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THE EFFECTS OF AGRONOMIC FACTORS ON THE ECONOMIC EFFICIENCY OF BLACK CUMIN PRODUCTION

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ABSTRACT

Background. Black cumin (*Nigella sativa* L.) known for its health benefits, can be grown under various production technologies associated with different production costs. Therefore, the aim of this study was to determine the economic profitability of black cumin cultivation under different agronomic conditions in north-eastern Europe.
Material and methods. The experiment had a fractional factorial and completely randomized design,with four replications. *Nigella sativa* L. was grown in integrated farming system during a two-year field experiment. The analysis of economic effectiveness was calculated according to agricultural accounting standards.
Results. The highest income of 627.10 USD·ha^{-1} was achieved in the treatment involving mechanical weed control. The highest profitability index was noted in treatments with seed dressing and no pathogen control during the growing season, and with mechanical weed control (1.46 and 1.56, respectively).
Conclusion. The agronomic efficiency of black cumin was low. The most profitable production system involved the latest seeding date, inter-row spacing of 30 cm and mechanical weed control. Total costs ranged from 1077.32 to 1177.32 USD·ha^{-1}.

Key words: black cumin, inter-row spacing, nitrogen, pathogen control, production costs, seeding date, weed control

INTRODUCTION

In traditional medicine, plants have been used in the treatment of various diseases for centuries. Black cumin (*Nigella sativa* L.) is one of the plant species whose health benefits have been well documented. Black cumin has been cultivated for at least 5000 years, particularly in ancient south Asia and north Africa. Today it is also grown in the Mediterranean Basin, in eastern and southern Europe, India, Pakistan, Syria, Turkey and Saudi Arabia (Khare, 2004). Black cumin is widely produced in Ethiopia which has approximately 12% share of the world market of *N. sativa* seeds. However, 99% of the produce is consumed on the domestic market. Ethiopia exported black cumin production at a value of 1.18 USD·kg^{-1} and imported at 5.80 USD·kg^{-1} (Yimam *et al*., 2015). Black cumin is well suited to the local growing conditions in Poland, but it is not widely cultivated.

The seeds of *N. sativa* have many medicinal uses due to a wide spectrum of their activity including antibacterial, anticarcinogenic, anti-inflammatory, anti-diabetic, antidepressant and analgesic properties. They also help reduce blood pressure, widen the airways, protect the stomach, liver and kidneys, and relax smooth muscles (Al-Jabre *et al*., 2003; Halawani, 2009; Khaled, 2009; Assayed, 2010; Boskabady *et al*., 2010; Abel-Salam, 2012; Borusiewicz and Janeczko, 2015). Black cumin oil is used as an antiseptic and local anesthetic. Black cumin seeds and oil are also

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used in the food-processing industry for flavoring cakes and bread products, as an ingredient of marinades and meat seasoning blends, and a preservative (Warrier and Nambiar, 2004). The yield of plants, in particular herbaceous plants, is determined by novel agro-technologies where both the quality of herbaceous raw materials and production efficiency are important considerations (Żuk-Gołaszewska *et al*., 2010; Żuk-Gołaszewska *et al*., 2013; Bieńkowski *et al*., 2015; Bieńkowski *et al*., 2017). The key components of effective production systems are nutrient supply (fertilization), seeding date, inter-row spacing and cultivation measures (Adil *et al*., 2014). In a study by Yimam *et al*. (2015), the highest black cumin seed yield of 1336.7 kg was achieved following the application of 60 kg N·ha^{-1}. Production costs can be effectively reduced by replacing mineral fertilizers with organic fertilizers. This is not only a good way to protect the environment but also to achieve high-quality herbal raw material. Ali and Hassan (2014) demonstrated that organic fertilizers and biofertilizers increased the quality of *N. sativa* seeds. D'Antuono *et al*. (2002) reported that black cumin yields were affected by seeding date. Wide-row planting facilitates mechanical weed control which contributes to the production of high-quality herbaceous raw material.

Although economic efficiency is an important consideration in herbaceous plant production (Bieńkowski *et al*., 2017), most studies investigating medicinal plants focus on biological rather than economic aspects. The fragmented structure of medicinal plant cultivation makes it difficult to perform reliable cost-benefit analyses. As a medicinal plant species, *N. sativa* could potentially be used for crop diversification and productivity improvement, in particular on small farms (Ahmad *et al*., 2004). The costs of black cumin cultivation have not been thoroughly analyzed to date. In view of the above, the objective of this study was to determine the effects of selected agronomic factors on the economic profitability of black cumin cultivation.

