Article

The Effect of Open Field and Foil Tunnel on Yield and Quality of the Common Thyme (*Thymus vulgaris* L.), in Organic Farming

Olga Kosakowska , Zenon Węglarz and Katarzyna Bączek

Department of Vegetable and Medicinal Plants, Institute of Horticultural Sciences, Warsaw University of Life Sciences–SGGW, Nowoursynowska 166, 02-787 Warsaw, Poland; zenon_weglarz@sggw.edu.pl (Z.W.); katarzyna_baczek@sggw.edu.pl (K.B.)

* Correspondence: olga_kosakowska@sggw.edu.pl; Tel.: +48-22-593-22-47

Abstract: Common thyme (*Thymus vulgaris* L., Lamiaceae) is regarded as one of the most important aromatic plant used both as a spice and medicine. The aim of this work was to investigate the yield and quality of common thyme grown for a fresh herb, cultivated in the organic farming system, within the temperate climate in Poland. Two methods of cultivation were applied: open field and foil tunnel. Three successive cuts of herb were possible to obtain during vegetation season, from the middle of July until the end of September. The raw material was analyzed for the content of essential oil (by hydrodistillation), phenolic acids and flavonoids according to Polish pharmacopeia (PP 6th). The composition of essential oil was determined by gas chromatography-mass spectrometry (GC-MS). Sensory evaluation was carried out by quantitative descriptive analysis (QDA) with a trained panelist. The yield of fresh herb was visibly higher when regards cultivation under foil tunnel in comparison to open field, reaching up to 6.74 kg FW × 10 m². The content of essential oil as well as the percentage share of thymol (a dominant constituent, achieving up to 57.08%) decreased with consecutive herbal cuts. The opposite result was observed for phenolic compounds (phenolic acids and flavonoids). It was shown that the amount of flavonoids was similar in both variants of cultivation, while phenolic acids were accumulated at higher level in the open field conditions. Sensory analysis indicated on slight differences in odor and taste attributes, between samples of fresh herb collected from open field and foil tunnel.

Keywords: common thyme; organic cultivation; essential oil; phenolic acids; flavonoids; sensory analysis

Citation: Kosakowska, O.; Węglarz, Z.; Bączek, K. The Effect of Open Field and Foil Tunnel on Yield and Quality of the Common Thyme (*Thymus vulgaris* L.), in Organic Farming. *Agronomy* **2021**, *11*, 197. <https://doi.org/10.3390/agronomy11020197>

Received: 23 December 2020

Accepted: 18 January 2021

Published: 20 January 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Common thyme (*Thymus vulgaris* L.) is an aromatic, perennial sub-shrub belonging to Lamiaceae family. This species, indigenous to Southern Europe, is cultivated all over the world, also in regions of temperate climate. It is considered as one of the most traded culinary and medicinal plants [1,2]. Thyme herb (*Thymi herba*) is a valuable raw material listed in the European pharmacopeia (EP) and classified by European Medicine Agency (EMA) as a traditional herbal product. It contains about 2.5% (according to EP not less than 1.2%) of essential oil, which is reported to be in the world's top ten of essential oils used in the industry [3–5]. The composition of essential oil fluctuates depending on the thyme chemotype. There are at least six chemotypes divided into two groups, as following: phenolic (thymol, carvacrol) and non-phenolic (linalool, geraniol, α -terpineol, *trans*-thujan-4-ol/terpinen-4-ol) [6–10]. The most popular and valuable for industrial purposes, as well as the only one completing EP requirements, is thymol chemotype, containing up to 80% of this compound [3]. *T. vulgaris* herb is also rich in non-volatile phenolic compounds. Among flavonoids, the most numerous are flavones (i.e., apigenin, luteolin, 6-hydroxyluteolin) and their glycosides, as well as methylated flavones (i.e., cirsilinol, eridictol, thymonin).

Phenolic acids are represented mainly by rosmarinic and caffeic acid [11–14]. Triterpenes (derivatives of ursolic and oleanolic acids) have also been identified in the herb of thyme [4].

In relation to the abovementioned biologically active compounds, common thyme herb reveals various pharmacological activities, whereas the most important seems to be: antimicrobial, spasmolytic, antioxidant, and antitussive [15,16]. According to EMA and World Health Organization (WHO), it is recommended as a remedy for the treatment of respiratory tract diseases, in the symptoms of bronchitis, catarrhs, common cold and sore throat. It can also be used in digestive disorders, e.g., dyspepsia, as well as externally, in minor wounds treatment and as an antimicrobial agent in oral hygiene. Thyme herb provides a product to prepare comminuted herbal substance, as well as liquid and dry extracts or other galenical preparations [4,17].

Such a high biological potential combined with the pleasant aroma of the herb make thyme to be widely used in various branches of industry [18]. The non-medicinal usage of this species includes its application as a cosmetic intermediate, a food preservative and additive, and the most important—as a culinary herb. When being used as a spice, common thyme not only makes meal more attractive from the sensory point of view, but also improves digestion and is a source of antioxidant compounds. Here, its herb can be used both in the form of dry raw material and the fresh one intended to direct consumption as a culinary seasoning. Taking into consideration the last worldwide trend of a healthy lifestyle, the demand on fresh aromatic herbs distinguished by a high dietetic and sensory value, has recently increased [19].

Given medicinal and aromatic plants, a special attention has been paid on their quality. It seems, that herbs cultivated in organic production system may meet the safety requirements concerning contamination by, i.e., pesticide and nitrate fertilizer residues [20,21]. In order to produce high quality plants in organic system, suggestions to cultivate some species under foil and/or mesh enclosures, has recently appeared. Such system allows not only to control some environmental factors (temperature and light) or prevent pathogen attack, but also creates an opportunity to cultivate aromatic plants, native to warmer climate in the temperate zone conditions, for both dry and fresh raw material [22–25].

