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Morphology and anatomy of the root system of new potato cultivars Part I. Morphology of the root system*

Morfologia i anatomia systemu korzeniowego nowych odmian ziemniaka Część I. Morfologia systemu korzeniowego

The purpose of this work was to assess the variability of morphology of the root systems of 17 potato cultivars and to consider a possible connection with their tolerance to high temperature and drought during growing season. The study was carried out in a greenhouse in 2014. Among the cultivars selected for the study 'Tetyda' was tolerant and 'Aruba' susceptible to these abiotic stresses. A device for the production of potato minitubers in aeroponics was used in the study. Measurements of root system properties were conducted at flowering period and at the beginning of tuberization. Significant differences were found among cultivars in terms of the maximum rooting depth, their fresh and dry matter and dry matter content in roots. Maximum rooting depth reached 109 cm. It was significantly positively correlated with the fresh matter of roots. A measure of the size of the potato plant root system used by most researchers is the dry matter of roots. In our study, it was from 0.93 to 4.78 g per plant depending on the cultivar and was highly correlated with the length of the stems and the fresh matter of above-ground part of plants. The dry matter content in roots ranged from 4.4% in the cultivar Miłek to 7.6% in the cultivar Tetyda with high tolerance to heat and drought stresses during the growing season. However, the demonstration of the relationship between tolerance of cultivars to these abiotic stresses during the growing season and the dry matter content in the roots will require further research.

Key words: aeroponics, depth range of root system, dry matter of root system, dry matter content in roots, *Solanum tuberosum* L.

Celem pracy była ocena zmienności morfologii system korzeniowego 17 odmian ziemniaka i rozważenie ewentualnego związku z tolerancją na wysoką temperaturę i suszę w okresie wegetacji. Badania przeprowadzono w szklarni w roku 2014. Wśród wyselekcjonowanych do badań odmian 'Tetyda' była tolerancyjna i 'Aruba' wrażliwa na stres abiotyczny. Do badań systemu korzeniowego zostało wykorzystane urządzenie do aeroponicznej produkcji minibulw ziemniaka umieszczone w hali wegetacyjnej. Pomiary przeprowadzono w czasie kwitnienia roślin, czyli na początku ich tuberyzacji. Stwierdzono istotne różnice między odmianami pod względem głębokości zasięgu korzeni, ich świeżej

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i suchej masy oraz zawartości suchej masy w korzeniach. Maksymalny zasięg korzeni osiągał wartość 109 cm. Był on pozytywnie skorelowany ze świeżą masą korzeni. Miarą wielkości systemu korzeniowego roślin ziemniaka stosowaną przez większość badaczy jest sucha masa korzeni. W naszych badaniach wahała się od 0,93 do 4,78 g na roślinę zależnie od odmiany i była wysoce istotnie skorelowana z długością łodyg i masą części nadziemnej roślin. Zawartość suchej masy w korzeniach wynosiła od 4,4% u odmiany Miłek do 7,6% u odmiany Tetyda, o wysokiej tolerancji na stres abiotyczny w okresie wegetacji. Jednak wykazanie zależności między tolerancją odmian na stres wysokiej temperatury i suszy w okresie wegetacji a suchą masą korzeni będzie wymagało dalszych badań.

Słowa kluczowe: aeroponika, głębokość zasięgu korzeni, sucha masa korzeni, zawartość suchej masy w korzeniach

INTRODUCTION

Root studies, which were far behind the other plant sciences, changed during the second half of the 20th century, but have accelerated since that time (Tracy et al., 2011; De Smet et al., 2012). It was not only the technological innovations that enabled this trend but mainly the notion that there is a missing gap in plant studies, that is incomplete without this link (Silberbush, 2013).

Potato (*Solanum tuberosum* L.) is a plant typical mainly for temperate climate. The crop grows best in a temperate climate and does not perform well in heat (Koman and Haverkort, 1995; Hijmans, 2003). It is characterized by specific temperature requirements and develops best at temperatures of about 20°C (Struik et al., 1989 a, 1989 b; Rykaczewska, 1993; Van Dam et al., 1996). Under high-temperature conditions tuberization is significantly inhibited and photoassimilate partitioning to tubers is greatly reduced (Ewing, 1981; Krauss and Marschner, 1984; Haynes et al., 1989; Lafta and Lorenzen, 1995; Van Dam et al., 1996; Rykaczewska, 2015a; 2015b).