MATERIAL AND METHODS

Black cumin was grown in a field experiment in 2008 and 2009 at the Agricultural Experiment Station in Tomaszkowo (53°43' N; 20°24' E), operated by the Faculty of Environmental Management and Agriculture, University of Warmia and Mazury in Olsztyn. Five experimental factors were analyzed: A – nitrogen (N) fertilization levels, (0) no N fertilizer and (1) 100 kg N·ha^{-1} (50 kg pre-sowing + 50 kg after seedling emergence); B – seeding date, (0) the earliest possible seeding date, (1) sowing delayed by 10 days, (2) sowing delayed by 20 days; C – inter-row spacing, (0) 15 cm, (1) 30 cm, (2) 45 cm; D – weed control, (0) mechanical weed control (inter-row manual weeding, twice during the growing season, (1) chemical weed control with the Reglone 200 SL – active substance diquat ion herbicide (immediately before seedling emergence); E – pathogen control, (0) seed dressing, no pathogen control during the growing season, (1) seed dressing, pathogen control with the Penncozeb 80 WP – active substance mancozeb fungicide during the growing season. The experiment was established on brown soil developed from light sandy loam and loamy sand (underlain by silt), of quality class IVa in the Polish soil quality classification system. Winter triticale was the preceding crop. After the preceding crop had been harvested, the plots were skimmed and ploughed in fall. A cultivator was used for tillage in spring. Mineral fertilizers were applied before sowing: 27 kg P·ha^{-1} as 46% triple granular superphosphate, and 100 kg K·ha^{-1} as 60% potash salt. The fertilizers were thoroughly mixed with the soil using a harrow. Before sowing, N fertilizer (46% urea) was applied in accordance with the adopted methodology. Black cumin was sown on 4 and 14 April (seeding date I), 14 and 24 April (seeding date II), 24 April and 4 May (seeding date III) in 2008 and 2009. The black cumin growing season in 2008 and in 2009 was dry and warm. The average temperatures during those two seasons were 14.8 and 15.1°C. In turn, the sum of rain fall was 250.9 and 262.2, respectively in 2008 and in 2009 year of study, while the multiannual (1961–2000) total was 367.2 mm·yr^{1}.

All calculations were performed in line with Polish agricultural accounting guidelines (Goraj, 2000), including the classical division into direct and indirect costs, which enabled us to calculate basic costs and revenues according to the method proposed by Augustyńska-Grzymek *et al*. (2009):

1. Production Value (PV)
2. Direct Costs (DC)
3. Direct Margin (DM)
4. Indirect Costs (IC)

5. Income (I)
6. Total Costs (TC).
7. Unit Production Cost (UPC).

In addition, the following indicators were calculated as described by Kisiel (1999):

Gross Margin Ratio

$$GMR = \frac{DM}{PV} \text{ x } 100\%$$

Profit Rate

$$PR = \frac{I}{PV} \text{ x } 100\%$$

Production Profitability Index

$$PPI = \frac{PV}{TC}$$

Relative Cost Index

$$RCI = \frac{TC}{PV}$$

The unit costs of tractor and machine operation as well as the costs of performing farming operations and agronomic treatments were calculated according to the method proposed by Muzalewski (2007). Prices and costs were expressed in USD based on the exchange rate quoted by the National Bank of Poland on 15 March 2018 (PLN 1 = 3.41 USD, 100 Rs = 1.54 USD).

RESULTS AND DISCUSSION

The seed yield of *N. sativa* grown on brown soil was low. The average seed yield over two years of the study was 227 kg·ha^{-1} (Table 1), and it varied across years. In the first year (2008), seed yield ranged from 159 to 262 kg·ha^{-1} and it was lower than in the second year (2009). In both years of the study, the lowest yield of herbaceous raw material was noted in the treatment with seed dressing and no pathogen control during the growing season. Delayed sowing generally increased seed yield.

In a study by Kara *et al*. (2015), the average seed yield of black cumin ranged from 201.0 to 407.1 kg·ha^{-1} in 2013, and from 458.9 to 790.3 kg·ha^{-1} in 2014.