Common thyme cultivation methods are known and widely presented in the literature data [26–31]. However, majority of publications concern conventional cultivation of this species, in order to produce dry herb and/or essential oil. The issue of common thyme organic farming is not numerous [23,32,33] and even scarce when regards production for a fresh herb as a culinary seasoning.

The purpose of the present work was to determine the yield and quality of common thyme grown for a fresh herb intended to direct consumption, cultivated in the open field and under foil tunnel, in organic farming system. The quality of obtained raw material was assessed by determining the content and composition of essential oil, the total content of flavonoids and phenolic acids, as well as sensory profile of herb odor and taste.

2. Materials and Methods

2.1. Field Experiment

The experiment was carried out at the experimental field of the Department of Vegetable and Medicinal Plants, WULS-SGGW (52°10′180″ N; 21°05′234″ E), on alluvial soil. It was performed in 2015 and 2016 (two one-year field experiments), but the results were shown as means of two years. The plant production was determined in accordance with standard cultivation of organic agriculture, and certified by Ekogwarancja Ltd. (Tomaszowice, Poland). In autumn 2014 and 2015, the field was organically fertilized by composted manure (30 t × ha^{−1}), and then plowed. Common thyme seeds (cultivar “Standard Winter”, organic quality) were received from Jelitto Company (Schwarmstedt, Germany). The seedlings were produced in the WULS-SGGW greenhouse. In the last decade of February, seeds were sown into multi-pots filled with a peat substrate of pH 6.0. In the first decade of May, well rooted seedlings were planted out. Two variants of cultivation were applied: plants were cultivated in the open field and under foil tunnel. The experiment was estab-

lished in randomized block design, in three replications. The size of each plot was 10 m², and plant's spacing 20 × 40 cm. Mean temperatures during vegetation season in 2015 and 2016 were recorded (Table 1). Drip water irrigation was applied in both variants of cultivation. In the foil tunnel, watering was used in the amount of 150 mm per month, whereas plants grown in the open field, depending on the rainfall, were additionally irrigated to a similar level. The water volume was measured by pluviometer. Soil parameters (pH, minerals, and organic matter content) were measured by the Agricultural and Chemical Station in Warsaw (Table 2).

Table 1. Mean temperatures in the vegetation seasons (°C).

Months	Open Field		Foil Tunnel	
	2015	2016	2015	2016
May	13	15	21	22
June	17	19	26	27
July	20	19	29	29
August	22	19	31	30
September	14	16	21	22

Table 2. Soil parameters (pH, the content of main nutrients and organic matter).

	Open Field	Foil Tunnel
pH	6.00 ± 0.12	6.10 ± 0.14
NO ₃ [−] (mg × L ^{−1})	70.75 ± 2.98	78.50 * ± 2.84
NH ₄ ⁺ (mg × L ^{−1})	17.70 ± 1.50	19.00 ± 1.27
P ₂ O ₅ (mg × 100 g ^{−1})	18.75 ± 1.21	20.75 ± 1.77
K ₂ O (mg × 100 g ^{−1})	38.25 ± 1.98	37.90 ± 1.91
Organic matter (%)	2.99 ± 0.41	3.01 ± 0.46

Tukey test; * $p < 0.05$, results are expressed as means of two years.

The harvest of common thyme herb was carried out on one-year old plants, both in 2015 and 2016. Presented results (Section 3) are expressed as means of two years. The results from each year are shown in Supplementary Materials. Harvest was conducted three times during plants vegetation, as following: first cut in the middle of July (marked as cut 1 in figures and tables), second cut (regrowth) in the second decade of August (cut 2) and third cut (regrowth) the end of September (cut 3). At each harvest, plants were collected in the stage of beginning of blooming. The herb (upper, not woody parts of shoots, with leaves and flowers) was cut from each plot, at a height of about 10 cm above ground in the first harvest, 13 and 16 cm in second and third, respectively. Then its fresh weight (FW) was estimated. Collected herb was immediately subjected to chemical and sensory evaluation. The raw material was stored at 4 °C, in plastic bags, up to five days.

2.2. Chemical Analysis

2.2.1. Content of Essential Oil

Fresh raw material (100 g) was used for hydrodistillation for 3 h using a Clevenger-type apparatus [3]. The content of essential oil was expressed as g × 100 g^{−1} of fresh mass of raw material. Obtained essential oils were stored in dark vials, at 4 °C.

2.2.2. Analysis of Essential Oils by GC-MS and GC-FID

The qualitative and quantitative analysis was performed by usage an Agilent Technologies 7890A gas chromatograph equipped with a flame ionization detector (FID) and MS Agilent Technologies 5975C Inert XL_MSD with Triple Axis Detector (Agilent Technologies, Wilmington, DE, USA). Capillary, polar column HP 20M (25 m × 0.32 mm × 0.3 µm film thickness) was applied (Agilent Technologies, Wilmington, DE, USA). Operation conditions was described previously by Bączek et al. [34].

2.2.3. Total Content of Phenolic Compounds

The total content of phenolic acids and flavonoids were carried out in accordance with Polish Pharmacopoeia 6th edition [35]. Phenolic acids content was determined by Arnov's method and expressed as caffeic acid equivalent, while flavonoids, by the aluminum chloride colorimetric method, and expressed as quercetin equivalent. Detailed description of these methods has already been given by Kosakowska et al. [36].

All chemical analysis were performed in triplicate.

2.3. Sensory Analysis

Sensory evaluation was determined in the sensory laboratory of the Department of Vegetables and Medicinal Plants, WULS-SGGW, which meets the required standards. Quantitative Descriptive Analysis (QDA) was applied. The evaluation was performed on the fresh common thyme herb, collected in the first cut, both from open field and foil tunnel. Here, attributes of its odor and taste were selected and estimated. In order to select attributes, "brainstorming" sessions were carried out by an expert panelist consisting of a minimum of 10 trained assessors. Evaluation was carried out in two independent sessions. The description of procedure has already been provided by Kosakowska et al. [25].

