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DIFFERENCES IN THE POLLEN CONTENT OF VARIETIES OF POLISH HONEY FROM URBAN AND RURAL APIARIES

– Research paper –

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Abstract: The value of honey as a natural food product is influenced by its pollen content, with the dominant type of pollen conferring specific medicinal properties. The present study examines the pollen spectra of 31 honeys from urban (linden, acacia, polyfloral, honeydew) and rural (rape, acacia, polyfloral, honeydew) apiaries in Poland. The pollen in content in honey ranged from 0.2 to 88 %. In total, 76 plant taxa were identified, 21 of which were assigned to forms A, B and C. Higher pollen grain content and a greater diversity of honey plant taxa were found in the urban honey, particularly polyfloral honey; this could be attributed to the rich variety of plants found in urban green areas compared to rural areas ones.

Keywords: bee product, pollen classification, honey plants, urban and rural areas

INTRODUCTION

About 75 % of bees forage less than 1 km from the hive (Minahan and Brunet, 2018). Within this range, they are able to collect nectar and pollen from honey plants (Sørensen et al., 2020; Tew et al., 2021). Nectar, a complex mixture of various sugars in solution, essential oils, vitamins, organic acids, dyes, enzymes, mineral salts and nitrogen compounds, is the primary provider of energy while the pollen is an important source of protein, as well as fats, vitamins, minerals and sugars; it also plays an extremely important role in bee development (Al-Kahtani et al., 2020).

When kept in an apiary located among monocultures, such as on a farm, bees only have access to a limited range of pollen types, and the resulting honey is characterized by a predominance of monoculture pollen. This situation is not favorable for the development of the bee colony due to the limited access to the protein compounds characteristic of certain pollen types. In the period of rape pollen harvest by bees, beekeepers observe poor the interest of bees in this plant, if there are other honey plants within the range of the flight. There should be no other plants, such as watermelon, melon, eggplant, cucumbers (cultivated species) and sage, common ivy, horseradish (noncultivated species) around the bee-pollinated crops, as these would attract the bees' attention (Dzhumamuratov and Ilyasova, 2021).

The growing interest of consumers in honeys and other bee products poses a challenge for apiary owners, who may choose to feed the colony nutrient solutions made of plant syrups such as nettle, thyme, hawthorn or chokeberry; the bees treat these syrups as nectar and thicken them to the consistency of

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honey (Dżugan et al., 2017). One way of determining the correct origin of honey is pollen analysis, which allows for unequivocal identification of honey varieties by the presence of dominant flower pollen. This information is particularly important for the consumer, who may select a variety of honey based on its specific taste, aroma and nutraceutical properties (Machado de Melo et al., 2018; Reis et al., 2021; Tafere, 2021).

The pollen content of mature honey depends on the amount of pollen collected by the bees, and on the methods of collection and processing. This is influenced by the structure of the digestive system of bees: honey that has been in the bee gut for a long time is generally poorer in pollen content, for example, in cases where the bee has had to forage a long distance from the hive (Albu et al., 2021). Lower pollen counts are also observed in honey produced by bees fed with sugar (Komin et al., 2020).

Rural areas are mainly treated as bee pastures (Gamrat et al., 2018). However, modern-day intensive agriculture practices, characterized by a lower diversity of undesirable plants, i.e. weeds, reduces the number of honey plants used by bees (Kovács-Hostyánszki et al., 2017; Wintermantel et al., 2019; Zhang et al., 2020). With the growing number of urban residents and a decrease in rural populations, there is increasing pressure for better use of green areas in urban agglomerations which could be used to produce honey and other natural food products (Nicewicz et al., 2021). In larger cities, apiaries can be maintained on avenue trees and shrubs, which give abundant fruit in spring and early summer; in addition, in smaller towns and housing estates, park vegetation can also act as a good source of pollen within range of the hive. More recent trends, such as sowing herbaceous plants on flower beds and the use of *green roofs*, as well as the cultivation of various ornamental plants related to consumer horticulture, ensure wider species diversity and increase the presence of valuable honey plants (Baldock et al., 2019; Samuelson et al., 2021; Sponsler and Bratman, 2021). This relationship is especially visible in cities with a high representative rank (Briscoe, 2020; Atik et al., 2021).

In contrast rural areas are more likely to be characterized by the presence of cultivated monocultures, with most non-crop plants being planted in domestic gardens; as such, bees will produce single-flowering honeys with limited pollen diversity, as confirmed by de Groot et al. (2021) and Richardson et al. (2020). In addition to human interference, the pollen composition of polyfloral honey from these areas will be influenced by various factors, such as the presence of accompanying plants throughout the growing season, the structure of the flowers from which the dusted or pollen-free nectar, climatic conditions, the pollen productivity of the parent plant, the distance between the hive and the flower field and the diameter or size of the pollen grain (Isopescu et al., 2017).

The aim of the present study was to determine the differences between urban and rural honeys based on the analysis of the pollen spectrum of the selected honey varieties. It was assumed that honeys from city apiaries will demonstrate a greater variety and number of pollen grains than those from rural areas, and that this should be particularly evident in the analysis of polyfloral honey.

MATERIALS AND METHODS

Sampling area

Three different areas of honey sampling were determined: central Poland (Warsaw), i.e. the densest area of the country by population, northern Poland (Szczecin), with a medium population density, and western Poland (Gorzów Wlkp.), with a low population density (Figure 1). Within each region, various rural spaces and urban agglomerations were selected.

Honeys

A total of 31 honeys of five types were analysed (Table 1): acacia, honeydew, linde, polyfloral and rape. Of these, 18 honeys were taken for analysis from central Poland (1, 2, 5-7, 10-14, 19, 20, 22-25, 27, 31), and 13 from the northern and western parts (3, 4, 8, 9, 15-18, 21, 26, 28-30). The analysis was performed in 2019. In addition, of the 31 honeys, 19 (5-13, 15, 17, 18, 22-28) were taken from urban areas, and 12 (1-4, 14, 16, 19-21, 29-31) from rural areas (Table 1). The type of honey was determined by the beekeeper depending on the availability of pollen. Tightly-closed glass jars were used to store honeys at 21 °C.

