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New aspects about *Supella longipalpa* (Blattaria: Blattellidae)

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ABSTRACT

The brown-banded cockroach, *Supella longipalpa* (Blattaria: Blattellidae) (*S. longipalpa*), recently has infested the buildings and hospitals in wide areas of Iran, and this review was prepared to identify current knowledge and knowledge gaps about the brown-banded cockroach. Scientific reports and peer-reviewed papers concerning *S. longipalpa* and relevant topics were collected and synthesized with the objective of learning more about health-related impacts and possible management of *S. longipalpa* in Iran. Like the German cockroach, the brown-banded cockroach is a known vector for food-borne diseases and drug resistant bacteria, contaminated by infectious disease agents, involved in human intestinal parasites and is the intermediate host of *Trichospirura leptostoma* and *Moniliformis moniliformis*. Because its habitat is widespread, distributed throughout different areas of homes and buildings, it is difficult to control. Considering its possible resistance to insecticides, the control situation may be far more complex. For improved control of *S. longipalpa* an integrated pest management program is needed. Sanitation, indoor insecticide spraying in the initial cockroach control phase and insecticide formulation baits are recommended simultaneously.

1. Introduction

There are about 4 600 cockroach species that have been identified worldwide, divided into eight families: Cryptocercidae, Blattidae, Blattellidae, Blaberidae, Polyphagidae, Nocticolidae, Tryonicidae and Lamproblattidae and about 445 genera [1–4]. Some cockroaches are considered to be pests because they invade homes, restaurants, and hospitals, and demonstrate extraordinary adaptation to a wide range of habitats; reproduce rapidly; have filthy habits and a bad smell; and play a role as allergens and vectors of food poisoning and infectious diseases [5–10]. Cockroach allergens may cause asthma and other long-term health issues in human, especially children [11].

The most common household cockroaches worldwide are: *Periplaneta americana* L. (*P. americana*, American cockroach), *Periplaneta australasiae* (Fabricius) (*P. australasiae*, Australian cockroach), *Blatta orientalis* L. (*B. orientalis*, Oriental or shad cockroach), *Blattella germanica* L. (*B. germanica*, the German cockroach or croton, running and water bug) and *Supella longipalpa* (Fabricius) (*S. longipalpa*, the brown-banded or tropical cockroach) [12–14]. In Iran, *B. germanica* (Blattaria: Blattellidae) is the most common pest cockroach species [15–22]. However recently *S. longipalpa* (Blattaria: Blattellidae), has expanded its distribution and infested the buildings and hospitals particularly in urban areas such as Tehran, Isfahan and Ahvaz. As in Iran, the distribution of the brown-banded cockroaches is increasing in the world [3,8,23–32].

Although many studies have been conducted on the brown-banded cockroach, so far a full review has not been conducted to synthesize the state of our understanding and knowledge gaps about this pest. In order to identify possible appropriate management approaches and research needs for Iran, this review was conducted between March 2014 and December 2015 on literature published about the brown-banded cockroach.

Scientific reports and papers about *S. longipalpa* and relevant topics were collected from various websites such as PubMed, ScienceDirect, Web of Science, Springer, Scopus, and Google Scholar, as well as specific scientific sites, between March 2014 and December 2015. About 241 scientific reports and papers were collected from the above mentioned scientific sources and after a preliminary review, 104 were selected to become part of the detailed synthesis.

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2. The most common pest cockroach species

Table 1 shows the most common worldwide household pest cockroach species, their description and habitats [12–14,33,34].

Table 1

The most common worldwide household pest cockroach species, their description and habitats [12–14,33,34].

Species	Description	Habitat
P. americana (Blattidae, Blattinae)	Reddish brown to dark brown, adults 3–8 cm long	Spread the damp basements and sewers, infest mostly the first floors of buildings
P. australasiae (Blattidae)	Large reddish brown with a conspicuous lateral pale stripe on tegmina and sharply contrasting pale or yellow margin on pronotum, adults 2.3–3.5 cm long	Prefer warmer climates and is not cold tolerant
B. orientalis (Blattidae)	Dark brown or black, females have traces of wings, short wings on males, adult females 1.8–2.9 cm long, adult males a little shorter	Develop in damp basements and sewers, forage mostly on first floors of buildings
B. germanica (Blattellidae, Blattellinae)	Light brown, longitudinal black stripes on back, adults 1.1–1.6 cm long, most common of the other kinds	Develop and live throughout buildings, particularly in kitchens and bathrooms
S. longipalpa (Blattellidae, Pseudophyllodromiinae)	Light brown, mottled, reddish-brown wings on female, lighter wings on male, adults 0.9–1.4 cm long	Develop and live throughout buildings

3. New aspects about *S. longipalpa* classification, distribution, diagnosis and habitats

3.1. Cockroach species category based the embryonic development time

Cockroaches were examined in three categories of their embryonic development time and including oviparous, ovoviviparous and viviparous cockroach species. Like *B. orientalis*, *P. americana* and *Eurycotis floridana* (*E. floridana*), *S. longipalpa* is categorized in the oviparous cockroaches. *Blaberus discoidalis*, *Byrsotria fumigata*, *Rhyparobia maderae*, *Nauphoeta cinerea*, *Phoetalia pallida*, *Schultesia lampyridiformis*, and *Panchlora nivea* are known as the ovoviviparous cockroaches. A conspicuous event in embryogenesis is detectable of juvenile hormone which produced by the corpora allata after first dorsal closure. Across most of the oviparous and ovoviviparous cockroach species, the timing of dorsal closure was consistently at about 45% of the total embryonic development time. However, *Diploptera punctata* (*D. punctata*) which completed its dorsal closure at 20.8% of the embryo development time, is only known as the viviparous cockroach [35].