Heat stress 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 development and may lead to a drastic reduction in economic yield (Wahid et al., 2007). For this task, however, a thorough understanding of physiological responses of plants to abiotic stresses, mainly heat and drought stresses, is currently imperative. Due to the increasing occurrence of periods of high temperatures and drought in Poland and potato production losses resulting from the action of these abiotic stresses, studies of potato tolerance to them were undertaken. The purpose of this work was to assess the variability of morphology and anatomy of the root systems of potato cultivars and to consider a possible connection with their tolerance to heat and drought stresses.

MATERIALS AND METHODS

The study was carried out in 2014 in the Potato Agronomy Department in Jadwisin. The root systems of 17 cultivars: Denar, Justa, Lord, Miłek (very early), Aruba, Bila, Etola, Gwiazda, Hubal, Michalina (early), Etiuda, Finezja, Gandawa, Kuba, Oberon, Stasia and Tetyda (medium early) were tested. Among the cultivars selected for the study Tetyda was tolerant and Aruba susceptible to abiotic stresses (high temperature and drought) (Rykaczewska, 2015 a).

A device for the production of potato minitubers in aeroponics of our own design (2.51 m length × 1.26 m width × 0.60 m depth) was used in the study, which was located in the greenhouse. Pre-sprouted minitubers of transversal diameter of about 1 cm were planted on 22nd May into baskets with dimensions of 5 × 7 cm filled with mineral wool. They were placed in holes on top of the device. In this way the foliage of the plants grew in the light while roots, stolons and tubers developed under total darkness inside the aeroponics chamber. The plant density was 40 plants/m2. A modified nutritive solution (pH=5.5, EC=2.5 mS cm−1, NO_3^-, $SO4_2^-$, $H_2PO_4^-$, CI−, K+, Ca_2^+, Mg_2^+, NH_4^+, Na+ and micronutrients) from Rolot et al. (2002) was prepared and supplied by fog nozzles located at the bottom of the device. Fog nozzles sprayed a small quantity of nutrient solution every 3 min for 10 s. during the day and every 5 min for 10 s. during the night. Residual nutrition solution was recirculated.

Plants were collected on 11th July (49 days after planting) during the flowering period and at the beginning of tuberization. The length of stems and the mass of the above-ground parts of the plant, the number and mass of tubers of transverse diameter greater than 1 cm and also the maximum depth range of roots, their fresh and dry weight and dry matter content were determined. Dry matter of roots and dry matter content were determined after drying at 50°C for 24 hours and next at 105°C until no further weight reduction was noted. The results of the experiment were analyzed with ANOVA. Number of repetitions was 3. Means were separated with Tukey's test at 5% p-value.

RESULTS

Significant differences among cultivars in terms of length of the stems, mass of above-ground part of plants, number and mass of tubers, the maximum rooting depth, fresh and dry matter of roots and dry matter content in roots were found (Table 1).