Pollens in honeys

The percentage of pollen grain types was determined by honey pollen analysis (J.L., 2009). The results were assessed based on the law regulating content of primary pollen in nectar pollens, as indicated in the PN-88/A-77626 Polish "Bee honey" standard, regulated by law (Ordinance

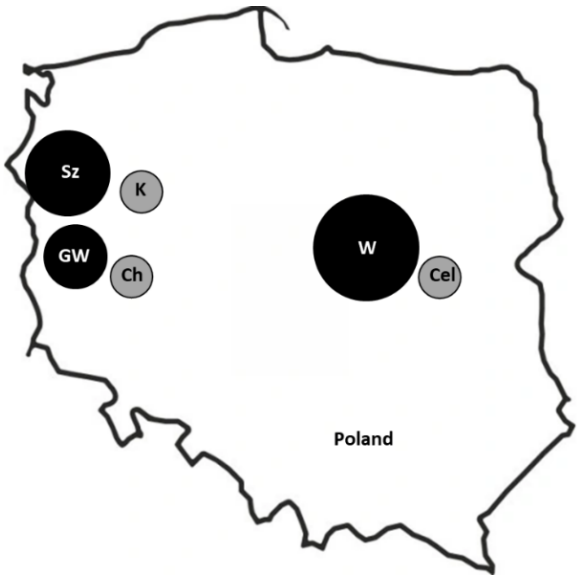


Figure 1. Location of the studied honeys: GW - Gorzów Wlkp., Ch - Chwalęcice, Sz - Szczecin, K - Kobylanka, W - Warsaw, Cel - Celinów, ● urban area, ● rural area

of the Minister of Agriculture and Rural Development of 14.01.2009 - on the methods of analysis related to the evaluation of honey). These methods are compliant with the requirements in force in the EU and recommended by the International Honey Commission (IHC) and by the Codex Alimentarius Commission FAO / WHO.

Briefly, 10 g of honey was dissolved in water at 50 °C (up to 20 ml volume) and centrifuged at 300 rpm for 10 minutes. The supernatant was removed from the sediment, the tube was refilled with water to 20 ml, and the sample was centrifuged again. A 0.1 ml sample of the pellet was evenly spread on a microscope slide for examination. In each sample of honey, over 300 pollen grains were counted in successive lines of field of view.

To precisely measure the pollen content, two measurements were conducted per sample, i.e. as two separate analytic procedures. Subsequently, each sample was analysed twice, resulting in four measurements. These values were then averaged to give the mean value of the closest two or three results, and these were used in calculations.

The identified pollen types were classified into four forms based on their percentage of the total pollen count (Louveaux et al., 1978): A - dominant pollen (> 45%, except for *Tilia* spp. - 20%, *Robinia* spp. - 30%), B - accessory (16-45%); C - isolated (3-15%), D - occasional (< 3%). In order to identify honeydew honeys, the number of pollen grains of wind-pollinating and non-nectar-producing plants was determined.

Statistical analysis

The results of the study are presented as the mean number of pollen grains, as well as their mean percentage share in the tested types of honey. To compare the variation in the numbers of pollen in honeys from rural and urban apiaries, the normality of the data set and the homogeneity of its variance were determined, and then an analysis of variance was performed. For both urban and rural polyfloral honeys, the relationship between pollen diversity and the type of honey plant was determined by simple linear regression.

RESULTS AND DISCUSSION

Characteristics of the pollen spectrum of five honey varieties

A bee colony can collect between 50 and 250 g of pollen a day and from 15 to 40 kg per year, and the total pollen grain content of honey has been found to range from 525 to 19525 grains per gram (Isopescu et al., 2017).

The presence of pollen determines the variety of the honey and its organoleptic, nutritional and health-promoting properties. In addition, specific types of honey are associated with specific healing properties. Spring honeys (rape, polyfloral), being especially rich in simple sugars, are recommended in cases of exhaustion and liver diseases in folk medicine. Summer honeys (linden, polyfloral), being rich in enzymes, with strong antibacterial properties, are believed to be beneficial for diseases of the lungs, heart and circulatory system, while honeydew honey, a source of more bioelements as other honeys, is recommended in folk medicine in the treatment of anemia (Szczęsna, 2020).

Flower pollen is produced in abundance by plants and spread as a part their reproductive strategy. The grains are usually spherical and range in size from 0.01 mm to 0.1 mm (Pomelli et al., 2020). The outer surface of the pollen grain is characteristic of individual plant species. It may be smooth or sculpted, it may contain pores or elongated furrows; the grains can also be colored due to the presence of plant pigments, anthocyanins and carotenoids (Dyakowska, 1959).

The pollen grains present in the studied honey species differed significantly in terms of their morphology (Figure 2). Among the identified pollen, the largest belonged to *Zea mays*, *Pinus* spp., *Larix* spp. and the smallest to *Castanea* spp. *Tilia*

spp. pollen is suboblate to oblate, with three pores arranged in short, wide furrows (*tricolporate*), and a surface closely covered with small, shallow pits. Grain length ranges from 25.5 to 28.9 μm, and their diameter from 32.3 to 35.8 μm (Tykhonov et al., 2017). *Robinia* spp. pollen is subtriangular with three pores; their length ranges from 22.0 to 27.0 μm, and diameter from 30.4 to 34.0 μm. The grains have a clear surface ornamentation (Bleha, 2019). *Brassica napus* pollen also demonstrates clear surface features (Thakur and Nanda, 2020).

The analysis of honey pollen from monofloral honey (*Tilia* spp., *Robinia* spp. and *Brassica* spp.), polyfloral honeys and honeydew honey revealed the presence of 76 taxa of honey plants and 15 wind-pollinating plants, including five honeydew plants. The share of individual pollen types ranged from 0.2 % to 88 % of total pollen content. Pollen grains were identified from 36 plant families. In many cases, the number of pollen grains of honey plants is significant, but they represent only single taxonomic families. Dobre et al. (2013) found similar numbers of taxa in single-flowered and polyfloral honeys from Romania (i.e. 77 pollen types from 35 families). This convergence of results is most likely accidental, as the literature data indicates that honeys from different regions have different numbers of pollen taxa: for example, honeys from North America and Lithuania were found to have 85 types of pollen from 61 families of honey plant (Jones and Bryant, 2014; Čeksteryte et al., 2013), those from Brazil had 69 pollen types (27 families) (Moraes et al., 2019) and 28 types (19 families) (Pinto da Luz and Barth, 2012), those from Canada had pollen from 33 families (Colwell et. Al., 2017) and those from Ethiopia from 13 families (Bareke and Addi, 2019).

