CHAPTER

3

Silver Nanoparticles for the Control of Vector-Borne Infections

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3.1 INTRODUCTION

Arthropods play a role in the transmission of various bacterial, viral, and protozoal diseases, such as plague, tularemia, yellow fever, Japanese encephalitis, malaria, leishmaniasis, and many others. The tendency of recent time is that many vector-borne pathogens are appearing in new geographical regions, and in endemic diseases there is also a tendency for an increase of incidence (Kilpatrick and Randolph, 2012; Medlock et al., 2012; El-Bahnasawy et al., 2013). Moreover, growing rates of insecticide resistance among arthropods transmitting infections are a serious problem influencing control of vector-borne diseases (Bridges et al., 2012; Smith and Goldman, 2012; Aïkpon et al., 2013; Yang and Liu, 2013; Coetzee and Koekemoer, 2013).

Resistance was described among all types of vectors (Raghavendra et al., 2011; Durand et al., 2012; Faza et al., 2013; Blayneh and Mohammed-Awel, 2014), and in many studies it was shown to reach extremely high levels. In a study on tick resistance, Faza et al. (2013) reported resistance levels among larvae of *Rhipicephalus microplus* (Acari: Ixodidae) to the organophosphates and pyrethroids as high as 75.49% and 97.44%, respectively. Among *Aedes aegypti* mosquitoes, resistance was observed in 100% of localities in which mosquitoes were exposed to insecticides DDT, bendiocarb, and temephos (Ocampo et al., 2011). In head lice, *Pediculus humanus capitis* De Geer (Phthiraptera: Pediculidae), frequencies of pyrethroid insecticide resistance kdr alleles were also found to be high (67–100%) (Toloza et al., 2014).

At the same time, presently available insecticidal substances possess many serious drawbacks, including drug residue contamination of the environment and, as a consequence, also of milk and meat products (Jayaseelan and Rahuman, 2012). Because of this, the interest of researchers has been directed to the

Nanotechnology in Diagnosis, Treatment and Prophylaxis of Infectious Diseases.
DOI: http://dx.doi.org/10.1016/B978-0-12-801317-5.00003-7

anti-arthropod potential of different types of other bioactive agents, including silver nanoparticles (AgNPs) (Rai and Ingle, 2012; Adhikaria et al., 2013; Suganya et al., 2014).

Different beneficial properties of silver have been known since ancient times, but development of technologies making it possible to easily produce silver in nanoparticle form has opened a new era in the biomedical application of silver. AgNPs have physical properties that are different from both silver ions and bulk material; their much higher biological activity caused by high surface area-to-volume ratio makes them promising agents in fighting against all possible types of pathogenic microorganisms—bacteria, fungi, protozoa, and viruses (Rai et al., 2009, 2014)—and also against vectors transmitting these microorganisms. Activity of AgNPs against microorganisms has been proven by hundreds of studies; however, investigations of anti-arthropod properties of AgNPs have been attracted attention recently. The aim of the present review is to summarize studies on activity of AgNPs against arthropod vectors of infectious diseases, such as lice, mosquito, ticks, and flies, and to formulate tasks for the studies that can be completed in the near feature.

3.2 LOUSE-BORNE INFECTIONS AND ACTIVITY OF AgNPs AGAINST LICE

There are more than 3,000 species of lice (order Phthiraptera), and among them only three are classified as human pathogens. They belong to sucking lice (Arthropoda: Insecta: order Phthiraptera: suborder Anoplura) and placed into two families—family Pediculidae, genus *Pediculus* (head louse and body louse) and family Pthiridae, genus *Pthirus* (pubic louse—*Pthirus pubis*). Although head and body lice have distinct ecology niches and minor variations in morphology and biology, recent genetic studies suggest that they can be considered more as different phenotypes of the same species, with differences mainly in gene expression and not in gene content (Veracx and Raoult, 2012). The traditional name for head louse is *P. humanus capitis*, and for body louse it is *Pediculus humanus humanus*, but because both lice belong to the same species, calling both of them *Pediculus humanus* (Smith, 2009) has been proposed; however, traditionally used names are still present in many studies.

The role of vectors transmitting infections is carried by both head and body lice. They can transmit life-threatening infections such as epidemic typhus (caused by *Rickettsia prowazekii*), relapsing fever (*Borrelia recurrentis*), and trench fever (*Bartonella quintana*) (Raoult and Roux, 1999; Fournier et al., 2002; El-Bahnsawy et al., 2012). These infections are of high concern in developing and developed countries; even if outbreaks of epidemic typhus and epidemic relapsing fever were fixed only in developing countries, significantly high seroprevalence against both bacteria among the homeless population of developed countries remind that these diseases have a high risk of outbreak throughout the world (Badiaga and Brouqui, 2012).

