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On the interference color variations in the *Hedychridium roseum* species-group (Hymenoptera Chrysididae) from Bulgaria

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ABSTRACT A number of the *Hedychridium roseum* species-group individuals (Hymenoptera Chrysididae), captured mainly in Bulgaria hare here studied. We discovered that the presence/absence on metasoma of red interference color is a variable and unstable feature both in the males and the females of this species-group. The body interference colors are directly connected to the cuticle inner structure and thus to body features. As a consequence, the variable metasoma coloration is a valid taxonomic feature ultimately related to the DNA of single individuals. In the case of *Hedychridium roseum* species-group the taxonomy is complex and often based on subtle features. A review including also the influence of interference colors is discussed and integrated with the most recent taxonomy. In addition, the presence in Bulgaria of the following six species is confirmed: *Hedychridium sculpturatum* (Abeille de Perrin, 1877); *H. scutellare* (Tournier, 1878); *H. rossicum* Gussakovskij, 1948; *H. roseum* (Rossi, 1790); *H. insulare* Balthasar, 1953; *H. caputaureum* G. Trautmann et W. Trautmann, 1919. The lognormal distribution of above species is entirely positive thus statistic inference shows that in Bulgaria all species of *Hedychridium roseum* species-group have been captured and studied.

KEY WORDS Chrysididae; interference colors; Bulgaria; distribution; Corsica; Sardinia; Tuscany; Genetic.

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INTRODUCTION

The *Hedychridium roseum* species-group (Linsenmaier 1959a, b) is one of most complex assemblage of sibling species in the family Chrysididae Latreille, 1802. The taxonomy of the group is difficult and the identification of some species is often in conflict by different authors. Traditionally one significant morphological feature of taxonomic value is the metasoma interference coloration, which often can be metallic-red, caused by the positive light interference, or non-metallic (cutaneous-brown caused by the non-positive interference in visible region of human perception).

In Chrysididae the cuticle interference colors are almost always present and used in taxonomy as color patterns for the body and the appendages. The interference colors are produced by presence in cuticle of reflecting layers (Kroiss et al., 2009). If the distance between reflecting layers is genetically controlled, large color changes could appears due to the chromosome combinations.

In the majority of Chrysididae a variability of interference colors is considered to be uncommon (apart of a few individuals considered as "anomalous"). Humidity status also changes the cuticle thickness producing a general shift toward green-blue color in wet specimens (Strumia & Dawah, 2019). If conflicting genes are present in a species, the presence of individuals with a different color is possible and expected. Such as a case is presented and discussed below. Evolutionary selection would cancel such variability toward the most efficient solution. This is apparently not our case.

In earlier studies all individuals of the *Hedychridium roseum* species-group were usually designated as "*Hedychridium roseum*", a species with a "clear brown non-metallic metasoma in most

cases". Similar individuals, but with metallic red metasoma were described in few cases as new species, or even included in different species-groups (e.g., *Hedychridium mediocrate* Linsenmaier, 1959). As a consequence, in most collections all old material was simply grouped under the name of "*Hedychridium roseum*".

Linsenmaier (1959a, b) divided the group on the basis of metallic or not metallic metasoma. He proposed two species-groups: *H. roseum* (Rossi, 1790) and *H. sculpturatum* (Abeille de Perrin, 1877). This unique interpretation caused confusion in taxonomy of *H. roseum* species-group. More recently, Arens (2004, 2010a, 2010b, 2011, 2012, 2014) performed an extended revision of the old "*H. roseum"* species-group, well supported by individual's body morphology, color and sculpture. These results and conclusions are based on the study of almost all available material kept in European collections. Arens' conclusion is the presence in Europe of nine species in the *H. roseum* species-group (Arens, 2010a), mainly based on body shape, metasoma coloration, size and the kind of cuticle sculpture. In addition, a set of subspecies and synonymies were discussed.

Arens' descriptions are sound and detailed, allowing in most cases a correct identification at species level, provided to take into account a possible variable metasoma coloration.

Interference colors

Interference colors in insect's cuticle follow from two effects: first, by interference from light diffracted from a periodic structure on cuticle surface and, second, by interference from equidistant reflecting layers inside cuticle. In Aculeate Hymenoptera the second effect is more frequent: the interference colors in the insect's cuticle stems from the reflection of light from a series of neighboring interfaces that are separated by distances comparable with a quarter of the light wavelength. As a result of wave superposition from these reflections, some wavelengths are reflected or transmitted in phase and are therefore reinforced, while others are out of phase and reduced in intensity or cancelled out; the net result is that only certain wavelengths are reflected or transmitted and the surface appears colored (M. Ragaei, 2015). Recently Kroiss et al. (2009) studied the cuticle structure of *Hedychrum rutilans* Dahlbom, 1854 (a Palearctic species) by means of a SEM microscope, showing that cuticle is a multilayer reflector consisting of about six parallel lamellae with a distance of about h=185 nm (see Kroiss et al., 2009: 984, fig. 1). For a positive interference in the reflected light the optical phase difference into reflection from the different layers must be an even integer number of half wavelengths (an uneven number cancel the interference). Thus the following equation must be satisfied: $m\lambda = 2nh\cos(\theta)$, where m is and integer number, n the medium refraction index, θ the angle with the surface normal, and h the distance between the reflecting layers. By increasing the angle θ the color of reflected light shifts towards blue. Assuming h=200nm, m=1, n=1.4 (about the water refraction index), we obtain λ= 560 nm, a bright green reflected interference color. If h increases to 300 nm the maximum of reflected wavelength move to near infrared (840 nm) thus producing the non-metallic brown color of cuticle material. The second order interference is in the blue-violet and ultraviolet and can be observed by human eye only as a weak violet shining. When h is too short the interference color is not possible into visible range and the cuticle lose its color showing only those of the cuticle material (color, usually light brown).