Table 1. Black cumin yield, kg·ha^{-1}

Item	Treatments	Seed yield 2008	Seed yield 2009	Average seed yield
(A) Nitrogen fertilizer	(0) – no fertilizer	216.90	238.32	227.61
	(1) – 100 kg·ha^{-1} N	189.92	265.77	227.85
(B) Seeding date	(0) – the earliest possible seeding date	193.10	221.84	207.47
	(1) – sowing delayed by 10 days	203.89	221.41	212.65
	(2) – sowing delayed by 20 days	213.25	312.89	263.07
(C) Inter-row spacing	(0) – 15 cm	204.98	242.23	223.61
	(1) – 30 cm	176.05	296.64	236.35
	(2) – 45 cm	229.20	217.26	223.23
(D) Weed control	(0) – mechanical	262.38	278.82	270.60
	(1) – chemical	144.44	252.27	198.36
(E) Pathogen control	(0) – seed dressing only	158.93	224.22	191.58
	(1) – seed dressing + one treatment with mancozeb during the growing season	247.88	279.87	263.88
	Mean	203.41	252.04	227.73

In both years, higher rainfall contributed to higher seed yields.In an experiment conducted by D'Antuono L. *et al*. (2002) under Mediterranean conditions, the average seed yield of *N. sativa* reached 787 kg·ha^{-1}, and it was 8% and 60% lower at the second and third seeding date, respectively, compared with the earliest seeding date (3 March). An analysis of another medicinal plant – coriander, revealed that its average seed yield in the tested farms was 1290 kg·ha^{-1} (Kumar and Kumar, 2017). Nitrogen fertilizer applied at 150 kg·ha^{-1} increased production costs but had no effect on seed yield. This suggests that coriander, similarly to other herbaceous plant species, responds better to organic fertilizers which is reflected in more desirable values of economic indicators. Mehta *et al*. (2012) analyzed the production costs of *Cuminum cyminum* L. and found that organic fertilizers (sheep manure and vermicompost) combined with seed inoculation with a biofertilizer (*Azotobaceter* sp.) contributed to a higher net return (17.14 USD·ha^{-1}) and a higher benefit: cost ratio (2.20).

The cost of tractor and machine operation in the analyzed treatments was approximately 225.6 USD·ha^{-1} (Table 2).

Table 2. Costs associated with tractor and machine operation in the analyzed production systems of black cumin

Production system*	Farming operations and treatments	Operating costs, USD·ha^{-1}			Efficiency per unit h·ha^{-1}	Operating costs per unit USD·ha^{1}
		tractors	machines	tractors and machines		
A–D**	manure loading, 10% of costs	46.1	0.0	46.1	0.1	2.3
	manure fertilization, 10% of costs	40.8	36.0	76.7	0.1	9.2
	liming, 25% of costs	21.3	7.8	29.1	0.1	3.8
	skimming	32.3	1.9	34.2	0.3	10.3
	harrowing	21.3	1.0	22.3	0.2	4.5
	deep ploughing	44.8	10.4	55.2	0.6	33.1
	cultivator tillage	24.3	7.1	31.4	0.4	12.6
	PK fertilization	21.3	7.8	29.1	0.2	5.8
	harrowing	21.3	1.0	22.3	0.3	6.7
	N fertilization	32.3	14.7	47.0	0.6	28.2
	sowing	21.3	4.6	25.9	1.2	31.1
	harvest	0.3	84.6	84.9	0.8	67.9
	transport	44.8	5.8	50.6	0.2	10.1
	∑	–	–	–	5.1	225.6
A***	N fertilization (50 + 50 kg·ha^{-1})	22.7	7.8	30.4	0.2	6.1
	∑	–	–	–	0.2	6.1
D***	chemical weed control – Reglone 200 SL	22.7	13.9	36.6	0.2	7.3
	mechanical weed control	14.6	4.6	19.2	1.2	23.0
	∑	–	–	–	1.4	30.3
E***	chemical pathogen control – Penncozeb 80 WP	22.7	13.9	36.6	0.2	7.3
	seed dressing	0.0	11.5	3.4	0.1	0.4
	∑	–	–	–	0.3	7.7

* refer to the Materials and Methods section
** farming operations and treatments applied in all production systems
*** farming operations and treatments applied in selected production systems

Once-over combine harvesting followed by deep ploughing had the highest share of total costs (67.9 USD·ha^{-1} and 33.31 USD·ha^{-1}, respectively). The present results are consistent with the findings of Bieńkowski *et al*. (2015).Labor costs expressed in hours per hectare (5.1 h·ha^{-1}) were comparable with the labor inputs in spring barley and spelt cultivation (Winnicki and Żuk-Gołaszewska, 2017; Żuk--Gołaszewska *et al*., 2013). The profitability of fenugreek production was determined by the cost of farming operations and treatments. The highest profits were generated in the system with optimal sowing date and mechanical weed control. Total production cost reached 1641.0 USD·ha^{-1} and the energy efficiency ratio was estimated at 0.53 to 0.60 (Bieńkowski *et al*., 2015).

