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NITROGEN FERTILIZATION VERSUS THE YIELD AND QUALITY OF CORIANDER FRUIT (*Coriandrum sativum* L.)

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Abstract. Coriander is a herbal plant, whose fruit has medicinal and aromatic use. The field research described herein was conducted in 2006–2008, where a controlled, one-factor experiment was set up in a random block design with four replications. The experimental factor was nitrogen fertilization in doses of 20, 40, 60, 80 and 100 kg N·ha^{-1} and a control treatment (no nitrogen fertilization). The objective was to determine the effect of nitrogen fertilization on the yield and quality of coriander herbal material (fruit). The experimental results showed that the weather conditions during the research determined the morphological traits and yield components as well as the volume of unprocessed herbal material obtained from coriander plants. The yield of coriander fruit was significantly higher in the season with high precipitations than in the other two years with lower precipitations. The respective differences were 44 and 32%. Nitrogen fertilization did not differentiate the number of plants per plot surface area, weight of fruits per plant or 1000 fruit weight, meaning that the fruit yields were not differentiated, either. However, a significant relationship has been shown between coriander yields and nitrogen fertilization in the years of the experiment. The experiment evidenced that the chemical composition of coriander fruits was more strongly determined by the weather conditions during the growing season than by nitrogen fertilization. A higher content of essential oil in fruit (1.50%) was obtained by coriander growing under drier weather; when the growing season was much wetter, the content of essential oil was much lower (1.07%). The major component of coriander oil was linalool, which made up 67.4% of the chemical profile. Nitrogen fertilization did not differentiate the chemical profile of coriander essential oil.

Key words:. *Coriandri fructus*, medicinal plants, fruit yield, essential oil, linalool

INTRODUCTION

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Coriander is a herbal plant used in many industries, including the manufacture of pharmaceuticals, food and cosmetics. The plant material used for processing by the herbal industry is the fruit (*Fructus Coriandri*) and essential oil (*Oleum Coriandri*) extracted from coriander fruit [Bourdock and Carabin 2009]. Coriander fruits are useful for processing because of their rich chemical composition as well as the rich taste and aroma. Coriander fruits owe their flavour mainly to essential oil, which contains many volatile compounds, such as linalool, geraniol, α-pinene, γ-terpinene and others [Diederichsen 1996, Weiss 2002]. Coriander oil also possesses medicinal properties, as: anti-bacterial, anti-fungal or anti-oxidant properties [Singh et al. 2006, Matasyoh et al. 2009, Asgarpanah and Kazemivash 2012].

Of all mineral nutrients, nitrogen has the most profound influence on agricultural and biological traits of plants [Rumińska 1983]. This element is the basic component of protoplasm. It plays an important role in the synthesis of many chemical compounds (including proteins and enzymes), which translates into the processes involved in the growth and development of plants [Podsiadło 2005, Carrubba 2009, Khan et al. 2012, Khalid 2013]. Nitrogen deficit in soil leads to retarded growth and loss of weight of plant aerial organs as well as premature ripeness of plants [Oliveira et al. 2003]. Excess nitrogen causes abundant growth of vegetative organs to the detriment of generative ones [Oliveira et al. 2003, Carrubba 2009], makes plants more vulnerable to lodging and diseases, prolongs the period of vegetation and delays maturity and harvest [Ebert 1982]. In short, a proper course of onthogenesis depends on nitrogen, which functions as a limiting factor of agricultural yields [Okut and Vidirim 2005, Rzekanowski et al. 2007, Khalid 2013].

Coriander does not have a high demand for nitrogen [Rumińska 1983], although it responds to nitrogen fertilization with higher fruit yields [Oliveira et al. 2006, Rzekanowski et al. 2007, Kumar et al. 2008, Carrubba 2009]. To produce 1 t of fruit, coriander takes up about 33 kg N from soil [Carrubba 2009]. Experimental research has proven that optimal doses of nitrogen, ensuring the best coriander yields, are within 20 to 90 kg $N \cdot ha^{-1}$ [Luayza et al. 1996, Okut and Yidirim 2005, Oliveira et al. 2006, Rzekanowski et al. 2007, Tehlan and Thakral 2008, Kumar et al. 2008]. Differences in nitrogen fertilization and coriander yields may stem from the geographical origin of this plant and its adaptation to warm and dry climates. In moderate climatic conditions, the uptake of nitrogen from soil and its effective use to produce yields can be modified by different thermal and moisture conditions. In north-eastern Poland, where our experiment was set up, the climatic conditions are even more demonstrably divergent from optimal ones for coriander, which may be a decisive consideration when selecting nitrogen fertilization levels.

The quality of unprocessed herbal material depends in the genotype of a plant [Gil et al. 2002, Kocourkova et al. 2005, Telci et al. 2006, Zheljazkov et al. 2008], but is also modified by climatic conditions or geographical location of a plantation [Misharina 2001, Telci et al. 2006, Zheljazkov et al. 2008] or applied agronomic treatments [Gil et al. 2002, Rzekanowski et al. 2007]. Of the agronomic factors, mineral fertilization affects the chemical composition of fruits or their content of biologically active substances [Diederichsen 1996, Weiss 2002]. Although Rumińska [1983] reports that coriander has relatively small nutritional requirements regarding nitrogen fertilization, experiments imply that N fertilization has a beneficial effect on the fruit content of essential oil [Rzekanowski et al. 2007].