The above interpretation is also supported by the observed shift toward green-blue color in the humid individuals, in contrast with dry specimens (Strumia & Dawah, 2019). It is worth to note that by performing quantitative spectra of reflected light it should be possible to measure the maximum wavelength of first and second order interference and to calculate the structure of reflecting layers on the basis of interference theory.

MATERIAL AND METHODS

The material from Bulgaria was captured mainly on central Bulgaria hills and it is keep in the Institute of Biodiversity and Ecosystem Research - Bulgarian Academy of Sciences, Sofia (some voucher also into F. Strumia collection). The material from Italy (Tuscany, Piedmont, Sardinia and Corsica) was mainly captured by Malaise Traps or by water plates and is now kept in F. Strumia collection and in the Natural History Museum of Pisa University. The western material was assembled in the frame of the "INTERREG" European research projects.

Sex	Locality	Latitude	Longitude	Date	Collector	Metasoma color
♂	Bulgaria, south of Petrich	41°22′05″N	23°11′14″E	30.07.2002	O. Todorov	Metallic red
♀	Bulgaria, south of Petrich	41°22′05″N	23°11′14″E	5-10.08.2002	O. Todorov	Non-metallic
♀	Bulgaria, Plovdiv	42°08′06″N	24°45′58″E	8-22.08.2002	S. Petrov	Non-metallic
♀	Bulgaria, Plovdiv	42°08′06″N	24°45′58″E	8-22.08.2002	S. Petrov	Non-metallic
♀	Bulgaria, Plovdiv	42°08′06″N	24°45′58″E	17-25.08.1999	S. Petrov	Non-metallic
♀	Bulgaria, south-west of Borika	42°28′55″N	23°36′40″E	6.08.2010	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Borika	42°28′55″N	23°36′40″E	6.08.2010	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Enina	42°40′50″N	25°24′57″E	23-29.07.2000	M. Langourov	Non-metallic
♀	Bulgaria, south-west of Zemen	42°28′19″N	22°44′06″E	13.07.2006	T. Ljubomirov	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	19-25.08.1998	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	27-30.07.1998	F. Strumia	Non-metallic
♀	Italy, near Pisa	43°40′31″N	10°19′36″E	26.07-05.08.1998	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	16-22.08.2000	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	3-11.08.1998	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	19-25.08.1998	F. Strumia	Non-metallic
♀	Italy, near Pisa	43°40′30″N	10°19′36″E	9-19.09.1998	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	11-16.08. 2000	F. Strumia	Non-metallic
♀	Italy, Piombino	42°56′44″N	10°29′56″E	21.08-01.09 2000	F. Strumia	Non-metallic
♀	Italy, Piombino	42°56′44″N	10°29′56″E	11-21.08 2000	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	26.07-05.08. 1998	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	9-15.08. 1998	F. Strumia	Metallic red
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	25-30.07. 1998	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	19-25.08. 1998	F. Strumia	Non-metallic
♀	Italy, San Pietro Belvedere, Pisa	43°34′19″N	10°39′56″E	19-25.08. 1998	F. Strumia	Non-metallic
♀	Italy, Piombino, Livorno	42°56′44″N	10°29′56″E	21.08-11.09.2000	F. Strumia	Non-metallic
♀	Italy, Piombino, Livorno	42°56′44″N	10°29′56″E	11-21.08. 2000	F. Strumia	Non-metallic
♀	Italy, Pisa	43°40′30″N	10°19′36″E	26.07-05.08. 1998	F. Strumia	Non-metallic
♀	Italy, Pisa	43°40′30″N	10°19′36″E	26.07-05.08. 1998	F. Strumia	Non-metallic
♀	Italy, Pisa	43°40′30″N	10°19′36″E	9-19.09.1998	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	3-11.08.2000	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	11-16.08.2000	F. Strumia	Non-metallic
♀	Italy, Chianni, Pisa	43°27′50″N	10°40′44″E	16-22.08. 2000	F. Strumia	Non-metallic
♂	Italy, Piombino, Livorno	42°56′44″N	10°29′56″E	4-13.07. 2000	F. Strumia	Non-metallic
♂	Italy, Montefalcone Nat.Res. Pisa	43°44′40″N	10°43′10″E	20-30.07.2000	F. Strumia	Metallic red
♂	Italy, Piombino	42°56′44″N	10°29′56″E	20.05.-03.06.2000	F. Strumia	Metallic red
♂	Italy, Piombino	42°56′44″N	10°29′56″E	4.07-13.07.2000	F. Strumia	Metallic red
♂	Italy, San Pietro Belvedere	43°34′19″N	10°39′56″E	9-15.08.1998	F. Strumia	Non-metallic
♂	Italy, Piombino, Livorno	42°56′44″N	10°29′56″E	4.07-13.08.2000	F. Strumia	Metallic red
♂	Italy, Piombino, Livorno	42°56′44″N	10°29′56″E	4.07-13.08.2000	F. Strumia	Metallic red
♂	Italy, Montefalcone Nat.Res. Pisa	42°44′40″N	10°43′10″E	20.07-30.07.2000	F. Strumia	Metallic red
♂	Italy, Piombino	42°56′44″N	10°29′56″E	20.05-03.06.2000	F. Strumia	Metallic red

Table 1. Data on the studied individuals of *Hedychridium sculpturatum.*

RESULTS

Recently it was possible to capture and study a large number of *H. roseum* species-group individuals in Bulgaria (by T. Ljubomirov), in Italy, Sardinia and Corsica (by F. Strumia). In addition, few more specimens from Greece, Turkey and Iran were available. It is thus possible to study the distribution of metasoma interference color, at least in the most frequently met species. Details on the origin of the material and the distribution of interference color on metasoma are presented in the following Tables.

