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Original Article

Nutritional Value of Garden Dill (*Anethum graveolens* L.), Depending on Genotype

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Abstract

The yield, chemical composition and antioxidant activity of eight genotypes ('Krezus', 'Turkus', 'Kozak', 'Szmaragd', 'Lukullus', 'Herkules', 'Ambrozja', 'Moravan') of garden dill (*Anethum graveolens* L.) biomass was estimated. Field experiments were conducted in 2011-2013 in Poland. The crop lasted 44 days and plants were collected at the 4-5 true leaf stage (a bunch harvest). The highest marketable yield was obtained for 'Krezus' and 'Szmaragd' cultivars (1.18 kg·m^{-2}), while the lowest for 'Herkules' (0.53 kg·m^{-2}). The dry matter of leaves ranged from 15.17% ('Ambrozja') to 19.27% ('Krezus'). The study also proved that the genotype influenced the content of chlorophylls *a*+*b*, e.g. 1.10 g·kg^{-1} ('Moravan') and 0.78 g·kg^{-1} ('Lukullus'), respectively carotenoids: 21.43 mg·100 g^{-1} ('Moravan') and 11.78 mg·100 g^{-1} ('Szmaragd'). The content of nitrates (371.48 mg·kg^{-1} 'Lukullus' - 110 mg·kg^{-1} 'Szmaragd'), K (11.30% 'Moravan' - 5.37% 'Kozak'), Ca (2.06% 'Turkus' - 1.77% 'Kozak'), and oils (99.13% 'Lukullus' - 93.82% 'Ambrozja') was also varied. In most cases the content of Mg, P, sugars and ascorbic acid was on similar level. The antioxidant activity was significantly different between tested groups (12.22 μM·g^{-1} 'Turkus' - 6.27 μM·g^{-1} 'Krezus'). The presented research proved that the genotype of garden dill affects yield and chemical composition of plants.

Keywords: antioxidant activity; chemical composition; garden dill; genotype; yield

Introduction

The secondary metabolites, produced by all plants, act as repellents to herbivores or as biocides against microbial pathogens. The content of a metabolite in medicinal plants is economically more important than the yield of the desirable part, because it determines the cost of extraction. Such plants play a significant role in human health protection and currently many people are turning to herbal medicine (Weisany *et al.*, 2015). Nowadays, the use of natural products in the pharmaceutical and food industries is gaining importance. The manufacturers search for natural compounds that preserve food and promote the perception of flavours and aromas (Garcez *et al.*, 2017). An extensive body of research has demonstrated that dill (*Anethum graveolens* L.) contains unique and valuable components such as: essential oils, proteins, fibre, fatty oil, carbohydrates and macroelements (e.g. Ca, K, Mg, P, Na), vitamin A and niacin (Ghassemi-Golezani *et al.*, 2011). Due to its combined properties, is widely used in traditional medicine, in the culinary, cosmetic and nutraceutical industries (Zheljazkov *et al.*, 2006). Extract of seeds exhibits antioxidant, anti-inflammatory, antifungal and antimicrobial activities that favor the preservation of food and protection against food pathogens (Garcez *et al.*, 2017). Dill also is used in treatment of most gastrointestinal problems, as a cholesterol-lowering and diuretic agent, and has lactagogue, anticonvulsion, antiemetic, antispasmodic and antidiabetic properties. The hebral extracts and oils are gaining popularity because they are commonly cultivated and safe for people (El-Zaeddi *et al.*, 2016), compared to the chemical preservatives used by large scale manufactures. Considering that dill is usually applied as a herb, its cultivation does not focus on maximum seed yield (Zheljazkov *et al.*, 2006). The yield, taste and quality depend

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on many factors, e.g. cultivar, climatic and soil condition, fertilization, seeding date, harvest date, weed competition, plant disease, management practices, stage of growth, geographical variation, water stress, wind of higher velocity, storage, and processing conditions (Bowes *et al*., 2004; El-Zaeddi *et al*., 2016; El-Zaeddi *et al*., 2017). It was also observed that plants grown at low density had lower proportion of steam and leaf tissue and more extensive development of umbellate fruiting structures compared to plants grown at high density (El-Zaeddi *et al*., 2017).

Due to the wide range of chemical composition and many pharmacological effects, there is a great promise for use of dill in development of novel drugs to treat human diseases as a result of its effectiveness and safety. For this reason, it is very important to increase knowledge concerning the detailed composition of garden dill depending on genotype, especially that currently available literature data are scarce. Dill is also undoubtedly the most widely used herbal spice in Poland and even outstrips parsley. This spring vegetable, harvested for bunches, is the principal flavor accent in Polish cuisine.

The aim of the present study was to determine the potential to grow dill as an essential oil crop in Poland and to observe the effect of genotype on yield, chemical composition and antioxidant activity. To meet these objectives field experiments and laboratory analyses were carried out in 2011 and 2013.