Most of the investigations on the quality of herbal material obtained from coriander took place under conditions of high insolation and low precipitation during the plant growth [Angelini et al. 1997, Stoyanova et al. 2002, Carrubba et al. 2006, Carrubba 2009, Telci et al. 2006, Moosavi et al. 2012], which are far less common in Poland. It was therefore assumed that some of the cited results, including the content of essential oil or its individual components, might not be relevant under Polish conditions. Also, there is some discrepancy in results on the content of essential oil in fruits of coriander grown in different parts of Poland [Rzekanowski et al. 2007, Zawiślak 2011]. This encouraged us to undertake a study located under the climatic conditions of north-eastern Poland.

The objective of this research has been to determine the effect of nitrogen fertilization on the chemical composition of coriander fruit from plants grown under the climatic and habitat conditions typical of north-eastern Poland.

SCOPE OF RESEARCH AND METHODS

The paper presents results of an experiment on coriander conducted by the Department of Agrotechnology and Crop Management, the University of Warmia and Mazury in Olsztyn in 2006–2008. The experiment was set up at the Experimental Station in Bałcyny near Ostróda (N – 53º35'; E – 19º51'). The field experiment was located on proper grey-brown podzolic soil, developed from light or medium loam, which in the Polish soil valuation system was classified as IIIa.

The research was based on a controlled, multiple, one-factorial experiment designed in a random block model with four replications. The size of a plot for harvest was 12 m^2. The experimental factor was nitrogen fertilization in doses of 20, 40, 60 (40 + 20), 80 (40 + 40) and 100 (60 + 40) kg $N \cdot ha^{-1}$; additionally, a control treatment was established with no nitrogen fertilization The nitrogen doses of 20 and 40 kg $N \cdot ha^{-1}$ were applied singly before sowing coriander seeds, while the other doses were spilt into two applications – pre-sowing and in the early leaf rosette formation phase (34% ammonium nitrate). The tested coriander was a Polish cultivar called Ursynowska (small-fruit variety, 1000 fruit weight of about 7 g, the content of essential oils in fruit from 0.9 to 1.0%) [Rumińska 1983]. The preceding crop was spring barley harvested for grain (in 2006 and 2008) or a mix of cereals and legumes harvested for herbage (in 2007). The whole field under the plot experiment was supplied with phosphorus and potassium fertilizers in the doses of 35.0 kg P (46% triple superphosphate) and 83.0 kg $K \cdot ha^{-1}$ (60% potassium salt), and with boron in the amount of 5.0 kg $B \cdot ha^{-1}$ (Solubor – $Na_2B_8O_{13} \cdot 4H_2O$). Weeds were controlled chemically by applying the herbicide Patoran (a.i. metabromuron, dose 3.0 $l \cdot ha^{-1}$). The disease prevention consisted of pre-sowing seed dressing with Oxafun T (a.i. carboxin + thiram, dose 3.0 $g \cdot kg^{-1}$) and foliar application of the fungicide Penncozeb 80 WP (a.i. mankozeb, dose 2.5 $kg \cdot ha^{-1}$) before the flowering stage. Coriander was sown in April (the second ten days in 2006 and 2008, and the first ten in 2008), by sowing 15 $kg \cdot ha^{-1}$ of seeds in rows spaced at

15 cm, to the depth of 1.5 cm [Rumińska 1983]. Coriander plants were harvested with a small plot combine harvester at the fruit full maturity stage.

Table 1. Phenological periods of coriander in the meteorological conditions in years of research

Phenological period	Number of days			Mean daily temperature of air (°C)			Rainfall sum (mm)		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Sowing – emergence	18	20	24	12.9	8.6	7.6	33.0	25.9	32.2
Emergence – stem elongation	36	34	36	13.3	16.7	12.9	105.8	62.8	48.4
Stem elongation – flowering	16	11	14	19.6	18.2	15.6	51.9	21.3	11.2
Flowering – fruit formation	11	10	10	21.0	15.9	17.1	14.0	51.0	15.6
Fruit formation – full maturity	35	52	48	19.3	18.3	18.5	95.0	236.8	92.8
Full maturity – harvesting	3	5	6	16.7	15.3	17.5	17.1	0.2	24.1
Vegetation season	119	132	138	17.1	15.5	14.9	316.8	398.0	224.3

The principal plant development stages were monitored during the growth of coriander (tab. 1), which lasted from 119 days (in 2006) to 138 days (in 2008). The three growing seasons were highly different in the weather conditions, both in temperatures and rainfalls. The highest mean daily air temperature occurred in 2006 (17.1ºC), but it was much lower in the subsequent years (15.5 and 14.9ºC). The highest rainfall was recorded in 2007 (398.0 mm), but less rain fell in the other two seasons (316.8 mm in 2006, 224.3 mm in 2008) (tab. 1). When the coriander fruit had reached technological maturity, the number of plants per 1 m^2 on each plot was determined, after which 10 plants were randomly chosen from each plot for morphometric measurements, such as: height of the stem, height of the first lateral branching, number of lateral branches, number of inflorescences per plant and weight of fruit per plant. The weight of 1000 fruit was assessed based on the yield harvested with a small combine harvester.

Coriander fruit harvested in 2007 and 2008, years which had the most different humidity conditions during the growing season, were taken for qualitative assays. The phytochemical analysis of the plant material consisted of determinations of the content and chemical profile of essential oil. The content of essential oil was determined with the direct method [Farmakopea Polska 2008] via distillation in a Derynga apparatus with closed water circulation [PN-R-87019:1991]. Trials pre-dried with anhydrous sodium sulfate (VI) – (Na_2SO_4). The chemical profile of essential oil was assayed by gas chromatography coupled with a mass detector (Varian 4000GC/MS/MS), column VF–5ms (analog DB-5), carrier gas Helium (0.5 $ml \cdot min^{-1}$), temperature program of 50ºC for 1 minute, buildup to 250ºC at a rate of $4ºC \cdot min^{-1}$, 250ºC for 10 min. The chemical profile of essential oil was assayed by gas chromatography coupled with a mass detector (on a Varian 4000GC/MS chromatograph).

