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THE ECONOMIC EFFICIENCY OF GROWING SWEET POTATO (*IPOMOEA BATATAS* L. [LAM.]) IN POLISH SOIL AND CLIMATE CONDITIONS

Key words: sweet potato, cultivation technologies, marketable yield, cultivars, direct costs, profitability index

ABSTRACT. The aim of this research was to determine the economic efficiency of sweet potato production in Polish conditions (49°49′ N, 21°50′ E). The study was based on the results of a 3-year (2017-2019) field experiment conducted in slightly acidic brown earth. The experiment used the random subblocks method, in which the main experimental factors were cultivation technologies: A) traditional, with no cover, B) with the use of PP spunbond nonwoven. Secondary factors included 5 cultivars of sweet potato of all earliness classes (Goldstar, Carmen Rubin, Satsumo Imo, Beauregard, White Triumph). Constant organic and mineral fertilization was used, and cultivation was carried out in accordance with normal agricultural practice. The propagating material included rooted cuttings of sweet potato from *in vitro* propagation, planted with 50 x 75 cm spacing. The economic effect of production was determined by all experimental factors. The profitability of production was increased by the use of PP spunbond nonwoven. The most beneficial economic factors were achieved when growing the Beauregard cultivar, and the least – when growing White Triumph. The largest cost of sweet potato commercial production were sweet potato cuttings, which amounted to 56%, and the smallest – plant protection products – 1% of direct costs per 1 ha of crops. Sweet potato production in Polish soil and climate conditions between 2017–2019 turned out to be cost-effective.

INTRODUCTION

Due to global warming in Europe and the World, sweet potato, sometimes referred to as yam (*Ipomoea batatas* L. [Lam.]), is becoming an alternative crop grown in Poland. This has been confirmed by much research [Krochmal-Marczak et al. 2010, 2014, 2018, 2019]. Sweet potato is grown in 117 countries in the World on a surface area of 8.6 million ha, yielding 105.2 million tons, with an efficiency of 12.20 Mg/ha while global production reached 112.8 million tons (112,835,316 tons) in 2017 [FAO 2018, FAOSTAT 2019]. Africa is the World's largest region where sweet potato is grown with an estimated value of 27.7 million tons (27,720,784 tons, 2017 estimate) and accounted for 24.57% world share in 2017. Moreover, most commercial production (95%) comes from developing countries, with China's share of 67.1% [FAO 2018, FAOSTAT 2019]. Like in the case of other crops, the profitability of sweet potato production is closely related to yield and the sales price of raw material (tubers) [Gołaś 2016, Prakash et al. 2016, Baranowska et al. 2017, Musilová et al. 2017]. According to Marek Gugała et al. [2014], the indication for the commercial production of roots and tubers is to obtain a profit adequate to expectations, and the decision to continue or discontinue cultivation should be preceded by a profitability analysis. For several years, intensive work has been conducted in order to introduce this plant into Polish climate and soil conditions. In a temperate climate, this species is an annual with good adaptability. Tubers, rich in nutrients, are consumed after cooking, frying or baking, whereas aerial parts can be used as valuable feed for animals or raw material for bioethanol or biogas production [Muhammad, Ginting 2014, Prakash et al. 2016]. Sweet potato tubers also have high technological potential. In developing countries, all parts of this plant are valued and used in multiple sectors of food and pharmaceutical industries [Tan 2015, Mekonnen et al. 2015, Szarvas et al. 2017]. According to Remya Monhanraj and Subha Sivasankar [2014] as well as Adrienn Szarvas et al. [2019], the sweet potato is a vegetable with broad applicability, mainly used to enrich the everyday diet, as well as a valuable medicinal plant with anti-inflammatory, anti-cancer and antidiabetic properties, which can be a valuable raw material for the pharmaceutical industry. Sweet potato tubers can also be used in food processing to produce sugar, flour, pasta, desserts, alcohol, and thanks to a high content of vitamins, macro- and microelements – to produce dietary supplements. Due to the high nutritional value of tubers, the species is becoming more and more popular in Poland, but there are still no up-to-date studies of the production costs of the sweet potato. However, economic efficiency must be checked to ensure sustainable development [Kassali 2011]. Therefore, the aim of this research was to assess the efficiency of sweet potato production in Polish soil and climate conditions.

