DOI: 10.37317/biul-2016-0015

KRYSTYNA RYKACZEWSKA
Instytut Hodowli i Aklimatyzacji Roślin — Państwowy Instytut Badawczy
Oddział w Jadwisinie, Zakład Agronomii Ziemniaka

Response of chosen potato cultivars to high temperature and drought stresses during the growing season under field conditions

Reakcja wybranych odmian ziemniaka na stres wysokiej temperatury i suszy w okresie wegetacji w warunkach polowych

Forecasts of global warming and periods of high temperature and drought occurring more frequent in Central Europe prompt us to study the physiological reaction of potato plants to these abiotic stresses. The purpose of the presented work was to assess the response of selected potato cultivars to high temperature and drought during the growing season under field conditions. The experiment was carried out with cultivars: Viviana (very early), Bohun (early), Bogatka, Honorata, Laskara, Lavinia, Malaga, Otolia (medium early). The field trial was set up in a randomized complete block design with three replicates. The high maximum temperatures during the day from June to August and higher level of rainfall in July contributed to secondary vegetation which lasted throughout August until mid-September. Summing up all the physiological defects of tubers and the evaluation of their share in the total yield allowed assessment of the tolerance of tested cultivars to heat and drought stresses during the growing season. It was found that the most tolerant cultivars were: Otolia, Honorata and Bohun.

Key words: abiotic stresses, drought, heat, immature tubers, physiological tubers defects, secondary vegetation, *Solanum tuberosum* L.

Prognozy ocieplania klimatu i okresy wysokiej temperatury i suszy w okresie wegetacji coraz częściej występujące w Europie Centralnej skłaniają nas do podjęcia badań nad fizjologiczną reakcją roślin ziemniaka na te stresy abiotyczne. Celem przedstawionych badań była ocena reakcji odmian na wysoką temperaturę i suszę w okresie wegetacji w warunkach polowych. Objęły one następujące odmiany: Viviana (bardzo wczesna), Bohun (wczesna), Bogatka, Honorata, Laskara, Lavinia, Malaga, Otolia (średnio wczesne). Doświadczenie polowe założone zostało metodą losowanych bloków w trzech powtórzeniach. Wysokie dzienne temperatury od czerwca do sierpnia i bardziej obfite opady w lipcu przyczyniły się do wtórnej wegetacji roślin trwającej przez cały sierpień aż do połowy września. Zsumowanie wszystkich defektów fizjologicznych bulw i określenie ich udziału w plonie ogólnym pozwoliło na ocenę tolerancji badanych odmian na stres wysokiej temperatury i suszy

---

Redaktor prowadzący: Renata Lebecka

w okresie wegetacji. Stwierdzono, że odmianami najbardziej tolerancyjnymi były: Otolia, Honorata oraz Bohun.

Słowa kluczowe: bulwy niedojrzałe, defekty fizjologiczne bulw, *Solanum tuberosum* L., stresy abiotyczne, susza, wtórna wegetacja, wysoka temperatura

INTRODUCTION

Heat stress due to increased temperature is an agricultural problem in many areas in the world (Birch et al., 2012). Transitory or constant high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield (Wahid et al., 2007; Hancock et al., 2014). In potato the adverse effects of heat stress can be mitigated by developing cultivars with improved thermotolerance using various genetic approaches (Levy et al., 1991; Veilleux et al., 1997). For this task, however, a thorough understanding of the physiological responses of plants to high temperature is imperative.

Potato (*Solanum tuberosum* L.) is a plant typical mainly of temperate climate. It is characterized by specific temperature requirements. The crop grows best in cool but frost-free seasons and does not perform well in heat (Hijmans, 2003). The limits and optimal values for the growth of the above-ground part of the potato plant and for the tubers are different (Marinus and Bodlaender, 1975; Struik et al., 1989 a, b; Van Dam et al., 1996). Haulm growth is fastest in the temperature range of 20°C–25°C whereas the optimal range for tuberization and tuber growth is 15°C–20°C. Under high-temperature conditions, tuberization is significantly inhibited and photoassimilate partitioning to tubers is greatly reduced (Ewing, 1981; Krauss and Marschner, 1984; Lafta and Lorenzen 1995). At a temperature higher than optimum a reduction or complete inhibition of tuberization and the intensified development of the aboveground part of plants takes place. The negative impact of high temperatures on tuber yield is the result of the consumption of assimilates by intensively growing shoots.