The statistical processing of the results comprised the ANOVA® analysis of variance for one-factor experiments, and the statistical error was assumed at the level of $\alpha = 0.05$. The Duncan's test was applied to testing confidence intervals, and statistically homogenous groups were assigned small letters in the tables. The statistical analysis was supported by STATISTICA 8.0® software, while the other calculations were performed on EXCEL® spreadsheets.

RESULTS AND DISCUSSION

Variance analysis of the coriander features specified in the work (fruit yield, plant number per 1 m^2, fruit weight per plant, 1000 fruit weight) are presented in Table 2. Coriander fruit yields were significantly varied between the three years (tab. 2). This suggests that the yield volume was conditioned by the course of weather conditions in a given plant growing season (tab. 1). High variability of coriander fruit yields has also been implied by other researchers [Angelini et al. 1997, Carrubba et al. 2006, 2009a, b, Zheljazkov et al. 2008]. The highest fruit yield, such as 2.19 t·ha^{-1}, was obtained in 2007 (tab. 3). In the other two seasons, the coriander fruit yields were significantly lower: 1.66 t·ha^{-1} in 2008 and 1.52 t·ha^{-1} in 2006. Compared with the best yield, this meant 24.2 and 30.6% less, respectively. The up-to-date research shows that coriander responds to the moisture and humidity conditions during its growth, so that the ultimate yield volume is altered. In a study carried out on Sicily, Carrubba et al. [2006] demonstrated a highly significant correlation between coriander yields and rainfall during the growing season. Compared to the fruit yield of 0.87 t·ha^{-1} produced by coriander plants exposed to the total rainfall of 200 mm, more abundant precipitation, such as 420 and 505 mm, enabled an increase in fruit yield up to 1.71 and 2.13 t·ha^{-1}, that is 97 and 145% higher, respectively. Rzekanowski et al. [2008] achieved the highest coriander yields (1.75 t·ha^{-1}) at the sum of natural precipitation and seasonal irrigation dose equal from 350 to 450 mm.

Table 2. Analysis of variance for analyzed features of coriander

Source of variation	Fruit yield	Plant number per 1 m^2	Fruit weight per plant	1000 fruit weight
Years (L)	*	*	*	*
Nitrogen fertilization (N)	n.s.	n.s.	n.s.	n.s.
L × N	*	n.s.	n.s.	*

* – significant at 5% probability level; n.s. – not significant

The doses of nitrogen analyzed in the reported experiment, same as in the study of Meena et al. [2006], did not have any significant influence on yields of coriander (tab. 2). This means that in the control variant (with no nitrogen fertilization), the yield of coriander fruit was statistically similar to the yields harvested from all nitrogen fertilized treatments. The high soil abundance in mineral nitrogen originating from mineralization of organic substance was most probably the reason why coriander plants did not respond to nitrogen fertilization. These results may prove than in good soil conditions and suitable preceding crops, coriander can yield high amounts of fruit, such as 1.84 $t{\cdot}ha^{-1}$ in soil nourished with just 20 kg $N{\cdot}ha^{-1}$. However, a significant correlation was detected for nitrogen fertilization in the years of the experiment (years x nitrogen fertilization interaction) (tab. 2, 3). Under the favourable weather conditions in 2007 (precipitation total 389.0 mm), the dose of 40 kg $N{\cdot}ha^{-1}$ proved to be optimal, ensuring the highest fruit yield, i.e. 2.39 $t{\cdot}ha^{-1}$. Under a less beneficial course of the weather in 2008 (224.3 mm of rain), the dose of nitrogen which proved to be optimal for the plant was higher: 60 kg $N{\cdot}ha^{-1}$ (1.77 $t{\cdot}ha^{-1}$); in 2006 (316.8 mm of rainfall and statistically the lowest fruit yields), the dose of 20 kg $N{\cdot}ha^{-1}$ (1.62 $t{\cdot}ha^{-1}$) appeared sufficient. Some references [Carrubba 2009] indicate that coriander shows a changeable response in terms of yields to increased nitrogen fertilization. Although nitrogen is a highly productive element, its effectiveness largely depends on overall, habitat-specific conditions.

Table 3. Fruit yield of coriander ($t{\cdot}ha^{-1}$)

Years of investigation	Nitrogen fertilization (N $kg{\cdot}ha^{-1}$)						Mean
	0	20	40	60	80	100	
2006	1.42^{e}	1.62^{d}	1.63^{d}	1.47^{e}	1.54^{d}	1.46^{e}	1.52^{c}
2007	2.32^{ab}	2.34^{ab}	2.39^{a}	2.05^{c}	2.10^{b}	1.96^{cd}	2.19^{a}
2008	1.55^{d}	1.55^{d}	1.53^{d}	1.77^{cd}	1.83^{cd}	1.75^{d}	1.66^{b}
Mean	1.76	1.84	1.85	1.76	1.82	1.72	–

a–e – homogeneous groups according to the Duncan's test (significance level 5%)

An optimum nitrogen dose regarding the yield of coriander was 20 kg $N{\cdot}ha^{-1}$ (yield of 1.14 $t{\cdot}ha^{-1}$) [Patel et al. 2013] or 60 kg $N{\cdot}ha^{-1}$ (yield of 1.13 $t{\cdot}ha^{-1}$) in India [Bhunia et al. 2009]. In Poland, the best was 70 kg $N{\cdot}ha^{-1}$ (yield of 1.77 $t{\cdot}ha^{-1}$) [Rzekanowski et al. 2007]. In Brazil [Oliveira et al. 2006], the coriander yield increased proportionally to the rising doses of nitrogen, and the highest coriander fruit yield was achieved (1.90 $t{\cdot}ha^{-1}$) when soil had been supplied with 80 kg $N{\cdot}ha^{-1}$. Also, Kumar et al. [2008], who conducted an experiment in India, and Moosavi et al. [2013], in a study carried out in Iran, reported the highest coriander fruit yield on a dose of 80 kg $N{\cdot}ha^{-1}$. Okut and Vidirim [2005], in the climatic conditions of Turkey, or Tehlan an Thakral [2008], in India, demonstrated the highest yields of this plant (1.03 and 1.36 $t{\cdot}ha^{-1}$, respectively) in soil nourished with 90 kg $N{\cdot}ha^{-1}$. In turn, Khalid [2013] completed an experiment in Egypt and reported the highest coriander fruit yield in response t the nitrogen dose of 200 $kg{\cdot}ha^{-1}$.