The prevalence of a particular type of individual honey pollen is classified into four categories depending on its percentage of total pollen content: A – dominant pollen (> 45 %, except for *Tilia* spp. - 20 %, *Robinia* spp. - 30 %), B – accessory (16-45 %), C – isolated (3-15 %), D – occasional (<3 %). The dominant pollen species in honey is influenced by its geographic location, the specificity of the landscape and the structure of land use (Mădaş et al., 2019; Albu et al., 2021).

The mean content of *Brassica* spp. pollen (80.1 %) found in rape honey from rural apiaries (Figure 3) was similar to previous findings from studies conducted in Poland (88 % on mean), Romania (93 %) and Lithuania (72 %) (Puzja-Jakubik et al., 2020; Kasprzyk et al., 2018; Čeksterytė et al., 2013; Isopescu et al., 2017). However, rape honey has been found to include pollen collected from plants flowering in semi-natural habitats, indicating that pollen collectors did not prefer the mass-flowering fields of *Brassica napus* (Danner et al., 2017). This was confirmed by Kasprzyk et al. (2018), who indicate lower levels of *Brassica* pollen in rape honey, while the share of *Prunus* spp. pollen, an accessory species, was as high as 30 %.

The linden honeys from urban apiaries were characterized by a decidedly low content of *Tilia* pollen grains (35.9%), in the contrast to Čeksterytė et al. (2013) and Isopescu et al. (2017) which found the presence of the pollen in question at the level of 88 % and 79 %, appropriately. This is not surprising, as contrary to popular belief, pure linden honey is rare, and mostly restricted to Southeast Europe; in Central Europe, linden almost never forms homogeneous stands, and the lime trees that are admixed in forests or that grow in parks and avenues do not provide enough nectar for the production of pure honey (Dyakowska, 1959). In the present study, the *Robinia* spp. pollen grain content of urban and rural acacia honey was found to be 47 %. This value falls between the data from Romania (58 %) (Isopescu et al., 2017) and Slovakia (33 %) (Adamchuk, 2021).

Regarding the arrangement of pollen forms according to Louveaux et al. (1978), similar profiles were noted in the linden and acacia honeys; however, in rapeseed honey, no honey plants were found in the accessory group (B). A detailed structure for these honeys is shown in Figure 2. The polymorph and honeydew honeys also yielded similar profiles in this regard: in the former, the mean shares of pollen were 16.6 % from form B, 7.3 % from C, 1.6 % from D and 0.9 % from the non-nectar species, while in the latter 18.7 % of grains were form B, 6.7 % from C, 1.6 % from D and 1.5 % from the non-nectar group.

The results of the detailed analysis of the individual tested honeys are given in Table 1. It was found that in linden honey, the share of *Tilia* spp. pollen ranged from 20.3 % to 46.6 %, and *Melilotus* spp. and *Prunus* spp. were included among the accessory pollen types. In acacia honey, the share of *Robinia* spp. pollen ranged from 36.9 % to 64.0 %, with *Salix* spp. and *Prunus* spp. being present as accessory pollen types. Similarly, Dobre et al. (2012), report a share of 34.6 % pollen from *Brassica* spp. in acacia honey.

In the studied rape honey, the proportion of *Brassica* spp. pollen was exceptionally high, ranging from 76.3 % to 87.8 %, and no pollen from accessory species was found. In the polyfloral honey, *Brassica* spp. pollen was found in 84.6 % of samples (with a mean share of 12.4 %); this was followed by *Prunus* spp. which was present in 30.8 % of the samples (17.3 %),

Fagopyrum spp. in 30.8 % of the samples (18.8 %), and both *Betula* spp. (27.2 %) and *Acer* spp. (18.3 %) present in 15.4 %. Dobre et al. (2012) report a greater share of *Brassica* spp. pollen (31 %) in polyfloral honey. Associated pollen was found in 33% of the examined honeydew honey samples, in the form of *Artemisia* spp., (26.1 %) and *Brassica* spp. (30.1 %).For bees, both in rural and urban areas, it is important to forage from a rich diversity of honey plant species, particularly in spring. Honey bees feeding on various plant taxa are better able to obtain all their necessary nutrients, while those feeding on monoculture have limited access (Pound et al., 2017). Hence, urban areas, characterized by greater plant species diversity, appear to be beneficial for the health and vitality of bees. In the present study, the city honeys demonstrated greater pollen diversity than the rural honeys, as indicated by the analysis of pollen forms A, B and C (Figure 4). For example, *Dianthus* spp., *Epilobium* spp., *Galeopsis* spp., *Melilotus* spp., *Plantago* spp., and *Taraxacum* spp. were found only in city honeys.