Despite the great importance of lice in transmission of life-threatening infections, there are only few studies on lousicidal activity of AgNPs (Jayaseelan et al., 2011; Marimuthu et al., 2012). In both studies AgNPs were biosynthesized using aqueous leaf extracts of *Tinospora cordifolia* and *Lawsonia inermis*, respectively, and they demonstrated significant activity against not only human head louse but also sheep body louse *Bovicola ovis* Schrank (Marimuthu et al., 2012). However, although the sizes of nanoparticles in both studies are equal, the activity of AgNPs produced using *L. inermis* was approximately 10-times higher, which is demonstrated by LC_{50} (Table 3.1).

TABLE 3.1 Studies on Pediculocidal, Larvicidal, and Acaricidal Activity of AgNPs

Aqueous leaf extract utilized for synthesis of AgNPs	Size and shape of AgNPs	Arthropod	LC_{50} (mg/L)	Ref.
LOUSICIDAL ACTIVITY				
T. cordifolia Miers (Menispermaceae)	55–80 nm	*P. humanus capitis* De Geer	12.46	Jayaseelan et al. (2011)
L. inermis	Average size of 60 nm, spherical	*P. humanus capitis* De Geer	1.33	Marimuthu et al. (2012)
LARVICIDAL ACTIVITY: AEDES MOSQUITO LARVAE[a]				
Fungus *Cochliobolus lunatus*	3–21 nm, spherical	*Ae. aegypti*	1.29, 1.48, and 1.58 against second, third, and fourth instar larvae, respectively	Salunkhe et al. (2011)
R. mucronata	60–95 nm, spherical	*Ae. aegypti*	0.585	Gnanadesigan et al. (2011)
Pergularia daemia	44–255 nm, spherical	*Ae. aegypti*	4.39, 5.12, 5.66, 6.18 against first to fourth instar larvae, respectively	Patil et al. (2012a)
Plumeria rubra plant latex	32–200 nm, spherical	*Ae. aegypti*	1.49, 1.82 against second and fourth instar larvae, respectively	Patil et al. (2012b)
Fungus *Chrysosporium tropicum*	20–50 nm, spherical	*Ae. aegypti*	3.47, 4, and 2 for the first, third and fourth larvae, respectively	Soni and Prakash (2012)
LARVICIDAL ACTIVITY: ANOPHELES MOSQUITO LARVAE				
T. cordifolia Miers (Menispermaceae)	55–80 nm	*Anopheles subpictus* Grassi	6.43	Jayaseelan et al. (2011)
Mimosa pudica Gaertn (Mimosaceae)	25–60 nm, spherical	*A. subpictus* Grassi	13.90	Marimuthu et al. (2011)
Nelumbo nucifera Gaertn. (Nymphaeaceae)	25–80 nm, spherical, triangle, truncated triangles, and decahedral-shaped	*A. subpictus* Grassi	0.69	Santhoshkumar et al. (2011)
Eclipta prostrata (L.) L. (Asteraceae)	35–60 nm, spherical	*A. subpictus* Grassi	5.14	Rajakumar and Rahuman (2011)
Fungus *Cochliobolus lunatus*	3–21 nm, spherical	*Anopheles stephensi* Liston	1.17, 1.30, and 1.41 against second, third, and fourth instar larvae, respectively	Salunkhe et al. (2011)
M. paradisiaca L. (Musaceae)	60–150 nm, rod-shaped	*A. stephensi* Liston	1.39	Jayaseelan et al. (2012)
P. daemia (Forssk.) Chiov. (Apocynaceae) plant latex	44–255 nm, spherical	*A. stephensi* Liston	4.41, 5.35, 5.91, 6.47 against first to fourth instar larvae, respectively	Patil et al. (2012a)

(*Continued*)

TABLE 3.1 (Continued)

