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VARIATION IN ELYTRAL MACULAR FORMS OF *COCCINELLA SEPTEMPUNCTATA* L. (COLEOPTERA: COCCINELLIDAE) IN NORTH AMERICA

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Abstract.—*Coccinella septempunctata* L. is a widespread Palearctic species that has been introduced several times into North America within the last century. It is generally considered monomorphic with seven elytral maculae in North America. In this paper, we document variation in elytral macular patterns of *C. septempunctata* based on examination of 674 (567 North American and 107 Palearctic) specimens of *C. septempunctata* and 382 digital submissions of North American *C. septempunctata*. Two beetles lacked apical maculae, and 18 beetles had paired humeral markings. Humeral markings were consistent in position and typically had less-dense black pigmentation than maculae. Sixteen of the 18 beetles with paired humeral markings were from 11 states in the United States, one was from Alberta, Canada, and one was from Italy. Some specimens had asymmetrical elytral markings that included pock marks, irregular fuscous markings, or both. Nineteen specimens of *C. septempunctata* (19 North American, 1 Palearctic) and 16 *C. septempunctata* in digital images had asymmetrical markings. Some beetles with paired humeral markings also had dark pock marks or irregular fuscous markings. We recommend examining additional *C. septempunctata* from various locations to accurately estimate frequency and pattern of variation in elytral macular forms. Possible causes and implications of variation in the elytral maculae of *C. septempunctata* are discussed.

Key Words: sevenspotted lady beetle, elytral maculae, humeral markings, identification, taxonomic determination

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The dorsum of most coccinellids (Coleoptera: Coccinellidae) has color patterns that vary among and within species (Honěk 1996). The basic unit of pattern on the elytra is a macula, or spot, that has a constant position within a species, but pattern of elytral maculation often varies in number and size of individual maculae (Johnson 1910,

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Honěk 1996). Variation in maculation pattern is due to genetics and environment (Honěk 1996). The degree of macular expression is genetic and ranges from immaculateness to coalescence that results in melanic forms (Johnson 1910, Majerus et al. 1982, Honěk 1996). Macular size is also influenced by environmental conditions such as temperature (Okuda et al. 1997).

Coccinella Linneaus is a genus of mainly Holarctic species that generally have red-orange elytra with black maculae (Gordon 1985, Kuznetsov 1997). Elytral color pattern is used with other morphological characters for species identification and nomenclature within the genus (Brown 1962, Gordon 1985, Gordon and Vandenberg 1991). *Coccinella septempunctata* is native to the Paleartic Region but has been introduced several times into North America within the last century, where it is now established and widespread (Gordon 1985, Gordon and Vandenberg 1991). Both its scientific name and common name (the sevenspotted lady beetle, Entomological Society of America 2009) are based on individuals with seven elytral maculae in North America and many parts of Eurasia (Gordon 1985, Gordon and Vandenberg 1991, Honěk 1996). In the Palearctic Region, additional variants of *C. septempunctata* have been documented including those that lack some maculae, ones with confluent maculae, and melanic individuals (Dobzhansky and Sivertskev-Dobzhansky 1927, Rhamhalinghan 1985, Kuznetsov 1997).

We recently encountered variants of the typical seven-spotted form of *C. septempunctata* in North America and in a limited number of Palearctic specimens. Heretofore, the presence of elytral macular variation has not been documented in North American populations of *C. septempunctata*, and some types of macular variation are apparently unreported for Palearctic specimens of this species. Lack of information about such macular forms may hinder proper identification of specimens. Moreover, apparent novelty of these macular forms provokes questions about their causes and whether such macular forms carry selective advantage over typical forms. In this paper, we document and describe variations in the patterns of elytral maculae in *C. septempunctata*, list possible causes, and discuss their implications.

Materials and Methods

Specimens of *C. septempunctata* with atypical elytral patterns were initially encountered opportunistically during field and museum work and during evaluation of digital images of *C. septempunctata*. After finding the initial elytral-macular pattern variants, specimens from several collections were checked for additional variants. Specimens were determined by using Gordon's (1985) key to *Coccinella* species of North America. Digital specimens of *C. septempunctata* were determined by matching as many characters as were visible in each image. A total of 674 (567 North American and 107 Palearctic) physical specimens of *C. septempunctata* were examined for variations in elytral macular patterns from the following collections: Delta Research Center collection, University of Missouri, Portageville (DRCC); USDA-ARS North Central Agricultural Research Laboratory collection, Brookings, South Dakota (NCARL); Severin-McDaniel Insect Research Collection, South Dakota State University, Brookings (SDSU); Iowa State University Insect Collection, Ames (ISUI); W. R. Enns Entomology Museum, University of Missouri, Columbia (UMRM); and personal collections of Paul K. Lago (PKLC) and two of

the authors (KF and KVT). A total of 384 digital submissions of *C. septempunctata* that had been uploaded to the Lost Ladybug Project (LLP) website (lostladybug.org) were also examined.