3.2. Classification

S. longipalpa is commonly known as the brown-banded cockroach and is also named the tropical cockroach (Order: Blattaria, Family: Blattellidae, Subfamily: Pseudophyllodromiinae) and can be considered as a nearly cosmopolitan cockroach [3,8–10,14,36].

3.3. Diagnosis and description

Choate illustrated a dichotomous cockroach morphological key. In this key, *S. longipalpa* is briefly identified by the morphological characters (Figure 1) [37].

The length of the brown-banded cockroach is about 9–14 mm. Two brown bands are continued across its yellowish-brown wing sheaths which are located at the base of the wings and near the middle legs in the adults. While in nymphs, two light tan bands are located across the midsection of the body. The wings are completely covering the abdomen of the males but in the females the wings are reduced and are not completely covering the abdomen [13,33,34]. They have a pronotum which is blackish brown with broad yellowish lateral margin, a tegmina which is yellow with a large reddish brown basal spot and also a small oblique paler band. Wings brown with varied dark markings. The general color of the cockroach is light brown. Sexes are dissimilar. Near the apex of the anal field, a broad pale colored band crosses the tegmina. Due to the color pattern this taxon is commonly known as the brown-banded cockroach. Its light body enables it to fly rapidly [3].

Immature cockroaches undergo incomplete metamorphosis from egg to nymph to adult. They don't have any larval form [33]. A female produces about 10–20 barrel-shaped oothecae during her lifetime. The oothecae are carried for 1–2 days and then attached to the side or underside of any structural objects such as shelves, furniture, or others in a protected location. The egg case length is 4–5 mm. Each ootheca possesses about 14–18 eggs. Eggs develop within the egg case for nearly a month before nymphs hatch (Figure 1). Development from egg to adult ranges from 90 to 276 days with an average of 161 days depending upon temperature. Adults can live from 131 to 315 days with an average of 206 days [13,33,34].

3.4. Distribution

S. longipalpa is native to the Nile Valley region of Africa and probably has been a peri-domestic pest for thousands of years [8]. It becomes well established on every continent but Antarctica [32] and has become more prevalent in recent years [3,8,23–32]. Researchers have reported *S. longipalpa* from Italy, Thailand, Bangkok, Malaysia, islands of the Ogasawara chain island of Japan, namely, Chichijima, Hahajima and Iwo islands, and Maharashtra state of India. The wide distribution of the brown-banded cockroach makes it very difficult to control [38]. In Iran it has recently become widespread and reported in hospitals and kitchen areas of houses in the cities of Ahvaz, Isfahan and Tehran. Previously the brown-banded cockroaches were not as common as other cockroaches such as *B. germanica*, *B. orientalis* and *P. americana* but recently it seems that its distribution is growing.

Figure 1. *S. longipalpa*.
A and B: Ootheca; C, D and E: Nymph; F, G and H: Male dorsal view; I and J: Male ventral view; K and L: Female dorsal view; M and N: Female ventral view.

3.5. Habitats and infestation of areas

S. longipalpa is a cosmopolitan and commensal cockroach with human habitation. It is omnivorous, capable of eating anything, and also adapted to dryer conditions than most other cockroaches. As a result of these traits, it can inhabit a wider variety of building spaces with warm conditions [32,33]. *S. longipalpa* cockroaches are commonly found in homes, apartments, hotels and hospitals and less frequently in stores, restaurants and kitchens. They prefer to live in and around heat-producing electric appliances. As it can sometimes be found nestling in the corners of television sets also called the TV cockroach [8,9,13,38].

Previously it was believed that the brown-banded cockroach did not require as much moisture as the German cockroach so they are normally found in rooms other than those containing wet areas such as kitchens or bathrooms. Therefore, warmer, dry areas were preferred [33]. However, my recent field observations have shown that it can be seen in the toilet and bathrooms. Nowadays because the kitchens of homes often are made open, they have become good places for the brown-banded cockroaches as I recently observed very high infestation with the brown-banded cockroaches in such kitchens. The brown-banded cockroach infestations are usually visible at night when the lights are off but in the case of severe infestation, the nymphs and males also may be seen during the day. Even at night the females do not exit their shelters unless they feel safe.

Houseman described areas of the home which like the German cockroach, can be infested by the brown-banded cockroach [13]. This widespread habitat of the brown-banded cockroach distributed throughout different areas of homes and buildings makes them very difficult to control [38].