Materials and Methods

All the reagents used in the experiment were of analytical grade. 1,1-diphenyl-2 picrylhydrazyl (DPPH); 6-ydroxy-2,5,7,8-tetramethylchroman- 2-carboxylic acid (Trolox) were obtained from Sigma (Germany). To determine dry matter five samples of leaves from each plot of treatment were randomly selected at harvest, then dried to constant weight at 105 ºC (dryer BINDER FD 240) and ground in a MF 10 Basic mill (IKA-Werke, GmbH & Co. KG, Staufen, Germany) to mesh size < 0.25 mm. In each treatment four replicates were used. The content of chlorophyll *a+b* and carotenoids was analysed using colorimetric methods (Rumińska, Suchorska, Węglarz, 1990). The nitrates were marked potentiometrically in 2% acetic acid extract (Nowosielski, 1988). The contents of Mg and P were analysed using colorimetric method, while the amounts of Ca and K by using the flame photometry method (Nowosielski, 1988). Colorimetric measurements were made using a Perkin Elmer Model Lambda 1A spectrophotometer (Perkin Elmer, Waltham, MA, USA.) and the flame emission spectroscopy with a Sherwood, Model 410, Cambridge, UK. The volatile fractions were prepared in a Dering apparatus by simultaneous distillation-extraction (SDE) in 1 ml hexane or in diisopropyl ether for 12 h. The oil was analyzed using a Saturn GC/MS/MS 2000 apparatus. The operating parameters were as follows: carrier gas - helium, at flow rate 2 ml/min, column - Chrompack capillary CP-sil 5 (CB, 25 m x 0.25 μm x 0.25 mm), temperature 50 °C - for 5 min, next 50-200 at 3 °C min^{-1}, finally 300 °C - 10 min. Volume injected: 5 μL, split ratio 1:50. The MS parameters were as follows: ionization potential 70 eV, ionization current 2 A, ion source temperature 200 °C. Identification of components in oil was based on computer matching with the NIST Spectral Library (NIST 05), Standard Saturn Mass Spectral Libraries and retention index. Commercial samples of some terpenes were used as standards. The sugars were assayed with the Lane-Eynon method in frozen biomass. To determine the content of L-ascorbic acid the Tillmans method was used (PN-A-04019, 1998). The antioxidant activity was examined using the DPPH radical-scavenging method (Yen and Chen, 1995). Field experiments were conducted in 2011-2013 in Research Station at Psary (51°11'25.27" N 17°2'3.08" E), belonging to the Department of Horticulture of Wrocław University of Environmental and Life Sciences. The fine clay soil (pH 7.6), containing 1.8% humus, 60 mg P, 180 mg K and 60 mg Mg in 1 dm^3, was fertilized with ammonium nitrate (100 kg N ha^{-1}), potassium sulphate (195 kg K ha^{-1}) and magnesium sulfate (450 kg ha^{-1}) before sowing. Dill seeds of 8 genotypes: 'Krezus', 'Turkus', 'Kozak', 'Szmaragd', 'Lukullus', 'Herkules', 'Ambrozja' and 'Moravan' were soaked with Grevit 200 SL (0.5%) and then sown on 5th April at the amount of 20 kg ha^{-1} onto plots of 1 m^2 area, in 20 cm spacing, at the depth of 2 cm. During plant growth the typical cultivation treatments (e.g. regular mechanical weeding, irrigation, plants protection against aphids) were applied. Plants were irrigated every 4 days with a dose 15 mm m^{-2}. The crop lasted 44 days and plants were collected on 14th May at the 4-5 true leaf stage (a bunch harvest). The average air temperatures and precipitation in April were: for 2011: 13.83 °C and 4.20 mm; for 2012: 10.83 °C and 26.40 mm; for 2013: 13.17 °C and 24.0 mm. In May were: for 2011: 15.83 °C and 54.20 mm; for 2012: 13.20 °C and 134.50 mm; for 2013: 14.78 °C and 41.40 mm. The data obtained were subjected to statistical analysis.

Results and Discussion

Yield

In Table 1, the productivity of different cultivars of dill, cultivated for bunches, are presented. The differences were statistically significant (α=0.05). Results showed that cv. 'Krezus' and 'Szmaragd' have the highest average fresh mass (1.18 kg m^{-2}) while the lowest was observed for 'Herkules' (0.53 kg m^{-2}). Literature data regarding the productivity of garden dill are divergent. Karkleliene *et al*. (2014) presented productivity of dill harvested after 50-60 days of growing. The highest yields were for cv. 'Common' (29.1 t ha^{-1}) and 'Szmaragd' while the lowest for 'Moravan'. Kawecka and Dyduch (2006) investigated the effect of cultivar, sowing date and year on productivity of dill under Polish climatic conditions. The research proved that these factors have a significant impact on the plant yield. The plants were cropped when the majority of them were 20-25 cm high. The biggest biomass was recorded for 'Ambrozja' (21.39 t ha^{-1}). The varieties 'Amat' (19.66 t ha^{-1}) and 'Fantazos' (19.10 t ha^{-1}) were also sufficiently high. The lowest yield was obtained for 'Kronos' (16.48 t ha^{-1}). The productivity of 'Szmaragd' amounted to 18.16 t ha^{-1}. The best sowing date proved to be month June (25.25 t ha^{-1}) and year 2003 (21 t ha^{-1}). Those studies confirmed that the yield of garden dill depends on many factors (e.g. term of seed sowing, harvest stage, climatic and soil condition) and emphasized the need for more controlled experiments to back up the clear-cut conclusions.

Table 1. The yield (kg·m^{-2}) of different cultivars of dill

Cultivar	2011	2012	2013	Mean
'Krezus'	1.12a	1.07b	1.35a	1.18a
'Turkus'	0.86c	0.75f	0.87c	0.83cd
'Kozak'	0.77e	0.72f	0.80d	0.76ef
'Szmaragd'	1.00b	1.20a	1.35a	1.18a
'Lukullus'	0.99b	0.92c	0.98b	0.96b
'Herkules'	0.56f	0.51g	0.53f	0.53g
'Ambrozja'	0.87c	0.85d	0.82d	0.85c
'Moravan'	0.80d	0.81e	0.73e	0.78e

a, b, c… – statistically not significant differences between examined groups each year

Dry matter

Dry matter (d.m.) was found to range from 15.17 to 19.27% (Table 2). According to USDA Food Composition Database, fresh dill weed contains 85.95 g of water per 100 g (14.05% d.m.). The genotypes tested in our experiments were characterized by higher content of dry matter. The lowest value was measured for 'Ambrozja' and the highest for 'Krezus'. It can be noted that in the year 2011 plants were characterized by highest content of dry matter while lowest, in most cases, was in 2013. Karkleliene *et al.* (2014) stated that d.m. contents in dill amount to 12.2, 13.3, 14.0 and 14.7% for 'Common', 'Moravan', 'Mammoth' and 'Szmaragd', respectively. Comparing these results, it can be seen that in our experiment cv. 'Moravan' and 'Szmaragd' were higher in weight by 41 and 20%, respectively.

Chlorophylls a, b and a+b content

Photosynthesis is the one of the most important processes that enables plant to grow by utilizing water, carbon dioxide and minerals. To convert the light energy into chemical energy the chlorophyll is necessary. It catalyzes the primary photochemical process which is an energy-storing chemical reaction (Huang *et al.*, 2017).