Carrubba [2009] points to the fact that nitrogen fertilization becomes more important for coriander yields when the plants face rainfall deficit during the growth, and adds that higher yields can be obtained by irrigating plants. This is supported by Rzekanowski et al. [2007], who concluded that a dose of nitrogen optimal for coriander plants growing under natural rainfall conditions was 70 kg N·ha^{-1} (yield of 1.64 t·ha^{-1}), but 50 kg N·ha^{-1} was sufficient when plants were artificially irrigated (yield 1.87 t·ha^{-1}). Channabasavanna [2002] concluded that 60 kg N·ha^{-1} is optimal for irrigated plantations of coriander in India.

The coriander yield components, that is the number of plants per plot surface area, weight of fruit per plant or 1000 fruit weight did not differ much between the three years of the experiment (tab. 2). In 2007, coriander produced plants with the biggest conformation, i.e. the tallest and most strongly branched, which may have indirectly caused a reduced number of plants per area unit. In the other two years, the number of plants before harvest was higher, but the difference became significant only in 2008. The highest and statistically similar weight of fruit per plant was produced by coriander in 2007 and 2008. In 2006, the value of this trait was significantly smaller, by 23.5 and 18.8%, respectively. Also, Carrubba et al. [2009a] showed a significant effect of the years of trials on the weight of fruit per plant. The most robust fruits were grown by coriander in 2006, when the 1000 fruit weight was the highest (10.9 g). In the other years, fruits were significantly smaller and the smallest 1000 fruit weight (8.6 g) was obtained in 2007, which is when the coriander yields were the highest. In that year, too, coriander was characterized by the highest weight of fruit per plant (1.53 g) but the lowest plant density per area unit (187.2 plants per 1 m^2). The lower yielding capacity of coriander plants in the other years is reflected by a demonstrably smaller number of plants per area unit and 1000 fruit weight. Carrubba et al. [2006], testing coriander under the climatic conditions of Sicily, did not detect any influence of years of the research on the 1000 fruit weight.

In our experiment, nitrogen fertilization did not differentiate significantly the number of plants per m^2 before harvest, weight of fruit per plant or 1000 fruit weight (tab. 2). Such non-significant impact of nitrogen nutrition on the yield components did not differentiate the yield of coriander fruits per area unit, either. The pre-harvest number of plants per m^2 in response to the nitrogen fertilization within 20–100 kg N·ha^{-1} varied within a narrow range of 209.0 to 217.6 plants, and was statistically similar to the control (210.4 plants) (tab. 4). The plant stand was almost double the optimal density (50–100 plants·1 m^{-2}) that ensures best coriander yields [Diederichsen 1996]. The nitrogen fertilization, against the control (1.15 g), evidently improved the weight of fruits per plant, but the differences were not confirmed statistically. The highest weight of fruit per plant (1.54 g) was ensured by nitrogen supplied in the dose of 60 kg N·ha^{-1}, and the value of this trait was almost 34% higher than the control (tab. 5). Significant impact of nitrogen fertilization on fruit yield per plant has also been verified in a plot experiment completed by Nowak and Szempliński [2011].

The 1000 coriander fruit weight, same as in the research reported by Okut and Yidirim [2005] or Nowak and Szempliński [2011], was not differentiated by nitrogen doses. In all the treatments, the values of this trait (9.9–10.2 g) did not diverge from the control (10.0 g) in a statistically significant manner (tab. 4). However, a significant correlation was determined between the 1000 fruit weight and nitrogen fertilization in the years of the experiment (tab. 2). In 2006, that is when coriander yields were the lowest, significantly most robust fruits were grown by coriander plants nourished with the nitrogen doses of 60 and 80 kg N·ha^{-1}. In 2008, nitrogen doses did not cause statistically significant variation in the 1000 fruit weight. In 2007, the year with the highest yields, the highest 1000 fruit weight was achieved in the control treatment (no nitrogen application), unlike in the treatments with increasing doses of nitrogen, where coriander tended to grow smaller fruits. However, the differences were not statistically significant (tab. 4). A similar relationship consisting of a non-significant decrease in the size of fruits due to higher nitrogen fertilization levels is known from studies on other plants [Budzyński et al. 2004, Krajewski et al. 2013].