A scheme commonly employed by coccinellid workers (Johnson 1910, Wingo 1952) to number elytral maculae (Fig. 1) was used as an aid in describing elytral patterns of variants of *C. septempunctata*. According to the scheme, maculae are numbered in ascending order from base to apex and from outer margin to sutural margin. Scutellar area maculae on elytra are counted together (or each as a half). Specimens were retained as either digitally-imaged, virtual vouchers through the Lost Ladybug Project database (LLPD) or as voucher specimens in the aforementioned collections.

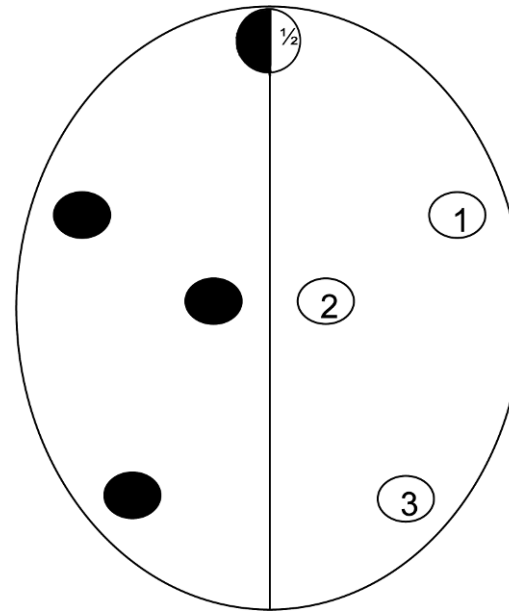

Fig. 1. Numbering scheme for elytral maculae on a seven-spotted beetle. Numerical designations of maculae: 1/2 = postscutellar, 1 = lateral, 2 = discal, 3 = apical.

Results

Several beetles were determined as *C. septempunctata*, although their elytral-macular patterns varied from the monomorphic form typical of this species in North America. However, they had several other characters typical of *C. septempunctata* in North America, such as head black with two, well separated pale areas; pronotum with anterior margin black, ventral pale area small and only extending posteriorly about 1/3 as far as white dorsal area; elytral suture red orange and not significantly darker than discal areas; and tarsal claw with large tooth (Gordon 1985).

Variation in elytral macular patterns of *C. septempunctata* was either symmetrical or asymmetrical between elytra of individual beetles. Symmetrical variation consisted of either a lack of macula number 3 (apical macula) on each elytron (Fig. 2) or the presence of humeral markings (Fig. 3). Two *C. septempunctata* lacked maculae, and 18 had paired humeral markings (Table 1). Both beetles lacking maculae were from South Dakota. Sixteen of the 18 beetles with paired humeral markings were from 11 states in the United States, one was from Alberta, Canada, and one was from Italy. Humeral markings were consistent in position on elytral humeri and typically lighter than maculae. An additional 18 beetles in LLP images had at least one humeral marking, but because of the angles at which these specimens were photographed, paired humeral markings could not be verified.

Asymmetrical markings consisted of either the presence of one or more mostly black, circular, concave pock marks (Fig. 4); irregular, fuscous markings that occurred sporadically and were generally subequal in size and color to maculae (Fig. 5); or both kinds of markings. Some beetles with paired humeral markings also had dark pock marks or irregular fuscous markings

