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Chemical and Nutritional Compounds of Different Parts of Lemongrass (*Cymbopogon citratus* (DC) Stapf.) Cultivated in Temperate Climate of Poland

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Abstract: Lemongrass (*Cymbopogon citratus* (DC) Stapf.) is a perennial plant indigenous to semi-tropical regions of Asia and cultivated in other semi-tropical countries. The present study aimed to examine the key chemical constituents of various parts of lemongrass cultivated in the temperate climate of Poland. The content of essential oil and its composition were determined in 4 plant parts: leaves (part C), overground shoots (part B), underground shoots (part A), and roots (part R). Moreover, the content of dry weight, chlorophyll, polyphenols and macro- and microelements was determined in the edible parts (excluding roots). The essential oil from the aerial part predominantly contained neral (> 30%) and geranial (> 40%), which is consistent with the data reported in literature; the main component of essential oil (EO) from the underground part was elemol (65%); interestingly, such a high concentration of it was found for the first time. The concentration of chlorophyll was found to be higher in leaves, as compared to parts B and A. The highest level of potassium, magnesium, zinc and sodium was found in part A while of calcium and copper in leaves. The quality of lemongrass raw materials grown in temperate climates did not differ significantly from those obtained in warmer regions. The study findings confirmed the usefulness of leaves as a raw material for the preparation of infusions (higher concentration of pigments, polyphenols and EO) and of near-ground parts of a plant as a culinary material (a higher content of macroelements at lower concentrations of green pigments and dry weight).

Key words: lemongrass, essential oil, polyphenols, macro- and microelements, chlorophyll

1 Introduction

Cymbopogon citratus (DC) Stapf. is a perennial plant native to tropical and semi-tropical regions of Asia and cultivated in South and Central America, Africa and other tropical countries. The plant forms extensive clusters composed of several or more blades growing from the rhizome connected with the fibrous root system of lemongrass. Plantations are used for 3-4 years and leaves can be cut every several months[1-3]. Dried leaves are a medicinal raw material and the basis to produce herbal teas. *C. citratus* are aromatic and yield volatile oils of commercial importance, which is commonly used in folk medicine for the treatment of CNS and GI disturbances, and as antispasmodic, analgesic, anti-inflammatory, anti-pyretic, diuretic and sedative agents[4, 5]. Fresh lower parts known as shoots can also be obtained from this plant (they are actually

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twisted leaves forming pseudo-stems). However, such a harvest runs out the plantation as the entire plant is dug out. The parts mentioned above are used as a culinary additive for various oriental dishes, including spicy, meaty, poultry, seafood and curry vegetable dishes. They give lemon taste and smell, emphasising the orientality of dishes. They are particularly popular in Thai cuisine, yet gain popularity worldwide, including Poland. Therefore, an attempt was made to test the chemical composition of raw materials of lemongrass cultivated under the climate conditions of Poland, where lemongrass can be cultivated only as an annual plant due to low winter temperatures. The content of essential oil and its composition were determined in 4 plant parts (leaves, overground shoots, underground shoots and roots). The EOs were also tested for their antioxidant activity. In the edible parts (excluding roots), the concentrations of dry weight, chlorophylls, polyphenols, macro- and microelements were determined. The knowledge regarding the content of active substances in individuals parts of lemongrass cultivated in Poland should enable to determine the optimal harvesting management in the annual cropping system; the entire plant with the underground part can be dug out or the plant can be cut over the ground at a chosen level. Our findings were compared with the literature data regarding to chemical composition of lemongrass cultivated in Egypt[3, 6], India[7, 8], Iraq[9], Nigeria[10], Angola[11], Ethiopia[2, 12], Wenezuela[13], Brasil[14].

2 Experimental Procedures

2.1 Plant material

C. citratus was cultivated in 2015-2017 in the experimental fields of the Research and Science Innovation Center in Wola Zdybska near Lublin (Poland) (51° 44'49" N 21° 50'38" E) on clay soil of loess origin. Agrometeorological conditions during plant vegetation were typical of the temperate climate (Table 1).