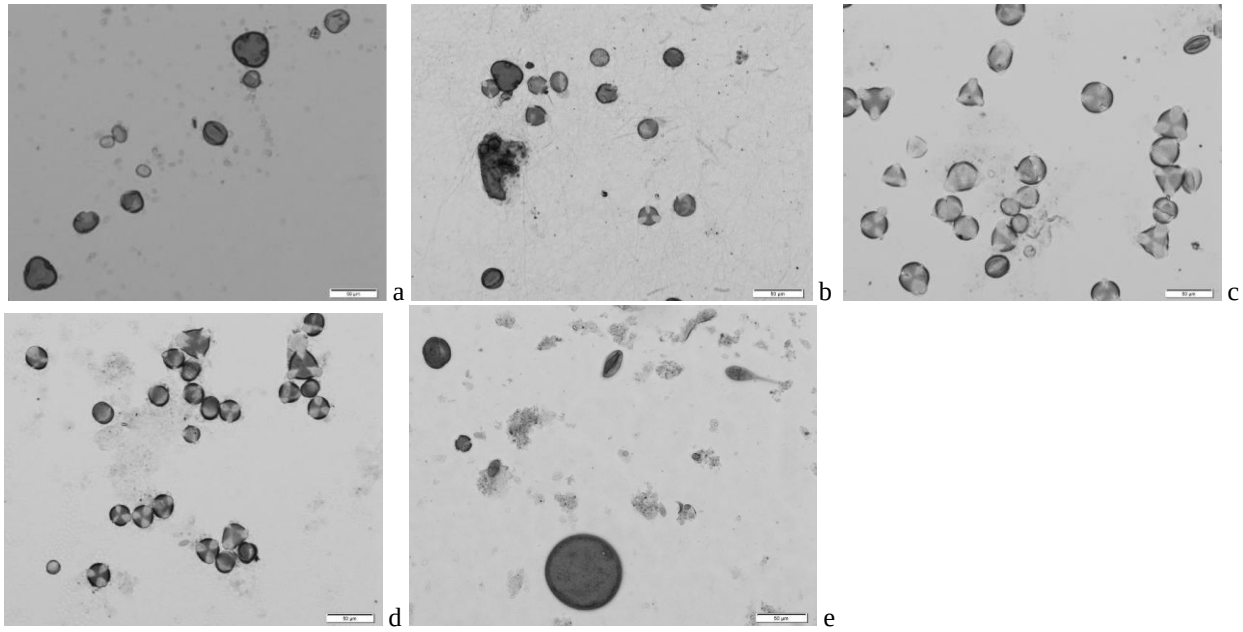


Figure 2. The pollen grains in each type of honeys: a - linde, b - polyfloral, c - acacia, d - rape, e - honeydew

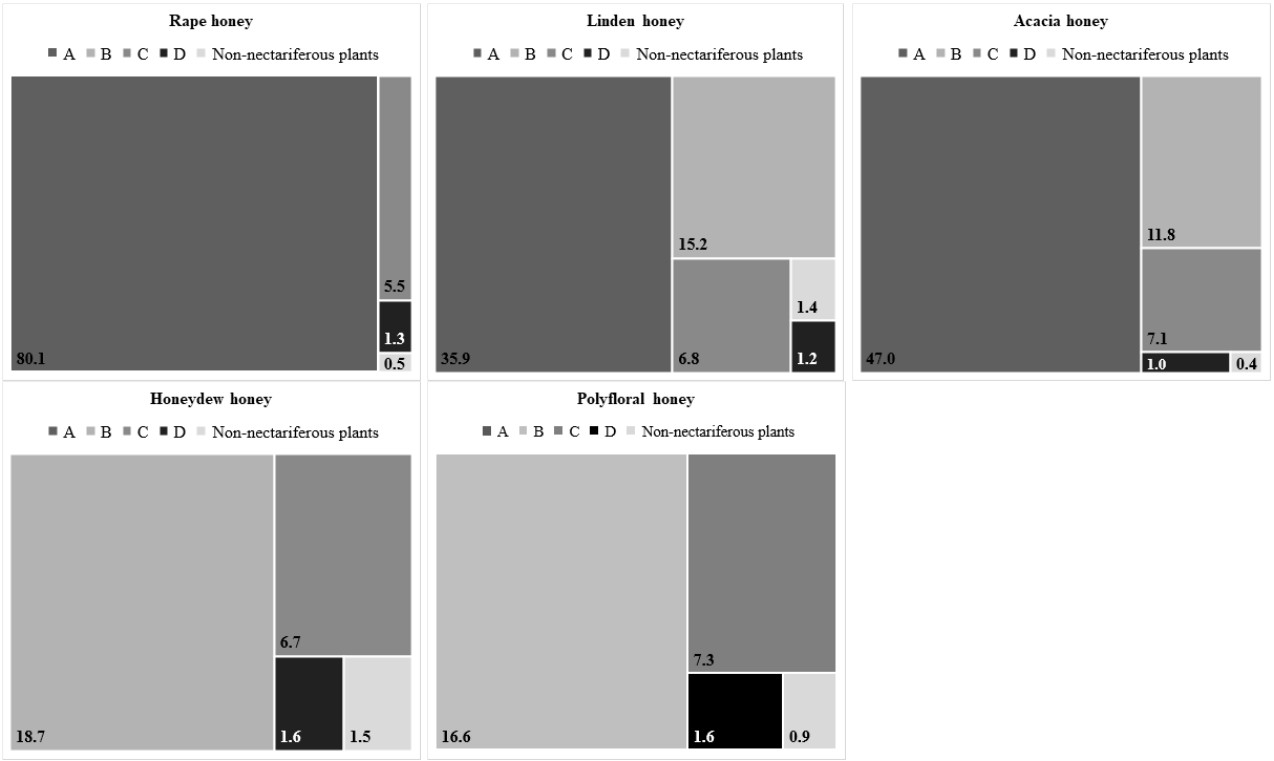


Figure 3. Mean % pollens composition in form of the pollens spectrum in the examined honey types

Table 1. Percentage of dominant and accessory pollen from honey plants in individual honey types

