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EFFECT OF IRRIGATION ON THE CONTENT AND YIELD OF STARCH IN EARLY POTATO CULTIVARS IN DIFFERENT REGIONS OF POLAND

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Abstract. The aim of this study was to assess the effect of irrigation on the content and yield of starch in several potato cultivars grown in different regions of Poland. Field experiments were conducted over the period 2009-2011 in Experimental Stations belonging to the Research Centre for Cultivar Testing in Słupia Wielka. Three factors were analysed: cultivation technology: (a) with irrigation and (b) without irrigation – as the control treatment; potato cultivars (Bellarosa, Cyprian, Owacja and Vineta) and three locations (Masłowice, Szczecin Dąbie, Węgrzce). The study was conducted with the randomized split-plot design with three replications. Permanent fertilization applied in the experiment amounted to: 100 kg N, 43.6 kg P and 124.5 kg K$\cdot$ha^{-1}. Cultivation and plant protection measures were performed in accordance with the principles of good agricultural practice. Irrigation was used when moisture content in the soil layer (0-30 cm) fell below 70% of the field water capacity. Tuber harvest was performed during their full physiological maturity. Tuber yield and the content and yield of starch were determined during harvest. Obtained results were subjected to analysis of variance (ANOVA). Significant effect of the studied factors on starch content and yield was proved. For starch yield, interaction between experimental location and cultivars, technology and irrigation and location, and the years of study and cultivars also appeared to be significant.

Key words: cultivars, location, potato, sprinkling irrigation, starch content

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INTRODUCTION

The use of irrigation significantly increases total and commercial tuber yield [Głuska 1998, 2003, 2004, Mazurczyk *et al.* 2006, Trawczyński 2009], but it has an effect on tuber quality. Irrigation applied at the proper growing period may prevent a decrease in potato tuber quality, causing an increase in starch content and a reduction in the amount of reducing sugars [Lisińska and Leszczyński 1989]. According to Pęksa [1991] as well as Nadler and Heuer [1995], sprinkling irrigation of some potato cultivars, particularly at the end of the growing period, may, however, contribute to a reduction in starch content and dry matter in tubers. In the opinion of Głuska [2003], replenishing water in periods of precipitation deficit provides not only optimal conditions for plant growth, but also improves the technological quality of tubers, i.e. causes their even maturation, ensures a regular tuber shape and stable levels of simple and reducing sugars as well as their even distribution in the parenchyma. Wojdyła *et al.* [2009] and Pińska *et al.* [2009] in turn stated that systems of emergency irrigation did not have a significant effect on the amount of starch in potato tubers, both post harvest and after 6 months of storage. The aim of this study was to estimate if emergency irrigation of early potato cultivars has a significant effect on the content and yield of starch in potatoes grown in various regions of Poland with different climate and soil conditions.

MATERIAL AND METHODS

This study was based on field experiments carried out over the period 2009-2011 at Varietal Assessment Experimental Stations. The study was conducted in the randomized split-plot design in a dependent system, with three replications. The experiment tested three factors: cultivation technology, cultivars and locations. The first order factor was cultivation technology: a) with irrigation; b) without irrigation, as the control treatment. The second order factor was 4 early potato cultivars: Bellarosa, Cyprian, Owacja and Vineta. The third order factor was the crop locations: 3 localities situated in 3 different physiographic regions of Poland: Masłowice, Szczecin-Dąbie and Węgrzce. Masłowice is situated in the south-west part of the Łódź voivodeship, in the district of Wieluń (51^{o}15' N; 18^{o}38' E; H = 174 m a.s.l.). Szczecin Dąbie (58^{o}23' N; 14^{o}40' E; H = 9 m a.s.l.) is located in the West Pomeranian Voivodeship. Węgrzce lies in the Lesser Poland Voivodeship (50^{o}07' N; 19^{o}59' E; H = 285 m a.s.l.).

The soil conditions in these localities are varied (Tables 1, 2). Field experiments were conducted in three types of soil: in Masłowice – in podsol, in Szczecin Dąbie – in muck soil, in Węgrzce – in typical brown soil formed from loess. The agricultural suitability of soil complexes (Table 2) varied from class V in Szczecin Dąbie to class IIIa (Masłowice) to class II (Węgrzce) [Marcinek *et al.* 2011].