The plants were collected in September, being in the 29 BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) stage at that moment, i.e. fully developed vegetative stage, fully tillering, with the maximum of shoots formed, but before the formation of the flower bud[15, 16]. The entire plants with the underground part were dug out; their length and weight were determined, subsequently their roots were cut off (part R). The aerial part was divided into individual shoots and cut according to colouring, starting with the near-ground part. The fragments were marked as part A, part B and part C, respectively (Fig. 1).

The mass of individual plant parts, percentage in the entire plant (with roots) and in the aerial part after root removal were determined. The length measurements were performed using a calibration measure to the accuracy of 1 mm; the mass of individual parts was determined with a calibration weighing scale to the accuracy of 0.01 g.

The content of dry weight (DW) in the samples was determined by over drying at 105℃ for at least 4 h. All mass measurements were performed to the accuracy of 0.001 g. Analysis was carried out in triplicates for each object.

Further determinations, i.e. total polyphenols, essential oil, chlorophylls, micro- and macroelement content, were

Table 1 Agrometeorological conditions during *C. citratus* vegetation in 2015-2017 seasons. Based on Jarczew station of Institute of Meteorology and Water Management – National Research Institute.

Years	Sum of monthly rainfall [mm]				
	May	June	July	August	September
2015	108.4	15.2	32.7	12.3	119.4
2016	64.7	52.7	88.9	43.4	6.1
2017	46.3	85.6	134.6	65.3	101.3
Means for 1996-2013	62.4	72.9	91.8	73.5	48.5
Years	**Average monthly temperature [ºC]**				
	May	June	July	August	September
2015	12.6	17.0	19.5	21.4	14.5
2016	14.7	18.8	19.4	17.9	14.6
2017	13.7	17.8	18.1	18.7	13.5
Means for 1996-2013	14.2	17.2	19.2	18.1	12.9

Fig. 1 Lines of plant division and individual fractions of *Cymbopogon citratus*: A – underground parts of shoots, B – overground parts of shoots, C - leaves (photographed by Marcin Dadasiewicz).

performed for the samples of individual *C. citratus* aerial parts (part A, B and C), dried in a laboratory drier with forced air circulation at 35℃. Additionally, the content and composition of essential oil were analysed in roots (part R).

2.2 Total polyphenols

Air-dried plant material was used for determinations. Water extracts were prepared pouring 200 mL of boiled water (temp. 80℃) to 2.0 g samples, receiving a dilution proportion of 1:100. The content of total polyphenols (TPC) was determined in such solutions using the Folin-Ciocalteu total phenolic assay[17], with gallic acid as a reference standard. Absorbance of the samples was measured with a UV-Vis spectrophotometer (UV-2600, Shimadzu, Japan) at 725 nm. The results were expressed as gallic acid equivalent (mg GA per 100 mL water extract).

2.3 Essential oils

The essential oils (EOs) of air-dried plant material were obtained by hydro-distillation for 3 h in a Deryng-type apparatus. The oils were stored in tightly sealed 1.5 mL amber vials at 4℃ prior to analysis.

2.3.1 GC/MS analysis

Analysis was performed with a Shimadzu GC-2010 Plus instrument coupled to a Shimadzu QP2010 Ultra mass spectrometer. Compounds were separated on a fused-silica capillary column ZB-5MS (30 m, 0.25 mm i.d.) with a film thickness of 0.25 mm (Phenomenex). The oven temperature program was initiated at 50℃, held for 3 min, then increased at the rate of 8–250℃/min, and held for 2 min. The spectrometers were operated in EI mode; the scan range was 40–500 amu, the ionization energy 70 eV, and the scan rate was 0.20 s per scan. The injector, interface, and ion source were kept at 250, 250, and 220℃, respectively. Split injection was conducted with a split ratio of 1:20 and helium was used as a carrier gas at a 1.0 mL/min flow rate. The retention indices were determined in relation to a homologous series of *n*-alkanes (C8–C20) under the same operating conditions.