The concentrations of chlorophyll *a*, *b* and *a+b* in cultivated garden dill are presented in Table 3. The highest amount of chlorophyll *a*, chlorophyll *b* and chlorophyll *a+b* were found in 'Moravan' (0.79 g kg^{-1} f.m., 0.31 g kg^{-1} f.m., 1.10 g kg^{-1} f.m., respectively) and 'Szmaragd' (0.74 g kg^{-1} f.m., 0.25 g kg^{-1} f.m., 0.99 g kg^{-1} f.m., respectively). The lowest concentration of chlorophyll *a* (0.56 g kg^{-1} f.m.) and chlorophyll *a+b* (0.78 g kg^{-1} f.m.) was observed in 'Lukullus', while chlorophyll *b* (0.18 g kg^{-1} f.m.) in 'Herkules'. In the work of Karkleliene *et al.* (2014) the highest content of chlorophylls was measured for cv. 'Moravan' (2.04 mg g^{-1}) and 'Common' (2.02 mg g^{-1}). The lowest quantity was recorded in 'Szmaragd'.

Table 2. The dry matter (%) of different cultivars of dill (N=4)

Cultivar	2011	2012	2013	Mean
'Krezus'	19.72a	19.38a	18.71a	19.27a
'Turkus'	18.06bd	17.29ce	17.07e	17.47ef
'Kozak'	18.41bcd	18.36b	18.40ab	18.39bc
'Szmaragd'	17.62f	17.59cd	17.34d	17.51e
'Lukullus'	17.66e	16.63f	16.31f	16.87g
'Herkules'	18.47bc	18.48b	18.60a	18.52b
'Ambrozja'	15.30g	14.86g	15.36g	15.17h
'Moravan'	18.74b	18.06bc	17.96c	18.25bd

a, b, c… – statistically not significant differences between examined groups each year

Table 3. Chlorophyll *a* (g·kg^{-1} f.m.), chlorophyll *b* (g·kg^{-1} f.m.), chlorophyll *a+b* (g·kg^{-1} f.m.), carotenoids (mg·100g^{-1} f.m.) content in different cultivars of dill (mean for 2011-2013) (N=4)

	Year/Cultivar	'Krezus'	'Turkus'	'Kozak'	'Szmaragd'	'Lukullus'	'Herkules'	'Ambrozja'	'Moravan'
Chlorophyll *a*	2011	0.70bc	0.71c	0.68cd	0.72b	0.54e	0.74ab	0.73b	0.79a
	2012	0.67cd	0.67cd	0.65cde	0.73b	0.54f	0.66cde	0.68c	0.77a
	2013	0.72cd	0.72cd	0.70de	0.78b	0.59f	0.71cd	0.73c	0.82a
	Mean	0.69cd	0.70cd	0.67de	0.74b	0.56f	0.70cd	0.71c	0.79a
Chlorophyll *b*	2011	0.19cd	0.19d	0.20cd	0.25b	0.22c	0.18d	0.22c	0.29a
	2012	0.20ce	0.20ce	0.22bd	0.25b	0.23bc	0.18ef	0.23bc	0.30a
	2013	0.21bc	0.20bd	0.21bc	0.24b	0.23b	0.19cd	0.22bc	0.33a
	Mean	0.20cf	0.20cf	0.21ce	0.25b	0.23bc	0.18fg	0.22bd	0.31a
Chlorophyll a+*b*	2011	0.88def	0.90cde	0.88def	0.97b	0.76g	0.92bcd	0.95bc	1.08a
	2012	0.87cd	0.86de	0.87d	0.98b	0.77g	0.84def	0.91c	1.07a
	2013	0.93cd	0.92cde	0.91cde	1.02b	0.82g	0.90cdef	0.95c	1.14a
	Mean	0.89cd	0.89cd	0.88d	0.99b	0.78e	0.89cd	0.93c	1.10a
Carotenoids	2011	18.25bcd	16.10f	18.83b	10.65g	18.44bc	17.35de	21.29a	21.29a
	2012	18.04de	16.31g	18.77c	12.18h	18.25d	17.68ef	21.70a	21.22ab
	2013	17.41d	15.85f	18.44c	12.52g	17.45d	17.10de	20.42b	21.79a
	Mean	17.90de	16.09g	18.68c	11.78h	18.04d	17.37def	21.14ab	21.43a

a, b, c… – statistically not significant differences between examined groups each year

Carotenoids

Carotenoids should be constituents of a healthy diet due to their antioxidant and immune system activity (Gammone *et al.*, 2015). The main sources of carotenoids are fruits and vegetables. For instance carotenes are involved in skin protection and the xanthophylls in eye preservation (Gammone *et al.*, 2015). Due to the fact that carotenoids are not synthesized by the human body they have to be obtained from dietary sources (Berman *et al.*, 2015). The proper intake of carotenoids in the human diet can reduce the occurrence of disease such as cancer, cardiovascular diseases, cataract formation and age related macular degradation. The deficiency of these compounds can result in clinical signs of conjunctiva, vision disability and increased mortality caused by weakened immunity (Saini *et al.*, 2015).

It was found that the highest quantity of carotenoids (Table 3) exhibits the 'Moravan' (21.43 mg 100 g^{-1} f.m.) and 'Ambrozja' (21.14 mg 100 g^{-1} f.m.), and the lowest in the 'Szmaragd' cv. (11.78 mg 100 g^{-1} f.m.). In the work by Karkleliene *et al.* (2014) also 'Moravan' was characterized by highest content of this pigment (10.3 mg 100 g^{-1}) and 'Szmaragd' contained 9.7 mg 100 g^{-1}.

NO_3 content

Nitrates occur naturally in food, drinking water and vegetables. The acceptable daily intake of 0-3.7 per mg kg^{-1} body weight for nitrates has been established by the EU Scientific Committee for Food (Tamme *et al.*, 2006). It is worth mentioning that nitrates (V) are low toxic and do not constitute a direct threat to human health, and deadly poisoning are rare (Telesiński *et al.*, 2013).

