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MORPHOMETRIC AND SOIL TEXTURE ANALYSIS OF SOIL MATERIAL FROM WASP NESTS *SCELIPHRON DESTILLATORIUM* (ILLIGER, 1807) (APOIDEA: SPHECIDAE)

Sophia Pytel-Huta [1], ***Roman Semashchuk*** [1], ***Andriy Zatushevsky*** [2], ***Josyf Tsaryk*** [1]

[1] *Ivan Franko National University of Lviv, 4 Hrushevsky St., Lviv 79005, Ukraine*

[2] *Explogen LLC, 20 Zelena St., Lviv 79005, Ukraine*

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Background. The article presents the data obtained as a result of our research on the nests of an aboriginal wasp species on the territory of Ukraine – *Sceliphron destillatorium* (Illiger, 1807) that belongs to the family Sphecidae. We collected 54 wasp nests in different regions: Zakarpattia (n = 4), Ivano-Frankivsk (n = 1), Rivne (n = 12) and Lviv (n = 35) Regions.

The data are presented as a result of measuring the main morphometric parameters of nests (length, width of cells and mass of nests) which are typical of the species under study. The paper also reports the results of the soil texture analysis of the soil material of twelve wasp nests from four different places of “mass nesting” and compares the results with the control samples of the surrounding soils in the corresponding areas.

The study aimed at investigating the structure of the nests of *S. destillatorium* wasps, determining the soil texture of the soil material of nests from different regions of Ukraine and comparing them.

Material and Methods. The nests of *Sceliphron destillatorium* wasps were the object of the study. The morphometric parameters of nests were measured with an automatic digital caliper 0–150 mm and Axis A500 technical chemical scales. The soil texture analysis was performed by the pipette method.

The potentiometric method was used to determine the pH of the soil material. In addition, the determination of the CO_2 carbonates was carried out according to the volumetric method.

Results. We have analysed 54 nests of *S. destillatorium*. 46 nests were found in "mass nesting places" (in some places several samples were found): in Lviv (3 sites) and Rivne Regions (1 site – Rivne Nature Reserve). The content of granulometric elements was determined in twelve wasp nests from these places and twelve control soil samples were taken around the places of "mass nesting" (three samples of surrounding soil from each location). In order to compare the particle size distribution of elements in all analysed samples (24), we drew cumulative curves and determined coefficients of uniformity and curvature.

Conclusions. Nest weighing revealed considerable variations in the mass of the nests – from 10.06 to 222.56 g – depending on the number of cells in a nest. The size of the nests also varied. The number of cells in the nests varied from 2 to 37 (mean = 13; n = 54 nests).

As a result of the soil texture analysis of the nest soil material, we determined the percentage of granulometric elements used by the wasps for the construction of their nests. It was found that fine sand was one of the predominant fractions in all twelve nests.

The similar content of all five fractions of soil material of wasp nests from different areas indicates that the soil texture of the nests which were built by *S. destillatorium* probably does not depend on their geographical location.

Keywords: insects, *Sceliphron destillatorium*, morphometry of the nests, soil texture analysis of the mud dauber wasp nests

INTRODUCTION

Mud dauber wasps of the genus *Sceliphron* Klug, 1801 (Sphecidae) are represented in the world fauna by 35 species (Pulawski, 2020). Eight species occur in the Western Palearctic (Diaz-Calafat, 2020), six of which are found in Ukraine including the most common native species *Sceliphron destillatorium* (Illiger, 1807), *Sceliphron spirifex* (Linnaeus, 1758), and *Sceliphron madraspatanum* (Fabricius, 1781), as well as three invasive ones: *Sceliphron curvatum* (Smith, 1870), *Sceliphron caementarium* (Drury, 1773) (Tymkiv *et al.*, 2015), and *Sceliphron deforme* (F. Smith, 1856), which was first recorded in Kharkiv Region (Kletionkin & Parkhomenko, 2023).

S. destillatorium is a South Palearctic species. It inhabits the territories from northern Africa and western Europe, through southern and central Europe, south-western Asia, central Asia to western Siberia, Mongolia and northern China (Wisniowski *et al.*, 2013).