Houseman reported before that they infested inside electronic equipment and in lamps or furnitures in dining-, bed- and living-rooms. While unlike the German cockroach, my recent observations showed that the brown-banded cockroach infest all electrical devices such as juicers, meat grinders, ovens, washing machines, *etc*., when they are not used. Houseman also stated that they usually do not aggregate as noticeably as *B. germanica*, whereas my recent observations showed that the brown-banded cockroaches are found in groups like the German cockroach. These findings, infestation of the electrical devices and their finding in groups, show that the brown-banded cockroach is more dangerous than the German cockroach. As a result, like its widespread habitat throughout different areas of homes and buildings, it is more difficult to control. If the resistance to insecticides is to be added to the issue, the condition will be far more complex.

A certain proportion of casein and glucose (*e.g.* a 15.5:85.5 casein: glucose ratio) is nutritionally beneficial for the larvae of the brown-banded cockroach, and if food lacks protein (casein) or carbohydrate (glucose) or a diet containing a 20:80 casein: glucose ratio it was found unsuitable or larvae grew very poorly [39]. It may be useful to control larvae by placing such food sources in appropriate areas.

4. New aspects about *S. longipalpa* morphology and physiology

4.1. Sensory structures

Sensory structures of the maxillary and labial palps in *S. longipalpa* were examined by Prakash *et al.* [40]. A new sensillum named "groove and slit" sensillum was described in *S. longipalpa*. As revealed by cobalt (II) uptake, the "groove and slit" sensillum appears to be olfactory based on its morphology and sensory projections leading to the antennal lobes of the brain. The maximum variety of sensilla including olfactory, gustatory, and mechanosensory was found on the most distal segments of the maxillary as well as labial palps. They observed a long micro-furrow on the maxillary palp near the ventral edge of the medial surface of the fifth segment which had in high density of sensilla (73 700 sensilla/mm^2). The high and thick pegs of the sensilla were mostly 3–5 and 1.5–1.8 μm, respectively with grooves along the hair-shaft and a slit near the distal tip. The slit and the typical arched fenestration at the tip, allowed the dendrites to sample the external environment [40].

4.2. Digestive tract

The Blattidae, Blattellidae (*S. longipalpa*) and Blaberidae cockroach families have similar digestive tract morphology but they have different digestive tract physiology. Any species has a different pH in its crop and along the midgut. Proteinases and amylases activities are differed among the species up to 100 times in comparable gut regions. Proteolytic activity is high and moderate in the midgut and in the crop of Blattidae family, respectively; in the other species, it is very low in the crop and increases to a moderate level in the posterior half of midgut. The level of amylolytic activity is similar in the examined gut compartments of Blattidae and Blattellidae (*S. longipalpa*) but low in the posterior half of midgut of Blaberidae. Blaberidae are also characterized by a high potential of the salivary glands, crop, and midgut to inhibit subtilisin, trypsin, and chymotrypsin. Inhibition of these proteinases by the extracts of the salivary glands and gut is very low and often undetectable in Blattidae and Blattellidae (*S. longipalpa*) [41].

4.3. Temperature dependent demography

Adults of *S. longipalpa* have a lifespan of 90–110 days at 30 °C. A single female can produce a maximum of 20 oothecae. The postembryonal development takes about 55 days at 30 °C, with 6–8 moults [6,38,42]. Tsai and Chi studied the demography of the brown-banded cockroach based on the age-stage (Table 2) [8]. The results indicated if *S. longipalpa* was introduced into the environment where the temperature was between 25 °C and 33 °C they would be expected to establish and increase in the absence of any limiting factors [10]. Since the temperature changes of the infestation places are one way to combat the brown-banded cockroach, its demography based on the age-stage is very valuable for its control.

Table 2
The demography of the brown-banded cockroach [8].

Demography	Temperature (°C)		
	25	29	33
Oothecae per female (number)	11.8	14.6	12.8
Newborn life expectancy (day)	157.2	207.7	147.9
Increase of intrinsic rate (per day)	0.016 1	0.030 6	0.039 8
Rate of net reproductive (offspring)	35.3	100.9	87.2
Time of mean generation (day)	222.1	151.1	112.5

4.4. Symbiont and lipophorin of hemolymph detected

Basement to the biology of hosts, bacterial endosymbionts of insects are increasingly being recognized as common, diverse, and integral [43]. Vaishampayan *et al.* [44] reported the presence of intracellular bacteria, *Wolbachia* in two cockroach species, *S. longipalpa* and *Blattella* sp. Studies showed that *Wolbachia* coexisted with *Blattabacterium*. Phylogenetic analysis revealed that *Wolbachia* forms a sister clade with supergroup F [44]. Another study showed that the brown-banded cockroaches harbored *Blattabacterium* and two lineages of *Wolbachia*, indicating the number of vertically transmitted symbionts in this insect as three lineages of bacterial symbionts [43].

