
x_6 – yield of tubers ($t \cdot ha^{-1}$)	41.1	46.4	35.9	41.8
x_4 – share of tuber mass of diameter < 40 mm (%)	6.5	5.8	8.6	4.8
x_3 – share of tuber mass of diameter 40–50 mm (%)	62.7	61.3	72.5	48.0
x_2 – share of tuber mass of diameter 50–60 mm (%)	28.6	29.7	17.9	41.5
x_1 – share of tuber mass of diameter > 60 mm (%)	2.2	2.9	1.0	5.3
x_7 – share of commercial tubers (%)	93.5	94.2	91.4	95.3
x_8 – commercial yield of tubers ($t \cdot ha^{-1}$)	38.6	43.9	33.0	39.9
x_9 – share of seed potatoes (%)	91.3	91.1	90.4	89.4
x_{10} – yield of seed potatoes ($t \cdot ha^{-1}$)	37.5	42.2	32.6	37.1

DISCUSSION

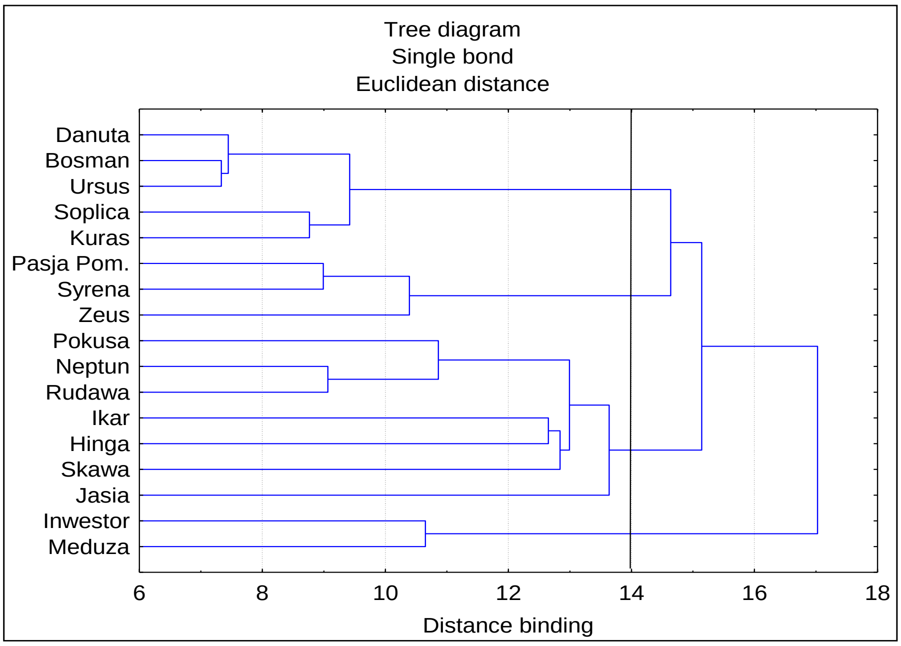

Fig. 1. Dendrogram illustrating taxonomic distances between the cultivars of potato

The vegetative propagation of potato causes that most of the analyzed features important in potato production are subject to high phenotypic variability and are largely dependent on fluctuations in environmental, weather and genotype factors [Das et al. 2010, Balzarini et al. 2011, Sawicka et al. 2015, Fu Yong Bi 2015, Bhandari et al. 2017]. In opinion of Das et al. [2010], Kamiński [2015], Bhandari et al. [2017], Petel et al. [2018] most of the potato traits are genetically determined. In the studies conducted, the genetic factor most strongly determined the number of shoots per plant (in 24.1%). Other features of moderately late and late potato cultivars were only slightly dependent on genetic characteristics (G) and their share in the total variance ranged from 1.3% for seed potato weight to 7.4% for participation of tubers of 50–60 mm diameter. The tuber yield depended only in 4.9% on the genotype, and the environmental conditions (E) and interaction of E × G were most affected. These results were confirmed by Balzarini et al. [2011], Ahmad et al. [2014], and Kamiński [2015]. Understanding genetic variability and its contribution to phenotypic variability is important not only for choosing the best parents for breeding, but also for developing proper crossbreeding plans and selection strategies. In the opinion of Patel et al. [2018] the height of the heritability index of potato cultivars increases with high genetic progress in the assimilation surface of leaves, the number of stems per plant, the number of tubers per plant, the processing capacity of tubers per plant, the color index of the flesh, the content of the sum of sugars and reducing sugars, and the total content of dry mass of tubers, harvested 90 and 105 days after planting (DAP). These authors recommend that genotype difference for giving reasons for high additivity genetic selection should be based on phenotypic efficiency. According to Flis et al. [2014], Kamiński [2015], Bhandari et al. [2017], Rahajeng and Rahayuningsih [2017], creating new, fertile, disease-resistant and qualitative potato cultivars is an increasingly difficult task as breeders are unable to meet the increasing demands due to ever-increasing populations of diseases and pests. The importance of genetic diversity is more and more important in the context of climate change and related events; hence it can serve as a set of many new features that tolerate various biotic and abiotic stresses. Diverse lines are needed to correct defects of marketable cultivars and create new ones. In this context, knowledge of all aspects of genetic variation, factors affecting the genetic diversity, methods of diversity analysis, their measurement and programs required for statistical analysis become an imperative for the development of breeding. According to Bhandari et al. [2017], hereditary (genetic) variability can be expressed in the form of altered morphology, anatomy, biochemical traits or physiological behavior (response to drought, excess water, etc.). Variability of genomes can be defined as diversity in several gene loci within the individual, thus deserving attention of farmers as much as possible.