From the economic perspective, production value may be more important than crop yield. Production value is determined by various factors, and the key determinant is the price of the final product and by-products. In black cumin, seed mass is relatively low but production value may be high at desirable seed prices. In the present study, the highest production value (1739.24 USD·ha^{-1}) was achieved in treatment D0 where direct payments were 310.85 USD·ha^{-1} (Table 3). In north-eastern Europe, the highest efficiency of black cumin production can be achieved when sowing is delayed by 20 days. In general, the costs of medicinal plant cultivation are higher on large farms compared with small farms. For example, the production cost of coriander seeds was higher on a large farm than on a small farm (448.23 vs. 350.93 USD·ha^{-1}). The lowest cost of coriander cultivation on a modern farm was 303.63 USD·ha^{-11} due to expenditures including protection material and hired labor (Kumar and Kumar, 2017). The economic efficiency of *Cuminum cyminum* production ranged from 144.61 USD·ha^{-1} in the control treatment to 223.15 USD·ha^{-1} in the treatment where sheep manure and biofertilizer were applied (Mehta *et al*., 2012). In an experiment conducted in Poland, the seed yield of red clover reached 229–453 kg·ha^{-1} and total production costs ranged from 1153.45 USD·ha^{-1}to 1226.73 USD·ha^{-1}. Total production value was higher in diploid varieties than in tetraploid varieties, at 2510.50–2590.34 USD·ha^{-1}, and economic efficiency was determined at 23428.4––23545.4 MJ·ha^{-1} (Żuk-Gołaszewska and Nasalski, 2006). Major costs were associated with tractor and machine operation, mineral fertilizers and labor inputs. Seeds had a relatively high share of production value when red clover was undersown in a spring barley crop. Production value is lower in herbaceous plants than in agricultural crops such as spring barley (Żuk-Gołaszewska *et al*., 2013).

In black cumin production, mineral fertilizers and manure had a considerable share of total costs. Although they were not applied directly to black cumin, manure accounted for 10% of costs and lime applied every four years for 25%. Agronomic treatments had a minor effect on total costs per ha which ranged from 1077.32 USD·ha^{-1} to 1177.32 USD·ha^{-1}, reaching the lowest value in treatment C0 with inter-row spacing of 15 cm.

Table 4 presents the indicators of economic efficiency in black cumin production. The highest gross margin of 951.39 USD·ha^{-1} was noted in treatment D1 with chemical weed control, whereas the lowest gross margin of 561.04 USD·ha^{-1} was recorded when sowing was delayed by 10 days. When indirect costs were deducted, the income was highest (627.10 USD·ha^{-1}) in treatment D0 with mechanical weed control, followed by treatment E0 where seeds were dressed and chemical pathogen control was not applied (534.59 USD·ha^{-1}). The highest profitability index, expressed as the revenue to cost ratio, was achieved in treatment D0 with mechanical weed control (1.56), followed by treatment E0 with seed dressing and no chemical pathogen control during the growing season (1.46). The most profitable production technology of black cumin in north-eastern Poland involved sowing in the last ten days of April/the first ten days of May, and inter-row spacing of 30 cm. The profitability index for these factors was highest in the above treatments, at 1.44 and 1.32, respectively (Table 4).

