INFLUENCE OF PLUVIO-THERMAL CONDITIONS, GROWTH BIOSTIMULATORS AND HERBICIDE ON DRY MATTER CONTENT AND STARCH IN EDIBLE POTATO TUBERS

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Abstract. In the changing climate conditions, the knowledge of the impact of weather factors on the quality of crop plant yield is of great significance. The field research was conducted in 2015-2017 in the area of eastern Poland in Biała Podlaska commune, in Lublin Voivodship, on light, acidic soil. The purpose of the study was to assess the impact of meteorological conditions and cultivation methods with the application of growth biostimulators and herbicide on dry matter and starch content in tubers of three edible potato cultivars. The examined factors were: I. cultivars of edible potato – Bellarosa, Owacja, Vineta, II. methods of using growth biostimulators: GreenOk-Uniwersal Pro and Asahi SL, as well as their combination with herbicide Avatar 293 ZC. A close relationship between pluvio-thermal conditions, cultivation methods and the percentage content of dry matter and starch in edible potato tubers was proven as a result of the conducted study. The highest concentration of the discussed components was obtained in 2015, in which there was a shortages of precipitation. The methods of cultivation employed in the experiment had a positive impact on the rise in dry matter and starch content in potato tubers in comparison with the control object. The highest dry matter (on average 23.31%) and starch content on average 16.31% in potato tubers was obtained after the application of biostimulator GreenOk-Universal Pro and herbicide Avatar 293 ZC (object 4).
Keywords: *Solanum tuberosum L., weather conditions, Asahi SL, GreenOk-Universal, Avatar 293 ZC, nutrients*

Introduction

In the XXI century farming limitation of use of mineral fertilizers and chemical agents for plant protection, is strived for and more and more often preparations of natural origin are used (Sawicka et al., 2016). In plant production, pro-ecological cultivation methods are being researched. These trends are also visible in potato cultivation. Potato (*Solanum tuberosum* L.) is one of the main cultivated plants not only in Poland, but also worldwide. It is cultivated in over 130 countries and consumed every day by more than a billion people (Ezekiel et al., 2013; Bishwoyog and Swarnima, 2016).

Dry matter and starch content is one of the most important features determining the nutritional and technological value of potato tubers (Ramezani and Aminlari, 2004; Storey, 2007; Murnice et al., 2011).

Edible potato tubers contain about 75% of water and 17-25% of dry matter after harvest. Dry matter content is of great significance, as it determines nutritional value, taste value, consistency of raw and processed tubers, as well as resistance to mechanical damage (Wierzbicka, 2011). Depending on dry matter content, potato cultivars can be divided into 3 groups: with low <20%, medium 20-23% and high content >23% (Wierzbicka, 2012).

The main component of potato tubers' dry matter is starch, its content in dry matter equals from 60 to 80% (Lutaladio and Castaldi, 2009). Starch is a natural polymer

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found in all plant organisms, further to being an indirect product of photosynthesis, hence it is called a renewable and biodegradable material. It more and more often replaces polymers of petrochemical origin in biotechnological processes and the chemical industry. Potato starch is found mainly in the form of grains with a diameter of 20 to 60 µm. Large grains are very useful in the processing of starch into glucose and dextrins, while small grains – in the production of starch-polyethylene concentrate (Leszczyński, 2004; Kołodziejczyk et al., 2013). Depending on the cultivar, edible potato tubers contain on average from 11.0 to 16.0% of starch, while starch potato tubers from 18.0 to 27.0%, respectively. Starch content is very significant on account of the usefulness of tubers in gastronomy and processing (Pobereżny and Wszelaczyńska, 2011). The impact of starch on the consistency of boiled tubers is connected with its swelling, which causes the destruction of cell structures (Lamberti et al., 2004). The caloric value of starch is the result of it being converted to glucose under the influence of enzymes, thus being quickly digested in the human organism (Leszczyński, 2012).