Due to very wide range of geographical and ecological diversity, late potato cultivars often show strong resistance to *Phytophthora infestans*, which early cultivars lack [Carputo et al. 2013, Flis et al. 2014, Bhandari et al. 2017]. According to Carputo et al. [2013] and Stefańczyk et al. [2017], these traits are owed to wild species that also provide the allelic diversity to guarantee a high level of polygenic features heterosis.

Analysis of variance components indicates the contribution of the environment (E) and the interaction of genotype × environment (G×E) in all studied characteristics. They showed, with the exception of shoot number, a high share of the environment in phenotypic variance (total) and explained in 32.4% to 94.6% the total phenotypic variability and in 65.8% the tuber yield variability. According to Sawicka et al. [2015, 2016], variability of the soil and atmospheric environment significantly modifies macro- and microelement levels in potato tubers by shaping the chlorophyll fluorescence indices. Pszczółkowski and Sawicka [2017] proved the impact of environmental factors on tuber yield of moderately early cultivars and their structure. Differentiation of the environment, in which plants grow, in their opinion, modifies internal regulation processes, both within a bush and in a plant. Thus, there may be variations within the plant, shoots, and crop associated with years and locations. Rahajeng and Rahayuningsih [2017] identified four main components that explained 79.0% of the total tuber yield variability. The characteristics that contributed the most to their variability were: the chlorophyll index, shoot weight and length. Lower share in total variance was revealed by G × E interaction, which for the total yield was 29.3%, and for the seed potato yield 58.1% of the phenotypic variation. Research on genetic-environmental variability is of particular importance in the process of the regionalization of new cultivars. The choice of cropping regions for a given cultivar depends on the variance proportion of the interaction effects: genotype (G) × environment (E) to variance of major genotypic effects. According to Annicchiarico et al. [2011], if variance of the main genotypic effects is predominant, the cultivar is considered broadly adapted to the growing conditions; in the opposite case, a narrow adaptive capacity is referred to.

Applying the multivariate analysis of variance allowed for calculating for each variable the variability coefficient, which is the quotient of the absolute measure of a feature variability, and as a non-dimensional value, it allows to compare the differentiation of both several communities in terms of the same characteristic and the same population in terms of several features [Gauch et al. 2008, SAS 9.2 2008]. For tuber yield and stem number, the average value of this coefficient was respectively 30.1 and 27.1%. The tuber yield was unstable, because variability coefficients ranged from 18.8% for tuber fractions 40–50 mm to 136.4% for the largest tubers share. Among the cultivars tested, the most stable in the total yield turned out to be the starchy ‘Skawa’, while the most variable – edible ‘Zeus’. Variability of tuber yield and its structure traits was also indicated by research of Flis et al. [2014], Rymuza [2015], Pszczółkowski and Sawicka [2017] as well as Rahajeng and Rahayuningsih [2017].