In the present investigation was found (Table 4) that genotype significantly influenced the nitrates content in seedlings of dill that ranged from 110.75 to 371.90 mg in 1 kg of fresh matter for 'Szmaragd' and 'Lukullus', respectively. Higher levels of nitrates, above 200 mg kg^{-1}, have also been reported for 'Turkus' (296.55 mg kg^{-1} f.m.) and 'Herkules' (247.49 mg kg^{-1} f.m.). In order to protect the consumer's health from food contaminated with nitrates, the Polish legislation introduced standards for permitted levels of the compounds in vegetables. According to Commission Regulation (2006) - EC No 1881/2006 of 19 December 2006 the permissible level of nitrate pollution in leaf vegetables is e.g.: fresh spinach (*Spinacia oleracea*) (2500-3000 mg NO_3 kg^{-1}) and lettuce grown in ground (2500-4000 mg NO_3 kg^{-1}). For herbs and spice plants such standards are not given (Dec *et al.*, 2008). Comparing research results with the acceptable standard of these compounds in leafy vegetables, it can be stated that the content was relatively small (below 200 mg kg^{-1} f.m.) and could be successfully used in the production of e.g. baby food. In addition, it should be noted that daily consumption of spice herbs is not high, therefore the daily intake of nitrate with these raw materials is small.

Macroelements

During the past few decades, extensive study on nutrient elements has been carried out to define their role in the plant. Interactions between these chemical substances are one of the main causes of deficiency and toxicity symptoms in higher plants. It occurs when the supply of one nutrient influences the uptake, transport, utilization and function of another nutrient within a wide range of plant tissues (Farzadfar *et al.*, 2017).

Table 5 presents content of K, Mg, P and Ca in different cultivars of dill. 'Moravan' was especially rich in K (11.30% d.m.) and the poorest was 'Kozak' (5.37%). According to USDA Food Composition Database dried dill contains 3.3% of K, which is significantly lower in comparison to our tested cultivars. Magnesium and phosphorus in all tested dill genotype was at similar level and was significantly lower compared to the USDA database (0.45 and 54%, respectively). We have found that the lowest Ca content was in cv. 'Kozak' (1.77%) and the highest in 'Turkus' (2.06%). In most cases the content of Ca was higher in testest varieties than in data presented in USDA (1.78%).

Essential oil constituents

One of the most important groups among secondary metabolites in dill are essential oils. Dill contains two types of essential oils which differ in their chemical composition and perform different functions. The first type could be extracted from weed (0.09 to 0.34 mL 100 g^{-1} of fresh mass) and the second from mature seeds (0.2 and 4.6 mL 100 g^{-1}). The essential fruit oil consists mainly of limonene and carvone, whereas weed oil includes α-phellandrene, myristicin and apiole (Bowes *et al.*, 2004). It is well-known that the specific aroma of plant is determined by the concentration and composition of essential oils (El-Zaeddi *et al.*, 2016) and is formed by complex of chemical substances, such as: alcohols, ketones, aldehydes, esters, terpenes and lactones (El-Zaeddi *et al.*, 2017). An important component identified in dill is dill ether, which due to its high odoractivity value, is considered as the character impact compound of its flavour. Smell reminiscent 'citrus-like' and 'pine-like' odors are assign to limonene and α-pinene, respectively (Callan *et al.*, 2007).

Table 4. NO_3 content (mg·kg^{-1} f.m.) in different cultivars of dill

Cultivar	2011	2012	2013	Mean
'Krezus'	150.36e	152.69e	144.56e	149.20e
'Turkus'	295.17b	296.35b	298.14b	296.55b
'Kozak'	181.36d	182.35d	186.25d	183.32d
'Szmaragd'	105.12g	112.54g	114.58gh	110.75gh
'Lukullus'	372.21a	370.25a	373.25a	371.90a
'Herkules'	269.47c	252.45c	258.25c	247.49c
'Ambrozja'	105.64g	120.23fg	124.23fg	116.70fg
'Moravan'	136.45f	123.69f	126.25f	128.80f

a, b, c... – statistically not significant differences between examined groups each year

Another important odorants showing high OAV are: α-phellandrene, myristicin and limonene. Apiole and myristicin, present in low quantities, could be typical for some varieties and lead to distinction of chemotypes. Due to the relatively soft dill peel the oil might be easily accessible. The essential oils have unique composition and are widely used in the food, cosmetic, pharmaceutical, perfumery and nutraceuticals industries (Zheljazkov *et al*., 2006), e.g. nearly pure D-limonene present in seed oil exhibits antimicrobial activity (Bowes *et al*., 2004). Literature data concerning the essential oil content of different genotypes of dill are scarce.

The mean content of oils in leaves is presented in Table 6. It can be seen that dill leaves contain α-phellandrene (50.78-64.55%), dill ether (14.87-24.81%), β-phellandrene (5.34-7.57%), apiol (1.05-6.92%), limonene (2.37-2.66%), *p*-cymene (1.33-2.29%), and a-pinene (1.24-1.72%) as main compounds. The highest total mean content of essential oils was noted for 'Lukullus' (99.13 ± 0.81) and the lowest for 'Ambrozja' (93.82 ± 0.80). The oil composition was found to be similar as reported in other studies, however differences were observed in their quantities. Hajhashemi *et al*. (2008) found that the aerial parts contain α-phellandrene (32%), limonene (28%) and carvone (28%) in greatest amounts. Whereas Rana *et al*. (2014) showed that the main compounds were α-phellandrene (31.8%), apiole (15.3%), dill ether (13.2%), limonene (11.8%), geraniol (10.6%) and p-cymene (5.3%). In the work by Jianu *et al*. (2012) dill stems contain: terpinene (31.66%), phellandrene (24.94%), limonene (12.95%), and p-cymene (12.59%). Rădulescu *et al*. (2010) reported that the oil composition depends on the dill parts. The highest area % of essential oils was in fruits and flowers (99.97 and 99.83%, respectively) and lowest in leaves (97.55%). The predominant oil in fruits was carvone (75.21%), while in flowers and leaves it was α-phelandrene (32.26, 62.71%, respectively) and limonene (33.22%, 13.28%, respectively). According to Olle *et al*. (2010) dill fruits contain 2.5-4% of essential oils (mainly carvone (40-55%)), while leaves contains 0.05-0.35% (mostly phellandrene, 46%). The differences in the amounts of individual oils result from e.g. climatic condition, fertilization or age of plant, and in the scientific data have not been sufficiently described.

