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Insecta Mundi. 1209.

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INSECTA MUNDI

A Journal of World Insect Systematics

0719

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Date of issue: July 26, 2019

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Insecta Mundi 0719: 1–9

ZooBank Registered: urn:lsid:zoobank.org:pub:E3EDA06F-80B3-4845-85ED-65A1B59E0CD1

Published in 2019 by

Center for Systematic Entomology, Inc.

P.O. Box 141874

Gainesville, FL 32614-1874 USA

<http://centerforsystematicentomology.org/>

Insecta Mundi is a journal primarily devoted to insect systematics, but articles can be published on any non-marine arthropod. Topics considered for publication include systematics, taxonomy, nomenclature, checklists, faunal works, and natural history. *Insecta Mundi* will not consider works in the applied sciences (i.e. medical entomology, pest control research, etc.), and no longer publishes book reviews or editorials. *Insecta Mundi* publishes original research or discoveries in an inexpensive and timely manner, distributing them free via open access on the internet on the date of publication.

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Electronic copies (Online ISSN 1942-1354, CDROM ISSN 1942-1362) in PDF format

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Layout Editor for this article: Robert G. Forsyth

Korean encyrtids (Hymenoptera: Encyrtidae) associated with scale insects (Hemiptera: Coccoomorpha)

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Abstract. Scale insects (Hemiptera: Coccoomorpha) are sap-sucking plant parasites and economically important pests on agricultural and horticultural crops. Scale insects are often difficult to control since their body is protected by a wax cover. Parasitic wasps that live and develop in scale insects are important natural enemies and effective biological control agents of pest scale insects. Chalcid wasps of the family Encyrtidae (Hymenoptera: Chalcidoidea) comprise the largest group of parasitoids of scale insects, followed by the family Aphelinidae. Here, an updated list of all thirty-six species of encyrtids in twenty-three genera that have been identified or reported from South Korea is provided, along with a dichotomous taxonomic key to separate them.

Key words. Parasitic wasps, checklist, dichotomous key, biological control.

Introduction

Scale insects (Hemiptera: Coccoomorpha) are small sap-sucking plant parasites and economically important pests on agricultural and horticultural crops. Scale insects are often difficult to control with pesticides, as their body is protected by a wax cover. Thus, the management of pest scale insects requires a combination of tactics including chemical, cultural and biological control (Ouvrard et al. 2013). Parasitic wasps that live and develop in scale insects are important natural enemies and effective biological control agents of pest scale insects. Most of the parasitoids associated with scale insects are chalcid species belonging to the families Encyrtidae, Aphelinidae, Eulophidae, Pteromalidae, Siphonophoridae, and Eupelmidae. Of these families, Encyrtidae are the major parasitoids of scale insects (Xu and Huang 2004).

The family Encyrtidae contains over 3,735 species in 460 genera worldwide and is thus one of the largest families belonging to the superfamily Chalcidoidea (Noyes 2019). The encyrtids form a large part of the chalcidoid fauna associated with scale insects (Hemiptera: Coccoomorpha); of the reported encyrtid genera, about 45 genera are parasitic on soft scale insects (Hemiptera: Coccidae) and 28 on armored scale insects (Hemiptera: Diaspididae) (Prinsloo 1997). These parasitoid species attack various species of scale insects. Thus, the greatest value of the encyrtids lies in their ability to control scale insect populations under natural and agricultural conditions in their native environments (Noyes 1990; Prinsloo 1997).

This family is distinguished from other Chalcidoidea by the following combination of characters: 1) both sexes with mesopleuron enlarged, often occupying more than half the mesosoma in side view, 2) mid coxae level with middle of mesopleuron in side view, 3) cercal plates advanced, not placed at apex of gaster and frequently in anterior two-thirds, 4) linea calva present and distinct, 5) mesoscutum transverse and without notauli, or if notauli are present then they are very shallow and curved, never deep and straight (Noyes 2019).