MATERIAL AND METHODS

Calculations were based on the results of a 3-year field experiment conducted between 2017-2019 in Żyznów (49°49′ N, 21°50′ E) in soil consisting of flysch sediments, with a mechanical composition of loam, valuation class IVb, defective wheat complex, with a slightly acidic pH. It was based on a random subblocks method in a dependence system, with three replicates. The main experimental factors were cultivation technologies: a) traditional, with no cover, as the control; b) with the use of PP spunbond nonwoven as the cover. Secondary factors included 5 cultivars of the sweet potato (Goldstar, Carmen Rubin, Satsumo Imo, Beauregard and White Triumph). Organic fertilization was carried out in autumn with the use of manure in the amount of 25 Mg/ha. In the spring, the field was harrowed, then, prior to planting, mineral fertilizers were sown in the following amount: 80 kg N – of urea 46%, 34.9 kg P – of granular superphosphate 19%, 99.6 kg K/ha – of potassium salt, 60%. The propagating material included rooted cuttings of sweet potato from in vitro propagation. They were planted with 50 x 75 cm spacing in mid-

May (26,667 cuttings ha). During vegetation, cultivation was carried out in accordance with normal agricultural practice. In Polish conditions, sweet potato tubers are ready for harvest in early October, but plants retain their green aerial parts until the first frost, and in a sunny autumn, in southern Poland, they can even be harvested in November. In the experiment, harvesting was carried out in mid-October with the use of an elevator potato digger. The economic efficiency evaluation of production included average yield from 2017-2019. Production costs and expenditure included agro-technical procedures carried out during vegetation, starting from tillage after pre-harvest crop, until tuber harvest and preparation for sale. Expenditure on production means was established on the basis of actual fertilizer usage, the number of sweet potato cuttings and materials (e.g. nonwoven, fertilizers) in reference to the surface area of 1 ha. Labour resources, traction equipment and the use of fuel were established with a model method based on standards including procedures and processes carried out during specific stages of cultivation, different in terms of cultivars and plant density per area unit [Harasim et al. 2004]. The costs of the production mean (fertilizers, covers) were calculated based on 2018 prices, established on the basis of historical records and information materials published by Agricultural Advisory Centers and TopAgrar Poland [TopAgrar.pl 2019]. The cost of the purchased manure was accounted for in 50%, based on the assumption that it is used to such an extent in the year of application, and the costs of materials were accounted for proportionately to the period of their use. PP nonwoven is used for 5 years (20% of the purchase price). The assumed production cost of one sweet potato cutting was PLN 0.50 per piece. The labor cost was estimated based on the parity rate accounting for the average wage in the national economy, according to the method of the Institute of Agricultural and Food Economics [TopAgrar.pl 2019]. The operating costs of a tractor, agricultural machines and tools were calculated based on a price list and the operating and economic indices for agricultural machines and tools, assuming a 15-year utilization period [TopAgrar.pl 2019].

The general yield was the mass of sweet potato tubers harvested from 1 ha. Marketable yield included tubers with a diameter above 40 mm with no external flaws, and secondary yield included small tubers with a diameter ≤ 40 mm as well as tubers with flaws and mechanical damages. For the calculations, the average marketable yield of tubers (38.10 Mg/ha) and secondary yield (15.41 Mg/ha) were established. The value of marketable and secondary yield was calculated with the assumption that the price of marketable tubers amounts to 50% of the wholesale price of imported sweet potato tubers. In the calculations, it was assumed that the price of marketable tubers was PLN 4 per 1 kg, and the price of secondary yield – PLN 0.50 per 1 kg. Economic calculations included direct costs covering the costs of fertilizers, cuttings, materials (PP nonwoven), fuel and grease, labor and the operating costs of agricultural machines and tools. Considering all of the above, the income category referred to as gross margin was calculated, which is the difference between the production value (W) and direct production costs (K). The form of indicators was adopted as Monika Gębska and Tadeusz Filipiak [2006]. This indicator was calculated based on the formula:

Direct gross margin = Total crop value (W) – Direct costs of production (K)

In this group of indicators, the profitability index was applied. The profitability indicator informs us to what extent the revenue from production covers the costs. This indicator was calculated based on the formula:

$$\text{Direct profitability index} = \frac{\text{Total crop value}}{\text{Direct cost of production}} \times 100$$

Humidity and temperature conditions during sweet potato vegetation were described with the use of the hydrothermal coefficient of Sielianinov, as illustrated in Table 1.