Inherited fungal symbionts have been largely overlooked, however, even though insect guts appear to be a key habitat for an incredible array of fungal diversity. Gibson and Hunter studied the foundations for understanding the roles of the vertically transmitted fungal and bacterial associates of the brown-banded cockroach and a parasitic wasp, *Comperia merceti* (Hymenoptera: Encyrtidae) (*C. merceti*) [43]. They found two fungal associates of the brown-banded cockroaches and reported the first record of vertically transmitted fungal symbionts in the order Blattaria. The wasp was found to house a close relative of one of the cockroach fungi [43].

Wood-eating cockroaches are closely related to termites. It has been suggested that the Blattaria (cockroaches) is a sister group of Mantodea (mantids), while Isoptera (termites) is a sister group of this complex by considering their common characteristics. Cross-reactivity of hemolymph lipophorin of cockroaches with the antiserum was much weaker than hemolymph lipophorin of termites. Nevertheless, a clear phylogenetic pattern emerged, showing greater reactivity with the more primitive cockroaches in the Cryptocercidae (*Cryptocercus*), Blattidae (*Periplaneta*) and Blattellidae (*Supella*), and essentially no cross-reactivity with the hemolymph of the advanced Blaberidae (*Blaberus* and *Diploptera*), in support of the wood-feeding cockroaches (*Cryptocercus*) as closely related to Isoptera [45,46].

Symbionts likely play important roles in the ecology and evolution of their insect associates and some insect symbionts have been shown to have ancient associations with their hosts. Symbionts also have recently been used to resolve phylogenetic positions. In this regard these findings are pertinent to *S. longipalpa*. The lipophorin of the hemolymph also supports the idea of the wood-feeding cockroaches (*Cryptocercus*) as being closely related to Isoptera.

4.5. Water relation and temperature sensitivity

The cuticular permeability and critical thermal maxima (CTM) were generally related to habitat humidity and temperature, respectively. Cuticular permeability was significantly greater in blattid species indicating reduced permeability may be an advanced derived character in the Blattellidae and Blaberidae. Cuticular permeability and CTM of *S. longipalpa* were between 14.3 and 53.7 μg/cm^2/h/mmHg for cuticular permeability and 51.4 °C for CTM, and the initial water content ranged from 62.7% to 71.8% which was distinct for several cockroach species. CTM does not appear to be associated with phylogeny [47]. This information may be useful for the *S. longipalpa* control.

4.6. Sex pheromone (supellapyrone)

Female brown-banded cockroaches attract males from a distance by emitting a sex pheromone which was isolated and identified as 5-(2,4-dimethylheptanyl)-3-methyl-2H-pyran-2-one (referred to as supellapyrone). This compound is not only a very different type of cockroach pheromone but also makes up an additional class of natural products namely, 3,5-dialkyl-substituted alpha-pyrones. The site of sex pheromone production in female *S. longipalpa* was localized to the fourth and fifth abdominal tergites. Behavioral assays of males with hexane extracts of various female body parts showed that these tergites were significantly more attractive than any other region of the body. Both behavioral and electroantennogram assays confirmed that the fourth and fifth tergites contained significantly more sex pheromone than any other tergites. The supellapyrone can be synthesized by direct coupling of a brominated pyrone with an alkylzinc reagent [48–54]. Supellapyrone may be used as a bait formulation for control of the brown-banded cockroaches.

Smith and Schal examined the termination of calling (pheromone release) contributing factors [55]. Calling ceased after mating and does not resume over the duration of the adult female *S. longipalpa* life. Calling was suppressed and basal oocyte growth was stimulated by the transient presence of a spermatophore, by the implantation of an artificial spermatophore, and by mating with vasectomized males. Calling resumed after oothecal deposition in females mated with vasectomized males. Ventral nerve cord transections, either immediately following copulation or after oothecal deposition, restored calling in mated females. The termination of calling is mediated neurally by a two-stage process, initiated by placement of the spermatophore in the bursa copulatrix and maintained by the presence of sperm in the spermatheca. The corpora allata and juvenile hormone, either directly or indirectly, regulate the onset of both pheromone production and calling in female *S. longipalpa* [55,56].

4.7. As a diet of the Argentine ant

Social insects use a complex of recognition cues when discriminating nestmates from non-nestmate conspecifics. In the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae) (*L. humile*), recognition cues can be derived from exogenous sources to acquire prey-derived hydrocarbons that are used in nestmate discrimination. The brown-banded cockroach was used as insect prey (its cuticular hydrocarbon profile) to discriminate *L. humile* nestmates from non-nestmates and intraspecific aggression [57,58]. *L. humile* was attacked by their nestmates following contact with a particular prey item, the brown-banded cockroach. Contact with prey, as brief as 2 min, provoked nestmate aggression. Ants contaminated with hydrocarbons extracted from *S. longipalpa* also released nestmate aggression behavior similar to that released by the whole prey item, confirming the involvement of hydrocarbons. In contrast to *S. longipalpa*, little or no nestmate aggression was induced by other ant prey from diverse taxa. A comparison of prey hydrocarbon profiles revealed that all hydrocarbons of *S. longipalpa* were very long chain components with 33 or more carbons, while other prey had either less, or none, of the very long chain hydrocarbons of 33 carbons or greater [59].