Permanent nitrogen-phosphorus-potassium fertilization was applied in the experiment in amounts: 100 kg N, 43.6 kg P and 124.5 kg $K \cdot ha^{-1}$. Nitrogen fertilization was applied in spring in the form of urea 46%. Its amount (N rate) was dependent on the height of the expected yield and the commercial trend of potato utilization. Demands for mineral fertilization with phosphorus and potassium were determined based on the current soil abundance and the quantity of the expected yield. Phosphorus was used in the form of superphosphate 40%, and potassium in the form of potassium salt 60%. Cultivation practices were performed in accordance with the principles of Good Agricultural Practice. Chemical plant protection was used for control of weeds, Colorado potato beetle and potato blight. The doses, times of application and choice of preparations were in accordance with the principles of Good Agricultural Practice and recommendations of IOR-PIB. The crops previous to the potato were spring cereals (spring wheat, spring barley, oats) and pea, mustard and headed cabbage (Table 2). Irrigation was applied at a decrease in moisture content in the arable layer of soil, 0-30 cm, below 70% of the field water capacity. The current soil moisture was checked every day using a tensiometer and according to the instrumented indications, sprinkling was performed at suitable times and doses (Table 3). Reel sprinklers, equipped with a low-pressure spreading console, were used for irrigation. A single dose of water was 16-30 mm.

Table 1. Available phosphorus, potassium and magnesium and pH of the soil in different localities (2009-2011)

Location	Year	Content of available forms, mg·100 g^{-1} in dry mass of soil			pH 1M KCl
		P_2O_5	K_2O	Mg	
Masłowice	2009	37.4	24.2	4.5	6.4
	2010	40.0	21.9	5.6	6.7
	2011	21.4	16.9	6.6	5.7
	mean	32.9	21.0	5.6	6.3
Szczecin Dąbie	2009	18.4	25.0	9.9	7.8
	2010	15.4	19.2	7.6	7.8
	2011	19.2	23.0	8.6	7.7
	mean	17.7	22.4	8.7	7.8
Węgrzce	2009	23.5	24.0	10.0	6.3
	2010	23.0	25.2	9.9	6.0
	2011	24.2	21.9	10.6	6.2
	mean	23.6	23.7	10.2	6.2

source: results of research performed in the Chemical-Agricultural Stations

Table 2. Conditions of field experiments

Soil conditions	Masłowice			Szczecin Dąbie			Węgrzce		
	year								
	2009	2010	2011	2009	2010	2011	2009	2010	2011
Complex of agricultural suitability of the soil	very good rye	very good rye	very good rye	cereal--fodder weak	cereal--fodder weak	weak rye	good wheat	very good wheat	very good wheat
Grading of the soil class	IIIb	IIIa	IIIa	V	V	V	II	II	II
Previous crop	mustard	pea	winter barley	headed cabbage	headed cabbage	spring wheat	spring barley	spring wheat	oats

Tuber harvesting was performed during the full physiological maturity of tubers, i.e. at stage 99 according to the BBCH scale. The area of plots to be harvested was 15 m^2. The total tuber yield was determined during the harvest and representative samples were collected to determine starch content, which was measured in fresh matter of the tubers on hydrostatic scales (according to Reimann-Parow). The obtained results of the analyses were subjected to the tripartite analysis of variation (ANOVA) and *t*-Tukey's multiple tests, at the significance level $\alpha_{0,05}$. Multiple comparison tests enabled a detailed comparative analyses of means, by separation of statistically homogenous groups of means (homogenous groups) and determination of the least significant differences of means, which for Tukey’s tests were determined using HSD (Tukey's Honest Significant Difference) [SAS 9.2 2008, Walesiak and Gatnar 2009].