Table 1. The hydrothermal coefficient of Sielianinov during the sweet potato vegetation period in 2017-2019 according to the COBORU meteorological station in Dukla

Month	Hydrothermal coefficient of Sielianinov			
	2017	2018	2019	mean
May	3.3	2.8	2.6	2.9
June	1.9	2.9	4.9	3.2
July	6.1	1.3	0.2	2.5
August	2.5	2.9	2.1	2.5
September	0.9	2.0	0.3	1.1
October	2.3	0.3	0.8	1.1
Mean	2.8	2.0	1.8	2.2

The following ranges of values for the coefficient of Sielianinov were assumed: 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 damp $1.6 < k \leq 2.0$; wet $2.0 < k \leq 2.5$; very wet $2.5 < k \leq 3.0$; extremely humid $k > 3.0$ according to Barbara Skowera [2014]

Source: own study according to data from the COBORU meteorological station at SDOO in Dukla

The years 2017-2019 were wet, whereas 2017 was extremely humid, which is reflected in the values of the hydrothermal coefficient of Sielianinov. However, a significant variation of the hydrothermal coefficient was observed between individual months of the vegetation period. In 2017, all vegetation months were wet, with an extremely humid July and a dry September, which did not affect the crops of the tubers that had matured before. In 2018, almost all months, except for October, were wet or very wet. In 2019, July and September were extremely dry, with a dry October, whereas all the other months were wet or very wet, with an extremely humid June.

The soil in the experiment belonged to Cambisols of the granulometric composition silty clay loam (Table 2).

The concentration of assailable phosphorus and potassium in soil was on a medium level, with a very high content of magnesium, and a medium level of copper, manganese, iron and zinc. The average content of humus in the topsoil was high and amounted to 2.71%. The soil was characterized by a slightly acidic pH (Table 3).

Table 2. The granulometric composition of soil in Żyznów (2017-2019)

Years	Composition content of the granulometric fractions [%]									Soil classification
	sand					silt			loam	
	mm									
	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
2017	0.924	1.45	3.70	6.99	6.21	15.168	16.70	13.840	35.013	silty clay loam
2018	0.936	1.45	3.71	6.98	6.21	15.162	16.71	13.824	35.011	silty clay loam
2019	0.937	1.45	3.72	6.96	6.21	15.159	16.70	13.844	35.012	silty clay loam
Mean	0.932	1.45	3.71	6.97	6.21	15.163	16.70	13.836	35.012	silty clay loam

Source: results of own experiment conducted in the District Chemical and Agricultural Station in Krosno

Table 3. Physical and chemical properties of soil in Żyznów (2017-2019)

Years	Macronutrients [mg/100 g of soil]			$CaCO_3$ [%]	Humus [%]	pH in KCL [1 mol/l]	Micronutrients [mg/100 g of soil]			
	P_20_5	K_20	Mg				Cu	Mn	Zn	Fe
2017	12.4	20.1	19.7	0.02	2.70	5.55	5.61	171	14.9	1581
2018	12.3	20.0	19.7	0.03	2.72	5.73	5.72	171	14.5	1573
2019	12.3	20.0	19.5	0.02	2.70	5.71	5.59	174	14.4	1571
Mean	12.3	20.0	19.6	0.02	2.71	5.66	5.68	172	14.6	1575

Source: own results, the tests were carried out at the District Chemical and Agricultural Station in Krosno

RESULTS AND DISCUSSION

The average yield of sweet potato tubers ranged from 21.90 Mg/ha to 52.90 Mg/ha, depending on the cultivation technology, cultivar and study years. All experimental factors modified the general yield of tubers. The highest yield-forming efficiency was observed in cultivation with the use of PP nonwoven (a yield increase of 11.4%) as compared to cultivation with no cover in the control group (Table 4).

Genetic features of the cultivars had the largest influence on yield mass. Beauregard was the highest-yield cultivar, whereas White Triumph – the lowest (Table 4). Sochinwechi Nwosisi et al. [2017] conducted a research on sweet potato yielding in various cultivation systems, confirming that Beauregard is a high-yielding cultivar, with a yield of 39.72 Mg/ha, which was the highest among all cultivars under study.