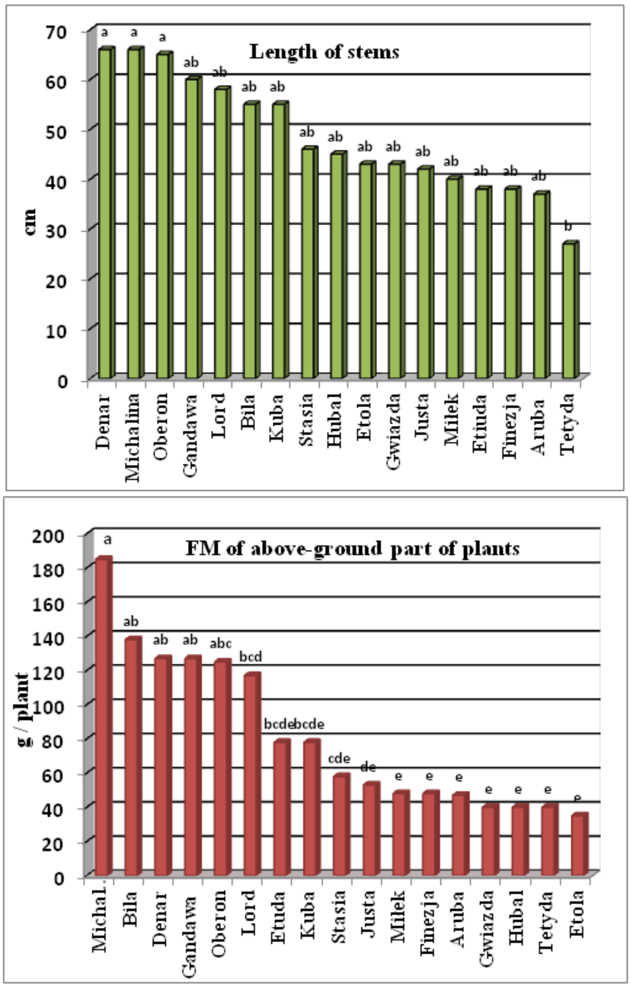
Table 1

Significance level of tested factors from the analysis of variance and mean values of features
Poziom istotności badanych czynników z analizy wariancji i wartości średnie cech

Characteristic Cecha	Source of variation — cultivar Źródło zmienności — odmiana Significance level of the ANOVA Poziom istotności ANOVA	Mean value Średnia
Length of stems in cm — długość pędu w cm	0.0007	48.6
Mass of above-ground part of plants in g/ plant — masa części rośliny powyżej gruntu	<0.0001	81.4
Number of tubers/ plant — liczba bulw z rośliny	<0.0001	3.0
Mass of tubers in g/ plant — masa bulw w g/ na roślinę	<0.0001	21.5
Depth range of roots in cm — zakres głębokości korzeni w cm	0.0011	82.6
Mass of roots in g/ plant — masa korzenie w g/ na roślinę	<0.0001	38.8
Dry matter of roots in g/ plant — sucha masa korzeni w g/ na roślinę	<0.0001	2.24
Root dry matter content in % — zawartość suchej masy korzeni w %	<0.0001	5.74

State growth of the above-ground parts of plants and tubers at the start of the root system studies

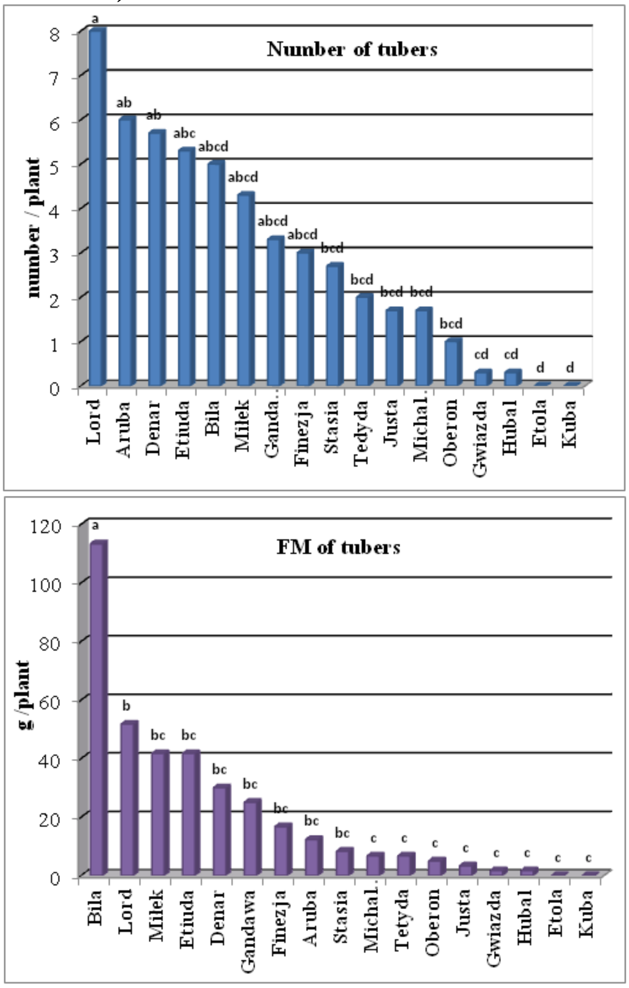
It was found that the cultivars with the highest stems belong to all groups of maturity: Denar (very early), Michalina (early) and Oberon (medium early) (Fig. 1). Between the length of stems and the above-ground part of plants of tested cultivars a significant positive correlation was found (Table 2). Michalina cultivar produced the highest fresh matter of the above-ground part and the cultivars Stasia, Justa, Miłek, Finezja, Aruba, Gwiazda, Hubal, Tetyda and Etola — the smallest (Fig. 1). These cultivars also belonged to all groups of maturity class.