Table 4. Components of fruit yield of coriander

	Years of investigation	Nitrogen fertilization (N kg·ha^{-1})						Mean
		0	20	40	60	80	100	
Number of plant per 1 m^2 at harvest time	2006	205.9	213.2	213.2	198.8	204.7	186.0	203.6^b
	2007	175.4	175.9	207.5	184.2	189.6	190.4	187.2^b
	2008	250.0	237.9	232.1	260.4	252.1	252.9	247.6^a
	mean	210.4	209.0	217.6	214.5	215.5	209.8	–
Fruit weight per plant (g)	2006	1.04	1.04	0.95	1.21	1.46	1.32	1.17^b
	2007	1.25	1.63	1.51	1.70	1.46	1.64	1.53^a
	2008	1.15	1.47	1.40	1.71	1.65	1.24	1.44^a
	mean	1.15	1.38	1.29	1.54	1.52	1.40	–
1000 fruit weight (g)	2006	10.3^{ab}	11.1^{ab}	10.8^{ab}	11.3^a	11.2^a	10.8^{ab}	10.9^a
	2007	9.1^b	8.8^b	8.8^b	8.6^b	8.2^b	8.2^b	8.6^c
	2008	10.5^{ab}	10.6^{ab}	10.1^{ab}	10.5^{ab}	10.3^{ab}	10.6^{ab}	10.4^b
	mean	10.0	10.2	9.9	10.1	9.9	9.9	–

a–c – homogeneous groups according to the Duncan's test (significance level 5%)

The value of coriander fruits for processing also depends on the content and chemical composition of essential oil [Telci et al. 2006, Burdock and Carabin 2009]. In our study, same as in reports by other researchers [Gil et al. 2002, Rzekanowski et al. 2007, Zheljazkov et al. 2008, Zawiślak 2011,], the content of coriander oil in seeds varied from year to year, which was obviously due to the changing weather conditions (fig. 5). It was significantly affected by weather conditions during the growing season, especially precipitation, temperature and insolation in the phase of fruits formation (tab. 1). In 2008, when the air temperature during the plant growing season was 14.9ºC and the total rainfall was 224.3 mm, the content of essential oil was 1.50%, thus being 0.43% higher than in 2007, when the vegetation season was quite warm (the average temperature of 15.5°C) but the precipitation was much higher (398.0 mm), which accounted for 59% during the fruits formation. The significant influence of rainfalls on the content of essential oil in coriander fruit has been implied also by Rzekanowski et al. [2007], who concluded that the content of essential oil was significantly higher in fruits from irrigated plants (1.78%) than from the control (1.53%). Our results on the content of coriander essential oil agree with the ones provided by other authors. Depending on the analyzed factors, the reported content of coriander essential oil ranged from 0.20 to 2.83% [Stoyanova et al. 2002, Telci et al. 2006, Rzekanowski et al. 2007, Kucharski and Mordalski 2008, Asgarpanah and Kazemivash 2012]. In individual years of the quoted experiments, the percentage of essential oil in coriander fruits varied from 0.65 to 2.20% [Zheljazkov et al. 2008], 1.87 to 2.33% [Zawiślak 2011] or 0.28 to 0.50% [Telci et al. 2006]. These differences may have been due to the different seed coriander genotypes used in the experiments.

In fruits from coriander plants growing on nitrogen fertilized plots, the average content of essential oil was from 1.25 to 1.31% and did not diverge from the control (1.30%). No distinct tendency was observed over the three years for changes caused by increasing nitrogen doses (tab. 5). Gil et al. [2002] did not show any differentiation in the essential oil content in coriander fruits caused by nitrogen fertilization by doses from 0 to 135 kg N·ha^{-1}. Khalid [2013] showed that nitrogen doses from 0 to 200 kg N·ha^{-1} did not differentiate the oil content in coriander fruit and fennel, but significantly increased this train in anise fruit. Quite different results were obtained by Rzekanowski et al. [2007], who found that nitrogen fertilization within 30–70 kg N·ha^{-1} differentiate the essential oil content in coriander fruit, but its significantly highest content was determined in response to the dose of 70 kg N·ha^{-1}. In turn, Moosavi et al. [2012] showed that nitrogen fertilization caused a significant increase in the content of oil in coriander fruits, with its highest concentration determined in fruits from plants fertilized with 120 kg N·ha^{-1}. This increase between the control (0.153%), and the highest nitrogen dose (0.33%) was more than double. Patel et al. [2013] concluded that the oil content increased significantly up to the dose of 40 kg N·ha^{-1}, and any further increase in nitrogen fertilization to 80 kg N·ha^{-1} caused a non-significant increase in its content Kahlid [2013] reports that the effect of nitrogen on the content of essential oils in plants could be the function of the influence of different nitrogen doses on the activity of enzymes and the metabolism of oil.

Table 5. Content of essential oil in coriander fruits of (%)

Year of investigation	Nitrogen fertilization (N kg·ha^{-1})						Mean
	0	20	40	60	80	100	
2007	1.08	1.10	1.08	1.02	1.06	1.06	1.07
2008	1.52	1.52	1.44	1.48	1.56	1.48	1.50
Mean	1.30	1.31	1.26	1.25	1.31	1.27	–

Our analysis of the fractional composition shows that – out of twenty determined chemical substances – linalool was the basic component of the chemical profile of coriander essential oil (tab. 6). In both years, linalool made up over 67% of all isolated chemical substances (fig. 1). Similar content of linalool was determined by Carrubba et al. [2009b] in coriander essential oil extracted from plants grown on Sicily, and its amount was significantly higher in the warmest and more humid plant growing season. The content of linalool in coriander essential oil is from 33.7 to 87.5% [Misharina 2001, Gil et al. 2002, Telci et al. 2006, Msaada et al. 2007, Zheljazkov et al. 2008, Zawiślak 2011]. This compound is responsible for the characteristic aroma of coriander oil [Carrubba et al. 2006]. The share of other compounds was much lower, and the following appeared in any notable quantities: α-pinene, γ-terpinene, camphor, cymene and limonene. The content of α-pinene in the coriander oil obtained in 2007 (9.4%) was slightly higher than in 2008 (7.2%). The share of γ-terpinene in herbal material was almost the same in both years (6.9% in 2007 and 6.5% in 2008). The content of camphor was 4.8 in the first and 5.7% in the second year, cymene – 3.4 and 3.5%, respectively, and limonene – 2.8% (in 2007) and 2.9% (in 2008) of all components of coriander essential oil (fig. 2). Other authors [Diederichsen 1996, Misharina 2001, Gil et al. 2002, Stoyanova et al. 2002, Weiss 2002, Kocourkowa et al. 2005, Zheljazkov et al. 2008, Carrubba et al. 2009a, b, Zawiślak 2011] name the same compounds as the basic ingredients of coriander oil. In turn, Carrubba et al. [2009b] demonstrated that the content of linalool and other major components of coriander oil was significantly varied between years of experiments.