2.4. Statistical Analysis

Data were subjected to statistical analysis using Statistica 12 software (StatSoft, Kraków, Poland). Mean values were compared by using the one way analysis of variance (ANOVA). Tukey Multiple Range test was applied. The differences between individual means were deemed significant at $p < 0.05$. Means marked with small letters represented values for following cuts in the open field, while means are marked with capital letters, values for following cuts in the foil tunnel. More details (e.g., $\pm$ standard deviation) are given in Supplementary Materials (Tables S1–S7).

3. Results and Discussion

3.1. Yield of Herb

The object of the present study was one-year-old common thyme plants cultivated for a fresh herb. Both from the open field and foil tunnel, three cuts of herb were obtained (Figure 1). According to Kołodziej [37], three cuts are possible from two-three year-old plants, and only one or two in the case of one-year old plants. Given the fact that common thyme is the most aromatic during the period of blooming (or at the beginning of full bloom), therefore, this time is considered as the best for harvesting. However, the period of plant's vegetation and blooming time can be different in various geographical zones depending on their climatic conditions. For instance, in Spain, which is major producer of thyme in the Mediterranean region, the harvest takes place from February to August, in France, from May to September, in Italy from May to December, while in Central Russia from June to October [27,38].

Results of our experiment show that common thyme regrew rapidly from first to second cut, both in the open field and foil tunnel. Here, the mass of fresh herb collected during the second cut (in August) was almost three times higher when compared to the first cut (in July) (Figure 1). This correspond to results obtained earlier by Edris et al. [33] and Hendawy et al. [29]. Later, in the period from second to third cut (in September), the growth of thyme visibly decreased. Common thyme is characterized by a high light and temperature requirements resulted from its Mediterranean origin. In Central Europe, the highest levels of temperature and sun radiation are noticed in the summer time (July–August), creating an optimal conditions for common thyme growth. It can be suspected that cutting itself also had an impact on the productivity of this species. Usually, cutting stimulates the plants regrowth, what may be associated with a high regenerative potential of Lamiaceae, including common thyme [39]. Nevertheless, more cuts may weaken plants, what was observed when regards third cut of our experiment.

Figure 1. Mass of common thyme herb ($\text{kg FW} \times 10 \text{ m}^2$). Tukey test; * $p < 0.05$; a, b, c are the means marked with small letters (values for following cuts in the open field) differ at $p < 0.05$; A, B, C are the means marked with capital letters (values for following cuts in the foil tunnel) differ at $p < 0.05$.

It was noticed that common thyme cultivated under foil gave almost twice the mass of herb when compared to those from the open field. That phenomenon can be explained mainly by a temperature value, which was 6–9 °C higher under foil tunnel than in open field (Table 1). Moreover, soil parameters may have also affected growth of plants. The soil richness (being a result of proper field management) is crucial in organic cultivation systems where mineral fertilization is highly limited or even banned. In our experiment, the soil from foil tunnel was richer in nitrate ($78.50 \text{ mg NO}_3^- \times \text{L}^{-1}$) in comparison to this from open field ($70.75 \text{ mg NO}_3^- \times \text{L}^{-1}$) (Table 2).

3.2. Essential Oil Content and Composition

The content of essential oil in fresh herb was at a level of $0.45\text{--}0.52 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$ in the case of plants cultivated in the open field and $0.28\text{--}0.72 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$ under foil tunnel (Figure 2). In both cultivation variants, the content of essential oil decreased with the subsequent herbal cuts, with its maximum in the first one (in July). It was noticed that in the case of first cut, the herb collected in foil tunnel contained more essential oil ($0.72 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$) than this from open field ($0.52 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$). In turn, when regards the last cut, the opposite relationship has been observed (Figure 2).

Figure 2. The content of essential oil in common thyme herb ($\text{g} \times 100 \text{ g}^{-1} \text{ FW}$). Tukey test; * $p < 0.05$; a, b are the means marked with small letters (values for following cuts in the open field) differ at $p < 0.05$; A, B, C are the means marked with capital letters (values for following cuts in the foil tunnel) differ at $p < 0.05$.

The content of essential oils in aromatic plants depends on various factors, both internal (genetic, ontogenetic, morphogenetic) and external (environmental such as temperature, day length, solar radiation, and postharvest) [40–43]. When regards common thyme, the impact of ontogenetic factors (the stage of plants development) on the essential oil content is widely described in the literature [27,28,38,40,44,45]. According to Badi et al. [28], the content of essential oil decreases during ontogenesis, from the beginning of blooming until fruit setting stage. Similar relationship was shown by Jordán et al. [44]. In turn, results of Rohloff [40] indicate that the content of essential oil increased with the plants development. Furthermore, studies conducted by Venskutonis [27] and Golparvar et al. [45] show that the content of essential oil fluctuates during ontogenesis, achieving the highest level at the beginning of blooming. Considering all these findings, it can be said that the content of essential oil in common thyme should be considered for each climate zone separately. Based on the abovementioned studies, it seems that the final content of essential oil in thyme herb is strongly affected both by plant's developmental stage and environmental factors. Results obtained in our work, indicating on decrease of essential oil content during vegetation period, correspond with those shown by Badi et al. [28] and Jordán et al. [44]. However, it should be underlined that in our experiment the herb of common thyme was harvested at the same developmental phase (beginning of blooming), at each of successive cuts. Therefore, the results should be considered rather in the context of seasonal climate changes than in relation with plant's ontogenetic development. Here, it is supposed that observed decreasing content of essential oil may result from parallel impact of shortening day and decreasing temperature noticed in Poland during vegetation season.