Aqueous leaf extract utilized for synthesis of AgNPs	Size and shape of AgNPs	Arthropod	LC_{50} (mg/L)	Ref.
P. rubra L. (Apocynaceae) plant latex	32–200 nm, spherical	*A. stephensi* Liston	1.10, 1.74 against second and fourth instar larvae, respectively	Patil et al. (2012b)
Euphorbia hirta L. (Euphorbiaceae)	30–60 nm, spherical and with cubic structures	*A. stephensi* Liston	10.14, 16.82, 21.51, and 27.89 against first to fourth instar larvae, respectively	Priyadarshini et al. (2012)
Cassia occidentalis L. (Calsalpiniaceae)	450 nm	*A. stephensi* Liston	0.30 ppm for 3 mg/L, 0.41 ppm for 1.50 mg/L, and 2.12 ppm for 0.75 mg/L	Murugan et al. (2012)
Vinca rosea (L.) (Apocynaceae)	25–47 nm, spherical	*A. stephensi* Liston	12.47	Subarani et al. (2013)
Nerium oleander L. (Apocynaceae)	20–35 nm, spherical- and cubic-shaped	*A. stephensi* Liston	20.60, 24.90, 28.22, and 33.99 against first to fourth instar larvae, respectively	Roni et al. (2013)
Dried green fruits of *Drypetes roxburghii* (Wall.) Hur. (Euphorbiaceae)	10–35 nm, polyhedral	*A. stephensi* Liston	0.795, 0.964, and 1.134 against second, third, and fourth instar larvae, respectively	Haldar et al. (2013)
LARVICIDAL ACTIVITY: CULEX MOSQUITO LARVAE				
T. cordifolia Miers (Menispermaceae)	55–80 nm	*C. quinquefasciatus* say	6.96	Jayaseelan et al. (2011)
M. pudica L. (Fabaceae)	25–60 nm, spherical	*C. quinquefasciatus* say	11.73	Marimuthu et al. (2011)
Nelumbo nucifera Gaertn. (Nymphaeaceae)	25–80 nm, spherical, triangle, truncated triangles, and decahedral-shaped	*C. quinquefasciatus* say	1.10	Santhoshkumar et al. (2011)
R. mucronata L. (Rhizophoraceae)	60–95 nm, spherical	*C. quinquefasciatus* say	0.891	Gnanadesigan et al. (2011)
Eclipta prostrata (L.) L. (Asteraceae)	35–60 nm, spherical	*C. quinquefasciatus* say	4.56	Rajakumar and Rahuman (2011)
Pithecellobium dulce Roxb. (Benth.) (Fabaceae)	50–100 nm, spherical	*C. quinquefasciatus* say	21.56	Raman et al. (2012)
M. paradisiaca L. (Musaceae)	60–150 nm, rod-shaped	*Culex tritaeniorhynchus* Giles	1.63	Jayaseelan et al. (2012)

(*Continued*)

TABLE 3.1 (Continued)

Aqueous leaf extract utilized for synthesis of AgNPs	Size and shape of AgNPs	Arthropod	LC_{50} (mg/L)	Ref.
V. rosea (L.) (Apocynaceae)	25–47 nm, spherical	*C. quinquefasciatus* say	43.80	Subarani et al. (2013)
Dried green fruits of *D. roxburghii* (Wall.) Hur. (Euphorbiaceae)	10–35 nm, polyhedral	*C. quinquefasciatus* say	0.92, 1.27, and 1.40 against second, third, and fourth instar larvae, respectively	Haldar et al. (2013)
Bark extract of *Ficus racemosa* L. (Moraceae)	Average size of 251 nm, cylindrical, uniform, and rod-shaped	*C. quinquefasciatus* Say	12.00	Velayutham et al. (2013)
Bark extract of *F. racemosa* L. (Moraceae)	Average size of 251 nm, cylindrical, uniform, and rod-shaped	*Culex gelidus*	11.21	Velayutham et al. (2013)
ACTIVITY AGAINST TICKS				
M. pudica L. (Fabaceae)	25–60 nm, spherical	*R. (B.) microplus* Canestrini	8.98 against larvae	Marimuthu et al. (2011)
Manilkara zapota (L.) P. Royen (Sapotaceae)	70–140 nm, spherical and oval	*R. (B.) microplus*	3.44 against larvae	Rajakumar and Rahuman (2012)
Cissus quadrangularis L. (Vitaceae)	Average size of 42 nm, spherical and oval	*R. (B.) microplus*	7.61 against larvae	Santhoshkumar et al. (2012)
O. canum Sims (Labiatae)	25–110 nm, rods and cylindrical	*H. anatolicum* (a.) *anatolicum* Koch, 1844	0.78 against larvae	Jayaseelan and Rahuman (2012)
O. canum Sims (Labiatae)	25–110 nm, rods and cylindrical	*H. marginatum* (m.) *isaaci* Sharif, 1928	1.51 against larvae	Jayaseelan and Rahuman (2012)
M. paradisiaca L. (Musaceae)	60–150 nm, rod-shaped	*H. bispinosa* Neumann	1.87 against larvae	Jayaseelan et al. (2012)
Euphorbia prostrata Ait. (Euphorbiaceae)	25–80, rod-shaped	*H. bispinosa* Neumann	2.30 against adult ticks	Zahir and Rahuman (2012)
ACTIVITY AGAINST FLIES				
M. paradisiaca L. (Musaceae)	60–150 nm, rod-shaped	*H. maculata* Leach	2.02 against larvae	Jayaseelan et al. (2012)
E. prostrata Ait. (Euphorbiaceae)	25–80 nm, rod-shaped	*H. maculata* Leach	2.55 against adult flies	Zahir and Rahuman (2012)
C. quadrangularis L. (Vitaceae)	Average size of 42 nm, spherical and oval	*H. maculata* Leach	18.14 against adult flies	Santhoshkumar et al. (2012)
M. zapota (L.) P. Royen (Sapotaceae)	70–140 nm, spherical and oval	*M. domestica*	3.64 against adult flies	Kamaraj et al. (2012)