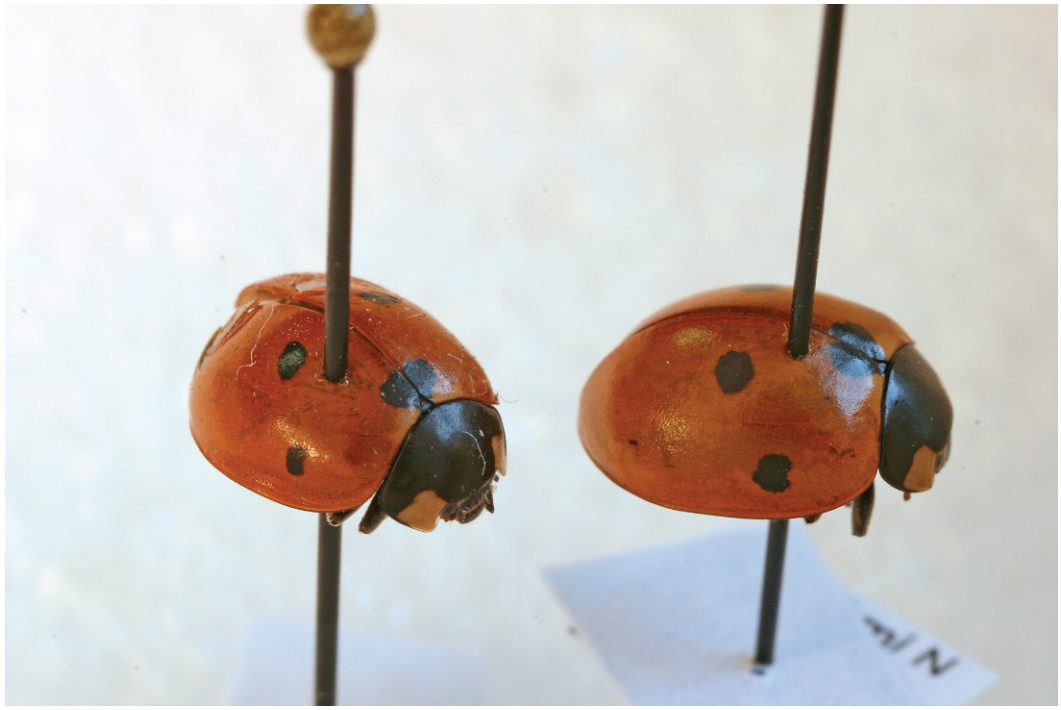

Fig. 2. Two *Coccinella septempunctata*, each with macula 3 (apical macula) inapparent on each elytron.

(Fig. 4). Twenty pinned specimens of *C. septempunctata* (19 North American, 1 Palearctic) and 16 North American *C. septempunctata* in LLP images had asymmetrical markings.

Discussion

To our knowledge, *C. septempunctata* lacking maculae and those with humeral markings have not been described for North American popula-

Fig. 3. Two specimens of *Coccinella septempunctata* with paired humeral markings.

Table 1. Specimens of *Coccinella septempunctata* with symmetrical variations in elytral macular patterns. NCARL = USDA-ARS North Central Agricultural Research Laboratory, Brookings, South Dakota; UMRM = W. R. Enns Entomology Museum, University of Missouri, Columbia; PKLC = private collection, Paul K. Lago; UASM = E. H. Strickland Entomological Museum at the University of Alberta, Edmonton; LLPD = Lost Ladybug Project digital image repository; DRCC = Delta Research Center, Portageville, Missouri.

Type of Elytral Macular Variation	Country, State or Province	Locality	Date	Collection
Macula number 3 inapparent	U.S.A., South Dakota	13 mi. south of Hermosa, Custer County, South Dakota, west side of State Highway 79	6 July 2008	NCARL
	U.S.A., South Dakota	1.5 mi. north of Brookings, Brookings County	29 June 2009	NCARL
Black humeral markings anterior to macula 1	Italy, Bologna	Farne	10 May [19?]45	UMRM
	U.S.A., Missouri	South Research Farm, University of Missouri, Columbia, Boone County, Missouri	20 July 1993	UMRM
	U.S.A., Mississippi	3 mi. northeast of Winona, Montgomery County	27 September 1995	PKLC
	Canada, Alberta	Kakwa Wildland Park, Sulphur Ridge	17–22 June 2006	UASM
	U.S.A., Maryland	Nanjemoy, Charles County	28 April 2007	LLPD
	U.S.A., South Dakota	Near Timon Campground, Lawrence County	28 June 2007	NCARL
	U.S.A., New York	Candor, Tioga County	17 August 2007	LLPD
	U.S.A., Michigan	Dearborn, Wayne County	4 August 2008	LLPD
	U.S.A., Arizona	Kingman, Mohave County	12 April 2009	LLPD
	U.S.A., Arizona	Bisbee, Cochise County	25 April 2009	LLPD
	U.S.A., Tennessee	Henderson County, 2 beetles	30 April 2009	DRCC
	U.S.A., Washington	Bothell, King County	30 April 2009	LLPD
	U.S.A., Missouri	Savannah, Andrew County	5 June 2009	LLPD
	U.S.A., New York	Ithaca, Tompkins County	12 June 2009	LLPD
	U.S.A., Colorado	Colorado Springs, El Paso County	16 June 2001	LLPD
	U.S.A., Colorado	Falcon, El Paso County	19 June 2009	LLPD
	U.S.A., Oregon	Elkton, Douglas County	18 July 2010	LLPD

tions, and thus, they represent previously unreported elytral-macular variants of this species in the region. The lack of maculae has been documented in Palearctic populations of *C. septempunctata* (Kuznetsov 1997). Among North American *C. septempunctata* in this study, individuals lacking macula 3 were both from South Dakota but respectively were from eastern and western borders of the state approximately 400 km apart. Beetles with humeral markings were from 11 states in the United States and Alberta, Canada, demonstrating that this character is widespread among populations of *C. septempunctata* in North America. The Italian specimen with humeral markings in our study shows that this elytral macular variation also occurs in Palearctic populations, but we are unaware of any reports that point out this feature in specimens from that region. However, too few individuals were found to infer geographical

Fig. 4. *Coccinella septempunctata* with humeral markings, two discal markings, and one subapical marking near elytral suture.