Among investigated features of medium late and late potato cultivars, the number of shoots in plant proved to be the strongest positively correlated with the weight of tubers of 40–50 mm diameter, and the most strongly, yet negatively – with the weight of large tubers with a diameter of 50–60 mm. This is confirmed by the results of Rymuza [2015] and Pszczółkowski and Sawicka [2017]. The share of small tubers weight of < 40 mm was significant and negatively correlated to the weight share of marketable tubers and the weight of seed potatoes and their yield. In turn, the total yield of tubers was positively correlated with the marketable yield and seed potato yield as well as marketable tubers weight share.

Cluster analysis allowed to aggregate cultivars in similar clusters. On the basis of this, four groups of potato cultivars were distinguished, differing in: the number of shoots per plant, the total yield, the weight of tubers with diameter < 40, 40–50, 50–60, and > 60 mm, the marketable tubers share and their yield, participation and yield of seed potatoes. The highest yields were recorded for cultivars producing 5.8 stems, the lowest – for those with the highest number of shoots (8.6) per unit area. In turn, the group of cultivars with the smallest number of stems (4.8) was characterized by the largest share of large and very large tubers in the crop, and the lowest participation of small and medium tubers. Based on the Mahanalobis distance, it was demonstrated that group 4 was the most distant (differentiated) from the remaining clusters. The use of this method for grouping the cultivars was confirmed by the results obtained by Ahmad et al. [2014], Rymuza et al. [2012, 2013], Rymuza [2015], Rahajeng and Rahayuningsih [2017], Pszczółkowski and Sawicka [2017]. In previous studies, Solankey et al. [2015], when analyzing the division of twenty genotypes into two major groups, indicated a genetic link between the clusters. In other studies, the cluster analysis of 116 genotypes led to the division of cultivars into 12 clusters [Mohammed et al. 2015].

Growing the new potato cultivars is a very complex, long-lasting process and is based on the research results of many scientific disciplines, therefore these methods can help in the future to accurately measure the utility traits and compare new cultivars not only for potatoes but also for other crops. Analysis of the main components based on the high statistical similarity of the division of seventeen medium-late and late potato cultivars into four clusters indicates that, among others, ‘Meduza’ and ‘Inwestor’ can be used as a source of genes in starch potato cultivars and improved to ensure the high yields.

CONCLUSIONS

The genetic factor of the tested moderately late and late cultivars was most strongly influenced on the number of shoots per plant, while environmental factors determined the general and marketable yield of tubers, the weight of tubers share of diameter < 40 mm, 40–50, and 50–60 mm, and the share of marketable tubers and seed potatoes.

The genotype × environment interaction most significantly determined the number of shoots per plant, the weight of tubers with diameter > 60 mm, and the yield of seed potatoes.

The highest stability of the traits was observed for the share of the weight of seed potatoes and marketable tubers, while the smallest – proportion of the largest tubers in the yield.

Increasing or decreasing the plant density of potato per unit area allows modeling the yield of individual tuber fractions.

The division of varieties into groups with specific properties obtained in the experiment can be used to create new variety creations and facilitate the selection of varieties for cultivation in specific climate and soil regions.

REFERENCES

Ahmad H.M., Awan S.I., Aziz O., Ali M.A., 2014., Multivariative analysis of some metric traits in bread wheat (*Triticum aestivum* L.). Eur. J. Biotechnol. Biosci. 1(4), 22–26.

Annicchiarico P., 2002. Genotype-environment interactions: challenges and opportunities for plant breeding and cultivar recommendations. FAO Plant Production and Protection Paper No. 174. Food and Agriculture Organization, Rome.

Annicchiarico P., Pecetti L., Abdelguerfi A., Bouizgaren A., Carroni A.M., Hayek T., Bouzina M.H., Mezni M., 2011. Adaptation of landrace and variety germplasm and selection strategies for lucerne in the Mediterranean basin. Field Crops Res. 120, 283–291.

Arvanitoyannis I.S., Mavromatis A.G., Vaitsi O., Korkovelos A., Golia E., 2012. Effect of genotype and geographical origin on potato properties (physical and sensory) for authenticity purposes. J. Agric. Sci. 4(4), 63–74.

Balzarini M., Teich I., Bruno C., Peña A., 2011. Making genetic biodiversity measurable: A review of statistical multivariate methods to study variability at gene level. Rev. Fac. Cienc. Agrar. 43(1), 261–275.