[a] *If not indicated, fourth instar larvae of mosquito were used.*

3.3 MOSQUITO-BORNE INFECTIONS AND ACTIVITY OF AgNPs AGAINST MOSQUITOES

Mosquitoes are involved in the transmission of a number of life-threatening diseases that have a great impact on worldwide morbidity and mortality (Tolle, 2009; Kamareddine, 2012), including malaria caused by Plasmodium, filariasis caused by worms, and viral-generated yellow fever, dengue infection, chikungunya virus infection, Rift Valley fever, Japanese encephalitis, West Nile encephalitis, and others (Reiner et al., 2013).

Mosquitoes transmitting human infections mainly belong to *Aedes*, *Anopheles*, and *Culex* genera. *A. aegypti* is the common vector of yellow fever and dengue; dengue is also often transmitted by another *Aedes* species—*Ae. albopictus*; *Ae. triseriatus* transmits La Crosse encephalitis, *Ae. japonicus* is a vector of Japanese encephalitis;, *Anopheles* spp. transmit plasmodia parasites causing malaria, and *Culex* spp. transmit several types of arboviral encephalitis (Eastern and Western equine encephalites, St. Louis encephalitis) and West Nile virus (Tolle, 2009). All these genera can transmit filariasis depending on geographical location; *Anopheles* is the most common vector in Africa, *Culex quinquefasciatus* is the most common in America, and *Aedes* is most common in the Pacific and in Asia (CDC, http://www.cdc.gov/parasites/lymphaticfilariasis/gen_info/vectors.html).

Most studies exploring activity of AgNPs against insects are directed at anti-mosquito activity (Table 3.1). Published studies used various sources for the biosynthesis of AgNPs, particularly different species of plants and fungi, and various stages of larvae life cycle as experimental models; nevertheless, all types of AgNPs demonstrated significant activity against all studied larvae of the *Ae. aegypti* mosquito, with ranges of LC_{50} from 0.59 mg/L (Gnanadesigan et al., 2011) to 6.18 mg/L (Patil et al., 2012a).

Activity of AgNPs against larvae of *Anopheles* mosquito was a little lower with LC_{50} reaching more than 20 mg/L in some studies (Priyadarshini et al., 2012; Roni et al., 2013); however, in other studies AgNPs also demonstrated good larvicidal effect with LC_{50} of less than 1.5 mg/L (Santhoshkumar et al., 2011; Salunkhe et al., 2011; Jayaseelan et al., 2012; Patil et al., 2012b; Haldar et al., 2013). Interesting results are being demonstrated in the ongoing study by Murugan et al. (2012); the authors evaluated not only larvicidal toxicity of AgNPs expressed in LC_{50} but also adult longevity in mosquitoes treated as larvae with an AgNP concentration of 0.1 ppm and number of eggs laid by female mosquitoes exposed as larvae to AgNPs exposed to the same concentration. Adult longevity (measured in days) in male and female mosquitoes was reduced by 29% and the number of eggs decreased by 32%; both results were significantly different ($P < 0.05$) from results of nonexposed mosquitoes.