Type of honey	No sample	Dominant pollen in studied type of honey [%]			Accessory pollen
		Brassica spp.	*Robinia* spp.	*Tilia* spp.	
Rape	1 - Cel (rural)	87.8	0.0	0.0	no pollen
	2 - Cel (rural)	79.7	6.9	0.0	no pollen
	3 - K (rural)	76.6	1.1	0.0	no pollen
	4 - K (rural)	76.3	10.5	0.0	no pollen
Linden	5 - W (urban)	6.9	15.5	46.6	no pollen
	6 - W (urban)	26.5	14.7	44.1	no pollen
	7 - W (urban)	0.0	7.2	44.3	no pollen
	8 - GW (urban)	21.9	12.4	39.4	no pollen
	9 - Sz (urban)	0.0	8.8	28.4	*Melilotus* spp. (20.0)
	10 - W (urban)	21.6	17.2	28.2	no pollen
	11 - W (urban)	4.5	5.5	20.3	*Prunus* spp. (18.7)
Acacia	12 - W (urban)	8.0	64.0	0.0	no pollen
	13 - W (urban)	5.8	49.2	2.5	no pollen
	14 - Cel (rural)	0.0	37.8	0.0	*Salix* spp. (24.5)
	15 - Sz (urban)	0.0	36.9	0.0	*Prunus* spp. (23.6)
Honeydew	16 - K (rural)	30.1	4.9	0.0	no pollen
	17 - GW (urban)	7.2	10.6	0.6	*Artemisia* spp. (26.1)
	18 - Sz (urban)	2.2	10.9	10.1	no pollen
Polyfloral	19 - Cel (rural)	21.3	8 .2	0.0	*Fagopyrum* spp. (18.0)
	20 - Cel (rural)	16.7	11.1	0.0	*Fagopyrum* spp. (20.4)
	21 - Ch (rural)	16.2	10.8	6.4	no pollen
	22 - W (urban)	18.6	12.1	0.7	*Prunus* spp. (16.6)
	23 - W (urban)	21.2	12.4	0.0	*Prunus* spp. (17.6)
	24 - W (urban)	6.0	16.3	2.3	*Aesculus* spp. (30.0), *Prunus* spp. (17.6)
	25 - W (urban)	11.2	9.6	0.5	*Prunus* spp. (17.2)
	26 - Sz (urban)	0.0	13.8	0.0	*Acer* spp. (18.1), *Betula* spp. (29.1)
	27 - W (urban)	9.0	14.2	1.7	no pollen
	28 - GW (urban)	0.0	11.6	0.0	*Betula* spp. (25.3), *Acer* spp. (18.4)
	29 - K (rural)	15.6	13.5	0.0	*Fagopyrum* spp. (15.0)
	30 - K (rural)	10.4	7.0	0.0	*Phacelia* spp. (18.3), *Malus* spp. (16.5)
	31 - Cel (rural)	14.5	10.5	6.6	*Fagopyrum* spp. (21.1)

rural - rural area, urban - urban area;
GW - Gorzów Wlkp., Ch - Chwalęcice, Sz - Szczecin, K - Kobylanka, W - Warsaw, Cel - Celinów

This observation reflects the diversity of plant species found on lawns. Although European city lawns are dominated by wind-pollinated grass species, incl. *Lolium perenne*, *Festuca rubra* and *Poa pratensis* (Knot et al., 2017), numerous honey-bearing species are also present, such as *Centaurea cyanus* (according to Pogorzelec, 2018 - honey yield 300 kg / ha), *Lamium purpureum* (200 kg / ha),

Malva neglecta (160 kg / ha), *Trifolium repens* (110 kg / ha), *Reseda lutea* (110 kg / ha), *Cirsium arvense* (80 kg / ha), *Taraxacum officinale* (20 kg / ha) (Gamrat and Saran, 2018). Recent trends in promoting lawn surface functionality and increasing the numbers of *flower meadows* with species including *Centaurea cyanus*, *Daucus carota*, *Leucanthemum vulgare*, *Lotus corniculatus*, *Silene dioica* and *Trifolium pratense* are believed to be responsible for the growing the size of honeybee population (Hicks et al., 2016; Mody et al., 2020). In addition to lawns and flower beds, urban green areas include avenues or parks. The pollen species diversity in city honeys is governed by the availability of honey plants around the apiary, and greater plant diversity is reflected in a greater share of their pollen types (Richardson et al., 2020).