Dry matter and starch content in *Solanum touberosum L*. tubers is determined by the genetic features of cultivars which are the result of biological progress, the level of agrotechnology and habitat conditions, especially the course of pluvio-thermal conditions during plant growth. Currently, in climate change conditions, the knowledge of the impact of weather factors on the growth and development of crop plants and the quality of yield is of great significance. According to Tosheva and Alexandrova (2004), Shahbazi et al. (2009), Usowicz et al. (2014), Radzka and Rymuza (2015) agro-climatic factors, further to topographical and soil factors, define the kind of agricultural production and its efficiency. Meteorological factors can determine the yielding variability of potato in 40%, and with unfavourable weather conditions even in 50% (Kołodziejczyk, 2013, 2014b). Potato’s water requirements in conditions of proper technology depend mainly on the duration of the growing season, the area of cultivation and the kind of soil (Kolbarczyk and Kolbarczyk, 2009). In Polish early potato cultivars have the highest yield with the precipitation of 250-300 mm (Nowak, 1989; Dzielżyc et al., 2012). The rise in air temperature of only 1-2°C increases crop plants’ water requirements in Polish conditions on average by 6.3-14.5 mm on a monthly basis (Ziernicka, 2004).

Agriculture in the 21st century still needs modern means of production that will allow moderating the unfavourable effect of meteorological conditions on plant yielding and thus, stimulate plants to grow and develop more effectively (Matysiak et al., 2011; Sawicka et al., 2011). A solution can be the introduction of natural or synthetic preparations, classified as biostimulators or growth stimulators to plant production, (Paradikovic et al., 2011; Kołodziejczyk, 2014a). Growth biostimulators are defined as preparations supporting the natural vital processes of plants and increasing the resistance of plants to stressful conditions, are preparations friendly for the environment and consumer’s (Sawicka et al., 2016; Pszczółkowski and Sawicka, 2018). However, the possibility of using these preparations in practice is not fully examined yet and the results of the research are often ambiguous and fragmentary.

Therefore, the purpose of the study was to assess the impact of pluvio-thermal conditions and cultivation methods with the application of growth biostimulators and herbicide on dry matter and starch content in tubers of three early edible potato cultivars.

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Materials and methods

Location of the experiment

The field experiment was conducted in 2015-2017 in eastern Poland, in the Biała Podlaska Commune (52°02'N; 23°07'E), located in the Lublin Voivodeship, on acidic light soil (*Figure 1*).

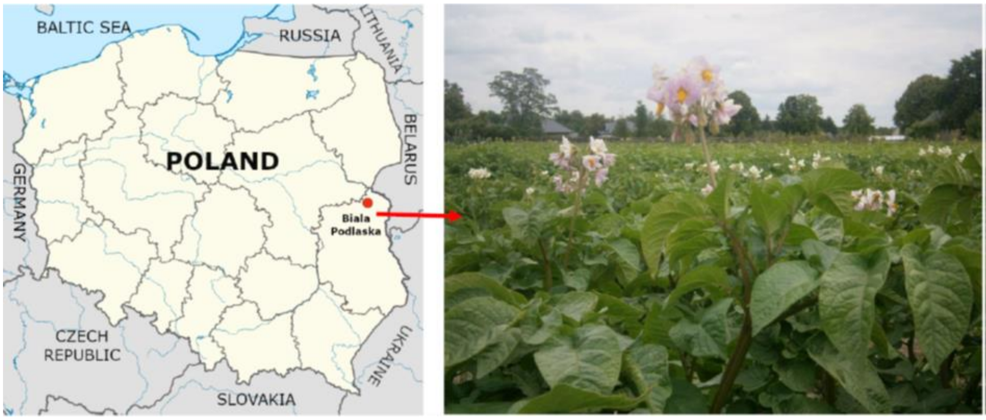

Figure 1. *Location of the experiment*

Experiment and plant material

A three-year experiment was performed in the split-plot system, in three replications. Two factors were examined in the experiment:

I. Factor – three early edible potato cultivars: Bellarosa, Owacja, Vineta.

II. Factor – methods of application of biostimulators and herbicide:

1. Standard object – mechanical treatment (without biostimulators and herbicide).
2. From sprouting of potato plants – mechanical treatment and after sprouting – GreenOK Universal–PRO bioactivator, three times to leaves: at a dose of 0.10 dm^3 ha^{-1} – peak–end of sprouting (phase BBCH 13-19) + 0.15 dm^3 ha^{-1} – covering of interrows (phase BBCH 31-35) + 0.15 dm^3 ha^{-1} – flower bud break (phase BBCH 51-55).
3. From sprouting of potato plants – mechanical treatment, and after sprouting – Asahi SL bioactivator, three times to leaves at a dose of 0.50 dm^3 ha^{-1} – peak–end of sprouting (phase BBCH 13-19) + 0.50 dm^3 ha^{-1} – covering of interrows (phase BBCH 31-35) + 0.50 dm^3 ha^{-1} – flower bud break (phase BBCH 51-55).
4. From sprouting – mechanical treatment, and after the final shaping of ridges and just before sprouting Avatar 293 ZC herbicide at a dose of 1.5 dm^3 ha^{-1} (phase BBCH 00-05). After sprouting – three applications of GreenOK Universal–PRO bioactivator at a dose of 0.10 dm^3 ha^{-1} – peak–end of sprouting (phase BBCH 13-19) + 0.15 dm^3 ha^{-1} – covering of interrows (phase BBCH 31-35) + 0.15 dm^3 ha^{-1} – flower bud break (phase BBCH 51-55).
5. From sprouting – mechanical treatment, and after the final shaping of ridges before sprouting of potato plants – Avatar 293 ZC herbicide at a dose of 1.5 dm^3 ha^{-1} (phase BBCH 00-05).

The biostimulator Asahi SL contains three active ingredients from the nitrophenol group: sodium para-nitrophenol – 0.3%, sodium ortho-nitrophenol – 0.2% and sodium

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5-nitroguaiacol – 0.1%. These substances occur naturally in plant cells and participate in many metabolic processes. The preparation is known in the USA by its trade name as Chaperone, and in Europe as Atonik (Babuška, 2004). The preparation GreenOK Universal-PRO, according to the producer's information (Latvian Institute of Humic Substances), is a liquid organic fertilizer with biostimulating effect, consisting of humic substance concentrate (20 g dm^3) and elements NPK (0.13-0.09-0.7%). The herbicide Avatar 293 ZC applied in the experiment is a preparation in the form of capsule suspension. It is applied to soil, before sprouting of plants on moist soil. It contains clomazone (a substance from the isoxazolidinone group) – 60 g dm^3 (5.13%) and metribuzin (a substance from the triazinone group) – 233 g dm^3 (20.64%).

Each year in autumn, before establishment of the experiment, natural fertilization was used at a dose of 25 t ha^{-1}, as well as mineral fertilization with phosphorus 44.0 kg P ha^{-1} (triple superphosphate 46%) and potassium 124.5 kg K ha^{-1} (potassium salt 60%), and during spring – nitrogen fertilization (ammonium nitrate 34%) at a dose of 100 kg N per 1 ha. Potato tubers were planted in the second decade of April (in 2015 and 2016) and in the third decade of April (in 2017). Protection treatment against diseases and pests was used according to needs, in accordance with the plant protection recommendations. Harvest was performed in the phase of full technological maturity of tubers.

The content of dry matter in fresh tuber mass was determined by means of the oven-dry method, that of starch on Reimann's balance.