Representatives of the genus build nests from wet soil material, which they twist into spherical balls using their mandibles and carry to the nesting site (Chatenoud *et al.*, 2012). Each nest consists of a number of tubular cells (shaped like "jugs"). In each of these cells, females store paralysed spiders to feed their offspring (Pytel-Huta, 2023; Yuan *et. al*., 2022). The number of victims varies depending on the sex of the future offspring and the size of the victim. Normally, a wasp lays an egg in a cell and usually attaches it to the first victim in the cell (Polidori *et al.*, 2005). After the female has built the first cell and provided her offspring, she builds the next cell (Park *et al.*, 2022).

After building several cells (the number varies), *S. destillatorium* covers the nest with an additional layer of soil material to protect the offspring from predators (e.g., parasitoid wasps, bee flies and birds) and changeable environmental conditions (e.g., extreme temperature, humidity and rainwater) (Park *et al.*, 2022).

S. destillatorium is a synanthropic species of wasp that is often found near human dwellings. The nests are placed on artificial structures, under the roofs of buildings, in attics, on walls, around doors, windows, on various objects, etc (Bogusch, 2022).

The quality of *Sceliphron* sp. wasp nests, their structure, the corresponding properties of the soil material and the location have a significant influence on the successful development of the offspring. Although nest-building behaviour, nesting preferences, and food-storage characteristics have been carefully studied, little is still known about the nest structure of *S. destillatorium* itself, or type of material they use to build it (Bogusch, 2022; Chatenoud *et al*., 2012; Yuan *et al*., 2022; Park *et al*., 2022; Ertürk *et al*., 2019).

With regard to the above mentioned, the aim of our research was to study the structure of *S. destillatorium* wasp nests, determine the granulometric composition of the soil material of nests from different regions of Ukraine and compare them.

MATERIALS AND METHODS

Research object and general methods. We collected the nests of *S. destillatorium* (n = 54 samples) in 2022–2023 from different regions of Ukraine: Zakarpattia (4), Ivano-Frankivsk (1), Rivne (12), and Lviv (35) Regions (**Fig. 1**). The main morphometric parameters (length, width of the cell and weight of the nest) were measured with a digital caliper 0–150 mm, Radwag AS 110/C analytical scales and Axis A500 technical chemical scales.

We placed the contents of the cells (wasp remains, damaged or empty cells, spiders and parasites) into test tubes and stored them for further processing.