4.8. Corpus allatum and juvenile hormone

In the corpus allatum of the adult female *B. germanica*, *S. longipalpa* and *D. punctata* during oocyte maturation, the cell number did not change but cell diameter increased significantly during the period of corpus allatum activation. The average cells per gland were 2 000 in *B. germanica*, 3 500 in *S. longipalpa* and 11 000 in *D. punctata*. The domain mean of cell diameter (μm) were 8.9–11.7 in *B. germanica*, 9.2–14.6 in *S. longipalpa* and 10.0–15.6 in *D. punctata*. During a 4-h incubation period, dissociated corpus allatum cells incorporated L-[methyl-3H]-methionine into juvenile hormone-III at rates comparable to intact glands. Corpus allatum activation in the first ovarian cycle of these species is associated mainly with an increase in cell size with minor changes in cell number [60].

A re-examination of the role of the corpus allatum in the maturation of male sexual readiness shows that, while sexual behavior develops in the absence of juvenile hormone in both *B. germanica* and *S. longipalpa*, juvenile hormone accelerates the expression of sexual readiness [61]. The release of juvenile hormone by the corpora allata closely parallels oocyte development in both mated and virgin *S. longipalpa* females over two gonotrophic cycles [62].

Allatostatins of the Tyr/Phe-Xaa-Phe-Gly-Leu/Ile-amide C-terminus family are a group of insect neuropeptides that occur in many orders of insects, but are known to inhibit juvenile hormone synthesis by corpora allata only in cockroaches, crickets, and termites [63]. The genomic DNA sequences that specify the preproallatostatin precursor for the cockroaches, *B. orientalis*, *B. germanica*, *Blaberus craniifer* and *S. longipalpa* were generated through a process of internal gene duplication which occurred before these species diverged from each other in evolutionary time [64]. Inhibition of juvenile hormone synthesis by corpora allata only in cockroaches, crickets, and termites may show their phylogeny relationship to each other.

5. New aspects about *S. longipalpa* public health importance

5.1. “Common pest” or “Dirty” species

There are “22 common pest” or “Dirty 22” species, categorized into four groups including “four cockroach species (group I)”, “two ant species (group II)”, “12 fly species (group III)” and “four rodent species (group IV)” that are known as the spreaders of foodborne diseases. *S. longipalpa* is in the “group I” comprising *B. germanica*, *B. orientalis*, *P. americana*, and *S. longipalpa* [65]. The inclusion of *S. longipalpa* in the “22 common pest" or "Dirty 22" species, as "group I" shows its public health importance and the need for its control.

5.2. Contamination by diseases and parasites agents

Like *P. americana* and *B. germanica* [19,66,67], *S. longipalpa* carries a variety of microorganisms, as a vector for pathogenic bacteria in urban environments as recently reported by Vazirianzadeh *et al.* in Iran [68], and it also has been reported as a source of allergens [69]. *S. longipalpa* contaminated by drug resistant agents of infectious diseases and parasites including *Bacillus cereus*, *Bacillus subtilis*, *Citrobacter freundii*, *Enterobacter agglomerans*, *Enterobacter aerogenes*, *Enterobacter cloacae*, *Escherichia coli*, *Klebsiella oxytoca*, *Klebsiella ozaenae*, *Klebsiella pneumonia*, *Proteus mirabilis*, *Proteus vulgaris*, *Salmonella typhimurium*, *Shigella boydii*, *Shigella dysenteriae*, *Serratia marcescens* and *Staphylococcus aureus* [68], and *Ascaris lumbricoides* (ova), *Entamoeba coli* (cysts), *Entamoeba histolytica*/*Entamoeba dispar* (cysts), *Enterobius vermicularis* (ova), *Taenia* spp. (ova), *Trichuris trichiura* (ova) and *Trichospirura leptostoma* (*T. leptostoma*) (intermediate host) [70–73], respectively.

5.3. Drug resistant bacteria spreading

The brown-banded cockroach can be involved as spreaders of drug resistant bacteria as mentioned above. Vazirianzadeh *et al.* isolated different drug-resistant bacteria from the brown-banded cockroach [68]. These bacteria are resistant to drugs including amikacin, ampicillin, cefalexin, cefotaxime, ceftazidime, ceftriaxone, cephalothin, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, nalidixic acid, nitrofurantoin, penicillin, tetracycline and trimethoprim-sulfamethoxazole [68]. This increases the possibility of human exposure to drug resistant bacteria in the environment [68] and suggests that the brown-banded cockroaches can play an important role as spreaders of antibiotic-resistant nosocomial infectious diseases.

Although studies indicated that different wide varieties of medically important fungi are found on the external surfaces of *B. germanica* and *P. americana* [19,67], no study has been conducted on *S. longipalpa*.