In Bulgaria, over 120 individuals of *H. roseum* species-group were captured and identified on the basis of Arens' descriptions (Arens, 2012). Below, we confirm the presence of six species of this group.

Data on studied species

Hedychridium sculpturatum (Abeille de Perrin, 1877)

= *Hedychridium sculpturatum pseudoroseum* Linsenmaier, 1959
= *Hedychridium placare* Linsenmaier, 1968
= *Hedychridium lampadum austeritatum* Linsenmaier, 1997

DISTRIBUTION. South Europe, Cyprus, Ukraine, Turkey, Russia, North Caucasus, Near East, Kirghizstan, Mongolia, Western Siberia (Arens, 2010a, 2012).

REMARKS ON COLORATION. In Bulgaria we captured 8 females with non-metallic metasoma and only one male (identified by the studied genital apparatus) with metallic red metasoma. In Italy, in addition, we studied 32 individuals of *H. sculpturatum*. The metasoma color distribution results in 31 females and 2 males having non-metallic metasoma and 1 female and 7 males having metallic red metasoma. In Italy only one female has the metallic red metasoma and only two males have non-metallic metasoma.

We can suppose that the majority of *H. sculpturatum* is sexually dimorphic (as noted by Arens): females mostly with non-metallic red metasoma and males mostly with metallic red metasoma. It is worth mentioning that the single female with red metasoma had been captured in Tuscany.

In Table 1 are shown the data of individuals of *H. sculpturatum* studied by us.

Hedychridium scutellare (Tournier, 1878)

= *Hedychridium scutellare palestinense* Balthasar, 1953
= *Hedychridium mediocre* Linsenmaier, 1959
= *Hedychridium mediocre sardiniense* Linsenmaier, 1959
= *Hedychridium scutellare maculiventre* Linsenmaier, 1959
= *Hedychridium scutellare sculpturatissimum* Linsenmaier, 1959
= *Hedychridium mediocre corsuense* Perraudin, 1978
= *Hedychridium tunesiense* Linsenmaier, 1959
= *Hedychridium maculiventre raucum* Linsenmaier, 1997
= *Hedychridium sardinum* Linsenmaier, 1997

DISTRIBUTION. South Europe from Portugal to Croatia, Greece, Russia, north Caucasus (Tyrner, 1991; Rosa et al., 2019).

REMARKS ON COLORATION. Four females from Bulgaria have non-metallic metasoma and only one female from Greece show a metallic red metasoma. No male individuals of *H. scutellare* from Bulgaria could be studied. More individuals are needed to prove the sexual dimorphism in the metasoma interference color. From Italy we could study only 3 females and 1 male, all individuals have metallic red metasoma. Two males and 1 female from Iran (in F. Strumia collection) have metallic red metasoma. Apparently, in *H. scutellare* both females and males have metallic red metasoma. The studied material is listed in Table 2.

Hedychridium scutellare is a new record for Bulgaria.

Hedychridium rossicum Gussakovskij, 1948

= *Hedychridium valesiense* Linsenmaier, 1959
= *Hedychridium valesiense turcicum* Arens, 2010

DISTRIBUTION. South and central Europe, Ukraine, Near East, Moldova, Russia (Orenburg Province, Sverdlovsk Province), Crimea (Arens, 2010a; Vinokurov, 2013; Martynova, 2015). *H. rossicum* is the most frequent species in Bulgaria, Italy and, perhaps, in south Europe as a whole.

REMARKS ON COLORATION. Arens (2010a) studied over 120 males of *H. rossicum*, including

Sex	Locality	Latitude	Longitude	Date	Collector	Metasoma color
♀	Iran, Bam	29°06′02″N	58°19′44″E	22.05-4.07.2017	M. Fallahzadeh	Metallic red
♀	Iran, Bam	29°06′02″N	58°19′44″E	22.05-4.07.2017	M. Fallahzadeh	Metallic red
♂	Italy, Barbaresco (Cuneo)	44º43′26″N	8º04′26″E	26.07.2017	F. Strumia	Metallic red
♀	Bulgaria, north of Enina	42°40′50″N	25°24′57″E	23-29.07.2000	M. Langourov	Non-metallic
♀	Bulgaria, south of Vitanovo	42°03′34″N	27°25′14″E	24.07-24.08.1999	S. Petrov	Metallic red
♀	Bulgaria, south of Brushlyan	42°03′34″N	27°25′14″E	8.06-24.07.1999	S. Petrov	Metallic red
♀	Greece, north-east of Liri	39°12′06″N	23°20′15″E	9.09.2014	T. Ljubomirov	Metallic red
♀	Bulgaria, west of Vulkovo	41°34′39″N	23°12′51″E	4.10.2003	T. Ljubomirov	Non-metallic
♀	Iran, south of Jiroft	28°41′07″N	57°55′17″E	20.04-5.05.2017	M. Fallahzadeh	Metallic red
♀	Italy, north-west of Piombino	42°56′02″N	10°29′44″E	11-21.08.2000	F. Strumia	Metallic red
♀	Italy, north-west of Piombino	42°56′02″N	10°29′44″E	11-21.08.2000	F. Strumia	Metallic red
♀	Italy, north-west of Piombino	42°56′02″N	10°29′44″E	11-21.08.2000	F. Strumia	Metallic red

Table 2. Data on the studied individuals of *Hedychridium scutellare.*

the holotype and in addition,reported two males from Italy (Aosta-Valley, Ozein 1000m, 05.08.1991, 2.7.1994, leg. P. Rosa) with metasoma partlially metallic green (Figs. 1–4). From Bulgaria we captured 75 individuals, 43 females and 28 males of *H. rossicum,* mainly on the mountains of central Bulgaria. The sexual dimorphism in this species is minimal and males and females are easily identified according the descriptions of Arens (2010a, 2010b). In addition, the genitalia of all males were studied to confirm the identifications. In all previous investigations it was stated that males have the metasoma dorsum metallic red by interference and females the metasoma non-metallic brown (Figs. 1–4).