Table 5. Macroelements content (% d.m.) in different cultivars of dill

	Cultivar	'Krezus'	'Turkus'	'Kozak'	'Szmaragd'	'Lukullus'	'Herkules'	'Ambrozja'	'Moravan'
K	2011	5.34g	9.31b	5.23g	8.74c	6.44f	6.94e	7.14d	10.34a
	2012	6.34f	9.71b	5.24g	8.45c	6.53f	6.84e	7.22d	12.07a
	2013	6.62efg	9.09b	5.65h	8.74bc	6.85ef	6.88e	7.61d	11.49a
	2011-2013	6.10g	9.37b	5.37h	8.64c	6.61f	6.88e	7.32d	11.30a
Mg	2011	0.34ab	0.32ab	0.34a	0.30ab	0.31ab	0.33ab	0.33ab	0.33ab
	2012	0.33ab	0.32abc	0.34a	0.30bc	0.32abc	0.32abc	0.32abc	0.32abc
	2013	0.31abc	0.32abc	0.33ab	0.32abc	0.34a	0.32abc	0.33ab	0.34a
	2011-2013	0.32ab	0.32ab	0.33a	0.31b	0.32ab	0.32ab	0.33a	0.33a
P	2011	0.29ab	0.30a	0.19d	0.25abc	0.27ab	0.28ab	0.28ab	0.26abc
	2012	0.31a	0.30a	0.23bcd	0.25ab	0.28a	0.25ab	0.24abc	0.23bcd
	2013	0.26a	0.27a	0.24ab	0.25ab	0.24ab	0.28a	0.26a	0.25ab
	2011-2013	0.29a	0.29a	0.22abc	0.25ab	0.26a	0.27a	0.26a	0.24ab
Ca	2011	1.93ab	1.98a	1.75abc	1.83abc	1.92abc	2.06ab	2.06a	2.02ab
	2012	2.00ab	2.09a	1.75bcd	1.80bc	1.93bc	1.87cd	1.82bc	1.80bc
	2013	1.82cde	2.11a	1.82cde	1.95b	1.85bcd	1.96b	1.92b	1.88bc
	2011-2013	1.91abc	2.06a	1.77bcdef	1.86bcde	1.90bcd	1.96abcd	1.93ab	1.90abcd

a, b, c... – statistically not significant differences between examined groups each year

Table 6. Mean oils content in different cultivars of dill (mean for 2011-2013)

Cultivar		'Krezus'	'Turkus'	'Kozak'	'Szmaragd'	'Lukullus'	'Herkules'	'Ambrozja'	'Moravan'
Capability (% f.m.)		0.30±0.08	0.27±0.06	0.26±0.06	0.29±0.04	0.30±0.07	0.25±0.05	0.24±0.05	0.28±0.04
Peak Name	tR (min)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)
(E)-2-Hexenal, 832	5.29	0.18±0.01	0.10±0.12	0.02±0.01	0.19±0.08	0.20±0.04	0.02±0.01	0.02±0.01	0.02±0.01
3-Thujene, 932	7.03	0.27±0.01	0.26±0.02	0.38±0.06	0.30±0.06	0.24±0.03	0.31±0.09	0.29±0.06	0.26±0.04
α-Pinene, 936	7.34	1.26±0.04	1.30±0.09	1.44±0.27	1.37±0.16	1.67±0.34	1.72±0.21	1.31±0.21	1.24±0.10
Camphene, 950	7.85	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01
Sabinene, 973	8.3	0.13±0.02	0.12±0.01	0.12±0.01	0.12±0.05	0.14±0.05	0.14±0.04	0.15±0.06	0.12±0.03
β-Pinene, 978	8.44	0.40±0.03	0.28±0.15	0.41±0.03	0.34±0.12	0.44±0.01	0.47±0.03	0.52±0.03	0.19±0.21
β-Myrcene, 987	8.58	0.35±0.08	0.21±0.15	0.54±0.10	0.47±0.05	0.49±0.17	0.25±0.05	0.33±0.04	0.34±0.09
α-Phellandrene, 1002	9.22	63.99±0.34	64.55±1.34	61.99±3.84	58.51±0.31	62.83±1.30	51.75±1.86	50.78±0.62	60.90±0.74
p-Cymene, 1015	9.67	1.39±0.08	1.71±0.46	2.02±0.09	2.29±0.37	1.58±0.25	1.95±2.66	1.51±0.07	1.33±0.04
Limonene, 1025	9.81	2.41±0.09	2.40±0.21	2.37±0.29	2.58±0.29	2.66±0.18	2.59±0.16	2.65±0.36	2.51±0.06
β-Phellandrene, 1023	9.94	6.68±0.08	6.81±0.87	7.05±0.19	5.34±0.26	6.44±0.24	6.91±0.21	7.57±0.26	5.48±0.32
α-Terpinene	10.57	0.02±0.00	0.03±0.02	0.02±0.00	0.03±0.02	0.02±0.00	0.02±0.01	0.02±0.00	0.02±0.00
Terpinolen, 1082	11.39	0.51±0.07	0.40±0.16	0.24±0.04	0.23±0.02	0.20±0.03	0.21±0.14	0.17±0.02	0.26±0.16
Fenchone, 1069	11.66	0.05±0.04	0.06±0.03	0.02±0.01	0.03±0.02	0.03±0.02	0.03±0.02	0.03±0.03	0.03±0.00
Cis-2-menthen-1-ol	12.58	0.02±0.01	0.03±0.01	0.02±0.00	0.02±0.01	0.02±0.01	0.02±0.02	0.05±0.04	0.03±0.01
Dill ether	14.47	17.42±0.82	14.87±0.23	17.42±0.35	21.64±1.43	20.22±1.52	24.81±1.88	24.69±0.47	17.33±0.56
cis, trans-Dihydrocarvone	14.75	0.09±0.04	0.09±0.06	0.12±0.07	0.07±0.03	0.08±0.04	0.08±0.03	0.10±0.05	0.18±0.13
Carvone	15.36	0.05±0.04	0.07±0.08	0.10±0.04	0.12±0.09	0.21±0.04	0.20±0.13	0.20±0.16	0.03±0.02
Germacrene D	22.65	0.30±0.17	0.15±0.03	0.44±0.04	0.24±0.20	0.43±0.02	0.21±0.13	0.18±0.11	0.23±0.22
Myristicin	23.36	0.50±0.03	0.51±0.08	0.02±0.00	0.09±0.12	0.16±0.13	0.37±0.61	0.66±0.73	0.97±1.30
Apiol, 1649	25.7	2.58±0.27	3.28±0.03	2.04±0.00	4.09±0.10	1.05±0.04	3.14±0.14	2.57±0.49	6.92±0.34
Total	-	98.62±1.13	97.24±1.67	96.81±3.90	98.09±2.29	99.13±0.81	95.22±4.13	93.82±0.80	98.41±1.94