In larvae of *Culex* mosquitoes, activity of AgNPs changed in wide ranges, starting from LC_{50} of 0.89 mg/L in AgNPs produced using aqueous extract of *Rhizophora mucronata* (Gnanadesigan et al., 2011) to 43.8 mg/L in AgNPs produced with aqueous extract of *Catharanthus roseus* (Subarani et al., 2013).

There are many studies that proved the anti-arthropod effects of AgNPs, but there is still no comprehensible scientific explanation for it. Some studies stated that larvicidal activity of AgNPs is concentration-dependent and is supposed to be caused by penetration of nanoparticles through the membrane of larvae (Sap-Iam et al., 2010; Salunkhe et al., 2011); however, more studies should be conducted to reveal all specific mechanisms of anti-arthropod activity of AgNPs.

3.4 TICK-BORNE INFECTIONS AND ACTIVITY OF AgNPs AGAINST TICKS

Ticks can carry viruses, bacteria, and protozoans, and they are vectors of many life-threatening infections. Tick-borne viruses ("tiboviruses") cause febrile illnesses with a rapid onset, fever, sweating, headache, nausea, weakness, myalgia, arthralgia, and sometimes polyarthritis and rash, infections that affect the central nervous system, such as meningitis, meningoencephalitis, or encephalomyelitis with paresis, paralysis, and other sequelae, and hemorrhagic diseases (Hubálek and Rudolf, 2012). Among bacterial diseases transmitted by ticks are Lyme disease, rickettsioses, and tularemia (Parola et al., 2005; Foley and Nieto, 2010; Kung et al., 2013); furthermore, ticks transmit the protozoan infection babesiosis (Schnittger et al., 2012). A bite from one tick may transmit several infections simultaneously (Pujalte and Chua, 2013).

Ticks most commonly transmitting infections belong to genera *Ixodes* and *Dermacentor*. *Ixodes scapularis* transmits Lyme disease, babesiosis, and anaplasmosis; *Dermacentor andersoni* and *Dermacentor variabilis* transmit Rocky Mountain spotted fever and tularemia (CDC, http://www.cdc.gov/ticks/diseases/).

Some ticks produce toxins that can cause tick paralysis, for example, *D. andersoni* (the Rocky Mountain wood tick), *D. variabilis* (the American dog tick), and *Ixodes holocyclus* (the marsupial tick) (Diaz, 2010; Pecina, 2012).

During evaluation of AgNP effects on ticks, most scientists studied the activity against larvae of ticks (Table 3.1), but only Zahir and Rahuman (2012) used adult ticks in the experiment. Another limitation of the present data is that only a few tick species were studied—*R. (Boophilus) microplus*, *Hyalomma anatolicum anatolicum*, *Hyalomma marginatum isaaci*, and *Haemaphysalis bispinosa*. However, all performed studies showed promising activity of AgNPs against both larvae and adult ticks with LC_{50} ranging from 0.79 mg/L (Jayaseelan and Rahuman, 2012) to 8.98 mg/L (Marimuthu et al., 2011). The best results were obtained with AgNPs produced using extract of *Ocimum canum* against ticks of *Hyalomma* spp. (Jayaseelan and Rahuman, 2012).

3.5 FLIES, THEIR ROLE IN TRANSMISSION AND SPREAD OF INFECTIONS, AND ACTIVITY OF AgNPs AGAINST FLIES

Flies play a double role in the transmission of infectious diseases. They can transmit infections through biting or can be a mechanical factor contributing to the spread of infections. Biting or hematophagous flies are involved in the transmission of bacterial infections, such as tularemia (deer fly, *Chrysops* spp.), protozoan infections such as leishmaniasis (sand fly, Diptera: Psychodidae) and African sleeping sickness (tsetse fly, *Glossina* spp.), and worm invasions such as onchocerciasis (blackfly, *Simulium* spp.) (Petersen et al., 2008; Traore et al., 2012; Holmes et al., 2013; Cruz et al., 2013).

Nonbiting synanthropic flies (some species are in the families Sarcophagidae, such as flesh flies, Muscidae, such as house flies and latrine flies, and Calliphoridae, such as blow flies and bottle flies) can contribute to the spread of infections by mechanical carrying of bacteria causing gastrointestinal infections (cholera, typhoid fever, salmonellosis) or contact infections (e.g., trachoma) (Graczyk et al., 2005). Likewise, flies can transmit oocysts of *Toxoplasma gondii* and of diarrhea-producing protozoan *Cryptosporidium parvum*, which recently has contributed significantly to the mortality of immunocompromised or immunosuppressed patients (Graczyk et al., 2005).