Forecasts of global warming and periods of high temperature and drought occurring more frequently in Central Europe (IPPC, 2014) prompt us to research the reaction of potato to high temperature and drought stresses during growing season. Thus, the purpose of the presented study was to assess the response of selected potato cultivars to these abiotic stresses during the growing season of 2015 year under field conditions.

MATERIALS AND METHODS

The study was conducted in 2015 at the Plant Breeding and Acclimatization Institute in the Research Center at Jadwisin (52°28’44”N and 21°02’38”E). The experimental objects were cultivars registered recently in the Polish List of Varietes (COBORU, 2015) (Table 1). The seed potatoes for the study were produced in the northern region of Poland with the most favorable environmental conditions for their production. In autumn, just after harvest (October), certified seeds of the cultivars were placed in a storage chamber under conditions optimal for seed potato storage (temperature of 3°C). Five weeks before planting the seeds were transported to a special room for pre-sprouting under optimal conditions for this process. Planting took place on April 28th in an experimental field, on a poor clayey sand of a good agricultural suitability. Natural fertilizer was used: firstly wheat straw and next a white mustard (*Sinapis alba* L.) plowed under after the first frost in autumn. Mineral fertilization was adjusted to the mineral content of the soil, and was applied in autumn in doses of 18 kg P·ha^{-1}, 100 kg K·ha^{-1} plus microelements. In the spring 100 kg N·ha^{-1} was sown.

Table 1

List of tested potato cultivars
Wykaz badanych odmian

No.	Cultivar Odmiana	Maturity type Typ dojrzałości	Year of registration* Rok rejestracji*	Yield**t·ha^{-1} Plon**	Breeder Hodowca
1	Viviana	Very early	2010	45.5	Böhm — NAOHG — Germany
2	Bohun	Early	2014	51.8	HZ Zamarte — Poland
3	Bogatka	Medium early	2013	52.1	HZ Zamarte — Poland
4	Honorata	Medium early	2012	44.1	Böhm — NAOHG — Germany
5	Laskara	Medium early	2013	55.2	PMHZ Strzekęcino — Poland
6	Lavinia	Medium early	2013	52.0	Böhm — NAOHG — Germany
7	Malaga	Medium early	2013	56.7	HZ Zamarte — Poland
8	Otolia	Medium early	2014	54.3	Böhm — NAOHG — Germany

Explanations:
* registration in the Polish National List of Varieties
** from the registration experiments of Research Centre for Cultivar Testing
Objaśnienia:
* rejestracja w Polskim Katalogu Odmian
** z doświadczeń rejestrowych COBORU

The field trial were set up in a randomized complete block design with three replicates. The size of each plot was 7.5 m^2, the number of plants per plot was 30 at 75 cm row spacing with plant separation in the same row of 33 cm. Crop pests and diseases were controlled as normally done in the area. Weather conditions were monitored using a Campbell Weather Station (Campbell Scientific Inc.). The meteorological factor during the growing seasons are given in Table 2. During the growing season the plant phenological stages were observed. A mechanical haulm destruction was done on September 16 and the harvest was performed on September 28, using a potato digger. 10 kg samples of tubers were taken manually from the middle of each plot and next the total yield was weighed. Directly after harvest, tuber size and quantity of tubers with physiological defects (chronologically younger/immature, multidirectional deformations and gemmations) were determined.

The results of the experiment were analyzed with ANOVA using a model of statistics program in Statistica. Means were separated with Tukey's test at 5% p-value.

RESULTS

Meteorological conditions and phenological stages

Chosen meteorological factors during the 2015 growing season are presented in Table 2. High temperature during the day and long-lasting drought had an impact on particular phenological stages of plants of tested potato cultivars. Plant emergence started 10–14 days after planting and ended after 14–28 days (Table 3).