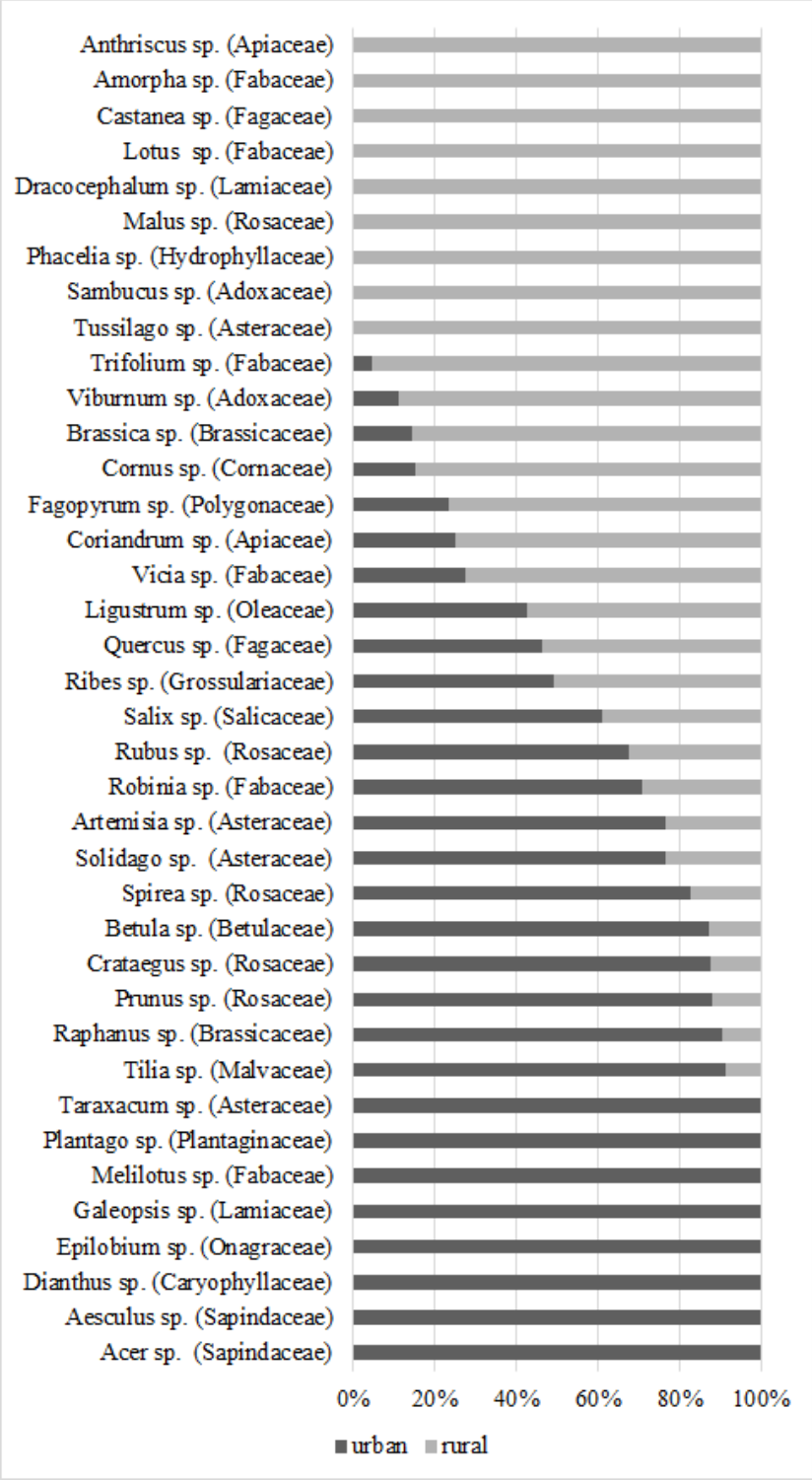


Figure 4. Summary of the cumulative percentage of pollen grains by pollen spectrum forms (species: A - dominant, B - accessory and C - isolated) in urban and rural honeys

In the Polish flora, very high honey values have been demonstrated by *Acer platanoides* (120 kg / ha) and *Tilia platyphyllos* (200 kg / ha), and high values by *Robinia pseudoacacia* (100 kg / ha), *Acer pseudoplatanus* (50 kg / ha), *Salix alba* (30 kg / ha) and the alien *Aesculus hippocastanus* (50 kg / ha) (Milecka et al., 2019). In addition, a number of honey-bearing shrubs are found, such as *Rubus idaeus* (250 kg / ha), *Ribes nigrum* (70 kg / ha), *Crataegus monogyna* (30 kg / ha) and *Prunus padus* (12 kg / ha), as well as various herbaceous species, including *Epilobium angustifolium* (600 kg / ha), *Melilotus alba* (200 kg / ha) and *Galeopsis tetrachit* (50 kg / ha) (Milecka et al., 2019). All these plant species were identified in the studied honeys. A number of honey-bearing species that were regularly visited by bees have been identified in British cities: *Cirsium arvense*, *Geum urbanum*, *Heracleum sphondylium*, *Leucanthemum vulgare*, *Ranunculus repens* and *Taraxacum officinale* (Baldock et al., 2019).

In turn, in contrast to urban honeys, the following taxa were found in rural honeys (Figure 4): *Amorpha* spp., *Anthriscus* spp., *Castanea* spp., *Dracocephalum* spp., *Lotus* spp., *Phacelia* spp., *Malus* spp., *Sambucus* spp. and *Tussilago* spp. In rural areas, most plants are cultivated in domestic gardens or as fruit trees on the roads. In the analyzed rural habitats, the studied honeys included pollen from plants used for their honey-giving qualities, such as *Dracocephalum* spp., *Phacelia* spp. (400 kg / ha) or *Amorpha* spp. (80 kg / ha), and for their culinary and medicinal values, e.g. *Sambucus* spp., *Malus* spp., *Castanea* spp. and *Tussilago* spp. Atanassova et al. (2004) report the dominance of pollen types from the *Fabaceae* family in honey collected from rural areas, including those of *Vicia* spp. (40 %) and *Lathyrus* spp. (44 %). *Fabaceae* pollen also dominated in our studied honey, but from *Amorpha* spp. and *Lotus* spp. Şik et al. (2017) found rural honey to be dominated by the following pollen types in descending order: *Apiaceae*, *Brassicaceae*, *Fabaceae*, *Lamiaceae* and *Rosaceae* which were presence in the studied rural honeys, too. Atanassova et al. (2009) also report a predominance of *Robinia* spp., (47 %) pollen, followed by *Trifolium* spp., (41 %), *Brassica* spp., (40 %) and *Vicia* spp. (14 %).

The numbers of pollen dominant in the studied honey cultivars collected in spring and summer

The presence of pollen from honey plants in the honey depends on the flowering period of the plants and the pollen uptake by bees, as well as on the method of honey harvesting by the beekeeper. For example, pollen grains may be introduced to honey by the centrifugation of the combs with the remnants of honey from the previous harvest; in such cases, the pollen analysis result may be inaccurate, as these admixtures may come from an earlier period or even from the previous year (Treper, 2020). However, no such errors were found in the honeys analyzed in our present study: all samples were taken from honeys from a certain season whose pollen composition is limited to the spring and summer periods.

Brassica spp. pollen was abundant in rural rape honey, with an average of 240 pollen grains per gram (Figure 5a). The flowering season of oilseed rape lasts three weeks and falls at the turn of April and May, as such, the pollen was also found in other varieties: this variety was quite numerous in polyfloral honey (52 grains per gram of honey) collected in urban apiaries (Figure 5b). In the present study, *Robinia* spp. pollen was abundant in urban acacia honey (69 grains per gram - Figure 5c) and urban polyfloral honey (42 grains per gram - Figure 5c). A much smaller amount was found in rural honeys, i.e. acacia (37 grains per gram - Fig. 5d) and polyfloral (10 grains per gram - Figure 5d). However, more *Robinia* pollen was recorded in rural honeydew honey (25 grains per gram) than in urban honey (17 grains per gram - Figure 5c, d). The flowering season of *Robinia* spp. falls mainly on the turn of May and June and lasts about 10 days.

Tilia spp. pollen was the most abundant in city linden honey (55 grains - Figure 5e), but it was also present in polyfloral and honeydew honey. The flowering season is mainly in July and lasts about 12 days. The small number of grains identified in the urban linden honey probably resulted from the rapid release of a large amount of pollen in a short time, which is characteristic of this species, and hence its significant seasonal variability, ranging from 79 to 968 grains (Weryszko-Chmielewska et al., 2019).