Bhandari H.R., Bhanu A.N., Srivastava K., Singh M.N., Shreya I., 2017. Assessment of Genetic Diversity in Crop Plants – An Overview. Adv. Plants. Agric. Res. 7(3), 00255. https://doi.org/10.15406/apar.2017.07.00255

Bleinholder H., Buhr L., Feller C., Hack H., Hess M., Klose R., Meier U., Stauss R., van den Boom T., Weber E., Lancashire P.D., Munger P., 2005. Compendium of growth stage identification keys for mono- and dicotyledonous plants. Poznań, Poland, 152 pp.

Carputo D., Alioto D., Aversano1 R., Garramone R., Miraglia V., Villano1i C., Frusciante L., 2013. Genetic diversity among potato species as revealed by phenotypic resistances and SSR markers. Plant Genet. Resour. 11(2), 131–139. https://doi.org/10.1017/S1479262112000500

Cooper J.M., Schmidt C.S., Wilkinson A., Lueck L., Hall C.M., Schotton P.N., Leifert C., 2006. Effect of organic, low – input and conventional production systems on disease incidence and severity in winter wheat. Asp. Appl. Biol. 80, 121–126.

Das A.B., Mohanty I.C., Mahapatra D., Mohanty S., Ray A., 2010. Genetic variation of Indian potato (*Solanum tuberosum* L.) genotypes using chromosomal and RAPD markers. Crop Breed. Appl. Biotechnol 10(3), 238–246.

Flis B., Domański L., Zimnoch-Guzowska E., Polar Z., Pousa S.A., Pawlak A., 2014. Stability Analysis of Agronomic Traits in Potato Cultivars of Different Origin. Am. J. Potato Res. 91(4), 404–413.

Fu Yong Bi., 2015. Understanding crop genetic diversity under modern Plant Breeding. Theor. Appl. Genet. 128(11), 2131–2142.

Gauch H.G., Piepho H.P., Annicchiarico P., 2008. Statistical analysis of yield trials by AMMI and GGE: Further considerations. Crop Sci. 48, 866–889.

Kamiński P., 2015. Ocena stabilności plonu i właściwości kulinarnych bulw ziemniaka na *Phytophthora infestans* [Comparative assessment and culinary properties of potato tubers resistant to *Phytophthora infestans*]. Doctoral dissertation. IHAR-PIB, Radzików, pp. 194.

Marcinek J., Komisarek J., 2011. Systematyka gleb Polski. Rocz. Glebozn. 62(3), 1–193. Wyd. „Wieś Jutra", Warszawa.

Mocek A., Drzymała S., 2010. Geneza, analiza i klasyfikacja gleb. Wyd. UP, Poznań, pp. 418.

Mocek A., 2015. Soil science. State Scientific Publisher, Warsaw, pp. 571

Mohammed W., Ali S., Shimelis B., Burga S., 2015. Genetic diversity of local and introduced sweet potato (*Ipomoea batatas* (L.) Lam.) collections for agromorphology and physicochemical attributes in Ethiopia. Sci. Technol. Arts Res. J. 4(1), 9–19.

Patel A.B., Patel R.N., Gami R.A., Patel J.A., Patel P.C., 2018. Genetic Variability Among the Potato (*Solanum tuberosum* L.) Genotypes as Affected by Harvesting Period for Processing Purpose and Tuber Yield. Curr. Agric. Res. J. 6(3), 372–377.

PN-R-0403:1997. Analiza chemiczno-rolnicza gleby. Pobieranie próbek.

PTG, 2008. Klasyfikacja uziarnienia gleb i utworów mineralnych. Polskie Towarzystwo Gleboznawcze, pp. 10.

Pszczółkowski P., Sawicka B., 2017. Phenotypic variability of the yield and its structure of mid-early potato cultivars. Acta Sci. Pol. Agricultura 16(3),147–161.

Rahajeng W., Rahayuningsih S.A., 2017. Diversity of sixty-two sweet potato accessions. Biodiversitas 18(1), 95–100.

Regulation of the Minister of Agriculture and Rural Development 29, (2003) on Detailed Requirements for Commercial Quality of Potatoes; Dz.U. 2003, No 194, item 1900; ISAP – Internet System of Legal Acts, Warsaw, Poland, 2003, pp. 13086–13088. http://prawo.sejm.gov.pl/isap.nsf/Doc

Roztropowicz S., 1999. Methodology of Observation, Measurements and Sampling in Agricultural Experiments with Potatoes; Plant Breeding and Acclimatization Institute: Section Jadwisin, Poland, 1999; pp. 1–50. (In Polish).