Table 2

Total rainfall, mean values of daily and maximum air temperature, number of days with maximum air temperature during growing season in the year of study
Suma opadów, średnie wartości dziennych maksymalnych temperatur powietrza, liczba dni z maksymalną temperaturą w okresie wegetacji w roku badań

Meteorological factor Czynnik meteorologiczny	Decade Dekada	Month Miesiąc					
		April IV	May V	June VI	July VII	August VIII	September IX
Total rainfall in mm Suma opadów w mm	I	9.0	25.0	0.4	12.7*	2.6	19.6
	II	2.3	5.4	10.5	35.3	0.0	8.9
	III	16.5	9.1	4.5	14.6	6.0	8.1
	total	27.8	39.5	15.4	62.6	8.6	36.6
Mean air temperature in °C Śr. temp. pow. w °C	I	4.5	12.4	18.5	21.1	24.5	15.4
	II	8.3	13.0	17.1	18.9	22.7	17.0
	III	12.0	13.2	16.9	19.0	20.4	12.9
	mean	8.3	12.9	17.5	19.6	22.5	15.1
Maximum air temperature in °C Max. temp. pow. w °C	I	17.9	22.8	29.9	35.0	36.2	34.4
	II	20.5	25.3	28.6	34.5	35.5	29.6
	III	22.9	22.4	26.7	32.1	34.0	23.0
	mean	20.4	23.5	28.4	33.9	35.2	29.0
Number of days with maximum air temperature Liczba dni z max. temp. > 25°C	I	0	0	7	8	9	1
	II	0	1	3	4	8	2
	III	0	0	2	4	7	0
	total	0	1	12	16	24	3
Number of days with maximum air temperature Liczba dni z max. temp. > 30°C	I	0	0	0	5	8	1
	II	0	0	0	1	6	0
	III	0	0	0	1	2	0
	total	0	0	0	7	16	1

Explanation: * additionally 10 mm of water from irrigation
Objaśnienie: * dodatkowo 10 mm wody z nawadniania

Table 3

Date of phenological stage of plants of tested cultivars in the year of study
Data stadium fenologicznego roślin badanych odmian w roku badań

Cultivar Odmiana	Plant emergence Wschody			Flowering Kwitnienie			Maturation Dojrzewanie		
	1	2	3	1	2	3	1	2	3
Viviana	May 8	May 11	May 13	lack	lack	lack	JULY 10	AUG 17	lack
Bohun	May 13	May 18	May 22	lack	lack	lack	AUG 10	AUG 24	lack
Bogatka	May 13	May 20	May 25	JUN 10	lack	lack	AUG 17	lack	lack
Honorata	May 10	May 19	May 25	JUN 10	lack	lack	AUG 17	lack	lack
Laskara	May 10	May 22	May 26	JUN 8	lack	lack	AUG 17	lack	lack
Lavinia	May 13	May 18	May 25	JUN 12	lack	lack	AUG 17	lack	lack
Malaga	May 9	May 13	May 20	lack	lack	lack	AUG 24	lack	lack
Otolia	May 13	May 16	May 22	JUN 10	lack	lack	AUG 17	lack	lack

Explanations: 1 — beginning; 2 — full; 3 — end
Objaśnienia: 1 — początek; 2 — pełnia; 3 — koniec; May — maj; JUN — czerwiec; JULY — lipiec: AUG — sierpień; lack — brak

The next phenological stage, a flowering, began on 8–12 June, but only in 5 cultivars. These cultivars lost buds, and there was no full flowering. This was probably related to the low rainfall and high temperatures in June. Plant maturation of the very early cultivar Viviana began on July 10 and the other cultivars between 10 and 24 August. None of the tested cultivars reached full maturity.

A higher level of rainfall in July, combined with a complementary dose of water from irrigation and very high maximum temperatures during the day, contributed to secondary vegetation which lasted throughout August until mid-September. Therefore, in order to feasibly harvest, a treatment of haulm destruction was necessary.

Yield, tubers with physiological defects and tuber size

Significant differentiation of cultivars in terms of the total yield and most of the studied traits of tubers was found (Table 4).