2.3.2 DPPH assay

EOs dissolved in MeOH were applied in triplicate on a 96-well microliter plate. The methanolic DPPH (50 mM) solution was added to the test samples, and MeOH was used as a control. The plates were shaken for 2 min and incubated for 30 min in darkness at room temperature. Reading was taken at a wavelength of 517 nm.

2.4 Macro- and micro-elements

After the plant material was dried, crushed, ground and wet mineralized in analytically pure HNO_3, the content of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn) was determined by atomic absorption spectrometry (AAS) according to EN-ISO 6869:2000[18], with the use of a SOLAR 939 (Unicam) spectrometer. The results were expressed as mg/kg of dry weight (DW).

2.5 Chlorophylls

Chlorophyll a and b were determined using a UV-Vis spectrophotometer UVS-2800 (Labomed Inc., USA), by reading the absorbance at 470, 645 and 662 nm. The content of chlorophylls was calculated according to Wellburn[19]. For chlorophylls determination, 0.4 g of air-dried lemongrass samples (part A, B and C) were homogenized

and extracted with acetone, using a magnetic stirrer at 700 rpm for 15 minutes. After the separation of the supernatant, the extraction was repeated Straumite *et al.*[20].

2.6 Statistical analysis

The analysis of all parameters in the samples of individual *C. citratus* parts was performed in triplicates. Statistica 9.0 StatSoft was applied to analyse data. One-way ANOVA, with a Tukey test was applied to evaluate the significant differences among means at a level of ($p<0.05$).

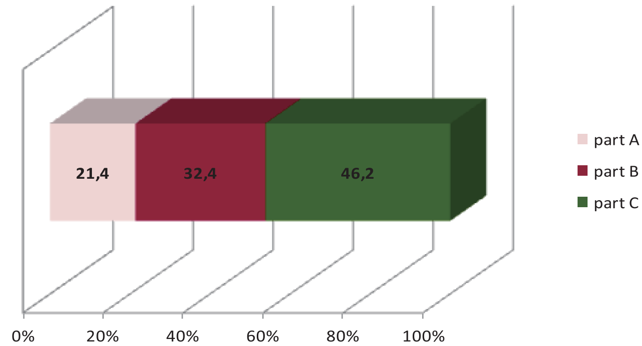

Fig. 2 Mass of an individual part in total aerial plant mass [%]. (part A - underground shoots, part B - overground shoots, part C - leaves).

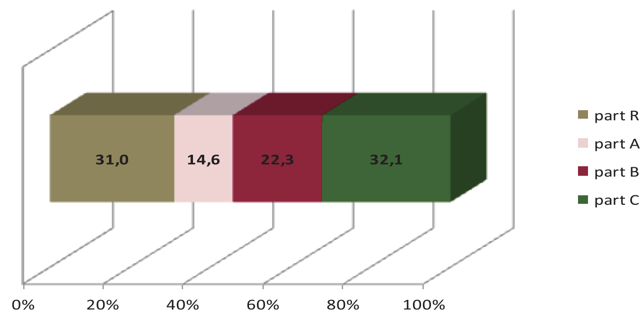

Fig. 3 Mass of an individual part in total plant mass [%]. (part R - roots, part A - underground shoots, part B - overground shoots, part C - leaves).