The most effective crop profitability measure is economic efficiency, that is the estimation of crop costs on the one hand, and income from sold yield on the other. The ratio of the two values determines the actual possible income of the producer. According to Wojciech Nowacki [2016], the income from sold crops depends on: the yield, includ-

Table 4. The influence of cultivation technology, cultivar and year on the general yield and share of marketable and secondary yield of tubers

Experimental factors		Total yield [Mg/ha]	Share of marketable tubers [%]	Yield of marketable tubers [Mg/ha]	Secondary yield [Mg/ha]
Cultivation technology	Traditional	36.02	59.12	21.30	14.72
	PP nonwoven	40.11	59.89	24.60	15.50
	$LSD_{0.05}$	1.90	ns*	1.13	0.77
Cultivars	Goldstar	35.70	55.61	19.85	15.85
	Carmen Rubin	49.50	63.43	31.40	18.17
	Satsumo Imo	30.30	57.15	17.30	12.98
	Beuregard	52.90	63.43	33.51	19.36
	White Triumph	21.90	57.95	12.69	9.22
	$LSD_{0.05}$	4.76	7.44	2.83	1.93
Years	2017	38.10	55.38	21.10	17.00
	2018	43.20	56.69	24.85	18.71
	2019	32.89	66.46	22.90	11.03
	$LSD_{0.05}$	2.85	4.46	1.70	1.16
	Mean	38.06	59.51	22.65	15.10

* not significant at $p_{0.05}$
Source: own study

ing marketable and secondary yield, and the market price of the product. The share of marketable tubers in the general yield was high and on average amounted to 59.51%. A higher share of tubers of this size range was observed in crops using nonwoven, although the increase was insignificant (Table 4). Genetic features of the cultivars had the largest influence on the share of marketable tubers in the general yield of tubers. The largest share of this size range of tubers was found in Beauregard, and the smallest in Goldstar (Table 4). Weather conditions in the study years had a significant influence on the share of marketable tubers. The highest share was noted in 2019, with wet or very wet months of May, June and August, conducive to mass-forming in tubers, and the smallest share of marketable-size tubers was observed in 2017 – an extremely humid year (Table 1 and 4).

The total value of tuber yield ranged from 55,370 to 143,720 PLN/ha, depending on the variety and from 92,560 to 106,155 PLN/ha, depending on the technology of cultivation (Table 5).

The value of yield is a derivative of size and quality. The general yield size had a significant influence on labor costs, whereas its structure, or the share of marketable and secondary yield, determined the value of production. The total yield value depended on the analysed factors. It was most visibly shaped by the sweet potato cultivar, and least – by the cultivation technology. The greatest total value of marketable and secondary yield

Table 5. Sweet potato tuber yield value

Experimental factors		Value of yield [PLN/ha]		
		marketable yield	secondary yield	total crop value
Cultivation technology	Traditional	85,200	7,360	92,560
	PP nonwoven	98,400	7,755	106,155
Cultivars	Goldstar	79,400	7,925	87,325
	Carmen Rubin	125,600	9,085	134,685
	Satsumo Imo	69,200	6,490	75,690
	Beuregard	134,040	9,680	143,720
	White Triumph	50,760	4,610	55,370
Years	2017	84,400	8,500	92,900
	2018	99,400	9,180	108,580
	2019	91,600	4,995	96,595
Mean		91,800	7,558	99,358

Source: own study

was observed in the case of Beauregard, and the smallest – in the case of White Triumph. The cultivation technology with use of PP nonwoven resulted in a higher production value than in traditional cultivation without covers (Table 5).

Direct costs of sweet potato production in the analysed years were similar and amounted to PLN 23,895 per ha in 2017, PLN 18,996 per ha in 2018 and PLN 21,299 per ha in 2019 (Table 6).