In total, 31 compounds were identified in investigated essential oil, comprising 97.45–99.79% of total identified fraction (Table 3). Here, monoterpenes created a fundamental part, with a domination of phenolic monoterpenes (thymol and carvacrol) where thymol was the leading isomer (forming up to 57.08%). This qualifies the present essential oil as a clear 'thymol' chemotype. It was noticed that the share of thymol was reduced in tandem with successive herbal cuts, both in open field and foil tunnel. Interestingly, when given the first cut, the content of thymol in essential oil was higher (57.08%) in the case of plants cultivated under foil tunnel than in open field (53.77%) (Table 3). Thymol is regarded as the most important constituent of thyme herb, due to its high pharmacological activity, mainly antimicrobial and antioxidant [15,16]. It is also responsible for the sensory profile of thyme herb [46]. The fluctuation of thymol content in common thyme was investigated earlier by other authors. It was found out that it depends on the various agents, such as: chemotype, cultivar, organic fertilization source, mineral fertilization, and, the most significant—stage of plants development [6–10,27,28,30,31,40,44,45]. Generally, thymol content seems to be strongly variable, however, most authors consider the beginning of blooming as a phase when it reaches its maximum level.

In the present study, monoterpene hydrocarbons, accounting of 29.30–36.01% of essential oil were represented mainly by γ -terpinene (up to 20.29%) and *p*-cymene (up to 11.80%). Content of *p*-cymene visibly increased during vegetation, in opposite to thymol (Table 2). This refers to results obtained by Hudaib et al. [38] indicating that monoterpene phenols (thymol and carvacrol) and their corresponding precursors (γ -terpinene and *p*-cymene) collectively show synchronized patterns of variations during vegetation season.

Table 3. Chemical composition of essential oils from common thyme herb (% peak area).

No	Compound	RI ^a	Cut 1		Cut 2		Cut 3	
			OF	FT	OF	FT	OF	FT
1	α -thujene	1023	0.62	0.53	0.70	0.68	0.67	0.61
2	α -pinene	1028	1.59	1.26	1.81	1.92	1.38	1.20
3	camphene	1074	0.42	0.25	0.46	0.30	0.49	0.40
4	β -pinene	1114	0.21	0.17	0.22	0.23	0.19	0.18
5	3-carene	1149	1.91	1.65	2.07	2.17	1.94	1.80
6	β -myrcen	1165	2.05	1.98	1.25	2.31	1.82	1.62
7	α -phellandrene	1169	0.18	0.16	0.19	0.20	0.16	0.14
8	α -terpinene	1182	0.39	0.24	0.35	0.38	0.34	0.36
9	limonen	1203	0.37	0.39	0.42	0.41	0.33	0.36
10	β -ocimene	1234	0.09	0.07	0.10	0.08	0.05	0.12
11	γ -terpinene	1247	19.79	17.15	18.04	17.68	20.29 *	17.23
12	<i>p</i> -cymene	1273	6.31b	5.13C	7.60ab	8.09B	8.27a	11.80A *
13	terpinolene	1279	0.07	0.32	0.08	0.09	0.08	0.10
14	3-octanol	1390	0.83	1.03	0.95	0.72	0.98	0.13
15	1-octen-3-ol	1446	0.84	0.92	0.96	1.10	0.68	0.90
16	β -cubebene	1539	0.14	0.13	0.14	0.13	0.76	0.79
17	linalool	1542	1.50	1.30	1.56	1.97	0.16	0.19
18	bornyl acetate	1576	0.11	0.19	0.11	0.10	0.09	0.11
19	β -copaene	1580	0.94	0.28	0.89	0.85	0.14	0.15
20	β -caryophyllene	1592	0.36	0.11	0.19	0.55	0.14	0.08
21	terpinen-4-ol	1599	2.31	2.37	2.36	2.47	2.99	2.52
22	cis- β -terpineol	1616	0.22	1.55	0.11	0.09	1.51	1.87
23	γ -elemene	1640	0.11	0.19	0.11	0.11	0.08	0.09
24	borneol	1687	0.81	0.61	0.77	0.43	0.70	0.49
25	geranial	1722	0.15	0.21	0.13	0.13	0.07	0.09
26	α -cadinene	1770	0.72	0.56	0.73	0.63	0.11	0.06
27	geraniol	1826	0.23	0.09	0.16	0.12	0.18	0.21
28	caryophyllene oxide	1975	0.12	0.11	0.13	0.08	0.09	0.17
29	germacrene-D-4-ol	2024	0.11	0.09	0.09	0.08	0.06	0.06
30	thymol	2163	53.77a	57.08A *	53.26a	52.41B	50.56b	51.39B
31	carvacrol	2214	2.52	2.63	2.60	2.48	2.14	2.23
	Monoterpene hydrocarbons		34.00	29.30	33.29	34.54	36.01	35.92
	Oxygenated monoterpenes		5.22	6.13	5.09	5.21	5.61	5.37
	Phenolic monoterpenes		56.29	59.71	55.86	54.89	52.70	53.62
	Sesquiterpene hydrocarbons		2.38	1.46	2.17	2.37	1.32	1.28
	Oxygenated sesquiterpenes		0.23	0.20	0.22	0.16	0.15	0.23
	Others		1.67	1.95	1.91	1.82	1.66	1.03
	Total content of identified compounds (%)		99.79	98.75	98.54	98.99	97.45	97.45

RI ^a –retention index on polar HP column; OF—open field, FT—foil tunnel. Tukey test; * $p < 0.05$; a, b—means marked with small letters (values for following cuts in the open field) differ at $p < 0.05$; A, B, C—means marked with capital letters (values for following cuts in the foil tunnel) differ at $p < 0.05$.

3.3. Phenolic Compounds Content

Recently, a special attention has been paid on the content and composition of non-volatile phenolic compounds in aromatic plants. This heterogenous group of molecules is basically formed by shikimic acid pathway and include more than 10,000 substances [47]. It is known that phenolics, especially flavonoids and phenolic acids, reveal various pharmacological activities, whereas the antioxidant properties seems to be the most important [48]. On the other hand, phenolics play a crucial physiological role in plant's tissues since they are involved in mechanisms of adaptation, protection and defense against biotic and abiotic stresses [48–51]. Moreover, they are linked with several other processes such like photosyn-

thesis, protein synthesis, enzyme activity, nutrient uptake, and hormone regulation [43]. In our experiment, it was noticed that the content of phenolic acids and flavonoids in common thyme herb depends on both cultivation variant and time of harvest (Figures 3 and 4).