5.4. Carry of human intestinal parasites

Like other cockroaches including *B. germanica*, *B. orientalis*, *P. americana*, *Periplaneta brunnea* (*P. brunnea*), *Periplaneta fuliginosa* (*P. fuliginosa*) and *Pycnoscelus surinamensis*, *S. longipalpa* have the potential to carry human intestinal parasites. Microscopic examination of the external body washes of pooled *S. longipalpa* cockroaches and individual gut contents revealed that the brown-banded cockroaches are carriers of *Entamoeba coli* and *Entamoeba histolytica/dispar* cysts as well as *Enterobius vermicularis*, *Trichuris trichiura*, *Taenia* spp. and *Ascaris lumbricoides* ova [70].

Clopton and Gold observed that *B. germanica* were experimentally infected with *Gregarina blattarum* (*G. blattarum*) by allowing them to feed on crushed dog kibble infected by *G. blattarum* oocysts, but like *B. orientalis*, *P. americana* and *P. fuliginosa*, *S. longipalpa* was not infected. These data suggest that *G. blattarum* comprises a complex of cryptic species marked by narrow host utilization rather than a single species parasitizing a broad array of cockroach taxa [71].

Moore and Gotelli observed when *S. longipalpa* was experimentally infected by the acanthocephalan parasite *Moniliformis moniliformis* (*M. moniliformis*), the activity and distance of traveling were reduced sharply in white versus red light [72].

5.5. Intermediate hosts

Illgen-Wilcke *et al.* [73] revealed that the *B. germanica* and *S. longipalpa* cockroaches can act as intermediate hosts of *T. leptostoma* as demonstrated by experimental infestation. The parasite developed from the embryonated egg into the infective larval stage (L_3) in cockroaches within 5–6 weeks. After experimental infection of marmosets (*Callithrix jacchus*), eggs were first found in faecal samples (prepatency) at 8–9 weeks postinfection. Patency lasts about 2 years. Despite the presence of living adult worms in the marmosets' pancreas, no additional eggs were observed in their faeces after the patent period [73].

The fitness of infected organisms can vary greatly depending on the temperature at which they find themselves. Understanding the role of temperature in the fitness of infected organisms can be crucial to population studies, epidemiological studies, and when screening for biological control agents. Guinnee and Moore found that infection by the acanthocephalan parasite *M. moniliformis* did not affect its intermediate host, *S. longipalpa* survival at any temperature but infection had a negative impact on cockroach fecundity except at higher temperatures (28 and 31 °C) and later in infection (> 20 days postinfection) [74]. At lower temperatures, infected and uninfected cockroaches had similar fecundities throughout the duration of the experiment (120 days) [74].

Like the German cockroach, the brown-banded cockroach is known as the spreader of foodborne diseases, contaminated by disease and parasite agents, involved in the spread of drug resistant bacteria, human intestinal parasites and intermediate hosts of *T. leptostoma* and *M. moniliformis* and also has a great public health importance; this emphasizes the need for control.

6. New aspects about *S. longipalpa* insecticides susceptibility, control and management

6.1. Susceptibility to repellents and insecticides

Prakash *et al.* [75] studied the residual repellency of *N,N*-diethylphenylacetamide against American, German and brown-banded cockroaches at various concentrations. *N,N*-diethylphenylacetamide exhibited residual repellency for 4, 3, and 2 weeks against American, German, and brown-banded cockroaches, respectively, at a concentration of 0.5 mg/cm^2 [75].

In a study conducted by Koehler *et al.* the LT_{50} values of 0.0550% abamectin bait were 3.4, 3.4, 2.4, 7.5, 2.9, and 4.5 days for *P. americana*, *P. fuliginosa*, *P. brunnea*, *P. australasiae*, *B. orientalis* and *S. longipalpa*. The LT_{50} (4.5 days) for *S. longipalpa* was highest after *P. australasiae* (LT_{50} = 7.5 days) and *P. brunnea* had the lowest LT_{50} (2.4 days). Although the bait was effective against various cockroach species, time to death for the larger species was longer than for the German cockroach [76].

Sharififard *et al.* [77] evaluated the toxicity of *Eucalyptus* sp. essential oil against the brown-banded cockroach. The results showed that *Eucalyptus* oil caused 100% mortality in the cockroach nymph population at concentrations higher than 5% after 24 h based on a continuous contact bioassay. The concentration of 2.8% (LD_{50}) and 5.7% (LD_{95}) were needed to kill 50% and 95% of the nymph population 24 h after contact exposure. The fumigation bioassay also caused 100% mortality of the nymphs in less than 24 h at a concentration of 50 μL/glass jar (1 L) of pure essential oil. *Eucalyptus* essential oil resulted in different repellency values of the cockroach at different concentrations. The highest repellency occurred in a concentration of 5%, resulting in 49.5% cockroach repellency. The *Eucalyptus* plant is compatible with the climate conditions of many areas of Iran such as Khuzistan. The essential oil of this plant can be considered as a potential alternative to control the cockroach in an integrated pest management (IPM) program [77].