The encyrtid parasitoid *Anicetus beneficus* Ishii and Yasumatsu was introduced from Japan to Jeju, South Korea in 1975 for biological control of the red wax scale *Ceroplastes rubens* Maskell (Hemiptera: Coccidae), which is a serious pest of citrus (Kim et al. 1979). Consequently, this project has been the focus of several taxonomic contributions (Paik 1978, 1980, 1994). Since then, Paik (1978) listed 38 species (including 13 undetermined species and one deliberately introduced species) in 26 genera of encyrtids in the catalogue of the Korean Chalcidoidea, but, only a list of the encyrtids and hosts was enumerated. Subsequently, species of the following genera have been added to the Korean fauna: *Acerophagus* Smith, *Adelencyrtus* Ashmead, *Anagyrus* Howard, *Aphycoides* Mercet, *Arrhenophagus* Aurivillius, *Caenohomalopoda* Tachikawa, *Callipteroma* Motschulsky, *Encyrtus* Latreille, *Leptomastidea* Mercet,

Rhopus Foerster, and *Zaomma* Ashmead (Paik 1980, 1994; Tachikawa et al. 1981; Trajapitzin and Paik 1996; Li and Byun 2001; Li et al. 2002). To date, 45 species belonging to 29 genera have been documented in Korea (Gim 2010; Choi et al. 2012; Suh 2019). Of these, 36 species belonging to 23 genera have been reported from scale insects (Choi et al. 2012; Suh 2019). Soft scale insects (Coccidae) constitute 27% (10 species), armored scale insects (Diaspididae) 22% (8 species), mealybugs (Pseudococcidae) 16% (6 species), gall-like scales (Kermesidae) 11% (4 species), felt scales (Eriococcidae) 8% (3 species), and others 16% (6 species) of primary hosts of encyrtids recorded in Korea.

The purpose of this paper is to provide an identification key to the genera and species of encyrtids associated with scale insects known to occur in Korea, based on characters of the adult female. This information will not only enable researchers to identify the species known to occur in Korea, but also aid in the recognition of possible biological control agents.

Materials and Methods

Information on the number of encyrtids associated with scale insects known to occur in South Korea and in all zoogeographic regions was gathered from published literature reporting South Korea's encyrtids (Paik 1978, 1980, 1994; Kim et al. 1979; Tachikawa et al. 1981; Trajapitzin and Paik 1996; Li and Byun 2001; Li et al. 2002; Gim 2010; Choi et al. 2012; Suh 2019) and the Universal Chalcidoidea Database (Noyes 2019), a website that includes worldwide information on species of encyrtids on scale insects. This paper provides a dichotomous key and a list of 36 species of encyrtids associated with scale insects reported from South Korea. While developing the key, the author was not able to examine specimens of these species from South Korea. It should be noted that the key was developed based on the literature (Tachikawa et al. 1981; Noyes and Hayat 1984; Li et al. 2002; Xu and Huang 2004; Zhang and Huang 2004, 2006; Zhang and Shi 2010; Wang et al. 2014; Japoshvili et al. 2016) and some collected specimens. Terminology for the morphological structures used in the key follows that of Noyes and Hayat (1984).

Results

The family Encyrtidae is one of the most successful groups of insects used in biological worldwide (LaSalle 1993; Noyes 2019). Based on the review of the literature and survey results, there are 45 species known to occur in South Korea which represent 1.2% of all described species. Of these, 36 species belonging to 23 genera have been reported from scale insects (Table 1). A dichotomous key to the Korean encyrtids associated with scale insects is provided below for the identification of encyrtid species recorded from scale insects in South Korea.

Table 1. Species of the family Encyrtidae associated with scale insects in South Korea.

Species	Original description	Korean record	Primary hosts reported in Korea	Remarks
<i>Acerophagus malinus</i>	Gahan 1946	Trajapitzin and Paik 1996	<i>Pseudococcus comstocki</i> (Hemiptera: Pseudococcidae)	
<i>Adelencyrtus aulacaspidis</i>	Brethes 1914	Paik 1978	<i>Aulacaspis rosae</i> (Hemiptera: Diaspididae)	
<i>Adelencyrtus kosef</i>	Li et al. 2002	Li et al. 2002	<i>Pseudaulacaspis cockerelli</i> (Hemiptera: Diaspididae)	
<i>Anagyrus antoninae</i>	Timberlake 1920	Paik 1978	<i>Antonina crawii</i> (Hemiptera: Pseudococcidae)	
<i>Anagyrus niger</i>	Ishii 1928	Paik 1980	–	Listed from Korea, but host record could not be found