Explanation — Objaśnienie:
FM – fresh matter; a, b, c, d, e - mean values followed by the same letters are not significantly different at the 0.05 level according Tukey's test; FM – świeża masa; a, b, c, d, e – wartości średnie oznaczone tymi samymi literami nie różnią się istotnie na poziomie 0,05 według testu Tukeya

Fig. 1. Length of stems and fresh matter of above-ground part of plants
Rys. 1. Długość łodyg i świeża masa części nadziemnej roślin

Between the growth of the above-ground part of plants and the number and matter of tubers there was a significant positive correlation, but after 49 days from planting most of the tested cultivars were at the initial phase of tuberization (Table 2, Fig. 2). The highest number of tubers were produced by the very early cultivar Lord and the largest matter by the early cultivar Bila. Cultivars Etola and Kuba were still in a very early stage of tuberization (tuber initiation).



Explanation — Objaśnienie:
FM – fresh matter; a, b, c - mean values followed by the same letters are not significantly different at the 0.05 level according Tukey's test
FM – świeża mas; a, b, c – wartości średnie oznaczone tymi samymi literami nie różnią się istotnie na poziomie 0,05 według testu Tukeya

Fig. 2. Number and fresh matter of tubers
Fig. 2. Liczba i świeża masa bulw

Characteristics of the root system

Rooting depth of the tested cultivars reached maximum value 109 cm, however it was characterized by high variation (Fig. 3). The cultivars Hubal, Michalina and Kuba were characterized by the longest roots while the very early cultivar Miłek the shortest. The fresh matter of the roots was significantly positively correlated with the rooting depth and the length of stems, and the fresh matter of above-ground part of plants, however the ranking of cultivars in this regard was slightly different (Table 2, Fig. 3). The roots of the very early and medium early cultivars are shown in a Figure 4.

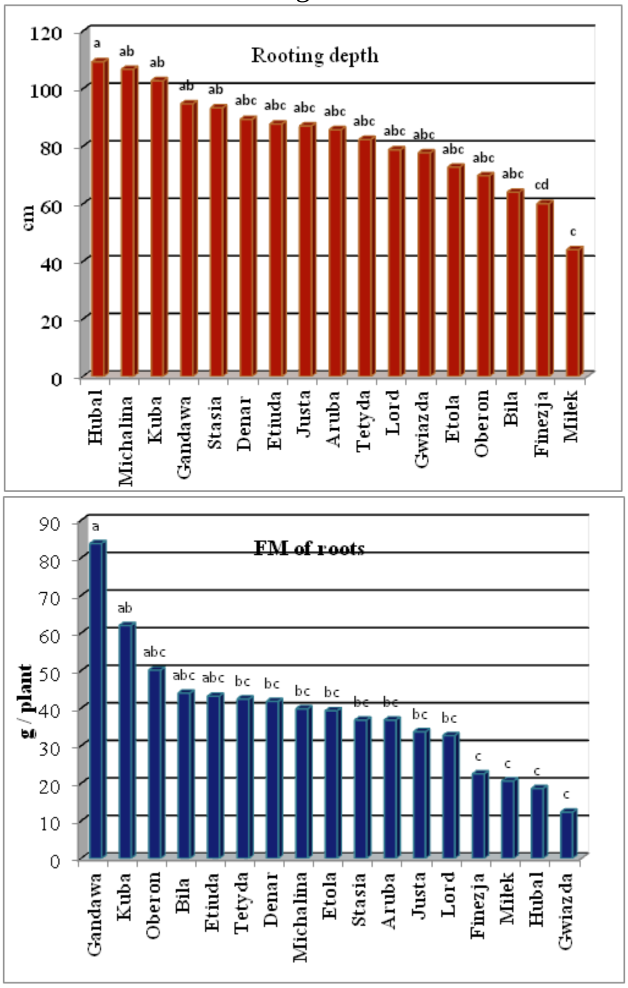


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Fig. 3. Rooting depth and FM of roots

Rys. 3. Głębokość zasięgu i świeża masa korzeni

Table 2

Correlation coefficients among the tested plant features
Współczynniki korelacji między badanymi cechami roślin