3 Results and Discussion

3.1 Biometric parameters

After harvesting, the plants were separated into individual shoots, which were cutting according to colouring. Starting with the near-ground part, the fragments were reaching length respectively: part A - 3 cm, part B - 12 cm (10-14 cm). The remaining part, i.e. leaves (part C), was 48 cm long on average (Table 2). The underground shoots (part A) weighed 46.6 g on average, which constituted 21.4% of the total aerial weight and 14.6% of the total plant weight with roots. This part was the smallest separated fragment of the plant (Table 2, Figs. 2 and 3). The leaves (part C) were the largest part >46% of the aerial part and >32% of weight of the plant with roots. Moreover, the leaves were characterised by the highest (19.6%) concentration of dry weight, as compared to other parts. The value of this parameter successively decreased together with the distance from the ground and was 17.5% for part A. Cultivating lemongrass under warmer climate conditions (e.g. Ethiopia[12], Egypt[6]), higher weights of plant are achievable, which was confirmed by the results reported by Zigene *et al.*[12] and Hamed *et al.*[6].

The total polyphenol content (TPC) in an aqueous extract of *C. citratus* varied with the plant part (Table 2). The leaf extract was characterised by the highest TPC, i.e. 6.57 mg GAE/100 mL extract. The closer the ground the plant part, the lower TPC in the extract - in part A, decreasing to 2.39 mg GAE/100 mL water extract. Soares *et al.*[11] have reported the similar TPC for water extract (4.28 mg GAE/100 mL), but yet they have not differentiated the plant parts but the mode of extraction of leaves. According to many other authors, including Figueirinha *et al.*[21], Tavares *et al.*[22], Uraku *et al.*[10], Costa *et al.*[23], lemongrass leaves can be the source of polyphenols, a very well known biologically active compounds. However, their findings cannot be compared with our results since the analytical methods used were different.

3.2 Essential oils

The GC/MS analysis showed that the chemical composi-

Table 2 Biometric parameters and total polyphenols content in individual *C. citratus* parts.

Part of plant	Length [cm]	Fresh mass [g/plant]	DW content [%]	TPC [mg GA /100 mL of water extract]
A	3 z	46.6 z	17.5 z	2.39 z
B	12 y	71.1 y	18.7 y	4.42 y
C	48 x	102.4 x	19.6 x	6.57 x
Mean	–	73.3	18.58	4.46

DW - dry weight; TPC - total polyphenols content; GA - gallic acid; the values denoted with the same letter in columns are not statistically significantly different at $p < 0.05$ (A - underground shoots, B - overground shoots, C - leaves).

tion of EOs from leaves (part C) was very similar to that of the EOs hydro-distilled from parts B and A, except for the presence of a sesquiterpene alcohol, elemol in part A (Table 3). Elemol was also the major component of the EO obtained from *C. citratus* roots (65%) – Fig. 4. The most characteristic components detected in the EOs from leaves and stems were neral (>30%) and geranial (>40%). The composition of EO obtained from the aerial parts of lemongrass did not differ from that of EO from the plants cultivated in other climate zones, e.g. India[7], Pakistan[24], Ethiopia[2], Wenezuela[13] Egypt[6]. The presence and percentages of elemol in the essential oil from roots of other *Cymbopogon* species have already been described in the literature, e.g. 19.1-42.3% in EO from the underground parts of *C. flexuosus*[7], 10.67%[25] and 14.5%[26] in *C. winterianus*, 9%[27] and 4.8%[28] in *C. nardus*[27], 4.9%[27] in *C. schoenantus*, and 9.43%[29] in *C. proximus*. To our best knowledge, we were the first to identify such a high concentration of elemol in *C. citratus* essential oil.

In the DPPH assay, the EO from part A of *C. citratus* presented the best antioxidant effect with EC_{50} 0.7 mg/mL (Table 4). The EO obtained from leaves showed weaker antioxidant activity, and EC_{50} was 1.6 mg/mL. EC_{50} value for pure citral (neral + geranial) was 3.0 mg/mL. The similar

Table 3 Relative percentages of compounds present in EOs obtained from different parts of *C. citratus*.