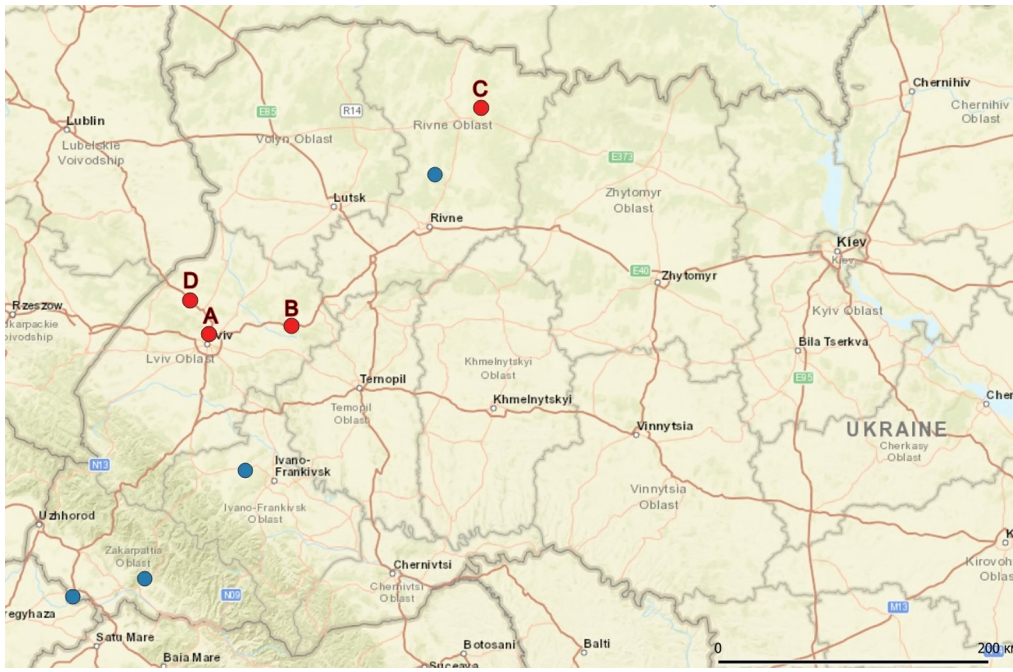

Fig. 1. Nest collection sites (places of "mass nesting" are marked in red: **A** – Velyki Hrybovychi; **B** – Olesko; **C** – lake Somyne; **D** – Dobrosyn)

46 nests of 54 were found in the places of “mass nesting” (some samples were found in the same place): Lviv Region (A – Velyki Hrybovychi; B – Olesko; D – Dobrosyn) and Rivne Region (C – lake Somyne, Karasynske district of Rivne Nature Reserve) (**Fig. 2**).

Fig. 2. Place of “mass nesting” *S. destillatorium* in Rivne Nature Reserve

We took three samples of soil from the localities around each place of “mass nesting” to compare the soil texture of the soil material of wasp nests (from the mentioned places of “mass nesting”) with the control samples of soil.

Methods of studying physical and physico-chemical properties of nest soil material. We determined the soil texture of twelve wasp nests (three nests from each place of the “mass nesting”) and twelve soil control samples. The purified wasp nests (of spiders, wasp remains and their parasites) were crushed with a wooden pestle in a porcelain mortar and sifted through a sieve with a hole diameter of 1 mm. The remaining particles larger than 1 mm (soil skeleton) were selected and weighed separately (see **Table**). While preparing samples of nest soil material for analysis, they were verified for the presence of carbonates using 10% HCl.

The soil texture was determined by the pipette method according to DSTU B V.2.1 – 19:2009. The soil material was dispersed with a 4 % solution of sodium pyrophosphate ($Na_4P_2O_7$) (Hatskevych *et al.*, 2021).

Potentiometric determination of soil pH. The suspension of each sample of soil material of wasp nests was prepared in the ratio of 1:5 – soil to water and the pH was measured with the potentiometric method according to DSTU ISO 10390:2001 Soil quality. Determination of pH (ISO 10390:1994, IDT) (National standard of Ukraine, 2012).

Determination of CO_2 of carbonates in soil. We used 10% HCl to determine the type and duration of boiling of the soil material from the nests and to calculate the appropriate weight of the soil sample for analysis. The determination of CO_2 carbonates was carried out according to Volumetric method (Kyrylchuk & Bonishko, 2011).

RESULTS AND DISCUSSION

We have analysed 54 nests of *S. destillatorium* collected in the Zakarpattia (n = 4), Ivano-Frankivsk (n = 1), Rivne (n = 12) and Lviv (n = 35) Regions. The largest number of nests – 46, were found in "mass nesting" places (Lviv (3 sites) and Rivne (1 – Rivne Nature Reserve) (**Fig. 3**).

All the nests were found in people's houses – in attics, attached to walls, wooden beams, or various objects (tents, old furniture, etc.).

Fig. 3. Nests of *S. destillatorium*

Morphometry of nests. Before conducting the soil texture analysis of the soil material, we measured the main morphometric parameters of 54 nests of *S. destillatorium*: nest weight, length, width and number of cells.

Nest weighing revealed considerable variations in the mass of the nests – from 10.06 to 222.56 g – depending on the number of cells in a nest. The nests under investigation varied in size and number of cells – between 2 and 37 cells (mean = 13; n = 54 nests) per nest. As most nests had open cells, it was difficult to determine whether the nest had been built during one or more seasons.

Cell length of *S. destillatorium* nests ranged from 21.3 to 38.5 mm (mean = 30.99 mm; n = 523 cells) and width from 6.2 to 13.04 mm (mean = 10.27 mm; n = 519 cells).

It should be noted that the presence of the so-called "silk threads" extending from the cocoon to the walls of the cell was observed in the nests of *S. destillatorium* (**Fig. 4**) (Harris, 2022). This created a space between the pupal cocoon and the inner wall of the cell. We hypothesize that it functions as a better thermal insulation of the pupa, as the cocoon is not in contact with the inner walls of the cell (soil material). In addition, if the remains of larval victims (spider remains) were stored in the cell, the layer of "silk threads" separated them from the cocoon, which could serve an additional protective barrier.