Figure 3. The total content of phenolic acids in common thyme herb ($\text{g} \times 100 \text{ g}^{-1} \text{ FW}$). Tukey test; * $p < 0.05$; a, b are the means marked with small letters (values for following cuts in the open field) differ at $p < 0.05$; A, B, C are the means marked with capital letters (values for following cuts in the foil tunnel) differ at $p < 0.05$.

Figure 4. The total content of flavonoids in common thyme herb ($\text{g} \times 100 \text{ g}^{-1} \text{ FW}$). Tukey test; * $p < 0.05$; a, b, c are the means marked with small letters (values for following cuts in the open field) differ at $p < 0.05$; A, B, C are the means marked with capital letters (values for following cuts in the foil tunnel) differ at $p < 0.05$.

As for phenolic acids, their content increased from the first to the last cut and was significantly higher in the case of plants cultivated in open field than in foil tunnel (Figure 3). This result can be related to the fact that the plants were more exposed to stressful conditions such as temperature and/or potential pathogen attack than those grown in foil tunnel. Therefore, the accumulation of phenolic acids, which are lignin's components making cell walls stronger and more resistant, could be enhanced in this variant of cultivations [52]. The predominance of phenolic acids in the herb from plants cultivated in open field than under foil tunnel was also observed in our previous studies concerning Greek oregano [25].

When regards flavonoids, the content of these substances in common thyme herb was similar in both cultivation variants and increased gradually from the first to the last harvest (Figure 4). Such a phenomenon may be explained by the fact that the process of herb cutting, regarding as a stress factor, could weaken plants and finally contributed to improved flavonoids synthesis. Taking into account that flavonoids are involved into distribution of auxins, it can be suspected that high flavonoids amount may be related with fast regrowth of plants [39,53]. It seems that seasonal temperature variations also could

affect the final content of flavonoids in herb of common thyme. These results, indicating the increase of flavonoids in herb with successive cuts, correspond with those obtained in the previous experiment, conducted on the sweet basil [24]. According to literature data, the content of phenolics in common thyme herb depends on various factors, i.e., the origin of plants and/or methods of extraction and purification [13,14,54,55].

3.4. Sensory Evaluation

In the case of spices, the general organoleptic characteristic and their acceptance by consumers are an important issue. Unpleasant smell or taste may cause the rejection of the product, even though its quality meets pharmacopeia or International Organization for Standardization (ISO) specifications [56]. Therefore, the sensory estimation seems to be a crucial factor affecting the overall quality of culinary herbs.

In the present work, two samples of common thyme fresh herb were selected for sensory analysis, namely these harvested in the first cut, both from open field and foil tunnel. Generally, the sensory profile of herb was conditioned by its essential oil composition, qualified as ‘clear thymol’ chemotype, whereas the sensory attributes of thymol are defined as herbal, medicinal, phenolic, and spicy [46]. Other volatile compounds present in essential oil in the considerable amounts, such as *p*-cymene and γ -terpinene, also may affect the sensory profile of investigated samples. Here, the odor of both above mentioned substances are regarded as gasoline and citrus, while γ -terpinene is additionally described as herbaceous and turpentine [57]. Results obtained in our work indicate on slight differences between common thyme herb collected from open field and foil tunnel, in respect of odor and taste notes (Figures 5 and 6). The following attributes were selected for odor: pungent, thyme-like, floral (sweet), coniferous, herbaceous, spicy, minty, anisic and fruity, while for taste: medicinal, pine, herbal, acidic, spicy, astringent, bitter, earthy and sweet. Herb collected in foil tunnel was characterized by a slightly higher intensity of pungent, herbaceous, minty and fruity notes in comparison to the sample from open field (Figure 5). When regards taste, herb from foil tunnel was more pine and herbal and less medicinal, acidic, spicy and astringent than this from open field (Figure 6). It seems that slight variations in odor and taste can be associated with the content of essential oil ($0.72 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$ in foil tunnel; $0.52 \text{ g} \times 100 \text{ g}^{-1} \text{ FW}$ in open field) and the percentage of thymol (57.08; 53.77%, respectively) (Figure 2, Table 3). Results obtained earlier by other authors show, that sensory notes of common thyme herb may be associated with methods of raw material conservation. Sarosi et al. [56] claims that lyophilized samples were distinguished by the higher minty odor attributes and were the most preferable by consumers. According to Król and Kiełtyka–Dadasiewicz [58], fresh herb of common thyme was regarded as the most herbaceous and refreshing among others, dried samples.

Figure 5. Sensory profile of common thyme herb odor.

Figure 6. Sensory profile of common thyme herb taste.

4. Conclusions

Results indicated that organic cultivation of common thyme, grown for the fresh herb consumption, in temperate climate of Central Europe can be successfully performed both in the open field and foil tunnel conditions. Three consecutive herbal cuts are possible to obtain from the one-year-old plantation during vegetation season, namely: from the middle of July until the end of September. The yield of fresh herb as well as its quality, reflected in a high content of pro-healthy compounds (essential oil and phenolics), were satisfied for each harvest. The content of biologically active compounds in the raw material depended both on cultivation variant and time of harvest. When regards sensory profile, slight differences between samples collected from the open field and foil tunnel were shown, related presumably to the essential oil content and composition. Based on the obtained results and taking into account the global warming phenomenon, it seems that organic cultivation of common thyme in Central Europe, in future may be extended from the early spring to late autumn. This would allow to produce its fresh herb for the most part of a year, providing a valuable raw material designed for a fresh market, intended to direct consumption.