The highest direct costs of production were noted in the case of Beauregard, and they were related to the highest yield of tubers, their harvesting, transportation and sorting. Cultivation technology with the use of PP nonwoven was characterised by higher direct

Table 6. Costs and economic efficiency of sweet potato production

Experimental factors		Direct costs of production [PLN/ha]	Direct gross margin [PLN/ha]	Direct profitability index [%]
Cultivation technology	Traditional	18,947	73,613	489
	PP nonwoven	23,847	82,308	445
Cultivars	Goldstar	21,417	65,908	408
	Carmen Rubin	21,817	112,868	617
	Satsumo Imo	21,117	54,573	358
	Beuregard	22,417	121,303	641
	White Triumph	20,217	35,153	274
Years	2017	23,895	69,005	389
	2018	18,996	89,584	572
	2019	21,299	75,296	454
Mean		21,397	77,961	465

Source: own study

production costs than cultivation without covers. The differences between direct production costs mainly depended on the costs of purchasing, applying and removing the PP covers. The average production value of the analysed sweet potato cultivars amounted to PLN 99,358 per ha, and the gross margin – PLN 77,961 per ha (Table 5 and 6). The calculated gross margin shows that the production of sweet potato in Polish soil and climate conditions between 2017-2019 was cost-effective.

The most important characteristic necessary for the economic evaluation of production is the gross margin as a result of the production value and direct production costs. The economic analysis showed that the largest gross margin of production, as compared to direct costs, was achieved by Beauregard, and the smallest – by White Triumph. In the case of growing sweet potato with the use of PP nonwoven covers, the gross margin was higher than in the control group. The greatest economic efficiency, expressed as the direct profitability index, was achievable in the case of two cultivars: Beauregard and Carmen Rubin, and definitely the lowest – in the case of White Triumph (Table 6).

The analysis of direct costs of sweet potato production revealed that the relatively largest share of total costs was the purchase of cuttings, which amounted to 56% of cultivation costs (Figure 1). A significant element of the cost structure of sweet potato production were special costs, which amounted to 28% of cultivation costs. They included the costs of labor, machine operation and PP nonwoven. The smallest share in cost structure covered plant protection products and mineral fertilizers (1% and 2%, respectively). Natural fertilization, i.e. manure, amounted to 6% of sweet potato cultivation costs, whereas mineral fertilization amounted to merely 2% of direct costs (Figure 1).

The most expensive was the use of potassic fertilizer with a dose of 99.6 kg K/ha– in the form of potassium salt; the purchase of nitrogenous fertilizers was 60% cheaper, and the lowest cost was noted in the case of phosphatic fertilizers with a dose of 34.9 kg P– in the form of granular superphosphate 19%.

According to Marek Gugała et al. [2014], Zbigniew Gołaś [2016] and Iwona Mystkowska et al. [2017], high labour intensity in the case of growing roots and tubers

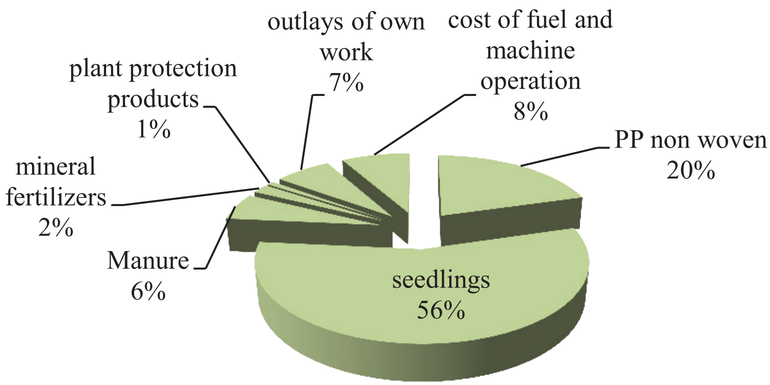

Figure 1. Direct cost structure per 1 ha of sweet potato crops
Source: own study

depends largely on technologies used, mainly related to the use of modern equipment. According to Barbara Krochmal-Marczak and Barbara Sawicka [2010], Barbara Krochmal-Marczak et al. [2014, 2018], in Polish soil and climate conditions, the sweet potato is an innovative crop and requires a lot of research on cultivation technologies facilitating the mechanisation of planting the propagating material, as well as the full mechanisation of sweet potato tuber harvesting resulting in decreased labour intensity. Rabirou Kassali [2011] believes that only increased sweet potato production, higher capital expenditure and increased efficiency can improve sweet potato production efficiency.