Properties of the soil material of the nests *Sceliphron destillatorium*

Place of "mass nesting" No 1										
Sample	Particle size in mm, number %							Weight nests, g	pH	$CaCO_3$, %
	Soil sceleton	Sand		Silt			Clay			
	>0.1	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001			
Ss001	0.20	17.8	46.2	24	0	4	8	17.21	6.05	5.3
Ss014	0.09	13	19	52	0	12	4	13.82	6.35	3.8
Ss051	1.67	7	32	43.6	0.04	10.72	6.64	163.06	5.94	7.1
Control Hr No 1	–	15	39.84	31.8	0.88	4.96	7.52	–	6.90	–
Control Hr No 2	–	5.4	34.6	28.48	7.12	13.2	11.2	–	7.02	23.65
Control Hr No 3	–	4.6	33.36	39.32	5.6	7.76	9.36	–	7.04	10.23
Place of "mass nesting" No 2										
Sample	Particle size in mm, number %							Weight nests, g	pH	$CaCO_3$, %
	Soil sceleton	Sand		Silt			Clay			
	>0.1	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001			
Ss028	0.94	28.57	25.31	23.96	6.16	6.96	9.04	19.34	5.73	5.7
Ss029	2.34	19.2	35.56	19.92	8.52	9	7.8	60.25	6.59	14.4
Ss065	4.04	23.4	37.56	19.88	7.68	3.64	7.84	76.11	6.11	8.3
Control Ol No 1	–	25	42.12	17.44	3.48	7.44	4.52	–	5.69	–
Control Ol No 2	–	11.6	31.96	28.6	9.52	7.2	11.12	–	6.79	10.96
Control Ol No 3	–	11.8	42.32	28.56	5.44	5.8	6.08	–	6.75	10.12

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Place of "mass nesting" No 3										
Sample	Particle size in mm, number %							Weight nests, g	pH	$CaCO_3$, %
	Soil sceleton	Sand		Silt			Clay			
	>0.1	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001			
Ss036	0.33	15	34	34.64	8.44	0.48	7.44	55.24	6.91	–
Ss040	4.05	24.4	54.8	11.24	0.2	2.76	6.6	50.94	6.02	–
Ss048	1.73	16.8	47.84	23.4	2.44	5.44	4.08	181.38	6.83	–
Control D No 1	–	19.6	58.6	13.56	3.72	0.36	4.16	–	7.17	–
Control D No 2	–	18.2	50.44	17.52	1.92	4.84	7.08	–	6.86	–
Control D No 3	–	30.2	53.4	7.52	2.4	1.52	4.96	–	6.82	0.94
Place of "mass nesting" No 4										
Sample	Particle size in mm, number %							Weight nests, g	pH	$CaCO_3$, %
	Soil sceleton	Sand		Silt			Clay			
	>0.1	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001			
Ss053	4.39	47.2	35.56	7.96	0.6	3.2	5.48	128.74	6.02	–
Ss055	9.97	38.2	39.04	9.52	3.08	5.36	4.8	222.56	5.68	–
Ss063	0.78	44.2	39.68	3.24	1.16	0.72	11	22.98	5.52	–
Control R No 1	–	43.6	36.44	8.24	5.16	2.04	4.52	–	6.84	0.76
Control R No 2	–	49.4	43.24	2.76	0.84	0.16	3.6	–	6.51	–
Control R No 3	–	50.4	41.76	3.44	0.72	0.16	3.52	–	6.47	–

Fig. 4. Cell of a *S. destillatorium* nest, before the nest was dismantled

Soil texture analysis. The data obtained as a result of determining pH of the soil material of the wasp nests ranged from 5.06 to 8.83 (mean = 6.75), but the pH of the soil sampled near the places of "mass nesting" was more alkaline and ranged from 6.54 to 8.66 (mean = 7.85) (see **Table**).