Species	Original description	Korean record	Primary hosts reported in Korea	Remarks
<i>Anagyrus schoenherri</i>	Westwood 1837	Paik 1978	<i>Phenacoccus pergandei</i> (Hemiptera: Pseudococcidae)	
<i>Anicetus beneficus</i>	Ishii and Yasumatus 1954	Paik 1978	<i>Ceroplastes rubens</i> (Hemiptera: Coccidae)	Deliberately introduced in 1975
<i>Anicetus ceroplastis</i>	Ishii 1928	Paik 1978	<i>Ceroplastes japonicus</i> , <i>Ceroplastes ceriferus</i> (Hemiptera: Coccidae)	
<i>Aphycoides fuscipennis</i>	Ashmead 1904	Paik 1994	–	Listed from Korea, but host record could not be found
<i>Aphycus apicalis</i>	Dalman 1820	Paik 1978	<i>Phenacoccus pergandei</i> (Hemiptera: Pseudococcidae)	
<i>Arrhenophagus chionaspidis</i>	Aurivillius 1888	Li and Byun 2001	<i>Pseudaulacaspis cockerelli</i> (Hemiptera: Diaspididae)	
<i>Blastothrix erythrostetha</i>	Walker 1847	Paik 1978	<i>Kermes vastus</i> (Hemiptera: Kermesidae)	
<i>Caenohomalopoda koreana</i>	Tachikawa, Paik and Paik 1981	Tachikawa et al. 1981	<i>Odonaspis secreta</i> (Hemiptera: Diaspididae)	
<i>Caenohomalopoda shikokuensis</i>	Tachikawa 1956	Trjapitzin and Paik 1996	<i>Odonaspis secreta</i> (Hemiptera: Diaspididae)	
<i>Callipteroma sexguttata</i>	Motschulsky 1863	Paik 1994	–	Listed from Korea, but host record could not be found
<i>Cerapterocerus mirabilis</i>	Westwood 1833	Paik 1978	<i>Eriopeltis festucae</i> (Hemiptera: Coccidae)	
<i>Cheiloneurus quercus</i>	Mayr 1876	Paik 1978	<i>Kermes miyasakii</i> , <i>Kermes vastus</i> (Hemiptera: Kermesidae)	
<i>Clausenia purpurea</i>	Ishii 1923	Paik 1978	<i>Planococcus citri</i> (Hemiptera: Pseudococcidae)	
<i>Comperiella bifasciata</i>	Howard 1906	Paik 1978	<i>Chrysomphalus bifasciculatus</i> (Hemiptera: Diaspididae)	
<i>Comperiella unifasciata</i>	Ishii 1925	Paik 1978	<i>Pseudaonidia duplex</i> (Hemiptera: Diaspididae)	
<i>Encyrtus aurantii</i>	Geoffroy 1785	Paik 1994	–	Listed from Korea, but host record could not be found
<i>Encyrtus infidus</i>	Rossi 1790	Trjapitzin and Paik 1996	<i>Eulecanium kunoense</i> (Hemiptera: Coccidae)	
<i>Encyrtus sasakii</i>	Ishii 1928	Paik 1978	<i>Takahashia japonica</i> (Hemiptera: Coccidae)	
<i>Leptomastidea bifasciata</i>	Mayr 1876	Paik 1994	–	Listed from Korea, but host record could not be found
<i>Mahencyrtus comara</i>	Walker 1837	Paik 1978	Undetermined mealybug (Hemiptera: Pseudococcidae)	
<i>Metaphycus eriococci</i>	Timberlake 1916	Suh 2019	<i>Acanthococcus lagerstroemiae</i> (Hemiptera: Eriococcidae)	
<i>Metaphycus tenuicornis</i>	Timberlake 1916	Paik 1978	<i>Kermes vastus</i> (Hemiptera: Kermesidae)	