Table 4

Mean squares, F values and significance level of tested factor — from the analysis of variance
Średnie kwadraty, wartości F oraz poziom istotności badanych cech — z analizy wariancji

Characteristics Cecha	Source of variation — cultivar Źródło zmienności — odmiana		
	M.S.*	F	Pr > F**
Total yield Plon ogólny	66	6.66	0.0008
Chronologically younger in % of total yield Bulwy chronologicznie młodsze w % plonu ogólnego	730	24.66	<.0001
Deformation in % of total yield Deformacje w % plonu ogólnego	459	13.96	<.0001
Gemmation in % of total yield Dzieciuchowatość w % plonu ogólnego	54	1.76	0.16
Sum of physiological defects in the total yield Suma defektów fizjologicznych w plonie ogólnym	1473	15.10	<.0001
Tubers smaller than 35 mm in total yield Bulwy mniejsze od 35 mm	136	15.58	<.0001

Explanations: * mean squares
** level P < 0.05 — differences statistically significant
Objaśnienie: * średnie kwadraty
** poziom P < 0,05 – różnice istotne statystycznie

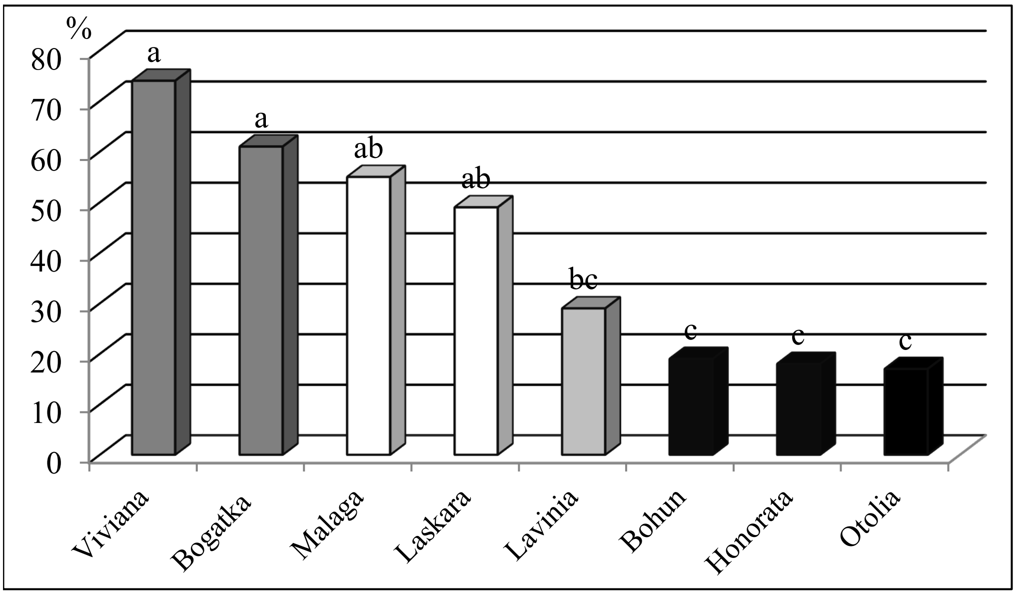
The yield of the tested cultivars was lower in the year of study than in the registration experiments of Research Centre for Cultivar Testing (Table 1, 5). The lowest yield was found in a very early cultivar Viviana and the highest in a medium early cultivar Bogatka (Table 5). Other cultivars were also significantly differentiated in terms of the size of the yield. The percentage share of tubers chronologically younger in the yield was the highest in cultivar Viviana, which was connected with the earliest start of maturation and a long period of secondary growth, until the haulm destruction (Table 3, 5). Other cultivars were not significantly different in terms of the diversity of this feature. However, there was a very large diversity of cultivars for multidirectional deformations that occur most frequently in cultivar Bogatka and in slight degree in cultivars Bohun and Otolia (Table 5).