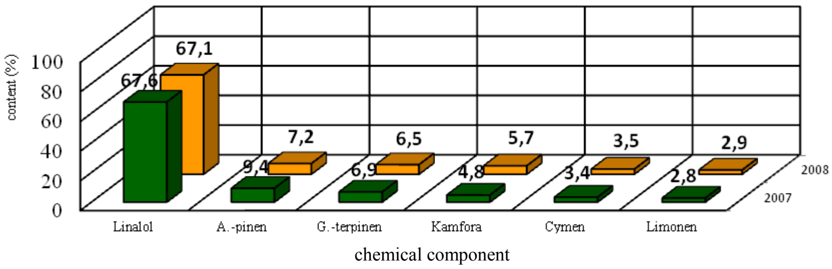

Fig. 1. Content of major chemical components of coriander essential oil of in the research

Some differences in the mean concentrations of the analyzed compounds were observed under the influence of nitrogen fertilization (tab. 6). Against the control, the content of linalool in nitrogen supplied treatments tended to increase, reaching the highest levels in fruits from the variant fertilized with the nitrogen doses of 60 and 80 kg N·ha^{-1} (68.5 and 68.6%), and the lowest one in fruits from coriander fertilized with 40 kg N·ha^{-1} (65.7%). Carrubba et al. [2009b] reviewed the relevant literature and concluded that no significant differences had been recorded in the content of linalool caused by nitrogen fertilization within the range of doses from 0 to 240 kg N·ha^{-1}. The highest content of α-pinene (8.8%) was obtained in the control, with nitrogen fertilization decreasing it by 0.4 to 1.2%. Also, the highest content of γ-terpinene (7.8%) appeared in the control, but as the nitrogen fertilization levels increased, the amount of this compound decreased to 7.4% in fruits from the variant fertilized with 20 kg N·ha^{-1} and to 5.6% from plots nourished with the nitrogen doses of 60 and 100 kg N·ha^{-1}. The content of cymene in oil varied from 2.6% (in the control) to 4.6% (at the nitrogen dose of

100 kg N·ha^{-1}), which suggests that concentrations of this compound tended to increase under the impact of higher nitrogen doses. The content of two other compounds, limonene and camphor, was most stable under the conditions of higher nitrogen fertilization, with the differences between their mean concentrations ranging from 0.1 to 0.4% (tab. 6).

Table 6. Major components of essential oil of coriander fruit (%) (average from two years)

Chemical component	Nitrogen fertilization (N kg·ha^{-1})						Mean
	0	20	40	60	80	100	
Linalool	66.5	67.2	65.7	68.5	68.6	67.7	67.4
α-pinene	8.8	8.4	8.4	7.6	8.2	8.4	8.3
γ-terpinene	7.8	7.4	6.8	5.6	7.0	5.6	6.7
Camphor	5.3	5.3	5.5	5.1	5.2	5.1	5.2
Cymene	2.6	2.8	3.4	4.4	2.9	4.6	3.4
Limonene	3.0	2.8	3.0	2.7	2.9	2.9	2.9
Total	94.0	93.9	92.8	93.9	94.8	94.3	–

These results support the findings reported by Carruba et al. [2009b] from experiments conducted on Sicily, in which both the type of nitrogen fertilization (organic, mineral) and nitrogen doses did not differentiate significantly the chemical profile of coriander oil.

CONCLUSIONS

1. The weather conditions during the experiment conditioned the morphological traits of plants, yield components and yields of coriander. At higher precipitation during the growing season, the yield of coriander was significantly higher, than in the other years with less rainfall.

2. Nitrogen fertilization did not differentiate the number of plants per area unit, weight of fruits per plant or 1000 fruit weight, and consequently did not alter the ultimate fruit yields from coriander. However, a significant relationship has been demonstrated between coriander yields and nitrogen fertilization in the years of the experiment. The lack of a clear response in coriander yielding on nitrogen fertilization may argue that this plant has little nutritional requirements and makes good use of nitrogen from the soil.

3. A higher content of essential oil in fruits was achieved by coriander grown under low precipitation during the plant growing season; when rainfall was more abundant, the content of coriander essential oil was distinctly lower.

4. The main component of coriander oil was linalool, which made up 67.4% of its chemical profile. Nitrogen fertilization did not differentiate much the chemical profile of coriander oil.

5. It is possible to obtain herbal material from coriander grown under the weather conditions in north-eastern Poland which will not differ much in its chemical composition from such plant material obtained in other regions, with a warmer climate.

REFERENCES

Asgarpanah, J., Kazemivash, N. (2012). Phytochemistry, farmacology and medicinal properties of *Coriandrum sativum* L. Afr. J. Pharm. Pharmacol., 6(31), 2340–2345.

Angelini, L.G., Moscheni, E., Colonna, G., Belloni, P., Bonari, E. (1997). Variation in agronomic characteristics and seed oil composition of new oilseed crops in central Italy. Indust. Crops Prod., 6, 313–323.

Bhunia, S.R., Ratnoo, S.D., Kumawat, S.M. (2009). Effect of irrigation and water use, moisture extraction pattern, nitrogen uptake and yield of coriander (*Coriandrum sativum* L.) in north-western irrigated plains of Rajasthan. J. Spec. Arom. Crops, 18(2), 88–91.