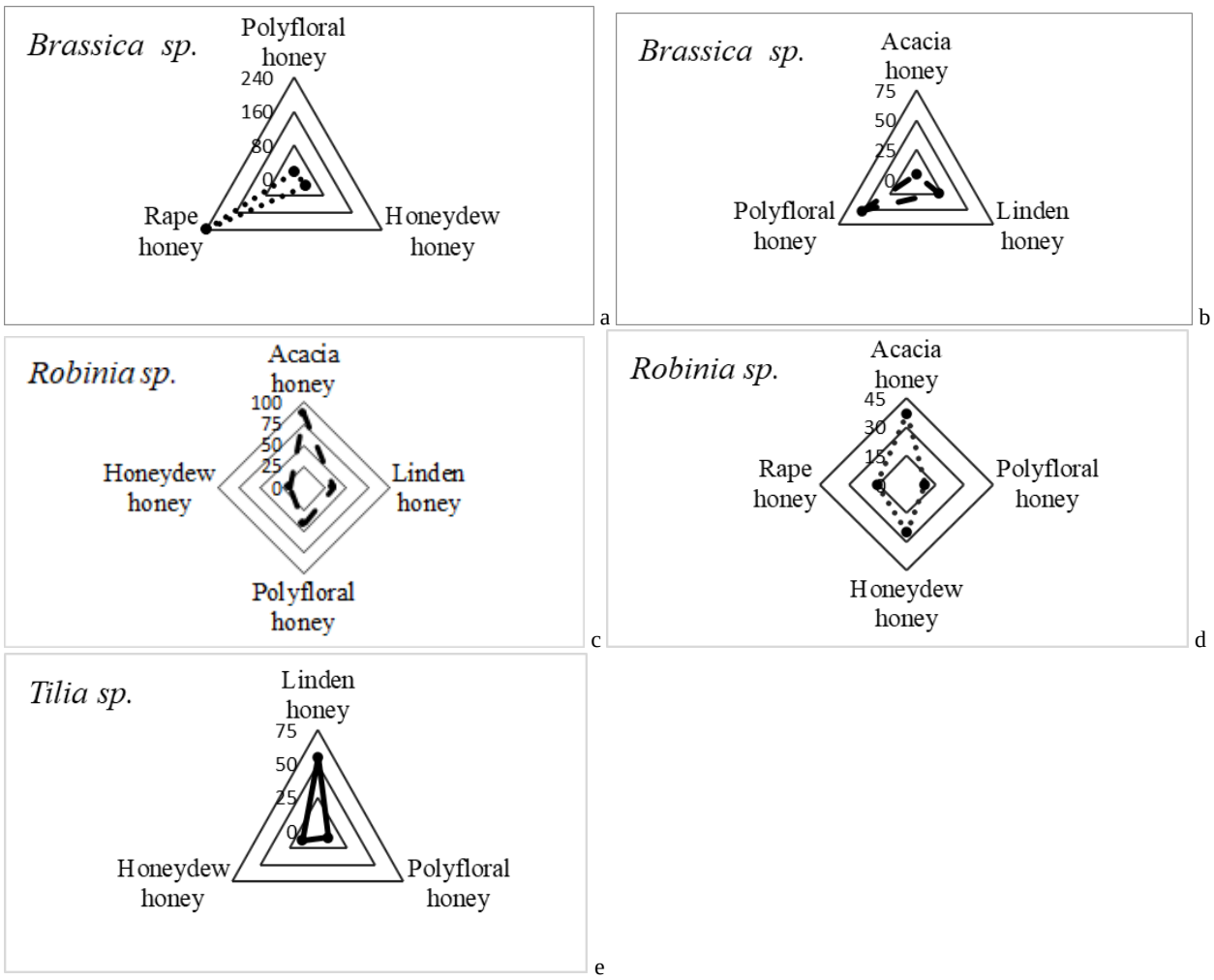


Figure 5. The number of dominant pollen grains in 1 gram in the studied types of honeys; - - rural, ··· urban, – rural and urban

Diversification of polyfloral honey with regard to location type

In polyfloral honey, significantly greater total pollen counts and melliferous plant species diversity were found in urban honey than in rural honey (Figure 6a, 6b). All three analyzed cities are characterized by a large share of green areas in relation to their area: in Warsaw, 5000 ha of the 52000 ha city area is greenery, while these figures are 3800 ha of 30000 ha in Szczecin, and 500 ha of 9000 ha in Gorzów Wlkp. (Wysmułek et al., 2020).Street squares, communication routes, family allotment gardens and home gardens provide a wealth of plant types, which is an optimal source of pollen varied in terms of chemical composition for bees. A particularly large amount of pollen grains was recorded in polyfloral honeys from Warsaw, with the richest pollen spectrum being observed in honey from ul Wiejska (*Wiejska street*) (586 pollen grains - 31 genera). This great diversity was probably related to the location of apiaries, being in the vicinity of large squares (the Home Army Battalion Miłosz, Strehla) and very large areas of park complexes (Marshal Edward Śmigły-Rydz Park, Janina Porazińska Park, Ujazdowski Park). Slightly smaller numbers of pollen grains were found in honey from apiaries located on ul Sokratesa (*Sokratesa street*) (448 - 33 genera). The bee flight zone encompassed Wawryszewski Cemetery, with a large variety of flowers, and a very large rest area around the Brustman Pond. An even smaller number of pollen grains was recorded in the honey from ul Bartycka (*Bartycka street*), which was close to the Burza Action Park and various domestic gardens. Among the Warsaw honeys, the least diverse in terms of pollen counts and genera were those from apiaries located at ul Wawelska (250 grains per gram, 18 species) and ul Nowoursynowska (301 grains, 19 species). The bee flight zone included a narrow part of Maria Skłodowska-Curie Park, which was very well developed in terms of small buildings (*Wawelska street*), and the grassy wastelands around the South Bypass of Warsaw (*Nowoursynowska street*). Green areas constitute almost 25 % of the area of Warsaw, and these green areas are grouped and evenly

distributed. Parks and gardens are located mainly in the central part of the city, and forests in the periphery. The green areas comprise 79 parks and gardens (9 % of urban green areas), forests (42 %), protected areas (14 %), trees (14 %), and a landscape park (21 %). The share of green spaces per capita in Warsaw varies significantly between districts (Bielecka et al., 2018). The greatest variety of pollen grains in Warsaw were found in honeys from one of the most densely-populated districts per gram of honey Śródmieście (*Wiejska Street*), and Bielany (*Sokratesa Street*), the latter being a district with a quarter of the population of Śródmieście. These numbers were related to the fact that the apiaries were located in the most representative part of the city and on the outskirts of the city near the protected Kampinowski National Park.