Data analysis

The results of the study were subjected to the statistical analysis by means of StatSoft Inc. STATISTICA v.10 using the method of the analysis of variance. Significance of variability sources was tested by means of the Fisher-Snedecor F test, and the assessment of significance of differences at the significance level $p = 0.05$ between the compared means using Tukey's range test was performed. In order to determine the relationship between pluvio-thermal conditions and dry matter and starch content in potato tubers, Pearson's r correlation coefficients were measured, and the significance at the confidence level 0.05 was tested with Student's *t* test. Statistical calculations were performed on the basis of average values from three years and means for three potato cultivars.

Weather conditions

Weather conditions in the growing seasons of 2015-2017 (years of research conduct) were characterized against the background of the years 1981-2010 on the basis of deviations of average monthly air temperature (°C) and the sum of precipitation (mm). The values of hydrothermal Sielianinov coefficient were measured (*Equation 1*), (*Table 1*) (Chereszkowicz, 1979; Skowera and Puła, 2004; Skowera et al., 2014).

$$K = \frac{P}{0.1\sum t} \tag{Eq.1}$$

K – value of hydrothermal coefficient,
P – sum of monthly precipitation,
$\sum t$ – monthly sum of average daily air temperature >0°C.

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Values of air temperature and precipitation sum from the growing period of 2015-2017 years and the years between 1981-2010 came from Meteorological Station in Cicibór Duży (51°19'N; 22°16'E), located at a distance of 6 km from Biała Podlaska and belonging to the Experimental Station of the Central Research Facility of Varieties of Cultivated Plants (COBORU) in Słupia Wielka.

During the conduct of research diverse pluvio-thermal conditions occurred (*Table 1-2, Figures 2-3*). Growing season of 2015 was characterized by a high shortage of precipitation in the period from June to August (that is during flowering, growth of tubers and crop accumulation), and the month of August 2015 was extremely dry, deviations from the average multi-year air temperature in that month amounted to +3.7°C, while precipitation in comparison to the years 1981-2010 was lower by 60 mm, these months in 2017 were similar but the drought turned out to be milder. In 2016, in the period of the largest demand of potato for precipitation, thermal-precipitation conditions were more beneficial when compared to the remaining years of research (*Table 1-2, Figures 2-3*).

Table 1. *Hydrothermal conditions in potato's growing season (mean for years 2015-2017)*

Month/ Year	***Sielianinov hydrothermal coefficient *(K)***					
	2015		**2016**		**2017**	
IV	1.43	optimal	1.19	quite dry	2.68	very humid
V	2.28	humid	0.47	very dry	0.93	dry
VI	0.59	very dry	1.53	optimal	1.97	quite humid
VII	0.80	dry	1.97	quite humid	1.24	quite dry
VIII	0.11	extremely dry	0.48	very dry	0.66	very dry
IX	1.66	quite humid	0.26	extremely dry	2.37	extremely humid

*Sielianinov hydrothermal coefficient *(K)* – formula as in research methodology;
**Month's classification: extremely dry $K \leq 0.4$, very dry $0.4 < K \leq 0.7$, dry $0.7 < K \leq 1.0$, quite dry $1.0 < K \leq 1.3$, optimal $1.3 < K \leq 1.6$, quite humid $1.6 < K \leq 2.0$, humid $2.0 < K \leq 2.5$, very humid $2.5 < K \leq 3.0$, extremely humid
$K > 3.0$ (Chereszkowicz, 1979; Skowera and Puła, 2004; Skowera et al., 2014)

Table 2. *Mean air temperature (°C) and precipitation sum (mm) (in the years 1981-2010)*

Meteorological factor	**Months**					
	IV	**V**	**VI**	**VII**	**VIII**	**IX**
Air temperature (°C)	7.9	13.9	16.6	18.8	17.9	12.7
Precipitation sum (mm)	35	59	66	70	67	54