Supplementary Materials: The following are available online at <https://www.mdpi.com/2073-4395/11/2/197/s1>, Table S1: Mass of common thyme herb (kg FW $\times$ 10 m²); Table S2. The content of essential oil in common thyme herb (g $\times$ 100 g⁻¹ FW); Table S3. The content of thymol in common thyme essential oil (%); Table S4. The content of *p*-cymene in common thyme essential oil (%); Table S5. The content of γ -terpinene in common thyme essential oil (%); Table S6. The total content of phenolic acids in common thyme herb (g $\times$ 100 g⁻¹ FW); Table S7. The total content of flavonoids in common thyme herb (g $\times$ 100 g⁻¹ FW).

Author Contributions: Conceptualization: Z.W. and K.B.; methodology: Z.W., K.B., O.K.; investigation: Z.W., K.B., O.K.; writing—original draft preparation: O.K.; writing—review and editing: Z.W., K.B., O.K.; supervision: Z.W. and K.B.; project administration: K.B.; funding acquisition: K.B. All authors have read and agreed to the published version of the manuscript.

Funding: The part of the present work was supported by Polish Ministry of Agriculture and Rural Development within the project ‘Practical aspects of organic cultivation of vegetables and herbs under covers or in a greenhouse’, no. HORre-029-27-21/14(29).

Acknowledgments: The technical help of Analytical Centre (WULS-SGGW) is gratefully acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Stahl Biskup, E.; Sáez, F. *The Genus Thymus; Medicinal and Aromatic Plants—Industrial Profiles Series*; Taylor and Francis: London, UK, 2002.
2. Wichtl, M. *Herbal Drugs and Phytopharmaceuticals, a Handbook of Practice on a Scientific Basis*, 3rd ed.; CRC Press: Stuttgart, Germany, 2004.
3. European Directorate for the Quality of Medicines and Health Care (EDQM), Council of Europe. *European Pharmacopoeia*, 7th ed.; European Directorate for the Quality of Medicines and Health Care (EDQM), Council of Europe: Strasbourg, France, 2010.
4. EMA (European Medicines Agency). *Assessment Report on Thymus vulgaris L., vulgaris zygis L., herba*; EMA/HMPC/342334; EMA: Amsterdam, The Netherlands, 2013.
5. Agili, F.A. Chemical composition, antioxidant and antitumor activity of *Thymus vulgaris* L. essential oil. *Middle East. J. Sci. Res.* **2014**, *21*, 1670–1676.
6. Morgan, R.K. Chemotypic characteristics of *Thymus vulgaris* L. in Central Otago, New Zealand. *J. Biogeogr.* **1989**, *16*, 483–491. [[CrossRef](#)]
7. Thompson, J.D.; Chalchat, J.C.; Michet, A.; Linhart, Y.B.; Ehlers, B. Qualitative and quantitative variation on monoterpene co-occurrence and composition in the essential oil of *Thymus vulgaris* chemotypes. *J. Chem. Ecol.* **2003**, *29*, 859–880. [[CrossRef](#)] [[PubMed](#)]
8. Torras, J.; Grau, M.D.; Lopez, J.F.; de las Heras, F.X. Analysis of essential oils from chemotypes of *Thymus vulgaris* in Catalonia. *J. Sci. Food Agric.* **2007**, *87*, 2327–2333. [[CrossRef](#)]
9. Chizzola, R.; Michitsch, H.; Franz, C. Antioxidant properties of *Thymus vulgaris* leaves: Comparison of different extracts and essential oil chemotypes. *J. Agric. Food Chem.* **2008**, *56*, 6897–6904. [[CrossRef](#)] [[PubMed](#)]
10. Satyal, P.; Murray, B.L.; McFeeters, R.L.; Setzer, W.N. Essential oil characterization of *Thymus vulgaris* from various geographical locations. *Foods* **2016**, *5*, 1–12. [[CrossRef](#)]
11. Vila, R. Flavonoids and further polyphenols in the genus *Thymus*. In *Thyme. The Genus Thymus; Medicinal and Aromatic Plants—Industrial Profiles Series*; Stahl-Biskup, E., Sáez, F., Eds.; Taylor and Francis: London, UK; New York, NY, USA, 2002; pp. 144–177.
12. Bazylo, A.; Strzelecka, H. A HPTLC densitometric determination of luteolin in *Thymus vulgaris* and its extracts. *Fitoterapia* **2007**, *78*, 391–395. [[CrossRef](#)]
13. Pereira, O.R.; Cardoso, S.M. Overview on *Mentha* and *Thymus* Polyphenols. *Curr. Anal. Chem.* **2013**, *9*, 382–396. [[CrossRef](#)]
14. Alu'datt, M.H.; Rababah, T.; Johargy, A.; Gammoh, S.; Ereifej, K.; Alhamad, M.N.; Brewer, M.S.; Saati, A.A.; Kubow, S.; Rawshdeh, M. Extraction, optimisation and characterisation of phenolics from *Thymus vulgaris* L.: Phenolic content and profiles in relation to antioxidant, antidiabetic and antihypertensive properties. *IJFST* **2015**, *51*, 720–730. [[CrossRef](#)]
15. Reddy, P.; Kandisa, R.V.; Varsha, P.V.; Satyam, S. Review on *Thymus vulgaris* traditional uses and pharmacological properties. *Med. Aromat. Plants* **2014**, *3*, 1–4. [[CrossRef](#)]
16. Dauqan, E.M.A.; Abdullah, A. Medicinal and functional values of thyme (*Thymus vulgaris* L.) herb. *JABB* **2017**, *5*, 17–22. [[CrossRef](#)]
17. WHO. *Herba Thymi*. In *WHO Monographs of Selected Medicinal Plants*; WHO: Geneva, Switzerland, 1999; pp. 259–266.
18. Lawrence, B.M.; Tucker, A.O. The genus *Thymus* as a source of commercial products. In *Thyme. The Genus Thymus; Medicinal and Aromatic Plants—Industrial Profiles Series*; Stahl-Biskup, E., Sáez, F., Eds.; Taylor and Francis: London, UK; New York, NY, USA, 2002; pp. 252–263.
19. Zarzuelo, A.; Crespo, E. The medicinal and non medicinal uses of thyme. In *Thyme. The Genus Thymus; Medicinal and Aromatic Plants—Industrial Profiles Series*; Stahl-Biskup, E., Sáez, F., Eds.; Taylor and Francis: London, UK; New York, NY, USA, 2002; pp. 263–293.
20. Salgueiro, L.; Martins, A.P.; Correia, H. Raw materials: The importance of quality and safety. A Review. *Flavour Frag. J.* **2010**, *25*, 253–271. [[CrossRef](#)]
21. Rheinholds, I.; Pugajeva, I.; Bavrins, K.; Kuckovska, G.; Bertkevics, V. Mycotoxins, pesticides and toxic metals in commercial spices and herbs. *Food Addit. Contam. Part B Surveill.* **2017**, *10*, 5–10. [[CrossRef](#)] [[PubMed](#)]
22. Romero-Games, M.; Anton, A.; Soriano, T.; Suarez-Rey, E.M. Environmental impact of greenbean cultivation: Comparison of screen greenhouses vs. open field. *J. Food Agric. Environ.* **2009**, *7*, 754–760.
23. Murillo-Amador, B.; Nieto-Garibay, A.; López-Aguilar, R.; Rueda-Puente, E.O.; Flores-Hernández, A.; Ruiz-Espinoza, H.F. Physiological, morphometric characteristics and yield of *Origanum vulgare* L. and *Thymus vulgaris* L. exposed to open-field and shade-enclosure. *Ind. Crop. Prod.* **2013**, *49*, 659–667. [[CrossRef](#)]
24. Bączek, K.; Kosakowska, O.; Gniewosz, M.; Gientka, I.; Węglarz, Z. Sweet basil (*Ocimum basilicum* L.) productivity and raw material quality from organic cultivation. *Agronomy* **2019**, *9*, 279. [[CrossRef](#)]
25. Kosakowska, O.; Węglarz, Z.; Bączek, K. Yield and quality of ‘Greek oregano’ (*Origanum vulgare* L. subsp. *hirtum*) herb from organic production system in temperate climate. *Ind. Crop. Prod.* **2019**, *141*, 111782. [[CrossRef](#)]
26. Rey, C.; Sáez, F. Field culture, *in vitro* culture and selection of *Thymus*. In *Thyme. The Genus Thymus; Medicinal and Aromatic Plants—Industrial Profiles Series*; Stahl-Biskup, E., Sáez, F., Eds.; Taylor and Francis: London, UK; New York, NY, USA, 2002; pp. 117–197.