Total and reducing sugars

Plants synthesize sugars, mostly sucrose, in the reactions of photosynthesis that drive the growth and development, being the source of energy and carbon. Sugars affect the expression of certain genes involved in many essential processes, e.g. photosynthesis, cell cycle metabolism, defense mechanisms, glyoxylate metabolism, glycolysis, nitrogen metabolism, sucrose and starch metabolism (Jang and Sheen, 1997).

The content of sugars in cultivated plants is presented in Table 7. Our study has revealed that dill genotype does not have a significant impact on the content of those compounds. Nevertheless, the highest amount exhibits the 'Lukullus' plant (4.98 g $100g^{-1}$) and lowest the 'Herkules' (3.96 g $100g^{-1}$). The best climatic conditions affecting sugar content were in 2013 and worst in 2011. Table 7 also shows that the reducing sugars constitute from 85 to 97 g $100g^{-1}$ of all assayed sugars. The highest amount was observed for 'Lukullus' and lowest for 'Herkules' and 'Szmaragd'. In the work of Karkleliene *et al.* (2014) the cultivars 'Moravan', 'Szmaragd', 'Common' and 'Mammoth' were similar in terms of total sugar content and amounted to 2.95, 3.07, 2.72 and 3.0 g $100g^{-1}$, respectively.

L-ascrbic acid

Ascorbic acid (AsA) is a naturally occurring compound in various vegetables and fruits (Magwaza *et al.*, 2017). Numerous factors have an impact on the level of ascorbic acid in plant organs (e.g. preharvest cultural practices, genotype, climatic conditions, harvesting procedures, and postharvest management) (Magwaza *et al.*, 2017) and is significantly different across species (Kka *et al.*, 2017). AsA has basic functions in plant physiology (Liang *et al.*, 2017), e.g. is a reducing agent in biochemical reaction, contributes to the antioxidant capacity of plant tissues, detoxifies reactive oxygen species and free radicals (Magwaza *et al.*, 2017) and promotes resistance to senescence and environmental stresses (e.g. ozone, high light, salt and dehydration stress) (Liang *et al.*, 2017). Its metabolism plays a significant role in photosynthesis, hormone biosynthesis (e.g. ethylene, jasmonic acid, salicylic acid, abscisic acid, gibberellic acid), growth regulation and senescence (Kka *et al.*, 2017; Liang *et al.*, 2017; Magwaza *et al.*, 2017). Enhancement of ascorbic acid content in crops can improve their shelf-life (Magwaza *et al.*, 2017). AsA is also important for human health. It protects against oxidative stress, participates in collagen synthesis, and promotes iron absorption and wound-healing. Moreover, due to the lack of human ability to synthesise ascorbic acid, it must be derived from diets (mostly from fruits and vegetables) (Liang *et al.*, 2017). Because of these unique functions more attention has been paid to ascorbic acid content in food.

In most cases the content of L-ascobic acid (Table 8) in fresh garden dill was similar, neverthless the highest average amount was observed in 'Turkus' (171.91 mg·$100g^{-1}$ f.m.) followed by 'Ambrozja' (136.28 mg $100g^{-1}$ f.m.) and 'Moravan' (124.88 mg $100g^{-1}$ f.m.), while the lowest in 'Szmaragd' (78.35 mg $100g^{-1}$ f.m.) and 'Lukullus' (88.80 mg $100g^{-1}$ f.m.). We have noticed that the ascorbic acid content decreased in subsequent years of cultivation. In most cases the content of AsA was much higher in comparison to the value presented by USDA (85.00 mg 100 g^{-1} f.m.). In the work of Naidu *et al.* (2016) the concentration of vitamin C in garden dill, determined by the visual titration method, amounted to 180.9 mg in 100g of fresh mass. Stan *et al.* (2014) reported a lower content, totalled at 121 mg $100g^{-1}$, found by using HPLC.

Table 7. Total and reducing sugars content (g·$100g^{-1}$ f.m.) in different cultivars of dill (N=4)

	Total sugars				Reducing sugars			
Cultivar	2011	2012	2013	Mean	2011	2012	2013	Mean
'Krezus'	4.66bc	4.73bd	4.92ac	4.77ac	4.02bcd	4.09bc	4.28ac	4.13bcd
'Turkus'	4.70abc	4.77bc	4.96ac	4.81ac	3.98bcd	4.05bd	4.24a	4.09bcd
'Kozak'	4.76ab	4.83ab	5.02ab	4.87ab	4.08ac	4.15ab	4.34a	4.19abc
'Szmaragd'	4.27de	4.34ef	4.53df	4.38df	3.86bcde	3.93bce	4.12cd	3.97ce
'Lukullus'	4.87a	4.94a	5.13a	4.98a	4.33a	4.40a	4.59a	4.44a
'Herkules'	3.85f	3.92g	4.11g	3.96g	3.75ef	3.82cdef	4.01cde	3.86def
'Ambrozja'	4.38d	4.45e	4.64ce	4.49ce	4.07bc	4.14bc	4.33bc	4.18bc
'Moravan'	4.41d	4.48e	4.67cd	4.52cd	4.15ab	4.22ab	4.41ab	4.26ab

a, b, c... – statistically not significant differences between examined groups each year