Table 3. Doses of water and dates of irrigation during the growing season of potato in 2009-2011 in localities: Masłowice, Szczecin-Dąbie and Węgrzce, mm

Location	Year					
	2009		2010		2011	
	date of irrigation	dose of water mm	date of irrigation	dose of water mm	date of irrigation	dose of water mm
Masłowice	30.04.2009	20.0	25.06.2010	20.0	20.05.2011	20.0
			28.06.2010	20.0	23.05.2011	20.0
			30.06.2010	20.0	30.05.2011	20.0
			08.07.2010	20.0	06.06.2011	20.0
					10.06.2011	20.0
					16.06.2011	20.0
Sum	–	20.0	–	80.0	–	120.0
Szczecin Dąbie	10.07.2009	20.0	18.06.2010	20.0	03.06.2011	20.0
			24.06.2010	20.0	09.06.2011	20.0
			30.06.2010	20.0	15.06.2011	20.0
			03.07.2010	20.0	01.07.2011	20.0
			09.07.2010	20.0		
			12.07.2010	20.0		
			17.07.2010	20.0		
			28.07.2010	20.0		
Sum	–	20.0	–	160.0	–	80.0
Węgrzce	15.05.2009	16.0	10.07.2010	16.0	11.06.2011	30.0
	21.05.2009	16.0	17.07.2010	16.0	17.06.2011	30.0
	25.05.2009	16.0			14.07.2011	30.0
	08.06.2009	16.0				
	16.06.2009	16.0				
	12.07.2009	16.0				
	03.08.2009	16.0				
Sum	–	112.0	–	32.0	–	90.0

Meteorological conditions in the years of the study and in each locality were varied. During the growing period (April-August) the values of the Sielianinov hydrothermal coefficient, which is a measure of the effectiveness of precipitation in a given month, were determined. Based on them, the years 2009 and 2011 can be classified as wet, while the year 2010 as very wet (Table 4).

Table 4. Values of the Sielianinov coefficient during the growing season of potato in 2009-2011 from the meteorological stations in Masłowice, Szczecin Dąbie and Węgrzce

Location	Month	2009	2010	2011	Mean
Masłowice	April	0.0	0.8	0.4	0.4
	May	1.5	4.8	0.7	2.3
	June	2.5	0.6	1.0	1.4
	July	1.7	2.6	2.0	2.1
	August	0.8	1.5	0.9	1.1
	mean	1.3	2.1	1.0	
Szczecin Dąbie	April	0.4	0.3	0.4	0.4
	May	1.5	1.4	1.3	1.4
	June	1.4	0.4	1.0	0.9
	July	0.8	0.7	3.1	1.5
	August	1.2	2.6	0.9	1.6
	mean	1.1	1.1	1.3	
Węgrzce	April	0.1	1.0	2.3	1.1
	May	2.2	5.6	1.1	3.0
	June	2.9	3.1	0.9	2.3
	July	1.2	2.2	3.2	2.2
	August	0.9	2.5	1.0	1.5
	mean	1.5	2.9	1.7	
Średnia	April	0.2	0.7	1.0	0.6
	May	1.7	3.9	1.0	2.2
	June	2.3	1.4	1.0	1.6
	July	1.2	1.8	2.8	1.9
	August	1.0	2.2	0.9	1.4
	mean	1.3	2.0	1.3	

Sielianinov coefficient was calculated according to the formula: $\frac{\sum \text{rainfall}}{\sum \text{of the average daily air temperature}}$

where the value of > 0.5 – very dry; 0.5 -1 – dry; 1.1-2 – moist; > 2 – very humid

RESULTS

Cultivation technology, irrespective of other experimental factors, had a significant effect on the content and yield of starch. The use of emergency irrigation contributed both to a decrease in starch content (by 0.7%) and to an increase in yield of this component, on average by 6.2%, i.e. by 0.5 $t \cdot ha^{-1}$ (Table 5).

The studied cultivars did not differ significantly in starch content in the fresh matter of tubers, although a tendency to higher accumulation of this component was observed in tubers of the cultivar Cyprian (Table 5). Starch yield, however, being the vector of starch content and tuber yield, indicated a significant variability among the cultivars. The cultivars Owacja and Cyprian showed higher yields of this component than the cv. Bellarosa. The highest yield of this tuber component was obtained in the cv. Owacja after treatment with irrigation, although this value did not differ significantly from the cultivars Cyprian and Vineta. The use of sprinkler irrigation in combination with the genetic properties of the cultivars contributed to an increase in starch yield, as compared with the control values, by 5.5% in cv. Cyprian and 7.5% in the cv. Owacja. Those values, however, appeared to be statistically insignificant (Table 5).