Compounds	RI#	Part of plant			
		R	A	B	C
camphene	950	–	0.4	0.2	–
6-methyl-5-heptene-2-one	978	–	1.3	1.6	1.1
limonene	1025	–	0.2	0.4	0.3
2-nonanone	1074	–	0.4	0.7	0.3
linalool	1086	–	0.5	0.7	0.5
rose furan	1091	–	–	0.9	–
isoneral	1140	–	–	0.3	1.1
isogeranial	1156	–	–	0.4	1.7
rose furan epoxide	1161	–	0.7	1.8	0.2
neral	1215	3.0	31.3	34.6	34.3
geraniol	1235	–	1.2	0.4	1.3
geranial	1244	7.4	41.1	48.0	45.3
m-eugenol	1346	–	0.6	0.6	–
geranylacetate	1362	–	2.1	0.5	–
β-elemene	1389	2.2	0.4	–	–
isocaryophyllene	1409	2.4	–	–	–
β-caryophylene	1421	–	0.6	1.8	0.6
trans-isoeugenol	1429	–	0.7	1.0	–
α-humulene	1455	–	–	0.3	–
ε-muurolene	1455	–	–	–	0.7
nerylisobutyrate	1468	–	–	–	0.3
γ-cadinene	1507	1.2	0.6	0.9	–
elemol	1541	64.9	14.0	0.8	–
caryophyllene oxide	1578	1.5	0.6	2.5	4.7
α-guaiol	1587	–	0.9	–	0.4
γ-eudesmol	1618	2.8	–	–	–
α-eudesmol	1653	9.4	1.5	–	–

Retention index on ZB-5MS column, (R - roots, A - underground shoots, B - overground shoots, C - leaves).