Table 8. Antioxidant activity (μM Trolox·g^{-1} f.m.) and L-ascorbic acid content (mg·$100g^{-1}$ f.m.) in different cultivars of dill (N=4)

	L-ascorbic acid				Antioxidant activity			
Cultivar	2011	2012	2013	Mean	2011	2012	2013	Mean
'Krezus'	125.26d	122.84c	119.48c	122.52c	6.16g	6.29g	6.37a	6.27e
'Turkus'	175.94a	171.80a	168.01a	171.91a	12.66a	12.79a	11.21ab	12.22a
'Kozak'	123.28e	122.33c	114.00e	119.87cd	10.94c	11.07bc	9.94ab	10.65abc
'Szmaragd'	83.49h	80.61g	70.96h	78.35f	6.33f	6.46f	8.02abc	6.94de
'Lukullus'	93.02g	89.30f	84.09g	88.80e	6.08gh	6.21gh	9.52a	7.27de
'Herkules'	122.78ef	119.60cd	115.97d	119.45cd	10.63cd	10.76cd	12.29ab	11.23ab
'Ambrozja'	137.83c	136.92b	134.08b	136.28b	11.62b	11.75b	11.94ab	11.78ab
'Moravan'	149.81b	113.97cde	110.86ef	124.88c	8.42e	8.55e	9.53ab	8.83cd

a, b, c... – statistically not significant differences between examined groups each year

DPPH

Nowadays, the increased interests in natural antioxidants, which are considered as important nutraceuticals on account of many health benefits, have been observed (Sharma and Bhat, 2009). To determine antioxidant activity many tests use accelerated oxidative conditions which provoke lipid oxidation, what makes these tests not always representative and for many antioxidants the risk of degradation is high. The risk of thermal degradation of tested molecules is eliminated in the diphenylpicrylhydrazyl (DPPH) free radical method because antioxidant efficiency is measured at ambient temperature, wherein the reactional mechanism between antioxidant and DPPH depends on the structural conformation of the antioxidant (Bondet *et al*., 1997).

From these findings it can be inferred that genotypes examined differ in antioxidant activity conducted with the DPPH method (Table 8). The greatest activity showed: 'Turkus' (12.22 μM Trolox g^{-1} f.w.), 'Ambrozja' (11.78 μM Trolox g^{-1} f.w.) and 'Herkules' (11.23 μM Trolox g^{-1} f.w.) while the lowest 'Krezus' (6.27 μM Trolox g^{-1} f.w.) and 'Szmaragd' (6.94 μM Trolox g^{-1} f.w.).

Conclusions

In the present study, eight genotypes of garden dill were tested. The conducted research proved that the genotype affects yield, content of bioactive compounds and antioxidant activity. The most favourable yielding featured cv. 'Krezus' and 'Szmaragd' and the least were 'Herkules'. The highest dry matter was obtained for cv. 'Krezus' and the lowest for cv. 'Ambrozja'. The lowest content of chlorophyll $a+b$ and carotenoids was observed in cv. 'Lukullus' and 'Szmaragd', respectively. The highest amount of these pigments was noted in cv. 'Moravan'. Nitrates were accumulated only to a small extent. The cultivar did not affect the content of Mg and P. The highest content of K was observed in cv. 'Moravan', while the highest quantity of Ca was reported for cv. 'Turkus'. The lowest amount of these macroelements was noted for cv. 'Kozak'. The highest total content of oils was observed in 'Lukullus' and lowest in 'Ambrozja'. The sugar content was the highest in cv. 'Lukullus' and lowest in 'Herkules'. The highest quantity of L-ascorbic acid and antioxidant activity were observed for cv. 'Turkus' and lowest for cv. 'Szmaragd' and 'Krezus', respectively. Owing to the considerable differences in composition it is possible to choose a dill variety for its desired use. In conclusion, it is worthwhile to screen the commonly used plants for different biological activities because they might present a new alternative source for possible bioactive substances.

References

Berman J, Zorrilla-Lopez U, Farre G, Zhu CF, Sandmann G, Twyman RM, … Christou P (2015). Nutritionally important carotenoids as consumer products. Phytochemistry Reviews 14(5):727-743.

Bondet V, Brand-Williams W, Berset C (1997). Kinetics and mechanisms of antioxidant activity using the DPPH free radical method. Lebensmittel-Wissenschaft & Technologie 30(6):609-615.

Bowes KM, Zheljazkov VD, Caldwell CD, Pincock JA, Roberts JC (2004). Influence of seeding date and harvest stage on yields and essential oil composition of three cultivars of dill (*Anethum graveolens* L.) grown in Nova Scotia. Canadian Journal of Plant Science 84(4):1155-1160.

Callan NW, Johnson DL, Westcott MP, Welty LE (2007). Herb and oil composition of dill (*Anethum graveolens* L.): Effects of crop maturity and plant density. Industrial Crops and Products 25(3):282-287.

Commission Regulation (2006). Commission Regulation (EC) No 1881/2006 of 19 December 2006: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1881&from=EN.

Dec D, Wołejko E, Kubicka H, Matusiewicz M, Żylińska B (2008). Zawartość azotanów (III) i (V) w wybranych roślinach przyprawowych pochodzących z handlu i ogródków przydomowych [The content of nitrates (III) and (V) in selected spice plants from trade and home gardens]. Ochrona Środowiska i Zasobów Naturalnych 35/36:255-259.

El-Zaeddi H, Martinez-Tome J, Calin-Sanchez A, Burlo F, Carbonell-Barrachina AA (2016). Volatile composition of essential oils from different aromatic herbs grown in Mediterranean regions of Spain. Foods 5(2):1-13.