Table 5

Total yield of tested cultivars and the percentage share of tubers with physiological defects and tubers smaller than 35 mm of transversal diameter in the total yield
Plon ogólny badanych odmian i procentowy udział bulw z defektami fizjologicznymi oraz bulw mniejszych niż 35 mm poprzecznej średnicy w plonie ogólnym

Cultivar Odmiana	Total yield Plon ogólny t·ha^{-1}		Tubers with physiological defects in % Bulwy z defektami fizjologicznymi w %						Tubers/ bulwy < 35 mm %	
			chronogically younger chronologicznie młodsze		multidirectional deformations deformacje wielokierunkowe		gemmation dzieciuchowatość			
Viviana	28.2	c	50.2	a	12.0	cd	12.0	a	15.0	abc
Bohun	31.8	bc	5.1	b	5.1	d	8.8	a	18.5	ab
Bogatka	44.2	a	10.8	b	39.9	a	9.8	a	9.9	cde
Honorata	35.9	abc	2.9	b	12.5	cd	2.9	a	17.2	abc
Laskara	37.4	ab	10.5	b	31.3	ab	6.9	a	3.2	e
Lavinia	38.3	ab	7.4	b	17.2	bcd	4.8	a	21.7	a
Malaga	34.6	bc	11.3	b	27.2	abc	16.4	a	11.9	bcd
Otolia	35.7	abc	2.6	b	7.7	d	6.9	a	3.9	ed
Mean — średnio	35.8		12.6		19.1		8.6		12.7	

Explanation: a, b, c, d, e — group acc. Tukey's test; mean values followed by the same letter are not significantly different at the 0.05 level
Objaśnienia: a, b, c, d, e — wartości średnie oznaczone tymi samymi literami nie różnią się istotnie na poziomie 0,05 według testu Tukeya



Explanation: a, b, c — group acc. Tukey's test; mean values followed by the same letter are not significantly different at the 0.05 level
Objaśnienia: a, b, c — wartości średnie oznaczone tymi samymi literami nie różnią się istotnie na poziomie 0,05 według testu Tukeya

Fig. 1. The percentage share of tubers with physiological defects in the total yield of tested cultivars
Rys. 1. Procentowy udział bulw z defektami fizjologicznymi w plonie ogólnym badanych odmian

The share of tubers with gemmations in the tested cultivars was from a few to several percent, but the differences among them were not statistically significant. The yield was characterized by a relatively high share of tubers with a transverse diameter less than 35 mm. Cultivars Laskara and Otolia had the least, about 3%, share of tubers of such size (Table 5).

Summing up all the physiological defects of tubers and the evaluation of their share in the total yield allowed assessment of the tolerance of tested cultivars to heat and drought during the growing season in the presented environmental conditions. It was found that the most tolerant cultivars were: Otolia, Honorata and Bohun (Fig. 1).

DISCUSSION

The problem of the negative impact of high temperature and drought during the growing period on the development and yield of the potato is generally well known and has been described by many authors (Levy and Veilleux, 2007; Haverkort and Verhagen 2008; Monneveux et al., 2014). The results presented in this communication complement our previous and ongoing work on this issue (Rykaczewska, 2013 b, 2014, 2015). Until now they have been carried out under controlled conditions.

However, during the growing period 2015 thermal conditions in the experimental field were similar to those that were determined in pot experiments. The temperatures in June, July and August exceeded 25°C, and in July and August even 30°C. In June with a very low rainfall there was no full flowering of plants and in July, after an application of irrigation and the increased amount of precipitation, the beginnings of secondary vegetation took place which continued until September. The phenomenon of potato second vegetation and second tuberization has been widely studied (Benoit et al., 1983; Ewing, 1981; Levy, 1985, Levy, 1986 a, b; Rykaczewska, 2015). The yield of potato in the experimental field in Jadwisin was always variable and dependent on the meteorological conditions and cultivars. In a year with less favorable weather it was on an average 34.4 $t \cdot ha^{-1}$ and varied from 26.1 to $50.0 \cdot tha^{-1}$ but in a year with more favorable weather was on average 48.4 $t \cdot ha^{-1}$ and varied from 31.8 to 60.1 $t \cdot ha^{-1}$ (Rykaczewska, 2013 a). Thus the level of the total yield of the tested cultivars in this 2015 study was similar to the yields obtained in previous years.