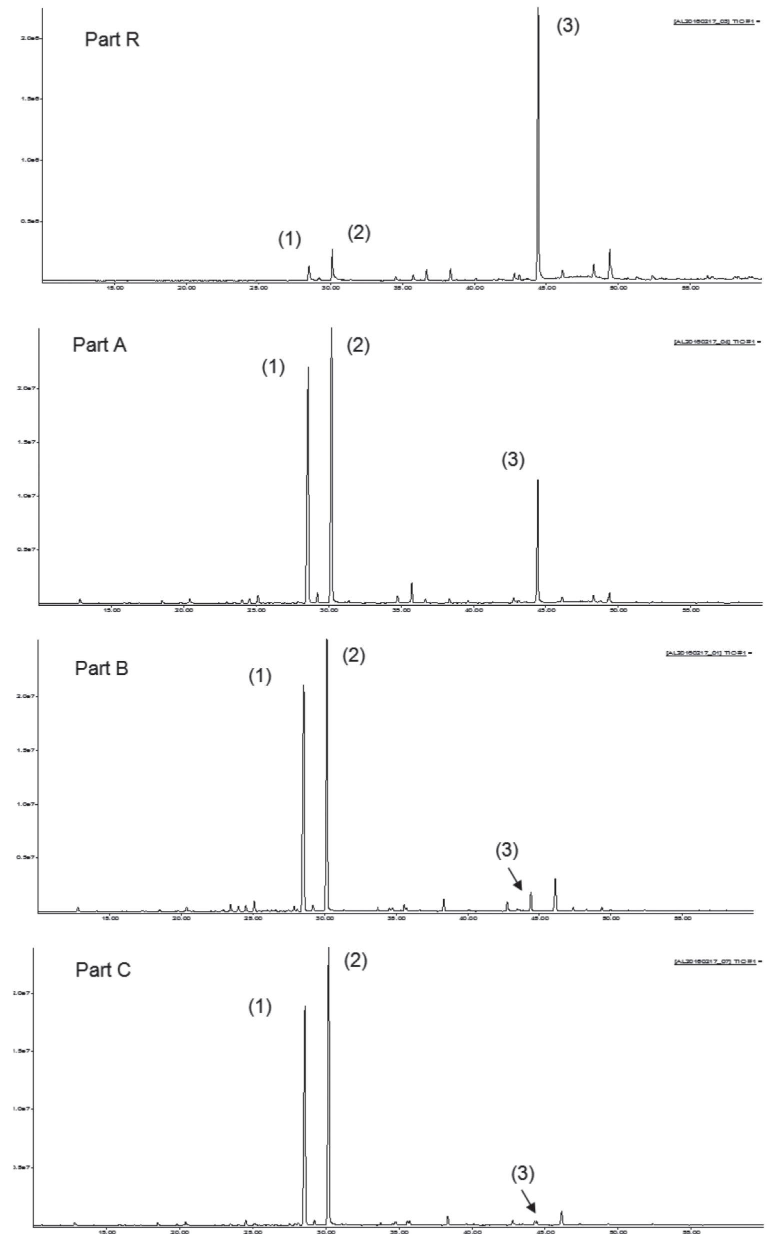

Fig. 4 GC/MS fingerprints of EOs obtained from different parts of *C. citratus*: (1) - neral; (2) - geranial; (3) - elemol (part R - roots, part A - underground shoots, part B - overground shoots, part C - leaves).

Table 4 Yield and antioxidant activity of EOs obtained from different parts of *C. citratus*.

Part of plant	EO content [mL/kg]	EC_{50} [mg/mL]
A	16	0.7
B	14	1.6
C	11	1.6
Citral (neral + geranial)	–	3.0

A - underground shoots, B - overground shoots, C - leaves

findings regarding antioxidant activity of the essential oil from various parts of *C. citratus* were reported by Hartatie *et al.*[30]; their data, however, cannot be compared with our results as they obtained the essential oil from fresh plants.

3.3 Macro- and microelements

Analysis of individual lemongrass parts demonstrated diverse amounts of mineral constituents, except for iron, whose average content was 91-94 mg/kg, irrespective of the plant part (Table 5). The highest content of potassium, magnesium, and zinc was found in the part nearest to the ground (part A) and decreased successively with the dis-

Table 5 The content of mineral constituents in different parts of *C. citratus*.

Part of plant	Mineral content [mg/kg DW]							
	Na sodium	K potassium	Ca calcium	Mg magnesium	Cu copper	Mn manganese	Fe iron	Zn zinc
A	58.4 x	21400 x	1650 z	2280 x	6.10 z	248.2 x	92.5 x	180.2 x
B	55.3 x	15800 y	2610 y	1980 y	7.32 y	361.0 x	94.3 x	134.2 y
C	36.5 y	10200 z	3020 x	1840 z	8.51 x	159.8 x	91.6 x	47.3 z
Mean	50.1	15800	2426	2033	7.31	256.3	92.8	120.6

DW - dry weight; the values marked with the same letter in columns are not statistically significant at $p < 0.05$ (A - underground shoots, B - overground shoots, C - leaves).

Table 6 The content of pigments in individual *C. citratus* parts.

Part of plant	Chlorophyll mg/100 g			Ratio Ch *a* / Ch *b*
	a	*b*	total	
A	8.74 x	3.53 x	12.26 x	2.48 x
B	12.73 y	5.38 y	18.10 y	2.37 x
C	27.15 z	8.97 z	36.12 z	3.03 y

Values marked with the same letter in columns are not statistically significantly different at $p < 0.05$. (A - underground shoots, B - overground shoots, C - leaves)

tance to the ground. A similar correlation was observed for sodium; nevertheless, the values for part A and B were comparable (58.4 and 55.3 mg/kg) and were not statistically significant. As far as calcium and copper are concerned, the opposite correlation was found; leaves contained the highest amount of these elements (3020 and 8.51 mg/kg, respectively) while the lowest amount was noted in part A (1650 and 6.1 mg/kg). The results for manganese were ambiguous, ranging from 160 mg/kg for leaves to 361 mg/kg for part B; the statistical analysis, however, did not confirm the significance of these differences.