The content of carbonates ranged from 3.8 % to 14.4 % (mean = 7.4 %, n = 6 (the other samples interacted with the acid very poorly)). However, percentage of the content of carbonates in the control soil samples taken near the places of "mass nesting" was higher and ranged from 0.76 % to 23.65 % (mean = 9.44 %, n = 6).

The soil texture analysis of the soil material of the nests (n = 12) revealed the following fractions: in six nests fine sand (0.25–0.05) ranging from 19 % to 47.84 % and coarse dust (0.05–0.01) ranging from 19.92 % to 52 % predominated (see **Table**).

On the other hand, in the other six nests the fractions of coarse sand (1–0.25)– 23.4 % – 47.2 % and fine sand (25.31 % – 54.8 %) predominated (see **Table**). It should be noted that sand fractions predominated in all the nests found in the territory of the Karasynske district of the Rivne Nature Reserve. The detailed percentage contents of all fractions are given in table.

The composition of the granulometric elements of the soil material of the nests, despite certain differences, is similar in different sampling sites indicating that the soil texture of the nests built by *S. destillatorium* probably does not depend on the geographical location. However, comparing the content of granulometric elements in the nest samples from the reserve with the control soil samples, we observed a similarity in the predominance of the coarse sand fraction, which indicates that the percentage content of the predominant fraction of nests probably depends on the composition of granulometric elements of the soil in the corresponding area (see **Table**).

In order to compare the particle size distribution of the soil material of wasp nests with control soils samples (i.e. surrounding soil), we created cumulative curves. From

each of the four identified “mass nesting” sites (A, B, C – Lviv Region and D – Rivne (Rivne Nature Reserve)), three control soil samples were collected (**Fig.1**).

As 6 to 23 wasp nests were collected from one site, we performed soil texture analysis on three nests from each site for comparison.

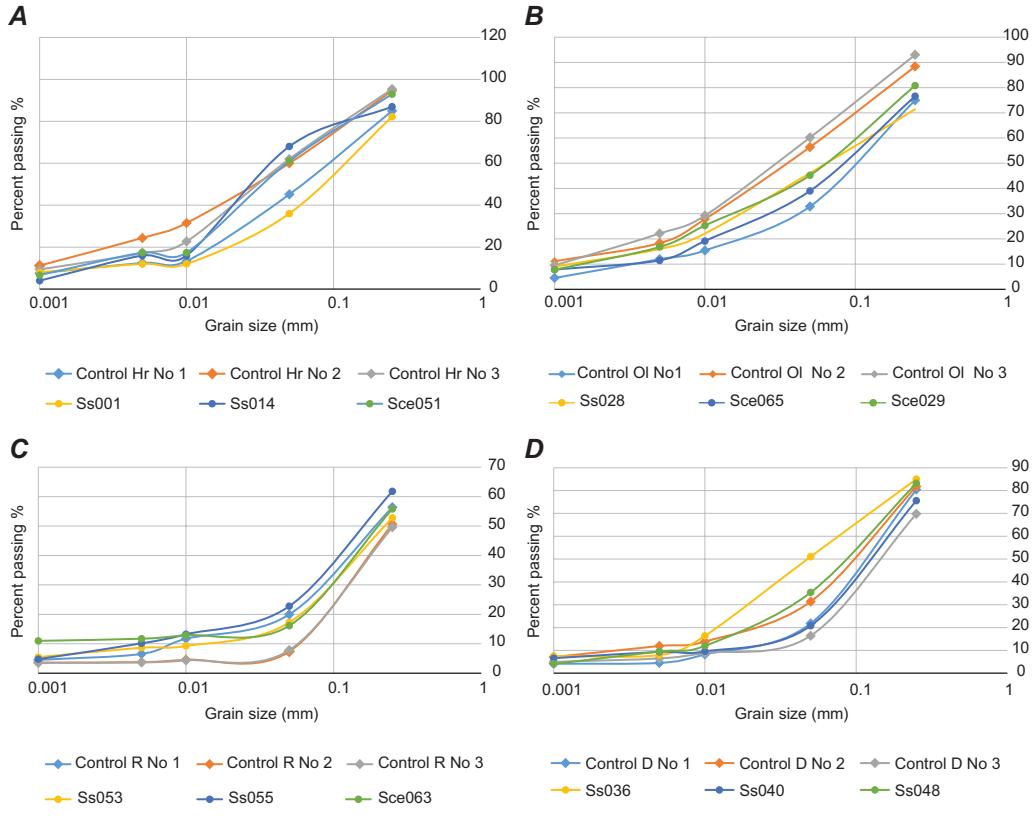

Fig. 5. Grain size distributions of the nest soil samples from different locations: ***A*** – Velyki Hrybovychi; ***B*** – Olesko; ***C*** – lake Somyne; ***D*** – Dobrosyn