Table 5. The content and yield of starch depending on the cultivars and cultivation technology

Cultivar	Starch content, %			Yield of starch, $t \cdot ha^{-1}$		
	Cultivation technology					
	A*	B**	mean	A*	B**	mean
Bellarosa	12.2	11.8	12.0	7.25	7.68	7.47
Cyprian	13.5	12.5	13.0	8.32	8.78	8.55
Owacja	12.9	12.1	12.5	8.25	8.87	8.56
Vineta	13.0	12.5	12.8	8.02	8.48	8.25
Mean	12.9	12.2	12.6	7.96	8.45	8.21
$HSD_{0.05}$						
technology			0.6			0.41
cultivar			ns***			0.82
cultivar × technology			ns			ns

* A – without irrigation; **B – with irrigation
*** ns – not significant at $p_{0,05}$

The content and yield of starch in tubers were modified by the meteorological conditions in the years of the study. The highest starch yield was recorded in 2009, with a dry April and a humid period in May-July, whereas the lowest yield was in the very wet 2010 (Table 6). Experimental location in combination with conditions in the years of the study had a significant effect both on the content and yield of starch. In Węgrzce, in a very good soil (loess), the highest starch content was obtained, but the highest yield of this component was obtained in Masłowice, in podsol of average quality. The lowest starch content and yield was obtained in Szczecin Dąbie, in the weakest soil (sandy loam). The significantly higher starch yield in Masłowice was obtained only in the years 2009 and 2011, which were similar in respect of total precipitation. In the very wet 2010, the value of starch yield did not differ among the localities (Table 6).

Table 6. The content and yield of starch in potato tubers depending on the location and years of testing

Location*	Starch content, %				Yield of starch, $t \cdot ha^{-1}$			
	year			mean	year			mean
	2009	2010	2011		2009	2010	2011	
Masłowice	12.5	11.9	12.7	12.4	10.12	7.30	10.16	9.19
Szczecin Dąbie	12.5	12.1	11.9	12.2	7.53	6.94	7.63	7.37
Węgrzce	14.2	12.3	13.1	13.2	9.50	6.55	8.10	8.05
Mean	13.1	12.1	12.6	12.6	9.05	6.93	8.63	8.20
$HSD_{0.05}$								
years				0.9				0.62
location				0.9				0.62
location × years				ns				1.86

* explanations as in Table 5

The effect of irrigation on starch yield depended on the study locations (Table 7). The most favourable effect of this practice was obtained in Masłowice, whereas the lowest value for this effect was observed in Szczecin Dąbie. The increase in starch yield after irrigation ranged from 3.8% to 8.0%, when compared with the control starch yield. The smallest increase in starch yield after irrigation, when compared to the control without irrigation, was observed on typical brown soil formed from loess in Węgrzce and amounted to 3.8%, i.e. 0.3 t·ha-1, whereas the highest effect of irrigation was 7.6%, i.e. 0.7 t·ha^{-1} after irrigation treatment, in conditions of podsol, in Masłowice (Table 7).

Table 7. The content and yield of starch in potato tubers depending on the technology and location of the research

Location*	Starch content, %			Yield of starch, t·ha^{-1}		
	Cultivation technology					
	A	B	mean	A	B	mean
Masłowice	12.9	11.8	12.4	8.86	9.53	9.19
Szczecin Dąbie	12.5	11.8	12.2	7.11	7.63	7.37
Węgrzce	13.3	13.1	13.2	7.90	8.20	8.05
Mean	12.9	12.2	12.6	7.96	8.45	8.20
$HSD_{0,05}$						
technology			0.6			0.41
location			0.9			0.62
technology × location			ns			1.20

* explanations as in Table 5

The yield of starch depended also on the response of cultivars to meteorological conditions in the years of the study (Table 8). A significant differentiation of starch yield, depending on the cultivar, was observed in 2011. The cultivar Owacja formed a significantly higher starch yield than cv. Bellarosa, whereas the cultivars Bellarosa, Cyprian and Vineta did not differ significantly from each other in respect of starch yield (Table 8).