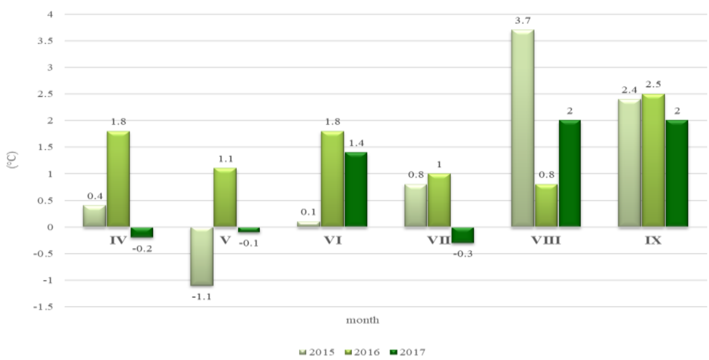

Figure 2. *Deviations of the atmospheric air temperature in April-September (2015-2017) from the long-term average value (1981-2010)*

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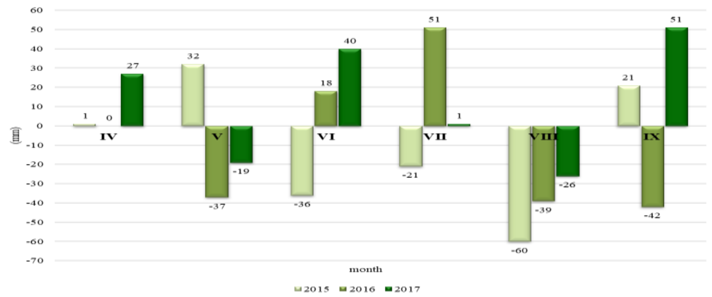

Figure 3. *Deviations of the sum of monthly precipitation in April-September (2015-2017) from the long-term average value (1981-2010)*

Results and discussion

The results of the study proved that there is a close relationship between pluvio-thermal conditions, cultivation methods and the percentage content of dry matter and starch in edible potato tubers.

The calculated Pearson's *r* correlation coefficients proved that there are significant negative relationships between the precipitation sum, Sielianinov hydrothermal coefficient, and dry matter and starch content in potato tubers (*Table 3*). A significant negative relationship between average precipitation sum in the years when the study was carried out and average dry matter and starch content in potato tubers was confirmed. In the case of dry matter content, the correlation coefficient was: $r = -0.62$ (strong correlation, substantial relationship), and in the case of starch content: $r = -0.56$ (moderate correlation, significant relationship). It means that the rise in precipitation sum had a significant impact on the drop in the percentage content of dry matter and starch in edible potato tubers.

Table 3. *The values of Pearson's r correlation coefficients between the percentage content of dry matter and starch in potato tubers and pluvio-thermal conditions (mean from three years and cultivars)*

Variable *X*	**Variable *Y***	***r (X. Y)*****	***r²***	***t***	***p***
dry matter content (%)	air temperature (°C)	0.20	0.04	1.37	0.1775
	precipitation (mm)	-0.62	0.39	-5.22	0.0000*
	Sielianinov hydrothermal coefficient *(K)*	-0.59	0.35	-4.78	0.0000*
starch content (%)	air temperature (°C)	0.24	0.06	1.61	0.1154
	precipitation (mm)	-0.56	0.31	-4.42	0.0001*
	Sielianinov hydrothermal coefficient *(K)*	-0.54	0.29	-4.16	0.0002*

R (X. Y) – Pearson's *r* correlation coefficient, r^2 – coefficient of determination, *t* – the value of Student's t test, *p* – significance level, *significant differences at $p<0.05$, **the ranges of correlation according to Sobczyk (2011): below 0.2 – very weak correlation (no relationship), 0.2-0.4 – weak correlation (clear relationship) 0.4-0.6 – moderate correlation (significant relationship), 0.6-0.8 strong correlation (substantial relationship), 0.8-0.9 – very strong correlation (very substantial relationship), 0.9-1.0 – full relationship

A significant negative relationship between Sielianinov hydrothermal coefficient (K) and dry matter and starch content in tubers was proven as well (*Table 3*). In the case of