Rymuza K., Turska E., Wielogorska G., Bombik A., 2012. Use of principal component analysis for the assessment of spring wheat characteristics. Acta Sci. Pol. Agricultura, 11(1), 79–90.

Rymuza K., Zarzecka K., Gugała M., 2013. Przydatność wielowymiarowej analizy porównawczej do oceny jakościowej bulw ziemniaka [Suitability of multidimensional comparative analysis for tuber quality assessment of potatoes]. Fragm. Agron., 30(2),134–142.

Rymuza K., 2015. Multi-trait evaluation of value for cultivation and use of early maturing edible potato cultivars registered in Poland. J. Ecol. Eng. 16(1), 50–56. https://doi.org/10.12911/22998993/586

Ryzak M., Bartminski P., Bieganowski A., 2009. Metody wyznaczania rozkładu granulometrycznego gleb mineralnych [Methods of determination of granulometric distribution of mineral soils]. Acta Agrophys., Rozpr. Monogr. 175(4), pp. 84.

SAS Institute Inc., 2008. SAS/STAT®9.2 User's Guide. Cary, NC, SAS Institute Inc.

Sawicka B., Michałek W., Pszczółkowski P., 2015. Dependence of chemical composition of potato (*Solanum tuberosum* L.) tubers on physiological indicators. Zemdirbyste-Agriculture 102(1), 41–50.

Sawicka B., Noaema A.H., Seead Hameed T., Skiba D., 2016. Genotype and environmental variability of chemical elements in potato tubers. Acta Sci. Pol. Agricultura 15(3), 79–91.

Skowera B., Kopcińska J., Kopeć B., 2014. Changes in thermal and precipitation conditions in Poland in 1971–2010. Ann. Warsaw Univ. Life Sci. SGGW, Land Reclam., 46(2), 153–162.

Solankey S.S., Singh P.K., Singh R.K., 2015. Genetic diversity and interrelationship of qualitative and quantitative traits in sweet potato. Intl. J. Veget. Sci. 21(3), 236–248.

Stefańczyk E., Sobkowiak S., Brylińska M., Śliwka J., 2017. Expression of the potato late blight resistance gene *Rpi-phu1* and *Phytophthora infestans* effectors in the compatible and incompatible interactions in potato. Phytopathology 107, 740–748.

Wang Y., Rashid M.A., Li X., Yao Ch., Lu L., Bai J., Li Y., Xu N., Yang Q., Zhang L., Bryan G.J., Sui Q., Zhechao P., 2019. Collecting and assessing the genetic diversity and population structure of sites and potato varieties in China. Plant Sci. 21. https://doi.org/10.3389/fpls.2019.00139

WRB, 2014. World reference database for soil resources. http://www.fao.org/3/a-i3794e.pdf

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Streszczenie. Hodowla nowych odmian ziemniaka określonej grupy wczesności jest ściśle związana z poznaniem zakresu zmienności i współzależności cech, tak w danym roku, jak i pomiędzy latami. Wyniki badań oparto na doświadczeniu polowym przeprowadzonym w latach 2010–2012, w środkowo-wschodniej Polsce (51°34’N, 23°02’E), na glebie płowej, lekko kwaśnej. Eksperyment wykonano metodą bloków zrandomizowanych, w trzech powtórzeniach. Badano 17 średnio późnych i późnych odmian ziemniaka. Zabiegi agrotechniczne i związane z ochroną roślin prowadzono zgodnie z zasadami dobrej praktyki rolniczej. Oceniano zmienność cech gospodarczych ziemniaka z zastosowaniem analizy wariancji, oceny komponentów wariancyjnych, analizy skupień oraz analizy składowych głównych (PCA). Dominującą rolę w zmienności fenotypowej plonu ogólnego, handlowego i sadzeniaków oraz ich struktury odgrywały lata badań (52,5–94,6%). Czynnik genetyczny stanowił od 1,3 do 24,1%, zaś interakcja: odmiany × lata − od 3,1 do 61,7% udziału wariancji w wariancji całkowitej. W wyniku analizy składowych głównych wyodrębniono cztery grupy odmian, o specyficznych właściwościach. Uzyskane wyniki badań mogą posłużyć w systemie decyzyjnym hodowli nowych odmian ziemniaka.

Słowa kluczowe: odmiany, plenność, frakcje bulw, liczba pędów, fluktuacja cech

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