We discover that this statement is variable since we found 5 males with non-metallic brown metasoma (about 20% of studied males) as in females - see Fig. 2. We also found two males (about 5%) with bicolor metasoma (one from Bulgaria, one from Italy) (Fig. 4). From Italy (Tuscany) we could study 18 additional individuals of *H. rossicum* with the following result: 13 females with non-metallic metasoma, 2 males with metallic red metasoma and 3 males with non-metallic metasoma. Similar result is obtained from the study of additional 26 individuals captured in Corsica Island: 17 females having non-metallic metasoma against 2 males having metallic red metasoma and 7 males having non-metallic metasoma. It follows that almost all studied females of *H. rossicum* have a non-metallic metasoma. On the contrary the males have either a red metallic metasoma or a non-metallic metasoma in a variable ratio, contrary to older studies (in addition 2 males with a mixed bicolor red and green metasoma, as shown in Figs. 1–4).

Hedychridium caputaureum G. Trautmann et W. Trautmann, 1919

= *Hedychridium chloropygum densum* Linsenmaier, 1959
= *Hedychridium chloropygum spatium* Linsenmaier, 1959
= *Hedychridium chloropygum ottomanum* Arens, 2010

Distribution. North and central Europe, Ukraine, Asia Minor, Russia, north Caucasus (Arens, 2010a; Table 4 Data of the studied individuals of *H. capuraureum.*

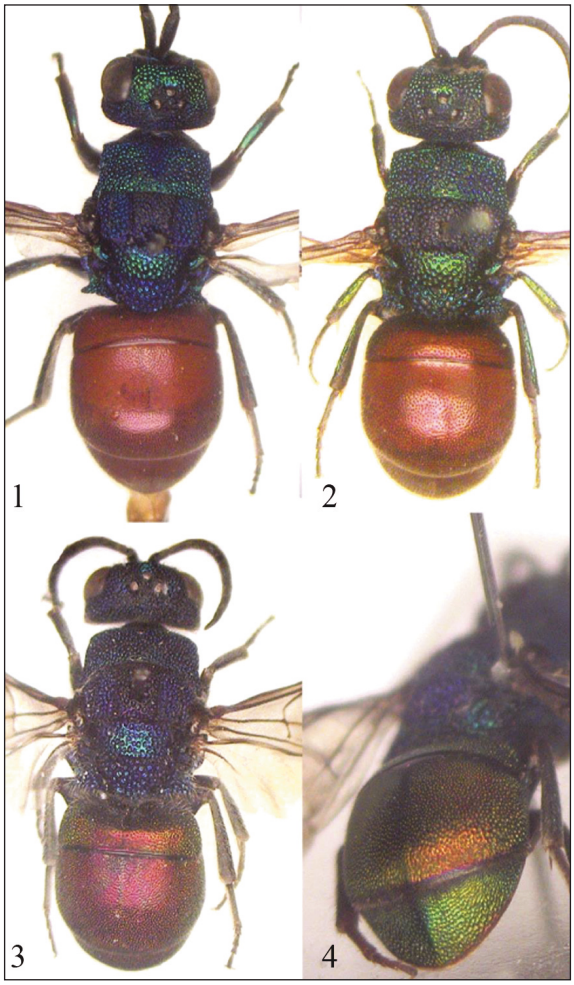
Remarks on coloration. In general, 11 females and one male of *H. caputaureum* were captured. They come from Bulgaria and Turkey. All females show non-metallic metasoma, while the single male has a red metallic metasoma. Study of more males is needed to establish the fraction of dimorphic metasoma color.

Sex	Locality	Latitude	Longitude	Date	Collector 11	Metasoma color
♂	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	9.08.1995	T. Ljubomirov	Metallic red
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	4.07.2013	T. Ljubomirov	Non-metallic
♂	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	29.06.2006	T. Ljubomirov	Metallic red
♂	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	23.06.2002	T. Ljubomirov	Metallic red
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	24.07.2002	T. Ljubomirov	Non-metallic
♂	Bulgaria, south-west of Barutin	41°34′08″N	24°10′08″E	7.08.2018	T. Ljubomirov	Metallic red
♂	Bulgaria, south-west of Barutin	41°34′08″N	24°10′08″E	7.08.2018	T. Ljubomirov	Non-metallic
♂	Bulgaria, east of Kladnitsa	42°33′13″N	23°11′39″E	4.07.1998	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Zheleznitsa	42°32′06″N	23°21′08″E	14.07.1999	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Zheleznitsa	42°32′06″N	23°21′08″E	14.07.1999	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Zheleznitsa	42°32′06″N	23°21′08″E	14.07.1999	T. Ljubomirov	Metallic red-green
♀	Bulgaria, west of Etropole	42°50′29″N	23°58′20″E	17.09.2002	T. Ljubomirov	Non-metallic
♂	Bulgaria, north of Bisstritsa	42°35′41″N	23°20′30″E	5.08.1998	T. Ljubomirov	Metallic red
♂	Bulgaria, north of Bisstritsa	42°36′03″N	23°20′13″E	5.08.1998	T. Ljubomirov	Metallic red
♂	Bulgaria, north of Bisstritsa	42°36′03″N	23°20′13″E	5.08.1998	T. Ljubomirov	Metallic red
♂	Bulgaria, north of Tchuypetlovo	42°31′43″N	23°14′08″E	22.07.1998	T. Ljubomirov	Mixe metallic red-green
♂	Bulgaria, north of Passarel	42°33′11″N	23°29′34″E	28.08.2001	T. Ljubomirov	Metallic red
♂	Bulgaria, south of Klokotnita	41°58′31″N	25°29′39″E	16.06.2005	T. Ljubomirov	Metallic red
♂	Bulgaria, south-west of Gorna Breznitsa	41°44′45″N	23°06′32″E	22.08.2002	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Medeni Polyani	41°51′11″N	23°45′55″E	16.08.2016	T. Ljubomirov	Metallic red
♀	Bulgaria, south-west of Tsaparevo	41°37′18″N	23°04′06″E	27.06.2008	T. Ljubomirov	Non-metallic
♂	Bulgaria, north of Varna	43°14′05″N	28°01′14″E	22.07.2001	I. Todorov	Metallic red
♂	Bulgaria, west of Gorna Breznitsa	41°44′24″N	23°06′01″E	10.07.2013	T. Ljubomirov	Metallic red
♂	Bulgaria, south-east of Ardino	41°34′38″N	25°08′42″E	15.08.2016	T. Ljubomirov	Metallic red
♀	Bulgaria, west of Milanovo	43°05′40″N	23°23′23″E	7.07.2015	T. Ljubomirov	Non-metallic
♂	Bulgaria, Muglizh	42°36′14″N	25°32′40″E	17-24.06.1995	I. Stoyanov	Metallic red
♂	Bulgaria, Muglizh	42°36′14″N	25°32′40″E	17-24.06.1995	I. Stoyanov	Metallic red
♂	Bulgaria, south of Petrich	41°22′05″N	23°11′14″E	10-20.07.2002	O. Todorov	Metallic red
♀	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Non-metallic
♂	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Metallic red
♂	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Metallic red
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	21.06.1997	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	21.06.1997	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	21.06.1997	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	21.06.1997	T. Ljubomirov	Non-metallic
♂	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	24.07.2002	T. Ljubomirov	Non-metallic

♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	4.07.2013	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Enina	42°40′50″N	25°24′57″E	23-29.07.2000	M. Langourov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′29″N	23°12′12″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′29″N	23°12′12″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′29″N	23°12′12″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′29″N	23°12′12″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′13″N	23°11′39″E	4.09.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′14″N	23°11′24″E	22.07.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Zheleznitsa	42°32′06″N	23°21′08″E	12.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Zheleznitsa	42°32′07″N	23°20′48″E	12.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Zheleznitsa	42°32′06″N	23°21′04″E	24.08.1998	T. Ljubomirov	Non-metallic
♂	Bulgaria, west of Milanovo	43°05′40″N	23°23′23″E	7.07.2015	T. Ljubomirov	Metallic red
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Kokalyane	42°34′19″N	23°24′46″E	20.09.2001	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Kokalyane	42°34′19″N	23°24′46″E	20.09.2001	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Kokalyane	42°34′19″N	23°24′46″E	20.09.2001	T. Ljubomirov	Non-metallic
♀	Bulgaria, Plovdiv	42°08′06″N	24°45′58″E	17-25.08.1999	S. Petrov	Non-metallic
♀	Bulgaria, north of Tchuypetlovo	42°31′18″N	23°14′41″E	14.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Tchuypetlovo	42°31′18″N	23°14′41″E	14.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Tchuypetlovo	42°31′18″N	23°14′41″E	14.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Kladnitsa	42°32′27″N	23°11′22″E	1.09.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Kladnitsa	42°32′27″N	23°11′22″E	1.09.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-east of Kladnitsa	42°32′06″N	23°12′42″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°35′54″N	23°14′49″E	22.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south of Sofia	42°35′54″N	23°14′49″E	22.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Gorna Breznitsa	41°43′12″N	23°06′39″E	19.06.2003	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Mikrevo	41°36′21″N	23°09′07″E	27.06.2008	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Deltchevo	41°33′11″N	23°38′00″E	28.04.2004	O. Todorov	Non-metallic
♀	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Non-metallic
♂	Bulgaria, west of Etropole	42°49′55″N	23°57′44″E	1.07.2010	T. Ljubomirov	Metallic red
♀	Bulgaria, west of Etropole	42°50′30″N	23°58′17″E	13.08.2018	T. Ljubomirov	Non-metallic
♀	Turkey, south-west of Eyüpler	37°44′58″N	30°49′18″E	29.07.2008	T. Ljubomirov	Non-metallic
♂	Italy, Vicarello	43º37′20″N	10º26′40″E	15.09.1991	F. Strumia	Non-metallic
♀	Italy, Chiani	43º27′50″N	10º40′44″E	29.07-09.08.2001	F. Strumia	Non-metallic
♀	Italy, Chiani	43º27′50″N	10º40′44″E	11-16.08.2000	F. Strumia	Non-metallic
♀	Italy, Piombino	42º56′44″N	10º29′56″E	4-18.07.2000	F. Strumia	Non-metallic

♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	6-16.09.1998	F. Strumia	Non-metallic
♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	25-30.07	F. Strumia	Non-metallic
♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	27.08-06.09.1998	F. Strumia	Non-metallic
♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	11-26.06 1998	F. Strumia	Non-metallic
♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	27.06-05.07.1998	F. Strumia	Non-metallic
♀	Italy, Vicchio, Firenze	43º33′20″N	10º32′53″E	18.08.1991	F. Strumia	Non-metallic
♀	Italy, Caselli Nat. reserve Pisa	43º13′46″N	10º41′57″E	20.07-02.08	F. Strumia	Non-metallic
♀	Italy, Gabbro	43º28′45″N	10º26′37″E	29.08-06.09.2014	F. Strumia	Non-metallic
♂	Italy, Caselli Nat. reserve Pisa	43º13′46″N	10º41′57″E	20.06-02.07.2019	F. Strumia	Metallic red
♂	Italy, Pisa	43º40′31″N	19º19′36″E	19.09.1991	F. Strumia	Non-metallic
♂	Italy, Marano, Pistoia	45º44′28″N	13º08′25″E	17.07.1989	F. Strumia	Non-metallic
♀	Italy, Cengio, Savona	44º23′10″N	8º11′36″E	4.09.1948	L. Berio	Non-metallic
♀	Italy, Cengio, Savona	44º23′10″N	8º11′36″E	4.09.1948	L. Berio	Non-metallic
♀	Italy, Chianni, Pisa	43º27′50″N	10º40′44″E	3-11.08. 2000	F. Strumia	Non-metallic
♀	France, Corsica, Castirla	42°22′58″N	9°09′08″E	24.06-24.07.2000	F. Strumia	Non-metallic
♀	France, Corsica, Castirla	42°22′58″N	9°09′08″E	27.06-08.07.2001	F. Strumia	Non-metallic
♀	France, Corsica, Castirla	42º22′58″N	9º09′08″E	3-15.07.2002	F. Strumia	Non-metallic
♂	France, Corsica, Castirla	42º22′58″N	9º09′08″E	30.06-13.07.1999	F. Strumia	Non-metallic
♂	France, Corsica, Castirla	42º22′58″N	9º09′08″E	1-23.08.2002	F. Strumia	Non-metallic
♀	France, Corsica, Castirla	42º22′58″N	9º09′08″E	3-15.07.2002	F. Strumia	Non-metallic
♀	France, Corsica, Castirla	42º22′58″N	9º09′08″E	30.06-16.07.1999	F. Strumia	Non-metallic
♀	France, Corsica, Cuttoli	41º57′50″N	8º50′50″E	10-25.07.2002	F. Strumia	Non-metallic
♂	France, Corsica, Cargese	42º08′10″N	8º35′30″E	21-22.08.1998	F. Strumia	Metallic red
♀	France, Corsica, Cargese	42º08′10″N	8º35′30″E	21-22.08.1998	F. Strumia	Non-metallic
♀	France, Corsica, Asco	42º28′30″N	9º01′20″E	4.07.2002	F. Strumia	Non-metallic
♂	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♀	France, Corsica, Ponte Leccia	42º27′07″N	9º14′40″E	14.06.1997	F. Strumia	Non-metallic
♂	France, Corsica, La Marana	42º34′01″N	9º31′32″E	14.06.1998	F. Strumia	Non-metallic
♀	France, Corsica, La Marana	42º34′01″N	9º31′32″E	18-26.08.1999	F. Strumia	Non-metallic
♂	France, Corsica, La Marana	42º34′01″N	9º31′32″E	7.-10.07.1998	F. Strumia	Non-metallic
♂	France, Corsica, La Marana	42º34′01″N	9º31′32″E	7.-10.07.1998	F. Strumia	Non-metallic
♂	France, Corsica, La Marana	42º34′01″N	9º31′32″E	21-22.08.1998	F. Strumia	Non-metallic
♀	France, Corsica, Conca Separellu	41º43′50″N	9º20′10″E	7.08.2004	F. Strumia	Non-metallic
♂	France, Corsica, Pielza	41º54′11″N	9º23'30″E	13.06.1997	F. Strumia	Metallic red

Table 3. Data on the studied individuals of *Hedychridium rossicum*.



Figures 1–4. *Hedychridium rossicum* Gussakovskij, 1948. Fig. 1: female with metasoma non-metallic (Bulgaria, south of Milanovo village, 764 m, 07.07.2015). Fig. 2: male with metasoma non-metallic (Bulgaria, north-west of Barutin village, 112 m, 07.08.2018). Fig. 3: male with metasoma metallic red (Bulgaria, west of Zheleznitsa village, 1140 m, 14.07.1999). Fig. 4: male with metasoma bicolor: second tergum metallic red, third tergum metallic green (Bulgaria, north-west of Bisstritsa village, 1100 m, 05.08.1998).

Hedychridium insulare Balthasar, 1953

= *Hedychridium roseum* var. *cypriacum* Balthasar, 1953
= *Hedychridium lampadum limassolense* Linsenmaier, 1959
= *Hedychridium mediocrum* Linsenmaier, 1987
= *Hedychridium mediocrate* Kimsey et R. Bohart, 1990

Distribution. Southwest Europe, Hungary, Ukraine, Near East, Cyprus, Syria, Armenia, Kazakhstan (Arens, 2010a).

Remarks on coloration. Only four females and two males were captured. All females have non-metallic metasoma while the two males have a metallic red metasoma. The study of more males is needed to establish the possible dimorphism in metasoma color. From Syria, Cyprus, Turkey and Greece we could study additional 10 females of *H. insulare*: all with non-metallic metasoma.

Hedychridium roseum (Rossi, 1790)

= *Hedychridium lampadum* Linsenmaier, 1959
= *Hedychridium lampadum sorianum* Linsenmaier, 1959
= *Hedychridium lampadum anatolicum* Arens, 2010

Distribution. Europe, Morocco, East Asia, Ukraine, Bulgaria, Greece Manchuria, Siberia, Russia (Martynova, 2015).

Remarks on coloration. In Bulgaria 6 males and 11 females were captured. All females show a non-metallic metasoma, while two males show metallic red metasoma coloration.

DISCUSSION

Tables 1–6 resume our captures from *Hedychridium roseum* species-group of Bulgaria. From this data follow a complex situation for the metasoma metallic color: this feature is unstable and variable. Apparently, the metasoma color suggests a connection to a sexual chromosome. The distance between reflecting layers in cuticle seems to be genetically variable. Fortunately, the identification keys of Arens are still useful, provided to skip metasoma color feature. The number of studied individuals from Bulgaria is limited (118) and for some uncommon species it is even too low to have a significant statistical meaning (Table 7).