Transmission of microorganisms by nonbiting flies occurs after their feeding on some infected sources and by mechanical dislodgement from the exoskeleton of flies or from their feces and vomit (Graczyk et al., 2004).

Studies of the activity of AgNPs against flies are very scarce. Several authors demonstrated activity of plant-synthesized AgNPs against hematophagous fly *Hippobosca maculata* Leach, including effects on fly larvae (Jayaseelan et al., 2012) and adult flies (Zahir and Rahuman, 2012; Santhoshkumar et al., 2012). Kamaraj et al. (2012) reported activity of AgNPs against the synanthropic fly *Musca domestica*. In all these studies AgNPs were biosynthetically produced using plant extracts with a wide range of obtained sizes of nanoparticles and their activity. The best results were demonstrated in AgNPs produced by using aqueous leaf extract of *Musa paradisiaca* with LC_{50} 2.02 mg/L (Jayaseelan et al., 2012).

3.6 CONCLUSIONS AND FUTURE PROSPECTS

Vector-borne infections are very important among infectious diseases with high morbidity and mortality worldwide. One approach to fighting against such infections is by controlling vectors transmitting them. The control of populations of mosquitoes, lice, flies, and ticks may help to reduce the prevalence of vector-borne infections, and production of substances that have high anti-arthropod activity and simultaneously are environmentally safe is an important challenge in modern science.

Published studies demonstrated promising activity of AgNPs against all types of vectors of infectious diseases. They showed broad-spectrum insecticidal activity that was especially well-studied against larvae of mosquitoes; insecticidal activity was also examined in a few studies that investigated the activity of AgNPs against flies, lice, and ticks. Interestingly, in all the published studies AgNPs were produced in a biosynthetical manner utilizing plant extracts or, in a few studies, fungi. In all studies AgNPs had significantly higher activity than that of corresponding plant extracts and higher than that of 1 mM $AgNO_3$ solution used for nanoparticle synthesis.

Despite high anti-arthropod activity, biosynthetically produced AgNPs and solvent extracts used for their production did not show any notable toxicity on environmental organisms, such as water fleas *Daphnia magna* and *Ceriodaphnia dubia*, and they did not show any undesirable effects in the animal model against cattle *Bos indicus* (Zahir and Rahuman, 2012); likewise, no toxicity was detected against fish *Poecilia reticulate* (Salunkhe et al., 2011; Patil et al., 2012a,b; Subarani et al., 2013). Thus, the control of arthropods with biosynthetically produced AgNPs is environmentally friendly.

At the same time, many questions in this area are still not clear and require future investigations. There is no complete understanding of the mechanisms of the anti-arthropod effects of AgNPs. Only a few studies hypothesized membrane-damaging larvicidal activity, but more efforts should be directed to formulating theories of mechanisms of larvicidal, lousicidal, and acaricidal effects. A broader species spectrum of flies and ticks should be evaluated. Furthermore, concentrations of AgNPs with pediculicidal effects should be studied regarding toxicity in mammal organisms. A better understanding of all these questions will help control arthropod-borne diseases.

References

Adhikaria, U., Ghoshb, A., Chandra, G., 2013. Nano particles of herbal origin: a recent eco-friend trend in mosquito control. Asian Pac. J. Trop. Dis. 3 (2), 167–168.

Aïkpon, R., Agossa, F., Ossè, R., Oussou, O., Aïzoun, N., Oké-Agbo, F., et al., 2013. Bendiocarb resistance in *Anopheles gambiae* s.l. populations from Atacora department in Benin, West Africa: a threat for malaria vector control. Parasit. Vectors 6 (1), 192.

Badiaga, S., Brouqui, P., 2012. Human louse-transmitted infectious diseases. Clin. Microbiol. Infect. 18 (4), 332−337.

Blayneh, K.W., Mohammed-Awel, J., 2014. Insecticide-resistant mosquitoes and malaria control. Math. Biosci. 252C, 14−26.

Bridges, D.J., Winters, A.M., Hamer, D.H., 2012. Malaria elimination: surveillance and response. Pathog. Glob. Health 106 (4), 224−231.

Coetzee, M., Koekemoer, L.L., 2013. Molecular systematics and insecticide resistance in the major African malaria vector *Anopheles funestus*. Annu. Rev. Entomol. 58, 393−412.