However, its quality was highly unsatisfactory due to the occurrence of physiological defects of tubers and a large share of small tubers in the total yield. All types of physiological defects of tubers which are listed in this paper, so chronologically younger tubers, multidirectional deformation and gemmation were associated with second growth of plants (Bodlaender et al., 1964; Ewing, 1981; Benoit et al., 1983; Radtke and Rieckmann, 1991). The experiment conducted by Bodlaender et al. (1964) showed that high temperature induces second-growth in potato tubers irrespective of the water supply and that drought is not necessary to induce the second growth. However according to Rykaczewska (2015) the number of tubers from the second tuberization is significantly dependent on the soil moisture during the impact of high temperature. Soil moisture favorable for plants led to an increase in the number of new tubers. The largest increases in the number of tubers as aresult of second tuberization occurred when the high temperature affected the plants in the earlier stage of plant development, in the first half of July (Rykaczewska, 2013 b, 2015).

In the study presented here temperatures higher than 25°C took place in June and continued in July and August. This led to the occurrence of numerous tubers with physiological defects. The most important is that the reaction of cultivars was significantly differentiated. It was demonstrated here that Viviana and Bogatka cultivars stood out with the largest number of tubers with physiological defects in the final yield and cultivars Otolia, Honorata and Bohun were the most tolerant to described stress conditions during the growing season. The diversity of response of potato cultivars to high temperatures and drought during the growing period draws the attention of many authors (Marinus and Bodlaender, 1975; Levy et al., 1991; Veilleux et al., 1997; Ahn et al., 2004; Monneveux et al., 2014; Rykaczewska, 2013 b, 2015). It is a very important issue because the finding of tolerant cultivars allows to nominating them for cultivation in regions with higher temperatures and also allows their use in breeding programs. However, breeders consequently did not consider tolerance to these stresses as priority objectives (Thiele et al., 2010; Monneveux et al., 2013). Meanwhile today, the progress of genomics and bioinformatics offers real opportunities for dissecting the genetic basis of drought and heat tolerance into component traits and selecting plants with favorable alleles in the underlying genes (Tuberosa, 2012). Other aspects that breeders of potato cultivars would have to take into account are quality aspects such as susceptibility to secondary growth.

CONCLUSION

Our research shows that the total yield is not the only indicator of potato tolerance to high temperatures stress during the growing season, but the assessment should also take into account the occurrence of secondary tuberization and physiological defects of tubers. The indication of tolerant cultivars allows their selection for cultivation in regions with higher temperatures and allow their use in breeding of new genotypes.

REFERENCES

Ahn Y. J., Claussen K., Zimmerman J. L. 2004. Genotypic differences in the heat-shock response and thermotolerance in four potato cultivars. Plant Sci. 166: 901 — 911.

Benoit G. R., Stanley C. D., Grant W. J., Torrey D. B. 1983. Potato top growth as influenced by temperatures. Am. Potato J. 60: 489 — 501.

Birch P. R. J., Bryan G., Fenton B., Gilroy E., Hein I., Jones J. T, Prashar A., Taylor M. A, Torrance L., Toth I. K. 2012. Crops that feed the world 8: Potato: are the trends of increased global production sustainable? Food Security 4: 477 — 508.

Bodlaender K. B. A., Lugt C., Marinus J. 1964. The induction of second-growth in potato tubers. Eur. Potato J. 7: 57 — 71.

Ewing E. 1981. Heat stress and tuberization stimulus. Am. Potato J. 58: 31 — 49.

Hancock R. D., Morris W. L., Ducreux L. J. M., Morris J. A., Usman M., Verrall S. R, Fuller J., Simpson C. G., Zhang R., Hedley P. E., Taylor M. A. 2014. Physiological, biochemical and molecular responses of the potato plant to moderately elevated temperature. Plant Cell Environ. 37: 439 — 450.