6.2. Attractiveness to bait

In a study, feeding preferences of individual American, smoky brown (*P. fuliginosa*), *S. longipalpa*, and *E. floridana* cockroaches were examined in the laboratory to test the hypothesis that dry distiller's grain is as attractive as dry cat chow, laboratory rat chow, or distiller's grain with uric acid. Except for *E. floridana*, females typically spent more time on baits than males did. Only *S. longipalpa* showed a significant preference for cat chow. Data were variable for the other three species, but it showed that adults readily accept dry distiller's grain. Dry distiller's grain is preferable for field studies of cockroach population dynamics [78]. It seems that cockroaches like more dry food than watery food.

Nalyanya *et al.* [79] evaluated several insecticide bait formulations for their attractiveness to cockroaches in olfactometer assays in the laboratory and in trapping experiments in the field. Included in the assays were bait stations, gels, pastes, and a powder that contained one of the following active ingredients: abamectin, boric acid, chlorpyrifos, or hydramethylnon. Results indicated baits that were most attractive to nymphs and adults of the German cockroaches were also the most attractive to nymphs and adults of the brown-banded cockroaches. In trapping experiments, Avert powder (abamectin), Maxforce station and gel, and Siege gel (all hydramethylnon) were consistently attractive to *B. germanica* and *S. longipalpa* adults and nymphs. Bioassays also demonstrate that attractiveness of bait can be dramatically affected by the age of the bait. One week of aging significantly reduced the attractiveness of Avert powder in both laboratory and field assays. Aging, however did not diminish the attractiveness of Maxforce gel, indicating that the formulation may be critical for retention of bait attractiveness [79].

Savoldelli and Suss showed that the attractiveness of hydramethylnon, imidacloprid and fipronil gels for adult *S. longipalpa* decreased in the course of time [38]. The majority of the adult cockroaches were killed in the first week than in the second and third weeks. There were significant differences among the baits in their attractiveness to the brown-banded cockroach. The most effective gels were those with hydramethylnon and fipronil 0.05%. After one week, more than 50% of the adults were killed with tested hydramethylnon formulations and fipronil 0.05% gel. In the following two weeks, the number of killed cockroaches increased and in the test with hydramethylnon 2% formulation, the mortality rate was 100%. The formulation with fipronil 0.03% killed about 50% of the adults in three weeks. The worst gel was the one containing imidacloprid, which killed less than 50% of the cockroaches after three weeks [38]. Similar results were obtained from 0.05% fipronil and 2.15% imidacloprid gel baits against German cockroach by Nasirian [16]. These studies show that the attractiveness of insecticide bait formulations to *S. longipalpa* and *B. germanica* are similar.

Anaclerio and Molinari investigated the attraction behavior of four synanthropic cockroach species of *B. germanica*, *S. longipalpa*, *B. orientalis* and *P. americana* [80]. Cockroach methanol faecal extracts showed a higher intraspecific attractivity than aqueous extracts in olfactometer bioassays. A gel with resistance to dehydration was prepared, and then cockroach methanol faecal extracts were added. Arena bioassays showed that the new gel containing cockroach faecal extracts was more attractive than commercial gel formulations [80]. Although more studies are needed in this field, it seems faecal extracts can be added to the commercial gel formulations in order to improve their attractiveness.

Although the German cockroach is the most important worldwide pest cockroach species and has shown resistance to different spectrum insecticides such as organochlorine, organophosphorus, carbamate, fipronil and spinosad [15–22,81–99], the susceptibility and mechanisms of insecticide resistance of the brown-banded cockroach is less well studied.

6.3. Control and management

The best method of cockroach pest management is still sanitation. Because all insects need food, water and shelter and cockroaches are often attracted by food residue and garbage, dishes should be washed promptly, food containers sealed tightly, residue on jars and surfaces cleaned, and spills moped up. Water leaks and sweating pipes should be repaired. Clutter that provides hiding places should be removed [14]. There are a variety of pest management tools and tactics to control the brown-banded cockroach. Physical removal, chemical contact pesticides, pesticide baits, and other tactics are used based on the infested area [33,100].

In apartment buildings it may be helpful to place screening over heating ducts, gratings, and other places where cockroaches may enter. Holes and cracks in walls must be repaired by caulk. Cockroach populations should be monitored by tools or traps such as commercially available sticky traps which also aid to control. Traps should be placed in corners and other areas along walls or edges where cockroaches have been observed. Insecticide and insect growth regulator baits are preferred over indoor insecticide spraying but in the initial cockroach control phase the indoor insecticide spraying is better than baits. The use of insecticides indoors is a questionable practice. Bait traps containing boric acid as the active ingredient are considered “least toxic” products [14,34,100]. For a successful control a combination of integrated pest management program such as sanitation, indoor insecticide spraying in the initial cockroach control phase and insecticide formulation baits are recommended simultaneously.