Cruz, C.F., Cruz, M.F., Galati, E.A., 2013. Sandflies (Diptera: Psychodidae) in rural and urban environments in an endemic area of cutaneous leishmaniasis in southern Brazil. Mem. Inst. Oswaldo Cruz. 108 (3), pii: S0074-02762013000300303.

Diaz, J.H., 2010. A 60-year meta-analysis of tick paralysis in the United States: a predictable, preventable, and often misdiagnosed poisoning. J. Med. Toxicol. 6 (1), 15−21.

Durand, R., Bouvresse, S., Berdjane, Z., Izri, A., Chosidow, O., Clark, J.M., 2012. Insecticide resistance in head lice: clinical, parasitological and genetic aspects. Clin. Microbiol. Infect. 18 (4), 338−344.

El-Bahnasawy, M.M., Khater, M.K., Morsy, T.A., 2013. The mosquito borne West Nile virus infection: is it threating to Egypt or a neglected endemic disease? J. Egypt. Soc. Parasitol. 43 (1), 87−102.

El-Bahnsawy, M.M., Labib, N.A., Abdel-Fattah, M.A., Ibrahim, A.M., Morsy, T.A., 2012. Louse and tick borne relapsing fevers. J. Egypt. Soc. Parasitol. 42 (3), 625−638.

Faza, A.P., Pinto, I.S., Fonseca, I., Antunes, G.R., Monteiro, C. M., Daemon, E., et al., 2013. A new approach to characterization of the resistance of populations of *Rhipicephalus microplus* (Acari: Ixodidae) to organophosphate and pyrethroid in the state of Minas Gerais, Brazil. Exp. Parasitol. pii: S0014-4894(13)00127-6. 10.1016/j.exppara.2013.04.006.

Foley, J.E., Nieto, N.C., 2010. Tularemia. Vet. Microbiol. 140 (3−4), 332−338.

Fournier, P.E., Ndihokubwayo, J.B., Guidran, J., Kelly, P.J., Raoult, D., 2002. Human pathogens in body and head lice. Emerg. Infect. Dis. 8 (12), 1515−1518.

Gnanadesigan, M., Anand, M., Ravikumar, S., Maruthupandy, M., Vijayakumar, V., Selvam, S., et al., 2011. Biosynthesis of silver nanoparticles by using mangrove plant extract and their potential mosquito larvicidal property. Asian Pac. J. Trop. Med. 4 (10), 799−803.

Graczyk, T.K., Grimes, B.H., Knight, R., Szostakowska, B., Kruminis-Lozowska, W., Racewicz, M., et al., 2004. Mechanical transmission of *Cryptosporidium parvum* oocysts by flies. Wiad. Parazytol. 50 (2), 243−247.

Graczyk, T.K., Knight, R., Tamang, L., 2005. Mechanical transmission of human protozoan parasites by insects. Clin. Microbiol. Rev. 18 (1), 128−132.

Haldar, K.M., Haldar, B., Chandra, G., 2013. Fabrication, characterization and mosquito larvicidal bioassay of silver nanoparticles synthesized from aqueous fruit extract of putranjiva, *Drypetes roxburghii* (Wall.). Parasitol. Res. 112 (4), 1451−1459.

Holmes, P., 2013. Tsetse-transmitted trypanosomes—their biology, disease impact and control. J. Invertebr. Pathol. 112 (Suppl), S11−S14.

Hubálek, Z., Rudolf, I., 2012. Tick-borne viruses in Europe. Parasitol. Res. 111 (1), 9−36.

Jayaseelan, C., Rahuman, A.A., 2012. Acaricidal efficacy of synthesized silver nanoparticles using aqueous leaf extract of *Ocimum canum* against *Hyalomma anatolicum anatolicum* and *Hyalomma marginatum isaaci* (Acari: Ixodidae). Parasitol. Res. 111 (3), 1369−1378.

Jayaseelan, C., Rahuman, A.A., Rajakumar, G., Vishnu Kirthi, A., Santhoshkumar, T., Marimuthu, S., et al., 2011. Synthesis of pediculocidal and larvicidal silver nanoparticles by leaf extract from heartleaf moonseed plant, *Tinospora cordifolia* Miers. Parasitol. Res. 109 (1), 185−194.

Jayaseelan, C., Rahuman, A.A., Rajakumar, G., Santhoshkumar, T., Kirthi, A.V., Marimuthu, S., et al., 2012. Efficacy of plant-mediated synthesized silver nanoparticles against hematophagous parasites. Parasitol. Res. 111 (2), 921−933.