Budzyński, W., Gleń, A., Bielski, S. (2004). Wartość technologiczna ziarna żyta mieszańcowego i populacyjnego w zależności od poziomu nawożenia azotem. Pam. Puł., 135, 19–32.

Burdock, G.A., Carabin, I.G. (2009). Safety assessment of coriander (*Coriandrum sativum* L.) essential oil as a food ingredient. Food Chem. Toxic., 47, 22–34.

Carrubba, A., Calabrese, I., Ascolillo, V. (2009a). Non-chemical weeds management in two Mediterranean culinary herbs. I[st] International Medicinal and Aromatic Plants Conference on Culinary Herbs. ISHS Acta Hort., 826, 51–58.

Carrubba, A., Catalano, C., Militello, M. (2009b). Effects organic and coinventional N-fertilization on quality traits in coriander (*Coriandrum sativum* L.). More Sustainability in Agriculture: New Fertilizers and Fertilization Management. 18[th] Symposium of the International Scientific Centre of Fertilizers, 174–179.

Carrubba, A., Torre, R., Saiano, F., Alonzo, G. (2006). Effect of sowing time on coriander performance in a semiarid Mediterranean environment. Crop Sci., 46, 437–447.

Carrubba, A. (2009). Nitrogen fertilization in coriander (*Coriandrum sativum* L.): a review and meta-analysis. J. Sci. Food Agric., 89(6), 921–926.

Channabasavanna, A.S. (2002). Standarization and economic analysis of fertilizer levels for coriander (*Coriandrum sativum* L.). J. Maharashtra Agric. Univ., 27(2), 160–162.

Diederichsen, A. (1996). Coriander – *Coriandrum sativum* L. Promoting the conservation and use of underutilized and neglected crops. IPGRI, Rome.

Ebert, K. (1982). Arznei- und Gewürzpflancen – Ein Leitfanden für Anbau und Sammlung. Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart.

Farmakopea Polska, VIII (2008). URPL,WMiPB. Warszawa.

Gil, A., Fuente, E.B., Lenardis, A.E., Lopez-Pereira, M., Suarez, S.A., Bandoni, A., Baren, C., Leo-Lira, P., Ghersa, C.M. (2002). Coriander essential oil composition from two genotypes grown in different environmental conditions. J. Agric. Food Chem., 50(10), 2870–2877.

Khalid, K.A. (2013). Effect of nitrogen fertilization on morphological and biochemical traits of some Apiaceae crops under arid region conditions in Egypt. Nus. Biosci., 5(1), 15–21.

Khan, S., Pariari, A., Shadap, A. (2012). Growth and yield of coriander (*Coriandrum sativum* L.) as influence by nitrogen and zinc level. Production and Menagement of Spices in West Bengal – a state level seminar during, 1–2 march: 1–2.

Kocourkova, B., Ruzičkova, G., Sedlakova, j., Kralik, J., Lojkova, J. (2005). The influence of cultivation environment to the contents, field and composition of coriander (*Coriandrum sativum* L.) essential oil. Herba Pol., 51(1), 102–103.

Krajewski, T., Szempliński, W., Bielski, S. (2013). Plonowanie nagoziarnistych i oplewionych odmian jęczmienia jarego nawożonego azotem. Annales UMCS, sec. E, Agricultura, 68(1), 18–29.
Kucharski, W.A., Mordalski, R. (2008). Porównanie efektywności uprawy kolendry siewnej (*Coriandrum sativum* L.) w systemach ekologicznym i konwencjonalnym. J. Res. Appl. Agric. Eng., 53(3), 152–155.
Kumar, A., Singh, R., Chhillar, R.K. (2008). Influence of omitting irrigation and nitrogen levels on growth, yield and water use efficiency of coriander (*Coriandrum sativum* L.). Acta Agron. Hung., 56(1), 69–74.
Luayza, G., Brevedan, R., Palomo, R. (1996). Coriander under irrigation in Argentina. In: Progress in new crops, Janick, J. (ed.). ASHS Press, Arlington, 590–594.
Matasyoh, J.C., Maiyo, Z.C., Ngure, R.M., Chepkorir, R. (2009). Chemical composition and antimicrobial activity of the essential oil of *Coriandrum sativum*. Food Chem., 113, 526–529.
Meena, S.S., Sen, N.L., Malhotra, S.K. (2006). Influence of sowing date, nitrogen and plant growth regulators on growth and yield of coriander (*Coriandrum sativum* L.). J. Spec. Arom. Crops, 15(2), 88–92.
Misharina, T.A. (2001). Influence of the duration and conditions of storage on the composition of the essential oil from coriander seeds. Appl. Biochem. Microbiol., 37(6), 622–628.
Moosavi, S.G., Seghatoleslami, M.J., Zareie, M.H. (2012). The effect of planting date and plant density on morphological traits and essential oil yield of coriander (*Coriandrum sativum* L.). Intl. J. Agri. Crop Sci., 4(8), 496–501.
Moosavi, G., Seghatoleslami, M., Ebrahimi, A., Fazeli, M., Jouyban, Z. (2013). The effect of nitrogen rate and plant density on morphological traits and essential oil yield of coriander. J. Ornam. Horticult. Plants, 3(2), 95–103.
Msaada, K., Hosni, K., Taarit, M.B., Chahed, T., Kchouk, M.E., Marzouk, B. (2007). Changes on essentials oil composition of coriander (*Coriandrum sativum* L.) fruits during three stages of maturity. Food Chem., 102, 1131–1134.
Nowak, J., Szempliński, W. (2011). Effect of nitrogen and boron fertilization on the morphometric features and yield of coriander (*Coriandrum sativum* L.). Acta Sci. Pol. Agricultura, 10(3), 111–118.
Okut, N., Yidirim, M. (2005). Effects of different row spacing and nitrogen doses on certain agronomic characteristics of coriander (*Coriandrum sativum* L.). Pak. J. Biol. Sci., 8(6), 901–904.
Oliveira, A.P., Alves, E.U., Bruno, R.L.A., Sader, R., Alves, A.U. (2006). Producao e qualidade fisiologica de sementes de coentro em funcao de doses de nirtogenio. Rev. Bras. de Sem., 28(1), 193–198.
Oliveira, A.P., Paiva Sobrinho, S., Barbosa, J.K.A., Ramalho, C.I., Oliveira, A.L.P. (2003). Rendimento de coentro cultivado com doses crescentes de N. Hortic. Bras., 21(1), 81–83.
Patel, C.B., Amin, A.U., Patel, A.L. (2013). Effect of varying levels of nitrogen and sulphur on growth and yield of coriander (*Coriandrum sativum* L.). The Bioscan, 8(4), 1285–1289.
Podsiadło, C. (2005). Nawozy i nawożenie. In: Agrotechnika roślin uprawnych. Karczmarczyk C. (red.). Wyd. AR Szczecin.
Rumińska, A. (1983). Rośliny lecznicze. Podstawy biologii i agrotechniki. PWN, Warszawa.
Rzekanowski, C., Marynowska, K., Rolbiecki, S., Rolbiecki, R. (2007). Effect of irrigation and nitrogen fertilization on the yield of coriander (*Coriandrum sativum* L.). Herba Pol., 53(3), 163–170.
Rzekanowski, Cz., Marynowska, K., Rolbiecki, S., Rolbiecki, R. (2008). Oddziaływanie wybranych czynników meteorologicznych na niektóre elementy plonu czterech gatunków ziół uprawianych w warunkach deszczowania. Acta Agroph., 12(1), 163–171.
Singh, G., Maurya, S., Lampasona, M.P., Catalan, C.A.N. (2006). Studies on essential oils. Part 41. Chemical composition, antyfungial, antioxidant and sprout suppressant activities of coriander (*Coriandrum sativum*) essential oil and its oleoresin. Flavour Fragm. J., 21, 472–479.