We have found that in the majority of females in *H. roseum* species-group the metasoma is non-metallic. Only in *H. roseum* a few Bulgarian females have the metasoma metallic red. In males the metasoma coloration is more variable and unpredictable. Arens (2010a) considered *H. sculpturatum*

Sex	Locality	Latitude	Longitude	Date	Collector	Metasoma color
♂	Bulgaria, north-west of Passarel	42°33′12″N	23°29′34″E	4.07.2013	T. Ljubomirov	Metallic red
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	4.07.2013	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	29.07.2001	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	24.07.2002	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	24.07.2002	T. Ljubomirov	Non-metallic
♀	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	24.07.2002	T.Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Gorna Breznitsa	41°44′38″N	23°06′14″E	16.06.2002	T. Ljubomirov	Non-metallic
♀	Bulgaria, Svilengrad	41°46′28″N	26°08′36″E	19.05.2010	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Enina	42°40′50″N	25°24′57″E	23-29.07.2000	M. Langourov	Non-metallic
♀	Bulgaria, north of Passarel	42°33′54″N	23°29′30″E	29.07.2001	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Zemen	42°28′19″N	22°44′06″E	13.07.2016	T. Ljubomirov	Non-metallic
♀	Turkey, north of Küllü	36°56′04″N	36°24′02″E	14-21.07.2007	M.F. Gürbüz	Non-metallic

Table 4. Data on the studied individuals of *Hedychridium caputaureum.*

Sex	Locality	Latitude	Longitude	Date	Collector	Metasoma color
♂	Bulgaria, north of Yakovo	41°31′21″N	23°07′50″E	3.07.2012	T. Ljubomirov	Metallic red
♂	Bulgaria, south of Klokotnita	41°58′31″N	25°29′39″E	21.07.2005	T. Ljubomirov	Metallic red
♀	Bulgaria, south-west of Gorna Breznitsa	41°43′12″N	23°06′39″E	15.07.2003	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Gorna Breznitsa	41°43′12″N	23°06′39″E	15.07.2003	T. Ljubomirov	Non-metallic
♀	Turkey, Mitisin	36°59′02″N	36°22′29″E	22.07.2008	T. Ljubomirov	Non-metallic
♀	Turkey, Gökçaay suburb	37°44′52″N	30°32′28″E	29.07.2004	J. Kolarov	Non-metallic
♀	Cyprus, Limassol	-	-	1.06.1949	A. Mochi	Non-metallic
♀	Cyprus, Limassol	-	-	3.06.1949	A. Mochi	Non-metallic
♀	Syria, Damascus	-	-	11.10.1954	A. Mochi	Non-metallic
♀	Syria, Damascus	-	-	10.10.1952	A. Mochi	Non-metallic
♀	Greece, Kiparissia	-	-	19.06.1955	G. Pagliano	Non-metallic
♀	Greece, Kiparissia	-	-	19.06.1955	G. Pagliano	Non-metallic
♀	Turkey, Erzurum	-	-	12.08.1992	E. Yildirim	Non-metallic

Table 5. Data on the studied individuals of *Hedychridium insulare.*

a sexual dimorphic species with females' non-metallic and male's metallic red metasoma. The data in Table 3 confirm this statement even though it is based on a single available male. For *H. scutellare* we find all females non-metallic while Arens (2010a) assume that the metasoma both in the males and the females is all red. In *H. caputaureum* the single male is metallic red and the Arens' (2010a) sentence is in agreement with our data. The six individuals of *H. insulare* are in agreement with Arens' statement.

In *H. roseum* the majority of individuals (both males and females) exhibit non-metallic metasoma but among the six males studied two have metallic red metasoma (12% of available data) thus evidencing the need of additional investigation.

Sex	Locality	Latitude	Longitude	Date	Collector	Metasoma color
♂	Bulgaria, north-west of Passarel	42°33′05″N	23°29′30″E	21.06.1997	T. Ljubomirov	Non-metallic
♂	Bulgaria, west of Milanovo	43°05′40″N	23°23′23″E	7.07.2015	T. Ljubomirov	Metallic red
♂	Bulgaria, south of Petrich	41°22′05″N	23°11′14″E	10-20.07.2002	O. Todorov	Metallic red
♂	Bulgaria, south-east of Kladnitsa	42°32′49″N	23°12′07″E	25.08.2000	T. Ljubomirov	Red metallic
♀	Bulgaria, north-west of Dospat	41°41′42″N	24°06′36″E	31.08.2015	T. Ljubomirov	Non-metallic
♂	Bulgaria, west of Dobrostan	41°53′22″N	24°52′54″E	24.08.2013	T. Ljubomirov	Non-metallic
♀	Bulgaria, Banitsa	43°20′20″N	23°41′07″E	16-30.06.2013	L. Toshkov	Non-metallic
♀	Bulgaria, south of Sofia	42°38′10″N	23°14′38″E	14.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Borino	41°40′37″N	24°19′22″E	16.08.2016	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Kladnitsa	42°33′29″N	23°12′12″E	25.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Zheleznitsa	42°32′08″N	23°20′44″E	28.08.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Zheleznitsa	42°32′13″N	23°20′24″E	6.08.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, north of Tchuypetlovo	42°31′18″N	23°14′41″E	14.09.2000	T. Ljubomirov	Non-metallic
♀	Bulgaria, east of Bossnek	42°29′03″N	23°13′38″E	19.08.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, Batchkovo	41°55′59″N	24°51′58″E	9.08.2013	T. Ljubomirov	Non-metallic
♀	Bulgaria, south-west of Zheleznitsa	42°31′35″N	23°21′06″E	23.07.1998	T. Ljubomirov	Non-metallic
♀	Bulgaria, west of Tipchenitsa	43°03′56″N	23°41′42″E	7.06.2009	T. Ljubomirov	Non-metallic

Table 6. Data on the studied individuals of *Hedychridium roseum.*

Studied individuals of *Hedychridium roseum* species-group from Bulgaria	
Hedychridium insulare Balthasar, 1953	4
Hedychridium scutellare (Tournier, 1878)	5
H. sculpturatum (Abeille de Perrin, 1877)	9
Hedychridium caputaureum Trautmann &Traut., 1919	11
Hedychridium roseum (Rossi, 1790)	17
Hedychridium rossicum Gussakovskij, 1948	72

Table 7. Studied individuals of *Hedychridium roseum* species-group from Bulgaria.