Comparing the soil material samples from the nests of *S. destillatorium* wasps with the control soil samples from all four sites, we could observe certain differences in the distribution of grains, which indicates that the wasps are able to sort and collect a specific number, size and type of soil particles for the construction of their nests. This fact was previously established for other species of the genus *Sceliphron* sp. (**Fig. 4**) (Park *et al*., 2022).

The use of soil material with a certain content of granulometric elements can ensure better compaction of the nest walls (Park *et al*., 2022). In order to evaluate and compare the sorting of the soil material of the nests with the control samples of the surrounding soils, we calculated the coefficients of uniformity and curvature based on the content of granulometric elements in each sample.

As a result, the coefficient of uniformity ranged from 14.6 to 53.4. The coefficient of curvature ranged from 1 to 4.2. However, two samples of nests of *S. destillatorium* from

the Rivne Nature Reserve significantly exceeded the value – between 6.5 and 49.27, respectively. However, in the control samples the values of the coefficient of homogeneity ranged from 6.31 to 80.37 and the curvatures from 0.98 to 4.75.

The coefficient values indicate that the soil material of the mud dauber nests is well sorted (i.e. uniformity coefficient values are greater than 6 and curvature coefficient values range between 1 and 4). Apparently, such distribution of the granulometric elements of the soil material of the nests provides for better cell density. However, the values of the coefficient of curvature of the nests from the Rivne Nature Reserve (6.5 and 49.27) are significantly higher than those of the others, which indicates that the soil material used for the nests construction is less sorted and, as a result, the nests are not as dense as those from other areas.

Although the proportion of clay (<0.001) in the soil material of the analysed nests ranges from 4 % to 11 %, the content of this fraction can also provide for better density.

CONCLUSIONS

As a result of the study, 54 nests of *S. destillatorium* have been found in different regions of Ukraine: Zakarpattia (n = 4), Ivano-Frankivsk (n = 1), Rivne (n = 12) and Lviv (n = 35) Regions. A significant number of them, 46 nests in particular, were found in the places of “mass nesting” (several nests were found in each of such places).

All the nests of the species under study were found in human dwellings: in the attics, attached to walls, wooden furniture, fabrics, etc.

As a result of measuring of the main morphometric parameters of 54 nests of *S. destillatorium*, it was determined that the length of the cells ranged from 21.3 to 38.5 mm (mean = 30.99 mm; n = 523 cells) and the width from 6.2 to 13.04 mm (mean = 10.27 mm; n = 519 cells). The nests under study were of different size, their weight ranged from 10.06 to 222.56 g and the number of cells varied from 2 to 37 (mean = 13; n = 54 nests).

The percentage of the granulometric elements of the twelve wasp nests, despite certain differences, is similar in different regions, so the soil texture of the nests probably does not depend on their geographical location. However, the predominant fraction of granulometric elements of wasp nests may depend on the particle size distribution of the soil in the corresponding area.

The distribution of granulometric elements of the soil material of the nests and the control samples of the surrounding soil indicates that *S. destillatorium* sort and collect a specific number, size and type of soil particles for construction of their nests.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Human Rights: This article does not contain any studies with human subjects performed by any of the authors.

Animal studies: All institutional, national and institutional guidelines for the care and use of laboratory animals were followed.

AUTHOR CONTRIBUTIONS

Conceptualization, [S.P-H.]; methodology, [S.P-H.; R.S.; A.Z.]; validation, [-]; formal analysis, [-]; investigation, [S. P-H]; resources, [S.P-H.; R.S.; A.Z.]; data curation, [-]; writing – original draft preparation, [S. P-H.]; writing – review and editing, [S.P-H.; R.S.; A.Z.; J. Ts.]; visualization, [S.P-H.]; supervision, [S.P-H., R.S.]; project administration, [S.P-H.]; funding acquisition, [-].