27. Venskutonis, P. Harvesting and postharvest handling in the genus *Thymus*. In *Thyme. The Genus Thymus*; Medicinal and Aromatic Plants—Industrial Profiles Series; Stahl-Biskup, E., Sáez, F., Eds.; Taylor and Francis: London, UK; New York, NY, USA, 2002; pp. 197–224.
28. Badi, N.H.; Yazdani, D.; Mohammad, S.; Nazari, F. Effects of spacing and harvesting time on herbage yield and quality/quantity of oil in thyme, *Thymus vulgaris* L. *Ind. Crop. Prod.* **2004**, *19*, 231–236. [\[CrossRef\]](#)
29. Hendawy, S.F.; Aziz, E.E.; Omer, E. Productivity and oil quality of *Thymus vulgaris* L. under organic fertilization conditions. *OJAS* **2010**, *3*, 203–216.
30. Juárez-Rosete, C.R.; Aguilar-Castillo, J.A.; Rodríguez-Medozo, M.N. Fertilizer source in biomass production and quality of essential oils of thyme (*Thymus vulgaris* L.). *EJMP* **2014**, *4*, 865–871. [\[CrossRef\]](#)
31. Wesołowska, A.; Jadcak, D. Comparison of the chemical composition of essential oils isolated from two thyme (*Thymus vulgaris* L.) cultivars. *Not. Bot. Horti. Agrobot. Clu. J. Napoca*. **2019**, *47*, 829–835. [\[CrossRef\]](#)
32. Seidler-Łożykowska, K.; Mordalski, R.; Kucharski, W.; Golcz, A.; Kozik, E.; Wójcik, J. Economic and qualitative value of the raw material of chosen species of medicinal plants from organic farming part I. Yield and quality of garden thyme herb (*Thymus vulgaris* L.). *Acta Sci. Pol. Agric.* **2009**, *8*, 23–28.
33. Edris, A.E.; Shalaby, A.S.; Fadel, H.M. Effect of organic agriculture practices on the volatile flavor components of in Egypt: III. some essential oilplants growing *Thymus vulgaris* L. essential oil. *J. Essent. Oil Bear. Plants* **2009**, *12*, 319–326. [\[CrossRef\]](#)
34. Bączek, K.; Kosakowska, O.; Przybył, J.L.; Kuźma, P.; Ejdys, M.; Obiedziński, M.; Węglarz, Z. Intraspecific variability of yarrow (*Achillea millefolium* L. s.l.) in respect of developmental and chemical traits. *Herba Pol.* **2015**, *61*, 37–52. [\[CrossRef\]](#)
35. Polish Pharmaceutical Society. *Polish Pharmacopoeia*, 6th ed.; Office of Registration of Medicinal Products, Medical Devices and Biocidal Products. Polish Pharmaceutical Society: Warsaw, Poland, 2002.
36. Kosakowska, O.; Bączek, K.; Przybył, J.L.; Ejdys, M.; Kuźma, P.; Obiedziński, M.; Węglarz, Z. Intraspecific variability in the content of phenolic compounds, essential oil and mucilage of small-leaved lime (*Tilia cordata* Mill.) from Poland. *Ind. Crop. Prod.* **2015**, *78*, 58–65. [\[CrossRef\]](#)
37. Kołodziej, B. *Uprawa Ziół Poradnik dla Plantatorów*, 2nd ed.; Powszechne Wydawnictwo Rolnicze i Leśne: Warsaw, Poland, 2018.
38. Hudaib, M.; Speroni, E.; Maria, A.; Pietra, D.; Cavrini, V. GC/MS evaluation of thyme (*Thymus vulgaris* L.) oil composition and variations during the vegetative cycle. *J. Pharm. Biomed. Anal.* **2002**, *29*, 691–700. [\[CrossRef\]](#)
39. Kopcewicz, J.; Lewak, S. *Fizjologia Roślin*; PWN: Warsaw, Poland, 2012.
40. Rohloff, J. Essential oil drugs—terpene composition of aromatic herbs. In *Production Practices and Quality Assessment of Food Crops*; Dris, R., Jain, S.M., Eds.; Kluwer Academic Publishers: Amsterdam, The Netherlands, 2004; Volume 3, pp. 73–128.
41. Figueiredo, A.C.; Barroso, J.G.; José, G.; Pedro, L.G.; Scheffer, J.J.C. Factors affecting secondary metabolite production in plants: Volatile components and essential oils. *Flavour Fragr. J.* **2008**, *23*, 213–226. [\[CrossRef\]](#)