Species	Original description	Korean record	Primary hosts reported in Korea	Remarks
<i>Metaphycus zebratus</i>	Mercet 1917	Paik 1978	<i>Eriopeltis festucae</i> (Hemiptera: Coccidae)	
<i>Microterys clauseni</i>	Compere 1926	Paik 1978	<i>Ceroplastes japonicus</i> , <i>Ceroplastes ceriferus</i> (Hemiptera: Coccidae)	
<i>Microterys ericeri</i>	Ishii 1923	Paik 1978	<i>Ericerus pela</i> (Hemiptera: Coccidae)	
<i>Microterys rufofulvus</i>	Ishii 1928	Paik 1978	<i>Takahashia japonica</i> (Hemiptera: Coccidae)	
<i>Psilophrys tenuicornis</i>	Graham 1969	Paik 1978	<i>Kermes vastus</i> (Hemiptera: Kermesidae)	
<i>Rhopus semiapterus</i>	Mercet 1921	Paik 1980	–	Listed from Korea, but host record could not be found
<i>Trichomasthus cyanifrons</i>	Dalman 1820	Paik 1978	<i>Eripeltis festucae</i> (Hemiptera: Coccidae); <i>Acanthococcus lagerstroemiae</i> (Hemiptera: Eriococcidae)	
<i>Zaomma eriococci</i>	Ferriere 1955	Suh 2019	<i>Acanthococcus lagerstroemiae</i> (Hemiptera: Eriococcidae)	
<i>Zaomma lambinus</i>	Walker 1838	Trjapitzin and Paik 1996	<i>Pseudaulacaspis pentagona</i> (Hemiptera: Diaspididae)	

Key to encyrtids associated with scale insects in Korea (females)

1. Dorsum of metasoma (or abdomen) with paratergites, at least represented by a membranous strip which connects the outer plates of the ovipositor to the sides of the last gastral tergite, either along its length or at the base near the cercal plates only; linea calva of forewing with undifferentiated margins; hypopygium triangular, usually extending to apex of gaster; all denticles of mandible sharp, without a truncation (with some exceptions); Tetracneminae **2**
- Dorsum of metasoma without paratergites (with some exceptions); linea calva of forewing with coarser and longer setae at base than those at apex, evenly pubescent; hypopygium often short and subrectangular, not extending to apex of gaster; mandible often with a truncation; Encyrtinae **8**
- 2(1). Pronotum separated medially; mesoscutum without notaular lines; primary parasitoids of Pseudococcidae ***Rhopus semiapterus* (Mercet)**
- Pronotum not separated medially; mesoscutum with notaular lines **3**
- 3(2). Scape longer than 3× its own width **6**
- Scape not longer than 3× its own width; primary parasitoids of Pseudococcidae; *Anagyrus* .. **4**
- 4(3). Antenna nearly all black ***Anagyrus niger* (Ishii)**
- Antenna with at least clava yellow to white **5**
- 5(4). F1–F6 of antenna dark, lightened apically ***Anagyrus schoenherri* (Westwood)**
- F1–F6 uniformly black ***Anagyrus antoninae* Timberlake**
- 6(3). Forewing infuscate (excluding those species with only a pattern of dark and light setae, or with an indistinct suffusion of yellow or pale brown, or with a small spot beneath marginal vein which does not or hardly extends past apex of stigmal vein); head and mesosoma bright red to orangish brown **7**
- Forewing hyaline (including those species with only a pattern of dark and light setae, or with an indistinct suffusion of yellow or pale brown, or with a small spot beneath marginal vein