Fig. 5. *Coccinella septempunctata* with large black spot on left elytron between apical macula and elytral suture.

patterns or estimate frequencies among North American or Palearctic populations, although incidence of the types of elytral-macular variation in this study appears relatively low. Many additional *C. septempunctata* from various locations need to be examined to accurately determine frequency and geographical pattern of variation in elytral-macular forms.

Causes of elytral-macular variation in *C. septempunctata* may be genetic or environmental (Dobzhansky and Sivertskev-Dobzhansky 1927, Britton et al. 1977, Honěk 1996, Okuda et al. 1997). As occurrence of maculae in regular positions on elytra is genetically controlled (Honěk 1996), we surmise that inapparency of macula 3 pairs in the two beetles from South Dakota was most likely genetic and precluded expression of melanin pigment at that particular position on elytra.

For beetles with paired humeral markings, it is unclear whether markings were due to genetics or environment. On one hand, the position of humeral markings corresponds to that of humeral maculae in some other *Coccinella* species (Gordon 1985, Kuznetsov 1997). These latter characteristics suggest a genetic basis. If additional live specimens with humeral markings are found, positions of markings should be carefully determined and crossing experiments conducted to test for a genetic basis of humeral markings. Future studies may also determine if occasional mating attempts with congeneric species occur successfully in order to ascertain whether genetic introgression may contribute to macular variation in *C. septempunctata*.

However, humeral markings were neither as large nor as contrasting as maculae, and thus, their presence may have a different basis than maculae. Markings were consistent in position on humeral angles of elytra among specimens, and they were directly above the point where the elytron contacts the basal sclerites of the hind wing below. The elytra were also slightly impressed where they met the wing-base sclerites. The correspondence of these morphological features suggests that the humeral spot serves a strengthening function or a response to abrasion with

wing-base sclerites. Majerus (1998) has proposed that melanin granules in the exoskeleton of dark-colored desert beetles increase their resistance to sand abrasion.

Several *C. septempunctata* in this study had dark pock marks or other irregular fuscous markings that were generally unpaired and varied in their position on elytra. The underlying cause(s) of the irregular marks in our specimens is unknown, and future experiments are needed to determine their origin. In general, atypical elytral markings in beetles may arise from teratologies (Sokoloff 1966) or as responses to injury (Shelford 1915; Unruh and Chauvin 1993; Majerus 1994, 1998). Injury to the epidermis of pupae results in asymmetric melanin deposition and spotting in ensuing adults of *C. septempunctata* (Majerus 1998). Elytral punctures used for marking adults of the Colorado potato beetle, *Leptinotarsa decimlineata* (Say), strongly resemble pock marks in our specimens of *C. septempunctata* (Unruh and Chauvin 1993) and thus suggest agent(s) capable of puncturing elytra may produce pock marks in *C. septempunctata*.

Future studies are needed to determine implications of variation in elytral-macular forms of *C. septempunctata*. It is not known whether the lack of maculae or presence of paired humeral markings confers any selective effect. From a practical standpoint, absence of particular maculae or appearance of non-macular markings in *C. septempunctata* may confound species-level determinations of individual beetles. For example, superficial examination of individual *C. septempunctata* with paired humeral markings or those with paired discal pock marks could lead to their misidentification as the typical nine-spotted form of *Coccinella novemnotata* Herbst, whereas individuals lacking macula 3 could be misconstrued as an elytral-macular form of *C. novemnotata* with five maculae that occurs mainly in western states of the U.S. (Brown 1962). Potential for these types of error emphasizes the need to carefully compare positions of maculae and other markings of undetermined specimens with descriptions and illustrations of *Coccinella* species and to include other characters, such as genitalia or markings on the head and pronotum, for making accurate species determinations (Brown 1962, Gordon 1985, Kuznetsov 1997). It also suggests that future identification guides for Coccinellidae need to describe and perhaps illustrate variation in elytral-macular forms of *C. septempunctata* such as those in this study.

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