The polyfloral honey from Szczecin contains around half the pollen grains of the polyfloral Warsaw honey. The bee flight zone included two family allotment gardens, home gardens, the Chopin Park with numerous planted species, including Linden trees (*Tilia* spp.); these are commonly planted in public parks and along streets in many European cities (Massetti et al., 2015). Szczecin is one of the greenest cities in Poland. There are 64.7 m^2 of recreational greenery per inhabitant, including parks (142.5 ha), lawns (55.2 ha), street greenery (138.9 ha), cemeteries (193.9 ha) and city forests (2,780.2 ha) (Czekiel-Świtalska, 2010).

The smallest number of pollen grains was found in polyfloral honey from Gorzów Wlkp., although the apiaries were located in the vicinity of the Przemysłówek Family Allotment Gardens, Górczyński Park and domestic gardens. These findings confirm those of Sołtys-Lelek and Gruszka (2021), which indicate that although the area of Gorzów Wlkp. is strongly transformed by humans, a large diversity of *Rosaceae* taxa can be found in the area.

Regardless of the analyzed honey variety, the linear regression analysis only found a positive relationship between total pollen count and honey plant type in relation to urban apiaries (Figure 7a).

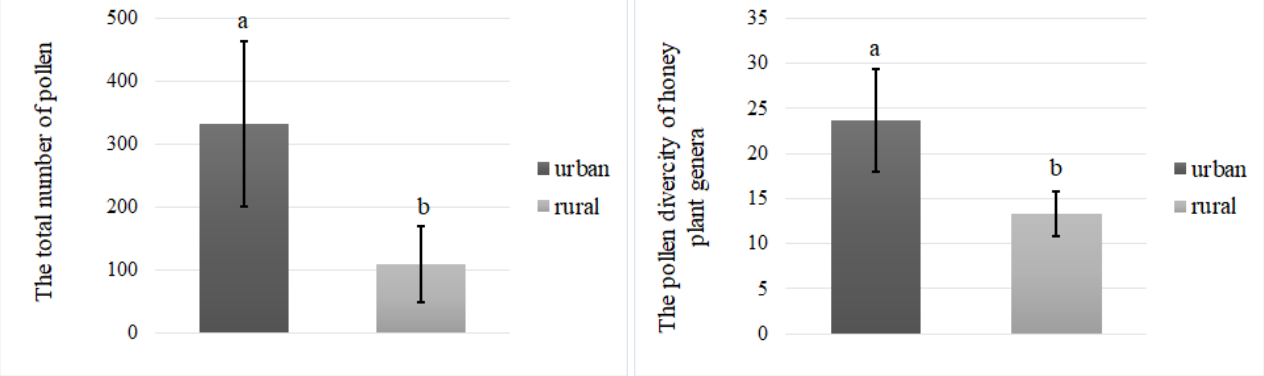
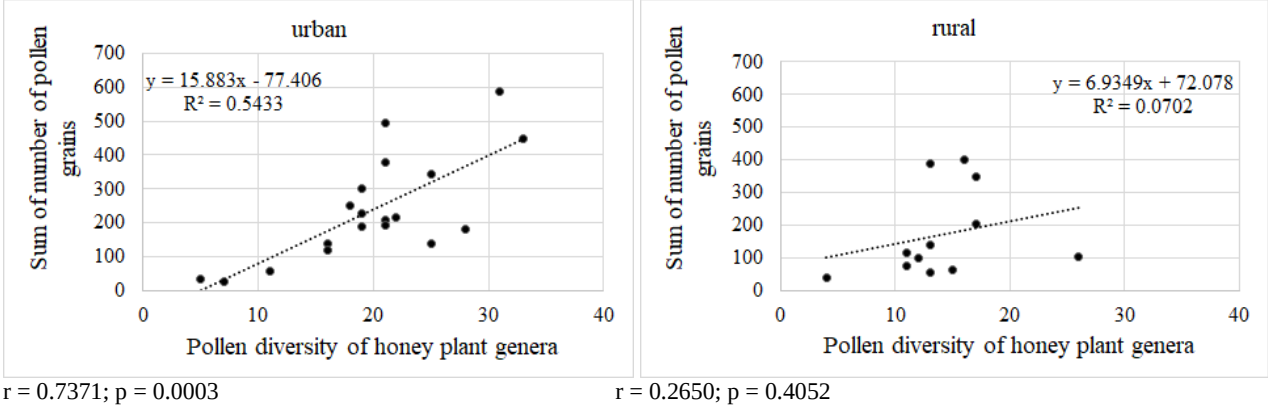


Figure 6a,b. The total number of pollen in 1 gram of urban and rural polyfloral honey (a) and the pollen diversity plant genera in urban and rural polyfloral honey (b)



r = 0.7371; p = 0.0003 r = 0.2650; p = 0.4052

Figure 7. Linear regression between the number of pollen in 1 gram of honey and the type of honey plants depending on the origin of the urban (a) or rural (b) apiary

CONCLUSIONS

The location of apiaries in rural and urban areas influences the type of honey produced. Rape honey is typically obtained from apiaries located near fields cultivated with rape, which are easily accessible for bees; the predominant pollen type in these honeys is *Brassica* spp. In turn, planting linden, mainly in green areas of urban agglomerations, makes it possible to obtain linden honey. The presence of acacia favors a greater number of *Robinia* spp., pollen grains; this is particularly true in rural and urban apiaries due to the management of urban green areas.

The assumed research hypothesis was confirmed: the richness of various green areas in cities (parks, avenues, squares, lawns, lawns, flower beds) results in a greater number of pollen grains and a greater variety of honey plants than in rural areas, which favors the production of mainly polyfloral honey with a large pollen spectrum. Moreover, urban areas, with their plant species diversity, are of great importance for ensuring the health and vitality of bees. Regardless of their taste and smell, the greater diversity of plant pollen found in the honeys collected from urban apiaries may result in them having stronger nutraceutical properties than rural honeys.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

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