Table 3. Production costs of black cumin, USD·ha^{-1}

Item	Treatments											
	A*		B			C			D		E	
	0*	1	0	1	2	0	1	2	0	1	0	1
Total revenue	1510.73	1513.58	1406.00	1433.34	1699.49	1491.20	1558.45	1489.19	1739.24	1357.91	1703.77	1512.94
Production value	1199.88	1202.73	1095.15	1122.49	1388.64	1180.35	1247.60	1178.34	1428.39	1047.06	1392.91	1202.09
Direct payments	310.85											
Total direct costs	759.53	844.96	844.96	844.96	844.96	828.54	844.96	844.96	787.85	844.96	844.96	844.96
Materials (seeds)	205.28											
Mineral fertilization	210.22	295.65										
46% urea	0.00	85.43										
46% triple superphosphate	123.41											
60% potash salt	86.80											
Organic fertilizer and other fertilizers:	269.78											
manure fertilization, 10% of costs	131.96											
liming, 25% of costs	137.82											
Crop protection:	74.24	74.24	74.24	74.24	74.24	57.82	74.24	74.24	17.13	74.24	74.24	74.24
Funaben plus 02 WS	0.70											
Penncozeb 80 WP	16.42	16.42	16.42	16.42	16.42	0.00	16.42	16.42	16.42	16.42	16.42	16.42
Reglone 200 SL	57.11	57.11	57.11	57.11	57.11	57.11	57.11	57.11	0.00	57.11	57.11	57.11
Total indirect costs:	317.79	332.36	332.36	332.36	332.36	332.36	332.36	332.36	324.29	332.36	324.22	332.36
costs of tractor and machine operation	239.71	251.35	251.35	251.35	251.35	251.35	251.35	251.35	244.31	251.35	244.31	251.35
labor costs	22.07	24.12	24.12	24.12	24.12	24.12	24.12	24.12	23.09	24.12	23.09	24.12
agricultural tax	34.90											
Other indirect costs (+7.5%)	21.12	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.91	21.99
Total costs	1077.32	1177.32	1177.32	1177.32	1177.32	1160.89	1177.32	1177.32	1112.14	1177.32	1169.18	1177.32

* for explanations see Table 1

Table 4. Indicators of economic efficiency in black cumin production

Item			Gross margin	Income USD·ha^{-1}	Gross margin rate %	Income rate %	Unit production cost USD·kg^{-1}	Revenue to cost ratio	Income to working hour ratio USD·h^{-1}
Treatments	A*	0*	751.20	433.41	49.72	28.69	4.74	1.40	78.80
		1	751.20	336.26	49.63	22.22	5.17	1.29	61.14
	B	0	668.62	228.68	47.55	16.26	5.67	1.19	38.76
		1	561.04	256.03	39.14	17.86	5.54	1.22	43.39
		2	588.38	522.17	34.62	30.73	4.48	1.44	88.50
	C	0	854.53	330.30	57.31	22.15	5.19	1.28	55.98
		1	662.66	381.13	42.52	24.46	4.98	1.32	64.60
		2	713.49	311.87	47.91	20.94	5.27	1.26	52.86
	D	0	644.23	627.10	37.04	36.06	4.11	1.56	106.29
		1	951.39	180.60	70.06	13.30	5.94	1.15	93.83
	E	0	858.81	534.85	50.41	31.38	4.43	1.46	93.79
		1	858.81	335.63	56.76	22.18	5.17	1.29	56.89

* for explanations see Table 1

CONCLUSIONS

1. The agronomic efficiency of black cumin was low. The highest profitability index was noted in treatments with mechanical weed control, and with seed dressing and no pathogen control during the growing season (1.56 and 1.46, respectively).
2. The most profitable production system involved the latest seeding date, inter-row spacing of 30 cm and mechanical weed control. Total costs ranged from 1077.32 to 1177.32 USD·ha^{-1}.

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EKONOMICZNA EFEKTYWNOŚĆ UPRAWY CZARNUSZKI SIEWNEJ W ZALEŻNOŚCI OD CZYNNIKÓW AGROTECHNICZNYCH

Streszczenie

O możliwości uprawy czarnuszki siewnej (*Nigella sativa* L.) obok jej walorów prozdrowotnych decyduje wybór technologii oparty o koszty produkcji. W pracy przedstawiono badania związane z poziomem opłacalności uprawy tego gatunku w warunkach zróżnicowanej agrotechniki północno-wschodniej Europy. Czynnikami doświadczenia były: nawożenie azotem, termin siewu, rozstawa między rzędami, mechaniczna i chemiczna regulacja zachwaszczenia, chemiczna ochrona roślin przez chorobami. Spośród analizowanych czynników doświadczenia najkorzystniejsze wyniki stwierdzono w przypadku mechanicznej regulacji zachwaszczenia, dla której obliczona nadwyżka bezpośrednia wyniosła 627,10 USD·ha^{-1}. Całkowite koszty produkcji kształtowały się w przedziale od 1077,32 do 1177,32 USD·ha^{-1}. Technologia uprawy czarnuszki siewnej, w oparciu o zaprawianie materiału siewnego bez kompleksowej ochrony przed patogenami w okresie wegetacji oraz mechaniczna regulacja zachwaszczenia, warunkowały najwyższą opłacalność, wynoszącą odpowiednio 1,46 i 1,56.

Słowa kluczowe: czarnuszka siewna, koszty produkcji, pielęgnacja plantacji, rozstawa między rzędami, termin siewu