Feature Cecha	Length of stems Długość pędu	FM of a-g part Św.mas.cz. rośl. pow. gruntu	Number of tubers Liczba bulw	FM of tubers świeża masa bulw	Rooting depth Głębokość ukorzenienia	FM of roots Świeża masa korzeni	DM of roots Sucha masa korzeni	Root DM (%) Sucha masa korzeni
Length of stems	+ 1.00	+ 0.87**	+ 0.08	+ 0.17	+ 0.27*	+ 0.45**	+ 0.40**	+ 0.07
FM of a-g part	+ 0.87**	+ 1.00	+ 0.29*	+ 0.40**	+ 0.21	+ 0.42**	+ 0.49**	+ 0.21
Number of tubers	+ 0.08	+ 0.29*	+ 1.00	+ 0.66**	- 0.24	+ 0.03	+ 0.02	+ 0.00
FM of tubers	+ 0.17	+ 0.40**	+ 0.66**	+ 1.00	- 0.42**	+ 0.07	+ 0.02	+ 0.14
Rooting depth	+ 0.27*	+ 0.21	- 0.24	- 0.42**	+ 1.00	+ 0.31*	+ 0.40**	+ 0.48**
FM of roots	+ 0.45**	+ 0.42**	+ 0.03	+ 0.07	+ 0.31*	+ 1.00	+ 0.95**	+ 0.00
DM of roots	+ 0.40**	+ 0.49**	+ 0.02	+ 0.02	+ 0.40**	+ 0.95**	+ 1.00	+ 0.30*
Root DM (%)	+ 0.07	+ 0.21	+ 0.00	+ 0.14	+ 0.48**	+ 0.00	+ 0.30*	+ 1.00

Explanations: a-g - above-ground; FM – fresh matter; DM - dry matter; * - significant at the level P < 0.05; ** - significant at the level P < 0.01

Fig.4. Root systems of very early cultivar Lord and medium early cultivar Tetyda 49 days after planting
Rys. 4. System korzeniowy bardzo wczesnej odmiany Lord i średnio wczesnej odmiany Tetyda 49 dni po posadzeniu

Dry matter of the roots was the highest in medium early cultivar Gandawa and the lowest in cultivars Gwiazda and Miłek (Fig. 5). There were positive correlations between the dry matter of roots and their fresh matter and the depth range and also the length of stems and the mass of the above-ground parts of plants (Table 2). The dry matter content in roots ranged from 4.4 % in the cultivar Miłek to 7.6 % in the cultivar Tetyda (Fig. 5). This feature was positively correlated with the depth range of roots and their dry matter content (Table 2).

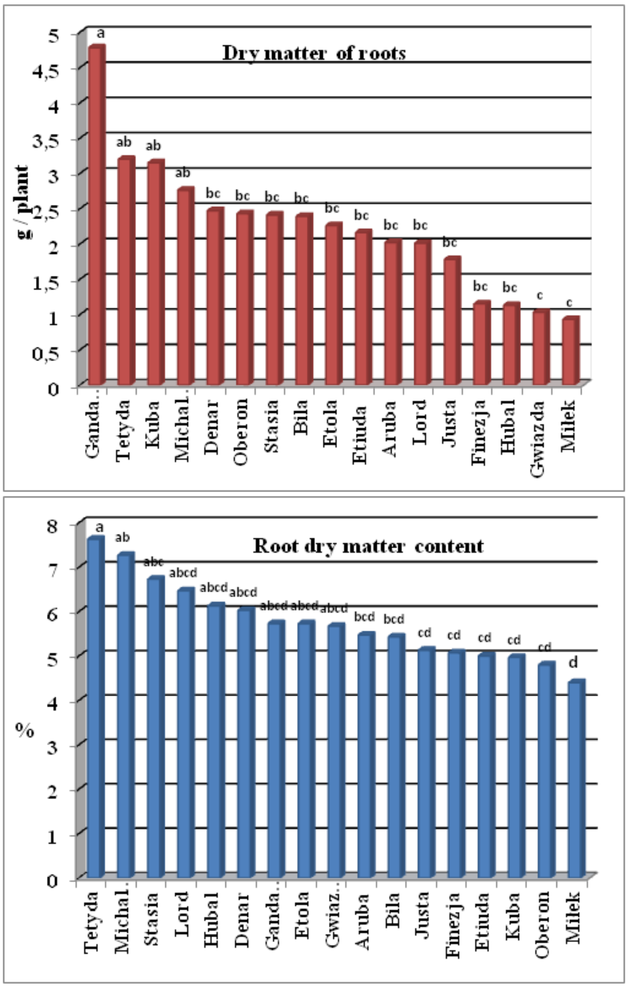

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Fig. 5. Dry matter of roots and root dry matter content
Rys. 5. Sucha masa korzeni i zawartość suchej masy w korzeniach