In *H. rossicum* we found that only 75% of males have metallic red metasoma; further, two individuals exhibit a bicolor metallic red and green metasoma; all females are non-metallic. *Hedychridium rossicum* is the most frequent species both in Bulgaria and in Italy. It is also the most variable regarding the metasoma coloration in males and females, as shown in the Table 4.

Our results from Bulgaria are in agreement with the studied material from Tuscany, Sardinia, and Corsica.

CONCLUSIONS

Our results confirm the presence in the *Hedychridium roseum* species-group of either individual with or without interference color on Metasoma. It should be expected that the evolutionary pressure must select the most favorable color cancelling the less favorable. If this do not happens some special effect on biology can preserve such a dimorphic population. A careful study of individuals' biology would suggest a possible explanation. Unfortunately Chrysididae are uncommon, fast moving and difficult to observe in the field. Some statistical insight can be searched and tested if enough material from a given locality becomes available.

We have data for 15 *Hedychridium roseum* individuals captured in Tuscany around Pisa.

In Fig. 5 the time distribution of captures is shown. Apparently the two color forms are active at different summer times, thus with a different in-

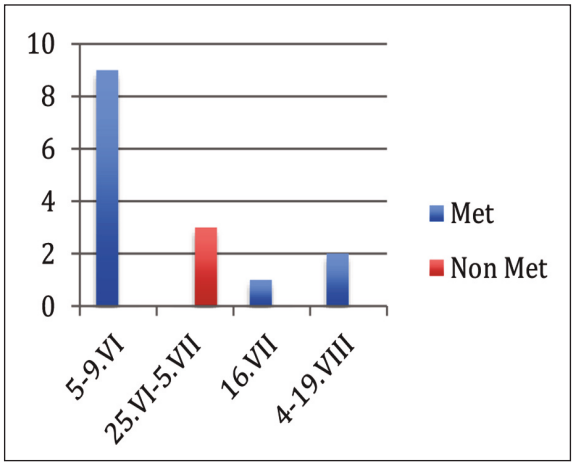


Figure 5. Time distribution of *H. rossicum* captures during the year.

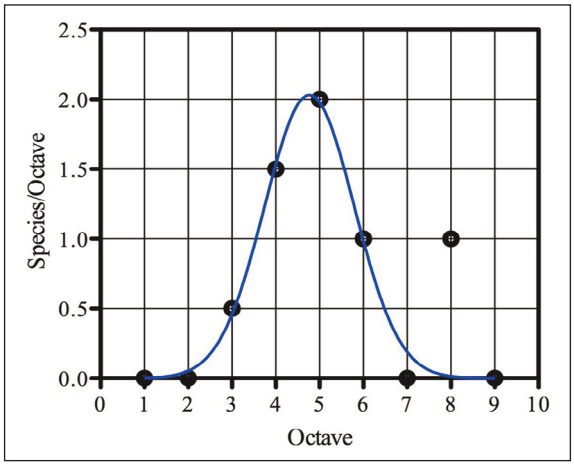


Figure 7. Lognormal distribution of the *H. roseum- group* species captured in Bulgaria. Note that the Lognormal is entirely restricted to positive values of Octaves.

teraction with the surrounding places and a different selection pressure. This is a possible explanation, even if the too reduced statistic can only suggest a direction for future investigations. The red metallic individuals are apparently more present in spring and in July and August. On the contrary, the less frequent individuals with non-metallic Metasoma were captured between June and July. The relative abundance of the six species captured in Bulgaria is summarized in Fig. 6.

The prevalence of *H. rossicum* may reflects a preference of collectors for locations most favorable to this species. The lognormal distribution can be calculated from above data and the result is shown in Fig. 7. Notably the lognormal distribution is entirely restricted to positive values of octaves. This shows that the presence of further species is not needed to optimize the lognormal distribution. Thus it follows that the observed six species of the *Hedychridium roseum*-group are the only one present in Bulgaria, and. no further species should be captured by further investigations.

In conclusion, the two-color form appears to be active in different time intervals and thus subjected to possible, different or independent, evolutionary selection pressure. Unfortunately the data numbers are too small and only a possible explanation can be suggested.

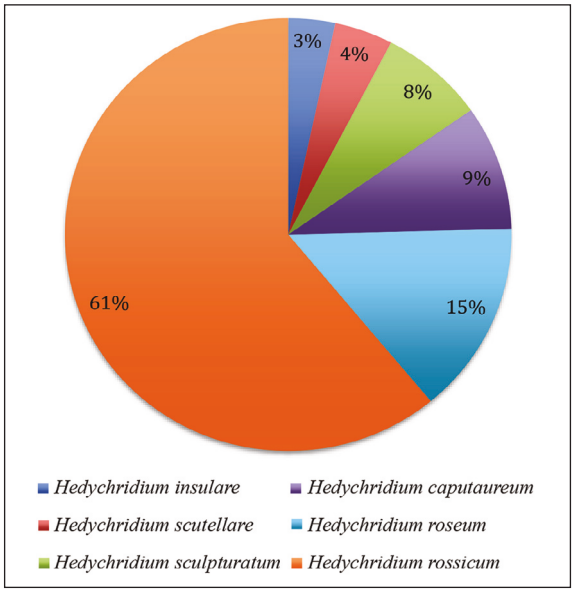


Figure 6. Relative abundance of the *Hedychridium roseum* species-group as observed in the Bulgarian material.

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