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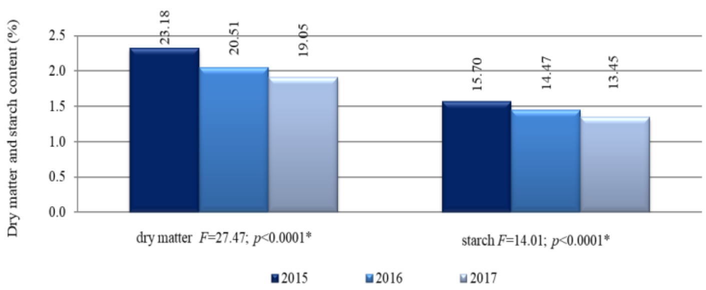
these features, a linear negative correlation in the range of moderate correlation (significant relationship) was obtained.

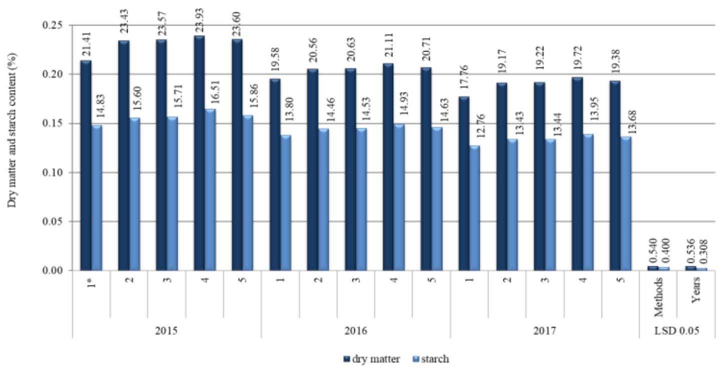
Analysing the impact of air temperature on dry matter and starch content, no significant statistical differences were proven, but instead, weak linear positive correlation (clear relationship) was found (*Table 3*). Other authors' studies also confirm the significant impact of pluvio-thermal conditions in particular periods of the growing season on dry matter and starch content in potato tubers. According to Skowera and Puła (2004), Wierzbicka (2011), Kołodziejczyk (2014b) substantial amounts of precipitation were a factor that significantly limited the storage of dry matter and starch in tubers. However, in the research conducted by Pszczółkowski et al. (2016) meteorological conditions with very humid May, June, July and dry August created favourable conditions for obtaining higher starch content in tubers. Wierzbicka (2012) and Kołodziejczyk (2014b) stated that air temperature, beside moisture conditions, has a significant impact on the storage of dry matter and starch in tubers, and especially warm and dry months late in the growing season create favourable conditions for the storage of dry matter and starch. Kalbarczyk and Kalbarczyk (2009) proved that the optimal air temperature allowing potato plants to grow and develop should be at the level of 15.2^{o}C.

Within own research significantly larger contents of dry matter and starch in edible potato tubers in dry growing season of 2015 than in the remaining years of research in which greater volumes of precipitation were recorded (*Figures 4-5*).



F - the value of *F* test in the analysis of variance, *– significant differences at $p<0.05$

Figure 4. *Average dry matter and starch content (%) in potato tubers in research years(2015-2017)*



* – labelling as in research methodology

Figure 5. *Average dry matter and starch content (%) in potato tubers depending on cultivation methods and research years*

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This study proved that the cultivation methods applied in the experiment with the use of growth biostimulators and herbicide had a significant impact on dry matter and starch content in potato tubers (objects 2.-5.) in comparison with only mechanical treatment (objects 1.) (*Figure 6*).