Table 8. Impact of cultivars and years on the content and yield of starch

Cultivar*	Starch content, %				Yield of starch, t·ha^{-1}			
	year			mean	year			mean
	2009	2010	2011		2009	2010	2011	
Bellarosa	12.6	11.6	11.9	12.0	8.54	6.08	7.77	7.46
Cyprian	13.4	12.5	13.0	13.0	9.29	7.68	8.68	8.55
Owacja	13.2	11.6	12.7	12.5	9.63	6.64	9.41	8.56
Vineta	13.0	12.5	12.6	12.7	8.76	7.33	8.66	8.25
Mean	13.1	12.1	12.6	12.6	9.06	6.93	8.63	8.21
$HSD_{0,05}$								
years				0.6				0.41
cultvars				0.9				0.82
cultivars × years				ns				2.48

* explanations as in Table 5

The use of linear regression enabled a determination of the optimal rate of irrigation required under Polish conditions for maximum starch yield. The amount of this rate was estimated at 98 mm. The determination coefficient of regression equation was 99% (R^2 = 0.99) and it can be regarded as highly reliable (Fig. 1).

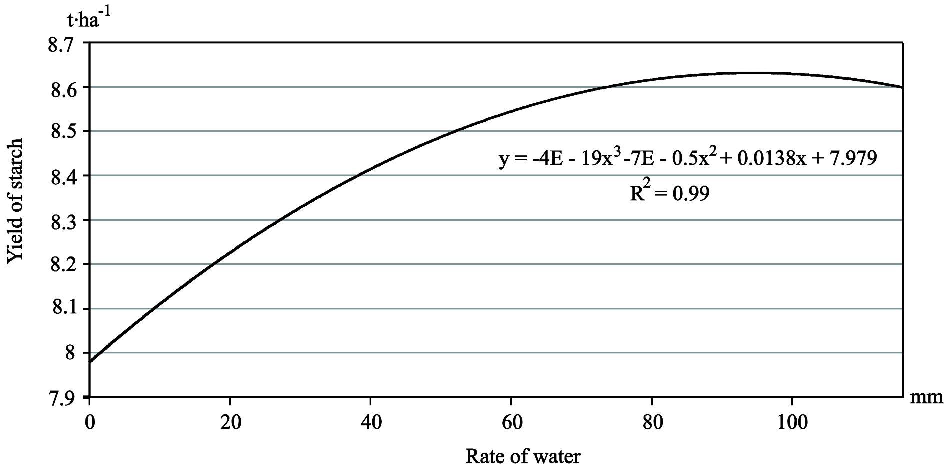

Fig. 1. Dependence of the yield of starch on irrigation

DISCUSSION

Sprinkler irrigation of potato plantations in Poland when there is insufficient precipitation during the growing period or when its distribution is uneven is, apart from mineral fertilization, the most significant factor determining the content and yield of starch in potato [Pińska *et al.* 2009, Trawczyński 2009, Wojdyła *et al.* 2009, Ossowski *et al.* 2013, Rolbiecki *et al.* 2015, Wszelaczyńska *et al.* 2015]. This is confirmed by the authors own study. The study indicates that the use of emergency irrigation resulted in a decrease in starch content on the studied cultivars, but the starch yield in these conditions increased by 5.5 to 7.5%, depending on the cultivar, and by 3.8-8.0%, depending on the location, in relation to the control treatment. In the opinion of Borówczak and Rębarz [2006], Pińska *et al.* [2009], Supit *et al.* [2010] and Rzekanowski *et al.* [2013], supplementary irrigation contributes to a decrease in dry matter and starch content in potato tubers. The present study confirms this view; whereas Ossowski *et al.* [2013] stated that irrigation of a potato plantation does not differentiate the levels of dry matter and starch, but it reduces the total sugar content in potato tubers, which is favourable for potato intended for processing for chips. Ballmer *et al.* [2012] indicated that in two out of three years potato irrigation contributed to a higher content of starch in tubers, as compared with plantations not irrigated. In the opinion of Głuska [1998, 2004], to obtain the starch content useful for food processing, in a moderate climate early cultivars require from 250 to 300 mm of precipitation during the growing period with a proportional distribution from April to the end of July. In light soils with a small content of humus the water needs of potato are higher by 20% due to the low degree of water retention [Głuska 2003, Mazurczyk *et al.* 2006, Pińska *et al.* 2009, Osowski *et al.* 2013].