Stoyanova, A., Konakchiev, A., Berov, O. (2002). Investigation on the essential oil of coriander from Bulgaria. Herba Pol., 48(2), 67–70.

Tehlan, S.K., Thakral, K.K. (2008). Effect of different levels of nitrogen and leaf cutting on leaf and seed yield of coriander (*Coriandrum sativum* L.). J. Spices Aromat. Crops., 17(2), 180–182.

Telci, I., Bayram, E., Avci, B. (2006). Changes in yield, essential oil and linalool contents of *Coriandrum sativum* varieties (var. *vulgare* Alef. and var. *microcarpum* DC.) harvested at different development stages. Europ. J. Hort. Sci., 71(6), 267–271.

Weiss E.A. (2002). Coriander. Spice Crops, CABI Publishing, 243–261.

Zawiślak, G. (2011). The chemical composition of essential oil from the fruit of coriander (*Coriandrum sativum* L.). Annales UMCS, sec. DDD, Pharmacia, 24, 2/21, 169–175.

Zheljazkov, V.D., Pickett, K.M., Caldwell, C.D., Pincock, J.A., Roberts, J.C., Mapplebeck, L. (2008). Cultivar and sowing date effects on seed field and oil composition of coriander in Atlantik Canada. Indust. Crops Prod., 28, 88–94.

NAWOŻENIE AZOTEM A PLON I JAKOŚĆ OWOCÓW KOLENDRY SIEWNEJ (*Coriandrum sativum* L.)

Streszczenie. Kolendra siewna jest rośliną zielarską, której owoce mają zastosowanie lecznicze oraz przyprawowe. Badania polowe przeprowadzono w latach 2006–2008 na podstawie ścisłego doświadczenia jednoczynnikowego założonego w układzie losowanych bloków, w czterech powtórzeniach. Czynnikiem doświadczenia było nawożenie azotem w dawkach 20, 40, 60, 80 i 100 kg N·ha^{-1} oraz kontrola (bez azotu). Celem badań było określenie wpływu nawożenia azotem na plon i jakość surowca zielarskiego kolendry siewnej. Na podstawie wyników badań wnioskuje się, że warunki pogodowe w latach badań determinowały elementy składowe plonu oraz plonowanie kolendry siewnej. W warunkach większych opadów w okresie wegetacji plon owoców kolendry był istotnie większy niż w latach o mniejszych opadach odpowiednio o 44 i 32%. Nawożenie azotem nie różnicowało liczby roślin na jednostce powierzchni, masy owoców z rośliny i masy 1000 owoców, a przez to plonu owoców kolendry. Wykazano jednak istotną zależność jej plonowania od nawożenia azotem w latach badań. Z doświadczenia wynika, że skład chemiczny owoców kolendry był w większym stopniu różnicowany warunkami pogodowymi w latach badań niż nawożeniem azotem. Większą zawartość olejku eterycznego w owocach (1,50%) uzyskała kolendra w warunkach niskich opadów w okresie wegetacji, a w warunkach wysokich opadów jego zawartość była wyraźnie mniejsza (1,07%). Głównym składnikiem olejku kolendrowego był linalol stanowiący 67,4% jego profilu chemicznego. Nawożenie azotem nie różnicowało profilu chemicznego olejku kolendrowego.

Słowa kluczowe: *Coriandri fructus*, rośliny lecznicze, plon owoców, olejek eteryczny, linalol

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