DISCUSSION

Observation of root systems under field conditions requires a lot of time and labour (Iwama, 2008). In our laboratory we applied the device for the production of potato minitubers in aeroponics of our own design, which allows the study of the root system in its entirety without damaging fragments thereof, that can happen for both field trials and the pot experiments.

In carrying out studies on the potato root system, the time for analysis is important. In our experience, we decided on the period of tuberization. At that time the roots are well developed and do not show signs of ageing (Rykaczewska, 2009). Period analysis of the roots in other studies varied and was performed on several dates (Vos and Groenwold 1986; Głuska, 2004; Lahlou and Ledent, 2005; Iwama, 2008) or fell at the beginning of plant maturity (Głuska, 2004; Iwama, 2008; Wishart et al., 2013). In our study, the fresh matter of the above-ground part of plants of particular cultivars during flowering stage was not dependent on the group of maturity class. Lack of close relationship between these features is emphasized in the literature (eg Rykaczewska, 2013). However the most important observation was a significant correlation between the mass of the aboveground parts of the plant and the mass of roots. Similar results were obtained by Iwama (2008) on Japanese cultivars. However, in previous studies on Polish cultivars, there is no reference of the size of the root system to the size of above-ground parts of plants (Głuska, 2004).

The maximum rooting depth of studied cultivars in our experiment reached 109 cm. In studies conducted at the beginning of potato plant maturation the roots reached a similar depth range, 105–126 cm (Głuska, 2004). Some authors express the size of the root system in relation to the unit area, or as the total length of all roots of a single plant. Iwama (2008) showed that the variation in root length per unit area varied from 0.38 to 4.86 km m^{-2} in wild potato relatives, while it varied from 1.12 to 1.69 km m^{-2} in cultivars and from 0.63 to 1.40 km m^{-2} in breeding lines. Wishart et al. (2013) calculated that total root length of twenty-eight genotypes varied from 40 to 112 m per plant. The often used measure of potato root system is the dry matter of roots. In our study, it was highly correlated with the length of the stems and the above-ground part of plants. In studies by Lahlou and Ledent (2005) in pot experiments in a greenhouse the dry matter of roots was similar and ranged from 0.84 to 3.80 per plant, but in the field it was higher, ranging from 1.1 to 11.8 g per plant. Similar results were obtained by Głuska (2004), where in a pot experiment the root dry matter range was even greater, from 0.5 to 11.4 g per plant. Cited authors have not studied the correlation of dry matter of roots with the fresh matter of the above-ground part of plants. Dry matter concentration in roots in our study averaged 5.74%, and ranged from 7.63% to 4.40%. These results are similar to those obtained by Iwama (2008), where the roots of examined potato cultivars growing under field conditions had an average of 7.1–7.4 % dry matter content.

Conducting our research with the aforementioned cultivar Tetyda with high tolerance to heat and drought stresses during the growing season (Rykaczewska, 2015 a) as one of the 17 potato cultivars, made it possible to show that the roots of Tetyda were characterized by the highest content of dry matter, although the advancement of its vegetation was less than many other cultivars studied. However, the demonstration of a relationship between tolerance of cultivars to heat and drought stresses during the growing season and the dry matter content in the roots will require further research.

CONCLUSION

Under global climate change, potato tolerance to abiotic stresses, high temperature and drought, will become more important for gaining stable yields in the future. Breeding of new cultivars with excellent root characteristics will contribute to more efficient utilization of water for potato production and will improve tolerance to high temperature during growing season. That is why morphological research in root characteristics should be continued in the future. The results of the studies presented in this paper made it possible to demonstrate the high variability of tested cultivars in terms of the many features of roots and their correlations. The demonstration of a relationship between tolerance of cultivars to heat and drought stresses during the growing season and the dry matter content in the roots will require further research.

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