- which does not or hardly extends past apex of stigmal vein); head and mesosoma brownish black with metallic reflections; primary parasitoids of Pseudococcidae *Clausenia purpurea* Ishii
- 7(6). Forewing mostly infuscate, with 5 hyaline maculations; primary parasitoids of Pseudococcidae *Callipteroma sexguttata* Motschulsky
- Forewing mostly hyaline, with fuscous bands; primary parasitoids of Pseudococcidae *Leptomastidea bifasciata* (Mayr)
- 8(1). Tarsi 4-segmented; primary parasitoids of Diaspididae *Arrhenophagus chionaspidis* Aurivillius
- Tarsi 5-segmented 9
- 9(8). Funicle less than 6-segmented 10
- Funicle at least 6-segmented 12
- 10(9). Funicle 5-segmented; primary parasitoids of Pseudococcidae *Acerophagus malinus* (Gahan)
- Funicle 4-segmented; primary parasitoids of Diaspididae; *Caenohomalopoda* 11
- 11(10). F1 about as long as wide, remaining funicle segments slightly wider than long; club a little longer than funicle *Caenohomalopoda koreana* Tachikawa, Paik and Paik
- F1 about slightly longer than wide, remaining funicle segments subquadrate; club a little shorter than or about as long as funicle *Caenohomalopoda shikokuensis* (Tachikawa)
- 12(9). Forewing brachyterous, not reaching apex of metasoma; primary parasitoids of Pseudococcidae *Mahencyrtus comara* (Walker)
- Forewing macropterous, extending to apex of metasoma or nearly so 13
- 13(12). Scutellum with a tuft (small close group) of black setae, if without a tuft of setae (some species in *Zaomma*) then at least with longer and more erect setae, or with 2 or more setae; forewing with a triangular expansion at apex of submarginal vein 14
- Scutellum without a tuft of setae; forewing without triangular expansion at apex of submarginal vein, if so, entire antenna flattened and expanded 19
- 14(13). Forewing with marginal vein at most slightly longer than broad, several times shorter than either stigmal or postmarginal veins; mandible edentate with a rounded, sharp edge; primary parasitoids of Coccidae; *Encyrtus* 15
- Forewing with marginal vein at least as long as stigmal vein; mandible with 3 denticles or 2 denticles and a truncation 17
- 15(14). Head and mesosoma yellowish to orangish brown; scutellum without transverse yellowish-white band *Encyrtus aurantii* (Geoffroy)
- Head and mesosoma metallic black; scutellum with transverse yellowish-white band 16
- 16(15). Scutellum with transverse yellowish-white band as long as 0.33× medial length of scutellum *Encyrtus infidus* (Rossi)
- Scutellum with transverse yellowish-white band as long as 0.5× medial length of scutellum *Encyrtus sasakii* Ishii
- 17(14). Forewing with marginal vein at least as long as 3× length of stigmal vein; parastigma strongly curved downward; hyperparasitoids of Coccidae, Pseudococcidae, Kermesidae *Cheiloneurus quercus* Mayr
- Forewing with marginal vein only slightly longer than stigmal vein; parastigma normal, not curved downward; primary parasitoids of Diaspididae and Eriococcidae; *Zaomma* 18
- 18(17). F1–F4 dorsal margins, F5–F6, and mid tibiae entirely white. *Zaomma eriococci* (Ferriere)