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МОРФОМЕТРІЯ ТА ГРАНУЛОМЕТРИЧНИЙ АНАЛІЗ ҐРУНТОВОГО МАТЕРІАЛУ ГНІЗД ОС *SCELIPHRON DESTILLATORIUM* (ILLIGER, 1807) (APOIDEA: SPHECIDAE)

[1]***Софія Питель-Гута,*** [1]***Роман Семашчук,***
[2]***Андрій Затушевський,*** [1]***Йосиф Царик***[1]

[1] *Львівський національний університет імені Івана Франка вул. Грушевського, 4, Львів 79005, Україна*

[2] *ТОВ "Експлоджен", вулю Зелена, 20, Львів 79005, Україна*

Вступ. Наведено дані досліджень гнізд аборигенного виду ос на території України – *Sceliphron destillatorium* (Illiger, 1807), що належить до родини Sphecidae. Проаналізовано 54 гнізда ос із різних регіонів: Закарпатська (n = 4), Івано-Франківська (n = 1), Рівненська (n = 12) та Львівська (n = 35) області.

Представлено дані внаслідок вимірювання основних морфометричних параметрів гнізд (довжини, ширини комірок і маси гнізд), характерних для досліджуваного виду. Наведено результати гранулометричного аналізу ґрунтового матеріалу 12 гнізд ос із чотирьох різних місць "масового гніздування" та їхнє порівняння з контрольними зразками навколишніх ґрунтів відповідних територій. Метою дослідження було вивчити будову гнізд ос *S. destillatorium*, встановити гранулометричний склад ґрунтового матеріалу гнізд із різних регіонів України та порівняти їх.

Матеріал і методи. Об'єктом дослідження були гнізда ос *Sceliphron destillatorium*. Вимірювання морфометричних показників гнізд здійснювали за допомогою автоматичного штангенциркуля Digital caliper 0–150 мм та ваги техніко-хімічної Axis A500. Визначення гранулометричного складу проводили методом піпетки.

Визначення pH ґрунтового матеріалу здійснювали потенціометричним методом. Крім того, проведено визначення карбонатів CO_2 об'ємним (газоволюметричним) методом.

Результати. Досліджено 54 гнізда *S. destillatorium*. 46 гнізд знайшли на місцях "масового гніздування" (в одному місці знайдено кілька зразків): Львівська (3 місцезнаходження) та Рівненська області (1 – Рівненський природний заповідник). Визначили вміст гранулометричних елементів 12 гнізд ос із цих місць і 12 контрольних проб ґрунту, які відбирали навколо місць "масового гніздування" (по три зразки навколишнього ґрунту). Щоб порівняти склад гранулометричних елементів у всіх аналізованих зразках (24), побудували кумулятивні криві, визначили коефіцієнти однорідності та кривизни.

Висновки. Зважування показало, що маса гнізд значно варіювала: 10,06–222,56 г, залежно від кількості комірок в одному гнізді. Розміри знайдених гнізд також були різними. Кількість комірок у гніздах коливалася від 2 до 37 (сер. = 13; n = 54 гнізда).

У результаті вимірювання довжини та ширини комірок гнізд *S. destillatorium* визначили характерні межі морфометричних параметрів для цього виду ос.

Провівши гранулометричний аналіз ґрунтового матеріалу гнізд, визначили відсотковий вміст гранулометричних елементів, які оси використовують для будівництва своїх гнізд, і встановили, що однією з переважаючих фракцій для всіх 12 гнізд був дрібний пісок.

Подібний вміст усіх п'яти фракцій ґрунтового матеріалу гнізд ос із різних територій вказує на те, що, ймовірно, гранулометричний склад гнізд, побудованих *S. destillatorium*, не залежить від їхнього географічного розташування.

Ключові слова: комахи, *Sceliphron destillatorium*, морфометрія гнізд ос, гранулометричний аналіз гнізд пелопея звичайного

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