The direct cost structure showed that the greatest cost was the planting material (56%), and relatively low costs concerned plant protection and fertilisation. According to Isah Musah Ahmad et al. [2014], the costs of fertilisation are necessary in order to obtain high yield and high-quality tubers. Research by Iwona Mystkowska et al. [2017], revealed that the share of fertilisers in the cost structure of potato crop ranged from 20.5% to 22.4%. The analysis of costs and gains conducted by Rabirou Kassali [2011] shows that labour constituted 68% of total production costs, nevertheless the production of sweet potato was cost-effective. Profitability had more influence on improving efficiency, and capital expenditure had the least influence on decreasing the profit. The smallest share in the direct cost structure was the cost of plant protection products, which amounted to 2%. Protection of the sweet potato against weeds is an issue only in the initial two months of vegetation, because shoots grow very quickly and, within six weeks, cover the entire plantation and choke out any weeds. The low share of this cost resulted from the only use of herbicides prior to starting the plantation (Devrinol 450 SC in the amount of 2 dm/ha + Command 480 EC – in the dose of 0.2 dm/ha). No fungicides or insecticides were applied to sweet potato crops as there were no signs of fungal diseases in the plantation. When it comes to pests, two species of slugs were observed: the grey field slug (*D. Reticulatum*) and the Spanish slug (*A. Lusitanicus*), but their number did not require the use of plant protection products. According to P. Prakash et al. [2016], starting a sweet potato plantation is one of the more costly and labour intensive stages of plant cultivation. Research by Ali Solomon et al. [2015], confirms that direct costs can amount to 68% of total production costs of the sweet potato, but the production of this species is still cost-effective.

To sum up, due to decreasing plant diversity, the cultivation of the sweet potato in Poland can bring quantifiable benefits to farms and become an alternative to other crops.

CONCLUSIONS

The economic efficiency of sweet potato production depended on all experimental factors. The most profitable economic factors were achieved in the case of growing the Beauregard variety, and the least – in the case of the White Triumph. The profitability of sweet potato commercial production was increased by the use of PP nonwoven. The greatest costs of growing sweet potato were the cuttings (56% of direct costs), and the smallest – the plant protection products and mineral fertilization. The production of sweet potato between 2017-2019 turned out to be cost-effective.

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EFEKTYWNOŚĆ UPRAWY BATATA (*IPOMOEA BATATAS* L. [LAM.]) W WARUNKACH GLEBOWO-KLIMATYCZNYCH POLSKI

Słowa kluczowe: słodki ziemniak, technologie uprawy, plon handlowy, odmiany, koszty bezpośrednie, wskaźniki opłacalności

ABSTRAKT

Celem badań było określenie opłacalności produkcji batata w warunkach Polski (49°49′ N, 21°50′ E). Badania oparto na wynikach trzyletniego (2017-2019) doświadczenia polowego przeprowadzonego na glebie brunatnej, lekko kwaśnej. Eksperyment założono metodą losowanych podbloków, w których czynnikami I rzędu były technologie uprawy: A) tradycyjna, bez okryw i B) z zastosowaniem agrowłókniny polipropylenowej. Czynnik II rzędu stanowiło 5 odmian batata: Goldstar, Carmen Rubin, Satsumo Imo, Beauregard, White Triumph. Stosowano stałe nawożenie organiczne i mineralne, a zabiegi pielęgnacyjne prowadzono według zasad dobrej praktyki rolniczej. Materiałem rozmnożeniowym były ukorzenione sadzonki batata, pochodzące z rozmnożenia *in vitro*, wysadzone w rozstawie 50 x 75 cm. Efekt ekonomiczny produkcji różnicowały wszystkie czynniki eksperymentu. Opłacalność produkcji zwiększało stosowanie włókniny polipropylenowej. Najkorzystniejsze wskaźniki ekonomicznie uzyskano uprawiając odmianę Beuregard, a najmniej korzystne – w uprawie odmiany White Triumph. Największym kosztem w produkcji towarowej były sadzonki batata, które stanowiły ponad 56% tych kosztów, najmniejszym zaś – środki ochrony roślin i wynosiły 1% kosztów bezpośrednich poniesionych na 1 ha uprawy tego gatunku. Produkcja batata w warunkach glebowo-klimatycznych Polski w latach 2017-2019, okazała się opłacalna.

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