Reducing the differences between plant needs and the amount of precipitation available may occur through genetic activities – growing a cultivar resistant to water stress [Styszko *et al.* 2001, Rolbiecki *et al.* 2015]. Domínguez *et al.* [2013] stated that a water deficit during the growing period caused a 12% loss of tuber plasticity, but at the same time the content of tuber dry mass increased by 1-2% in relation to the control treatment.

Analysis of regression allowed us to draw a 3rd degree curve, in the case of starch yield, and thus to determine the optimum irrigation level in respect of this characteristic. Rababah [2016] showed that a polynomial curve is the best approximation in the case of dependence of the second degree, similar to an arc. It is constructed in such a way that the error function is a 4th degree Chebyshev polynomial. The dependence indicated in the conducted study shows the effectiveness and simplicity of this method for the function approximation and meets the conditions of the best homogenous approximation, giving the highest possible accuracy.

Sprinkler irrigation is a method increasing profitability and a way to provide high quality tubers in potato production [Muhammad *et al.* 2015].

CONCLUSIONS

1. Irrigation of potato plantations contributed to a decrease in starch content in tubers, but at the same time it caused a significant increase in yield of this component in relation to the control treatment.
2. Irrigation effect, in respect of starch content, depended on the study location. The most favourable effect was obtained in Central Poland, whereas the least favourable was in the conditions of the West Pomeranian region.
3. Starch yield was modified by the properties of the studied cultivars. The cultivars Owacja and Cyprian were characterized by a significantly higher yield of this component than cv. Bellarosa.
4. Significant differentiation of starch yield, depending on the cultivar, was observed only in the humid year.
5. The optimal rate of irrigation of early potato cultivar for Poland, in respect of starch yield, was determined based on 3 locations and amounted to 98 mm.

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WPŁYW NAWADNIANIA NA ZAWARTOŚĆ I PLON SKROBI WCZESNYCH ODMIAN ZIEMNIAKA W RÓŻNYCH REGIONACH POLSKI

Streszczenie. Celem badań była ocena wpływu nawadniania kilku odmian ziemniaka uprawianych w różnych regionach Polski na zawartość i plon skrobi. Eksperymenty polowe przeprowadzono w latach 2009-2011 w Stacjach Doświadczalnych Oceny Odmian. Analizowano trzy czynniki: technologie uprawy: (a) z nawadnianiem i (b) bez nawadniania – jako obiekt kontrolny; odmiany ziemniaka (Bellarosa, Cyprian, Owacja i Vineta) oraz trzy lokalizacje (Masłowice, Szczecin Dąbie, Węgrzce). Badania prowadzono metodą losowanych podbloków, w układzie zależnym, w trzech powtórzeniach. W doświadczeniu stosowano stałe nawożenie w wysokości: 100 kg N, 43,6 kg P i 124,5 kg $K \cdot ha^{-1}$. Zabiegi uprawowe i ochrony roślin prowadzono zgodnie z zasadami dobrej praktyki rolniczej. Nawadnianie stosowano przy spadku wilgotności w warstwie gleby 0-30 cm poniżej 70% polowej pojemności wodnej. Zbiór bulw wykonano w okresie ich pełnej dojrzałości fizjologicznej. W czasie zbioru oznaczono plon bulw oraz zawartość i plon skrobi. Uzyskane wyniki poddano analizie wariancji (ANOVA). Udowodniono istotny wpływ badanych czynników na zawartość i plon skrobi. W przypadku plonu skrobi istotne okazało się też współdziałanie lokalizacji doświadczenia i odmian, technologii z nawadnianiem i lokalizacji oraz lat badań i odmian.

Słowa kluczowe: deszczowanie, lokalizacja, odmiany, skrobiowość, ziemniak

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