42. Başer, K.H.C.; Bouchbauer, G. *Handbook of Essential Oils: Science, Technology and Applications*; Chemical Rubber Company Press: London, UK, 2009.
43. Verma, N.; Shukla, S. Impact of various factors responsible for fluctuation in plant secondary metabolites. *JARMAP* **2015**, *2*, 105–113. [\[CrossRef\]](#)
44. Jordán, M.J.; Martínez, R.M.; Goodner, K.L.; Baldwin, E.A.; Sotomayor, J.A. Seasonal variation of *Thymus hyemalis* Lange and Spanish *Thymus vulgaris* L. essential oils composition. *Ind. Crop. Prod.* **2006**, *24*, 253–263. [\[CrossRef\]](#)
45. Golparvar, A.R.; Hadipanah, A.; Salehi, S. Comparative effect of harvest time on essential oil and thymol content of (*Thymus vulgaris* L.) and (*Thymus daenensis* Celak) in Iran Province. *Electron. J. Biol.* **2014**, *10*, 85–92.
46. Clark, G.S. An aroma chemical profile. Thymol. *Perfumer Flavorist* **1995**, *20*, 41–44.
47. Taiz, L.; Zeiger, E. *Secondary Metabolites and Plant Defense Plant Physiology*, 4th ed.; Sinauer Associates: Sunderland, MA, USA, 2006.
48. Andersen, R.M.; Markham, K.R. *Flavonoids: Chemistry, Biochemistry, and Applications*; Taylor and Francis, CRC Press: Boca Raton, FL, USA, 2006; ISBN 0-8493-2021-6.
49. Agati, G.; Azzarello, E.; Pollastri, S.; Tattini, M. Flavonoids as antioxidants in plants: Location and functional significance. *Plant Sci.* **2012**, *196*, 67–76. [\[CrossRef\]](#) [\[PubMed\]](#)
50. Goleniowski, M.; Bonfill, M.; Cusido, R.; Palazon, J. Phenolic Acids. In *Natural Products*; Ramawat, K.G., Merillon, J.M., Eds.; Springer Berlin Heidelberg: Berlin, Germany, 2013.
51. Mouradov, A.; Spangenberg, G. Flavonoids: A metabolic network mediating plants adaptation to their real estate. *Front. Plant Sci.* **2014**, *5*. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Weng, J.K.; Chapple, C. The origin and evolution of lignin biosynthesis. *New Phytol.* **2010**, *187*, 273–285. [\[CrossRef\]](#) [\[PubMed\]](#)
53. Di Ferdinando, M.; Brunetti, C.; Fini, A.; Tattini, M. Flavonoids as Antioxidants in plant under abiotic stresses. In *Abiotic Stress Responses in Plants: Metabolism, Productivity and Sustainability*; Ahmad, P., Prasad, M.N.V., Eds.; Springer Science and Business Media: Berlin, Germany, 2012; pp. 159–179.
54. Alizadeh, A. Essential oil constituents, phenolic content and antioxidant activity in Iranian and British *Thymus vulgaris* L. *IJACS* **2013**, *30*, 213–218.
55. Amamra, S.; Cartea, M.E.; Belhaddad, O.E.; Soengas, P.; Baghiani, A.; Kaabi, I.; Arrar, L. Determination of total phenolics contents, antioxidant capacity of *Thymus vulgaris* extracts using electrochemical and spectrophotometric methods. *Int. J. Electrochem. Sci.* **2018**, *13*, 7882–7893. [\[CrossRef\]](#)

-
56. Sárosi, S.; Sipos, L.; Kókai, Z.; Pluhár, Z.; Szilvássy, B.; Novák, I. Effect of different drying techniques on the aroma profile of *Thymus vulgaris* analyzed by GC–MS and sensory profile methods. *Ind. Crop. Prod.* **2013**, *46*, 210–216. [[CrossRef](#)]
 57. Baranauskienė, R.; Kazernavičiūtė, R.; Pukalskienė, M.; Maždžierienė, R.; Venskutonis, P.R. Agrorefinery of *Tanacetum vulgare* L. into valuable products and evaluation of their antioxidant properties and phytochemical composition. *Ind. Crop. Prod.* **2014**, *60*, 113–122. [[CrossRef](#)]
 58. Król, B.; Kiełtyka-Dadasiewicz, A. Wpływ metody suszenia na cechy sensoryczne oraz skład olejku eterycznego tymianku właściwego (*Thymus vulgaris* L.). *ŻNTJ* **2015**, *4*, 162–175.