- F4 partially, F5–F6, and mid tibiae mostly white, but basally black *Zaomma lambinus* (Walker)
 20
- 19(13). Antenna entirely flattened and expanded 20
 — At least funicle cylindrical 24
- 20(19). Forewing hyaline, or more or less uniformly infuscate, with 1 or 2 hyaline spots or bands, without
 infuscate rays or bands; primary parasitoids of Coccidae; *Anicetus* 21
 — Forewing with infuscate rays or bands 22
- 21(20). Third claval segment without or with very few stripelike sensillae; clava dorsally at most as
 long as funicle *Anicetus ceroplastis* Ishii
 — Third claval segment with many stripelike sensillae, which are not parallel to outer margin;
 clava dorsally longer than funicle *Anicetus beneficus* Ishii and Yasumatsu
- 22(20). Forewing with 1 or 2 transverse dark brown bands or with several fuscous lines radiating from
 a longitudinal fuscous line in center of wing between which are wedge-shaped hyaline spots;
 primary parasitoids of Coccidae *Cerapterocerus mirabilis* Westwood
 — Forewing with 1 or 2 longitudinal infuscate rays; primary parasitoids of Diaspididae; *Comperiella*
 23
- 23(22). Forewing with 2 longitudinal infuscate bands strongly diverging, the lower band extending to
 wing apex *Comperiella bifasciata* Howard
 — Forewing with 2 longitudinal infuscate bands more or less parallel, the lower band short, not
 extending to wing apex *Comperiella unifasciata* Ishii
- 24(19). Notaular lines present in anterior 1/3 of mesoscutum 25
 — Notaular lines absent 28
- 25(24). Forewing infuscate; hypopygium extending to apex of gaster or nearly so; primary parasitoid of
 Pseudococcidae *Aphycus apicalis* (Dalman)
 — Forewing hyaline; hypopygium not extending to more than 4/5 of gaster; primary parasitoids of
 Coccidae, Eriococcidae, and Kermesidae; *Metaphycus* 26
- 26(25). Antennal funicle segments longer than wide *Metaphycus tenuicornis* (Timberlake)
 — Antennal funicle segments as long as or shorter than wide 27
- 27(26). Maxillary palp 4-segmented *Metaphycus zebratus* (Mercet)
 — Maxillary palp 3-segmented *Metaphycus eriococci* (Timberlake)
- 28(24). Forewing infuscate or with distinct infuscate pattern (excluding species with indistinct suffusion
 of yellow or pale brown, or with a small spot beneath marginal vein that does not or hardly
 extends past apex of stigmal vein) 29
 — Forewing hyaline (including species with indistinct suffusion of yellow or pale brown, or with
 a small spot beneath marginal vein that does not or hardly extends past apex of stigmal
 vein) 34
- 29(28). Forewing with marginal vein less than 1.5× as long as wide 30
 — Forewing with marginal vein at least 2.0× as long as wide 31
- 30(29). Forewing with postmarginal vein about as long as stigmal vein; gaster with hypopygium extending
 about 4/5 of gaster; primary parasitoids of Coccidae *Aphycoides fuscipennis* (Ashmead)
 — Forewing with postmarginal vein shorter than stigmal vein; gaster with hypopygium extending
 to apex of gaster; primary parasitoids of Kermesidae *Psilophrys tenuicornis* Graham
- 31(29). Frontoververtex coarsely pitted; primary parasitoids of Coccidae and Eriococcidae
 *Trichomasthus cyanifrons* (Dalman)
 — Frontoververtex smooth; primary parasitoids of Coccidae; *Microterys* 32

- 32(31). Forewing with 2 transverse infusate bands, sometimes inner band touching outer band medially so that wing has 1 hyaline maculation on fore and hind margins, respectively *Microterys clauseni* **Compere**
- Forewing with 3 transverse infusate bands, medial band narrower and interrupted; outer band sometimes touching inner band **33**
- 33(32). Body yellowish-brown to red brown, at most gaster dark-brown *Microterys rufofulvus* **Ishii**
- Body dark-brown to black-brown, head sometimes yellow-brown ... *Microterys ericeri* **Ishii**
- 34(28). Hypopygium reaching apex of gaster or nearly so; primary parasitoids of Coccidae and Kermesidae *Blastothrix erythrostetha* (**Walker**)
- Hypopygium not longer than 4/5 of gaster; primary parasitoids of Diaspididae; *Adelencyrtus* **35**
- 35(34). Clava longer than funicle *Adelencyrtus aulacaspidis* (**Brethes**)
- Clava at least a little shorter than funicle *Adelencyrtus kosef* (**Li and Byun**)

Discussion

Although some taxonomic contributions have been made in the Korean fauna of encyrtids, some taxa are recorded under synonymized names and new records have been reported recently (Gim 2010; Choi et al. 2012; Suh 2019). This work provides an updated list and a key for the identification of Korean encyrtids associated with scale insects and adds to our understanding of the Korean fauna of parasitic Hymenoptera. Thus, the species of encyrtid parasitoids documented in this study may be good source of biological control agents against economically important pest species in Korea and other countries.

To date, the Encyrtidae associated with scale insects are now represented in the Korean fauna by 36 species of encyrtids in 23 genera. However, more species of encyrtids associated with scale insects are likely to be found in Korea if taxonomic studies and concerted efforts to collect these tiny parasitic wasps continue.

Acknowledgments

I am grateful to Drs. Gregory A. Evans (USDA/APHIS/NIS, Washington, DC, USA) and Takumasa Kondo (Corporación Colombiana de Investigación Agropecuaria (Corpoica), Centro de Investigación Palmira, Palmira, Valle, Colombia) for reviewing the manuscript. Funding for this project came from the Animal and Plant Quarantine Agency.

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Received May 1, 2019; accepted June 10, 2019.

Review editor Kevin Williams.