The highest content of dry matter as well as starch was found in the tubers harvested from objects 4. where mechanical treatment was used from sprouting of plants and Avatar 293 ZC herbicide at a dose of 1.5 dm^3 ha^{-1} just before sprouting, and GreenOK Universal–PRO bioactivator at a dose of 0.10 dm^3 ha^{-1} + 0.15 dm^3 ha^{-1} + 0.15 dm^3 ha^{-1} three times after sprouting; and from objects 5. where mechanical treatment was used and then Avatar 293 ZC herbicide at a dose of 1.5 dm^3 ha^{-1} (*Figure 6*). The research of Sawicka (2003), Czeczko and Mikos-Bielak (2004), Sawicka and Krochmal-Marczak (2009), Kołodziejczyka (2016) also confirms the rise in dry matter and starch content in potato tubers in the conditions of using growth biostimulators. However, according to Maciejewski et al. (2007), the applied biostimulators Asahi SL and Atonik, did not have any impact on dry matter and starch content in potato tubers. The research of Gugała and Zarzecka (2010) indicated a positive impact of herbicides on the rise in dry matter and starch content in potato tubers. The mechanical and chemical treatment applied by these authors had a positive impact on the rise in dry matter and starch content in potato tubers in comparison with only mechanical treatment. However, in the study of Barabaś and Sawicka (2016), dry matter and starch content did not depend on potato cultivation method.

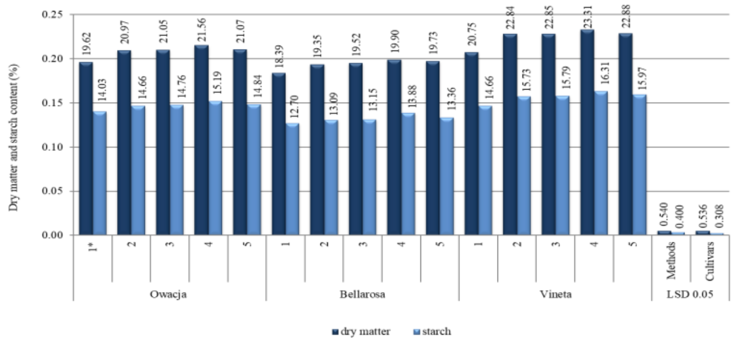

Figure 6. *Average Dry matter and starch content (%) in potato tubers depending on cultivation methods and planted potato cultivars (mean for years 2015-2017)*

The study proved that the cultivars' genetic features had a significant impact on dry matter and starch content in tubers (*Figure 6*). The highest average dry matter and starch content was stored in the Vineta cultivar (from 20.75% to 23.31% dry matter content and from 14.66% to 16.31% starch content), and the lowest in the Bellarosa cultivar (from 18.39% to 19.90% dry matter content and from 12.70% to 13.88% starch content) (*Figure 6*). According to other authors as well, the content of nutrients in potato tubers depended mainly on the cultivars' genetic features (Zarzyńska and Goliszewski, 2006; Abong et al., 2010; Krzysztofik and Skonieczny, 2010). However, Bombik et al. (2003) indicated that not only the genotype (cultivar) but also the environment and the genotype-environment interaction had a significant impact on most of the analysed quality features of potato tubers. Rytel (2004) and Lisińska (2006) stated that 20-22% content of dry matter and 15-17% content of starch determine the

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usefulness of cultivars to being processed into chips, and in the case of crisps, the values should be: 21-25% of dry matter and 16-20% of starch, respectively. The high content of dry matter in tubers causes lower fat absorption during technological processes, which makes the final product healthier for the consumer.

Conclusions

The content of dry mass and starch in edible potato tubers was determined by thermal-precipitation conditions. In the years characterized by a larger sum of precipitation in the growing period, potatoes gathered less dry mass and starch in comparison to the warm and dry growing season of 2015. Application in the experiment of the treatment methods with the use of GreenOk-Uniwersal Pro and Asahi SL biostimulators and their combination with Avatar 293 ZC herbicide positively impacted the increase of content of dry mass and starch in potato tubers in comparison to the tubers gathered from the control object. Moreover, genetic features of the cultivars had a significant impact on the content of dry mass and starch. The largest concentration of the discussed components was found in Vineta cultivar.

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