6.4. Biological control or biocontrol

Biological control includes using the predators, parasites, or diseases of cockroaches to control their populations. This type of control probably has its greatest potential for use in "highly sensitive" areas where conventional insecticides cannot be used as part of an IPM program [13]. Cockroaches are among the most important pests in urban environments. Most of the cockroaches are household and the structural pests in temperate regions are tropical or subtropical in origin. They seem to be ideal candidates for classical biological control [101]. *C. merceti*, an encyrtid parasite of cockroach eggs [102]; *C. merceti* and *Anastatus tenuipes* (Hymenoptera: Eupelmidae) (*A. tenuipes*), host-specific oothecal parasitoids [103]; *Steinernema carpocapsae* (Rhabditida: Steinernematidae) (*S. carpocapsae*) nematode [104]; and dust-formulation of *Metarhizium anisopliae* (Hypocreales: Clavicipitaceae) (*M. anisopliae*) isolate IRAN 437C, as a common entomopathogenous fungus [31] have been used for the biocontrol of the brown-banded cockroaches.

C. merceti, an encyrtid parasite of cockroach eggs, was reared and released as the principal measure employed for suppressing the brown-banded cockroaches in 1978. This natural enemy of the brown-banded cockroaches showed promise as the most effective and efficient approach for controlling this pest in large buildings [102].

In a study of the impact of biological parameters, such as longevity, brood size, development period, sex ratio, and fecundity of *C. merceti* and *A. tenuipes*, host-specific oothecal parasitoids of *S. longipalpa*, it was found that there were no differences among them except their response to superparasitism, the number of progeny produced per adult female, and the number of hosts parasitized by adult females. In oothecae superparasitized by *C. merceti*, all of the progeny completed development but they were weak and smaller in size due to sibling competition. In the case of *A. tenuipes*, the supernumeraries were eliminated in the early stages of development and only normal progeny were produced from superparasitized oothecae. *C. merceti* produced more progeny per female, parasitized more hosts than *A. tenuipes*, and was the successful competitor in multiparasitism [103].

Koehler *et al.* [104] evaluated the susceptibility of American cockroach, smoky brown cockroach (*P. fuliginosa*), oriental cockroach, German cockroach and the brown-banded cockroach to *S. carpocapsae* under laboratory conditions. A 1 mL water suspension containing 500 000 nematodes was placed on filter paper in a Petri dish or the pad of a bait station. German, brown-banded, oriental, and smoky-brown cockroaches died within one day after placement in the Petri dishes. The relative order for the LT_{50}s was American > oriental > smoky-brown > brown-banded = German. All cockroaches actively groomed nematodes from legs and antennae of forced (Petri dish) exposure. The LT_{50}s for *S. carpocapsae* for non-forced (bait station) exposure were significantly greater than those for forced exposure. The LT_{50}s were 3.25, 4.13, 9.86, and 11.38 days for the brown-banded, German, oriental, and smoky-brown cockroaches, respectively. The relative order of the LT_{50}s after forced (American > oriental > smoky-brown > German = brown-banded) and non-forced (American > smoky-brown > oriental > German > brown-banded) exposure to *S. carpocapsae* was inversely related to the moisture of their preferred habitats [104].

In a recent biocontrol study, the efficacy of a dust-formulation of *M. anisopliae* isolate IRAN 437C, as a common entomopathogenous fungus, was evaluated against *S. longipalpa*. Results showed that cockroach mortality rates and survival time (ST) increased and decreased, respectively with an increased proportion of conidia from 1% to 100% but records taken for mortality and ST from proportions of 25%, 50% and 100% were not significantly different. The mortality rates reached 100% and 90%–100% in adults and nymphs, respectively on the seventh day. The lowest ST_{50} was related to the proportion of 100% (3 days). Conidia dust-formulation of *M. anisopliae* isolate IRAN 437C could present a promising alternative to control the brown-banded cockroach [31].

The brown-banded cockroaches mainly infest buildings and hospitals and the results of the biocontrol of these few studies have shown good results in the laboratory and field. However, they have not been used in full scale control practice.

7. Conclusions

Recently the brown-banded cockroach, *S. longipalpa*, has become widely distributed and infested the buildings and hospitals in different areas of Iran. The current review study was prepared to collect and discuss new scientific aspects about the brown-banded cockroach to help understand the public health issues and management options.

Like the German cockroach, the brown-banded cockroach is known as a spreader of foodborne diseases and drug resistant bacteria, contaminated by infectious diseases agents, involved in human intestinal parasites and intermediate hosts of *T. leptostoma* and *M. moniliformis*. Because of its widespread habitat in different areas of buildings and hospitals, it is difficult to control. If the resistance to insecticides is to be added the issue, the condition is seen as far more complex.

Although the German cockroach is the most important worldwide pest cockroach species and has shown resistance to different insecticides such as organochlorine, organophosphorus, carbamate, fipronil and spinosad while the susectibility and mechanisms of insecticide resistance of the brown-banded cockroach are less studied.

Biocontrol studies have shown good results in the laboratory and field, but have not been used in full scale control practice. Because the brown-banded cockroach inhabits buildings and hospitals, biocontrol practices may not be quite appropriate. For successful control, a combination of IPM program such as sanitation, indoor insecticide spraying in the initial cockroach control phase and insecticide formulation baits are recommended simultaneously.

Conflict of interest statement

I declare that I have no conflict of interest.

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