Although the mineral constituents are considered to be of low importance for the preparation of infusions, for which lemongrass leaves are used, they can be of nutritional value for culinary applications of near-ground fragments (part A and B). Nevertheless, Salvador *et al.*[31] have demonstrated a high level of iron in *C. citratus* tea (105-106 mg/L), which was the highest value among other tested herbal teas prepared from *Matricaria chamomilla* L. (54 mg/L), *Mentha piperita* L. (43-58 mg/L) or *Camellia sinensis* (L.) O. Kuntze (0.21-0.26 mg/L). Furthermore, as compared to the values presented, AL-Joburi[9] has reported a double content of Mg in lemongrass leaves cultivated in Iraq, a comparable content of K (11900-25300 mg/kg) and copper, a slightly lower amount of iron (52.35-84.20 mg/kg), and a significantly lower amount of zinc (23-58 mg/kg), depending on growth regulators used on lemongrass plantation.

3.4 Chlorophylls

The highest amounts of pigments were observed in *C. citratus* leaves (part C); 27.15 and 8.97 mg/100 g for chlorophyll a and b, respectively (Table 6). In lemongrass parts closer to the ground, the content of pigments successively decreased, reaching 8.74 mg/100 g of chlorophyll a and 3.53 mg/100 g for chlorophyll b. The colour of plant material is important when the plant is used for the preparation of teas; generally, a clear, deep colour of infusions is desirable. When lemongrass is added to dishes (soups or sauces), the colouring, otherwise, can be considered undesirable (particularly the greenish one). The results regarding chlorophyll pigments confirmed that upper parts of plant (leaves) could be a good material for infusions while the lower parts (of a slight concentration of pigments) - as a flavour and aroma enhancer in meals. Both d'Ávila *et al.*[14] and AL-Joburi[9] have reported even 10-fold higher values of all pigments analysed (chlorophyll a as well as b); however, their determinations were carried out in fresh leaves of *C. citratus* while in our study dry plant material was used. Unfortunately, the authors mentioned above did not determine the content of pigments in the individual parts of the plant.

Our studies demonstrate the distribution of important bioactives, as essential oil as well as polyphenols and some nutritional substances in lemongrass cultivated in Poland. No other so comprehensive analyses of the plant material obtained from various parts of lemongrass plants are available in the literature. Our findings showed, that the different part of lemongrass could be used, depending on their further application. Moreover, based on our results, the

height of cutting as well as the method of harvesting can be regulated, according to the application planned, e.g. for drying, for teas, infusions, production of essential oil or culinary additives.

4 Conclusions

1. The individual parts of *C. citratus* harvested in its 29 BBCH stage are characterised by diverse composition.
2. Essential oils obtained from the aerial part of lemongrass are rich in monoterpene aldehydes, neral (>30%) and geranial (>40%). The major component detected in the essential oil from roots was sesquiterpene alcohol, elemol (65%).
3. The concentration of pigments (chlorophyll a and b) determined in leaves (part C) was higher compared to that in lower parts (B and A).
4. The concentration of mineral constituents is correlated with the distance from the ground; thus, the highest content of potassium, magnesium, zinc and sodium was detected in part A while of calcium and copper in leaves. The amounts of Fe were comparable in all parts of lemongrass.
5. Our study results confirm the usefulness of lemongrass leaves as a material for infusions (higher concentration of pigments, polyphenols and essential oil) and of near-ground parts for culinary purposes (higher concentration of macronutrients at lower concentration of green pigments and dry weight).
6. The material obtained from *C. citratus* cultivated under Polish climate conditions shows that the content and composition of essential oil, mineral constituents and chlorophyll which are comparable to lemongrass cultivated in other world regions.
7. Our findings showed the distribution of important bioactive and nutritional compounds in *C. citratus* plants, allowing to obtain raw materials most optimally, depending on their further applications.

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Conflicts of Interest

The authors declare no conflict of interest.

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