Haverkort A. J., Verhagen A. 2008. Climate change and its repercussions for the potato supply chain. Potato Res. 51: 223 — 237.
Hijmans R. J. 2003. The effect of climate change on global potato production. Am. J. Potato Res. 80: 271 — 280.
IPCC 2014. Climate Change 2014. The Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5) http://ar5-syr.ipcc.ch/topic_observedchanges.php.
Krauss A., Marschner H. 1984. Growth rate and carbohydrate metabolism of potato tubers exposed to high temperatures. Potato Res. 27: 297 — 303.
Lafta A. H., Lorenzen J. H. 1995. Effect of high temperature on plant growth and carbohydrate metabolism in potato. Plant Physiol. 109: 637 — 643.
Levy D. 1985. The response of potatoes to a single transient heat or drought stress imposed at different stages of tuber growth. Potato Res 28: 415 — 424.
Levy D. 1986 a. Genotype variation in the response of potatoes (*Solanum tuberosum* L.) to high ambient temperatures and water deficit. Field Crop Res. 15: 85 — 96.
Levy D. 1986 b. Tuber yield and tuber quality of several potato cultivars as affected by seasonal high temperature and by water deficit in a semi-arid environment. Potato Res. 29: 95 — 107.
Levy D., Kastenbaum E. Itzhak Y. 1991. Evaluation of parents and selection for heat tolerance in the early generations of a potato (*Solanum tuberosum* L.) breeding program. Theor. Appl. Genet. 82: 130 — 136.
Levy D., Veilleux R. E. 2007. Adaptation of potato to high temperature and salinity — a review. Am. J. Potato Res. 84: 487 — 506.
Marinus J., Bodlaender K. B. A. 1975. Response of some potato varieties to temperature. Potato Res. 18: 189 — 204.
Monneveux P., Ramírez D. A., Pino M.T. 2013. Drought tolerance in potato (*S. tuberosum* L.): can we learn from drought tolerance research in cereals? Plant Sci. 205–206: 76 — 86.
Monneveux P., Ramírez D. A., Awais Khan M., Raymundo R. M., Loayza H., Quiroz R. 2014. Drought and heat tolerance evaluation in potato (*Solanum tuberosum* L.). Potato Res. 57: 225 — 247.
Radtke W., Rieckmann W. 1991. Maladies et ravageurs de la pomme de terre. Ed. Th. Mann, traduction Michel Magnenat: 150.
COBORU 2015. Polish List of Varieties. http://www.coboru.pl/polska/Rejestr/ListyOdmian/lista_rolnicze _2015.pdf.
Rykaczewska K. 2013 a. Assessment of potato mother tubers vigour using the method of accelerated ageing. Plant Prod Sci. 16: 171 — 182.
Rykaczewska K. 2013 b. The impact of high temperature during growing season on potato cultivars with different response to environmental stresses. Am. J. Plant Sci. 4: 2386 — 2393.
Rykaczewska K. 2014. Search for potato cultivars tolerant to high temperature periodically occurring during the growing season. ESA XIIIth Congress 25–29 August 2014, Debrecen, Hungary. Book of Abstracts: 399.
Rykaczewska K. 2015. The effect of high temperature occurring in subsequent stages of plant development on potato yield and tuber physiological defects. Am. J. Potato Res. 92: 339 — 349.
Struik P. C., Geertsema J. Custers C. H. M. G. 1989 a. Effect of shoot, root and stolon temperature on the development of the potato (*Solanum tuberosum* L.) plant. I. Development of the haulm. Potato Res 32: 133 — 141.
Struik P. C., Geertsema J., Custers C. H. M. G. 1989. Effect of shoot, root and stolon temperature on the development of the potato (*Solanum tuberosum* L.) plant. III. Development of tubers. Potato Res 32: 151 — 158.
Thiele G., Theisen K., Bonierbale M., Walker T. 2010. Targeting the poor and hungry with potato science. Potato J. 37: 75 — 86.
Tuberosa R. 2012. Phenotyping for drought tolerance of crops in the genomics era. Front Physiol. 3 (347): 1 — 26.
Van Dam J., Kooman P. L., Struik P. C. 1996. Effects of temperature and photoperiod on early growth and final number of tubers in potato (*Solanum tuberosum* L.). Potato Res 39: 51 — 62.

Veilleux R. E., Paz M. M., Levy D. 1997. Potato germplasm development for warm climates: genetic enhancement of tolerance to heat stress. Euphytica 98: 83 — 92.

Wahid A., Gelani S., Ashraf M., Foolad M. R. 2007. Heat tolerance in plants: an overview. Environ. Exp. Bot. 61: 199 — 223.

ACKNOWLEDGEMENTS

The author offers special thanks for the valuable technical assistance of A. Gajos during the whole period of the growing season.

The research was partly funded by the Ministry of Agriculture and Rural Development.