El-Zaeddi H, Martinez-Tome J, Calin-Sanchez A, Burlo F, Carbonell-Barrachina AA (2017). Irrigation dose and plant density affect the volatile composition and sensory quality of dill (*Anethum graveolens* L.). Journal of the Science of Food and Agriculture 97(2):427-433.

Farzadfar S, Zarinkamar F Hojati M (2017). Magnesium and manganese affect photosynthesis, essential oil composition and phenolic compounds of *Tanacetum parthenium*. Plant Physiology and Biochemistry 112:207-217.

Gammone MA, Riccioni G, D'Orazio N (2015). Marine carotenoids against oxidative stress: Effects on human health. Marine Drugs 13(10):6226-6246.

Garcez JJ, Barros F, Lucas AM, Xavier VB, Fianco AL, Cassel E, Vargas RMF (2017). Evaluation and mathematical modeling of processing variables for a supercritical fluid extraction of aromatic compounds from *Anethum graveolens*. Industrial Crops and Products 95:733-741.

Ghassemi-Golezani K, Zehtab-Salmasi S, Dastborhan S (2011). Changes in essential oil content of dill (*Anethum graveolens*) organs under salinity stress. Journal of Medicinal Plants Research 5(14):3142-3145.

Hajhashemi V, Abbasi N (2008). Hypolipidemic activity of *Anethum graveolens* in rats. Phytotherapy Research 2293):372-375.

Huang DL, Gong XM, Liu YG, Zeng GM, Lai C, Bashir H, … Wan J (2017). Effects of calcium at toxic concentrations of cadmium in plants. Planta 245(5):863-873.

Jang J-C, Sheen J (1994). Sugar sensing in higher plants. The Plant Cell 6(11):1665-1679.

Karkleliene R, Dambrauskiene E, Juskeviciene D, Radzevicius A, Rubinskiene M, Viskelis P (2014). Productivity and nutritional value of dill and parsley. Horticultural Science 41(3):131-137.

Kawecka M, Dyduch J (2006). Ocena cech biometrycznych i potencjału plonotwórczego roślin kilku odmian kopru ogrodowego (*Anethum graveolens* L.) w uprawie polowej na zbiór pęczkowy. Ocena potencjału plonotwórczego [Evaluation of biometric features and yield potential of plants of several garden dill varieties (*Anethum graveolens* L.) in field cultivation for bunches. Evaluation of yield potential]. Acta Agrophysica

8(3):611-617.

Kka N, Rookes J, Cahill D (2017). Quantitation of ascorbic acid in *Arabidopsis thaliana* reveals distinct differences between organs and growth phases. Plant Growth Regulation 81(2):283-292.

Liang D, Zhu TT, Ni ZY, Lin LJ, Tang Y, Wang ZH, … Xia H (2017). Ascorbic acid metabolism during sweet cherry (*Prunus avium*) fruit development. PloS One 12(2):1-16.

Magwaza LS, Mditshwa A, Tesfay SZ, Opara UL (2017). An overview of preharvest factors affecting vitamin C content of citrus fruit. Scientia Horticulturae 216:12-21.

Naidu MM, Vedashree M, Satapathy P, Khanum H, Ramsamy R, Hebbar HU (2016). Effect of drying methods on the quality characteristics of dill (*Anethum graveolens*) greens. Food Chemistry 192:849-856.

Nowosielski O (1988). Metody oznaczania potrzeb nawożenia roślin ogrodniczych [Methods for determining the needs of fertilizing horticultural plants]. PWRiL, Warszawa.

Olle M, Bender I (2010). The content of oils in umbelliferous crops and its formation. Agronomy Research 8(3):687-696.

PN-A-04019 (1998). Produkty spożywcze - Oznaczanie zawartości witaminy C [Food products - Determination of vitamin C content].

Rana VS, Blazquez MA (2014). Chemical composition of the essential oil of *Anethum graveolens* aerial parts. Journal of Essential Oil Bearing Plants 17(6):1219-1223.

Rădulescu V, Popescu ML, Ilieş DC (2010). Chemical composition of the volatile oil from different plant parts of *Anethum graveolens* L. (Umbelliferae) cultivated in Romania. Farmacia 58(5):594-600.

Rumińska A, Suchorska K, Węglarz Z (1990). Rośliny lecznicze i specjalne [Medicinal and special plants]. SGGW AR Warszawa.

Saini RK, Nile SH, Park SW (2015). Carotenoids from fruits and vegetables: Chemistry, analysis, occurrence, bioavailability and biological activities. Food Research International 76:735-750.

Sharma OP, Bhat TK (2009). DPPH antioxidant assay revisited. Food Chemistry 113(4):1202-1205.

Stan M, Soran ML, Marutoiu C (2014). Extraction and HPLC determination of the ascorbic acid content of three indigenous spice plants. Journal of Analytical Chemistry 69(10):998-1002.

Tamme T, Reinik M, Roasto M, Juhkam K, Tenno T, Kiis A (2006). Nitrates and nitrites in vegetables and vegetable-based products and their intakes by the Estonian population. Food Additives and Contaminants 23(4):355-361.

Telesiński A, Grzeszczuk M, Jadczak D, Wysocka G, Onyszko M (2013). Ocena zmian zawartości azotanów (V) w wybranych ziołach przyprawowych w zależności od sposobu ich utrwalenia i czasu przechowywania [Evaluation of changes in the content of nitrates (V) in selected spice herbs depending on the method of their fixation and storage time]. Żywność. Nauka. Technologia. Jakość 5(90):168-176.

Weisany W, Raei Y, Pertot I (2015). Changes in the essential oil yield and composition of dill (*Anethum graveolens* L.) as response to arbuscular mycorrhiza colonization and cropping system. Industrial Crops and Products 77:295-306.

Yen GC, Chen HY (1995). Antioxidant activity of various tea extracts in relation to their antimutagenicity. Journal of Agricultural and Food Chemistry 43(1):27-32.

Zheljazkov VD, Craker LE, Xing BS (2006). Effects of Cd, Pb, and Cu on growth and essential oil contents in dill, peppermint, and basil. Environmental and Experimental Botany 58(1-3):9-16.