Kamaraj, C., Rajakumar, G., Rahuman, A.A., Velayutham, K., Bagavan, A., Zahir, A.A., et al., 2012. Feeding deterrent activity of synthesized silver nanoparticles using *Manilkara zapota* leaf extract against the house fly, *Musca domestica* (Diptera: Muscidae). Parasitol. Res. 111 (6), 2439−2448.

Kamareddine, L., 2012. The biological control of the malaria vector. Toxins (Basel). 4 (9), 748−767.

Kilpatrick, A.M., Randolph, S.E., 2012. Drivers, dynamics, and control of emerging vector-borne zoonotic diseases. Lancet 380 (9857), 1946−1955.

Kung, F., Anguita, J., Pal, U., 2013. *Borrelia burgdorferi* and tick proteins supporting pathogen persistence in the vector. Future Microbiol. 8 (1), 41−56.

Marimuthu, S., Rahuman, A.A., Rajakumar, G., Santhoshkumar, T., Kirthi, A.V., Jayaseelan, C., et al., 2011. Evaluation of green synthesized silver nanoparticles against parasites. Parasitol. Res. 108 (6), 1541−1549.

Marimuthu, S., Rahuman, A.A., Santhoshkumar, T., Jayaseelan, C., Kirthi, A.V., Bagavan, A., et al., 2012. Lousicidal activity of synthesized silver nanoparticles using *Lawsonia inermis* leaf aqueous extract against *Pediculus humanus capitis* and *Bovicola ovis*. Parasitol. Res. 111 (5), 2023−2033.

Medlock, J.M., Hansford, K.M., Schaffner, F., Versteirt, V., Hendrickx, G., Zeller, H., et al., 2012. A review of the invasive mosquitoes in Europe: ecology, public health risks, and control options. Vector Borne Zoonotic Dis. 12 (6), 435–447.

Murugan, K., Shri, K.P., Barnard, D., 2012. Green synthesis of silver nanoparticles from botanical sources and their use for control of medical insects and malaria parasites. <http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=281989>.

Ocampo, C.B., Salazar-Terreros, M.J., Mina, N.J., McAllister, J., Brogdon, W., 2011. Insecticide resistance status of *Aedes aegypti* in 10 localities in Colombia. Acta Trop. 118 (1), 37–44.

Parola, P., Paddock, C.D., Raoult, D., 2005. Tick-borne rickettsioses around the world: emerging diseases challenging old concepts. Clin. Microbiol. Rev. 18 (4), 719–756.

Patil, C.D., Borase, H.P., Patil, S.V., Salunkhe, R.B., Salunke, B.K., 2012a. Larvicidal activity of silver nanoparticles synthesized using *Pergularia daemia* plant latex against *Aedes aegypti* and *Anopheles stephensi* and nontarget fish *Poecillia reticulata*. Parasitol. Res. 111 (2), 555–562.

Patil, C.D., Patil, S.V., Borase, H.P., Salunke, B.K., Salunkhe, R.B., 2012b. Larvicidal activity of silver nanoparticles synthesized using *Plumeria rubra* plant latex against *Aedes aegypti* and *Anopheles stephensi*. Parasitol. Res. 110 (5), 1815–1822.

Pecina, C.A., 2012. Tick paralysis. Semin. Neurol. 32 (5), 531–532.

Petersen, J.M., Carlson, J.K., Dietrich, G., Eisen, R.J., Coombs, J., Janusz, A.M., et al., 2008. Multiple *Francisella tularensis* subspecies and clades, tularemia outbreak, Utah. Emerg. Infect. Dis. 14 (12), 1928–1930.

Priyadarshini, K.A., Murugan, K., Panneerselvam, C., Ponarulselvam, S., Hwang, J.S., Nicoletti, M., 2012. Biolarvicidal and pupicidal potential of silver nanoparticles synthesized using *Euphorbia hirta* against *Anopheles stephensi* Liston (Diptera: Culicidae). Parasitol. Res. 111 (3), 997–1006.

Pujalte, G.G., Chua, J.V., 2013. Tick-borne infections in the United States. Prim. Care. 40 (3), 619–635.

Raghavendra, K., Barik, T.K., Reddy, B.P., Sharma, P., Dash, A.P., 2011. Malaria vector control: from past to future. Parasitol. Res. 108 (4), 757–779.

Rai, M., Ingle, A., 2012. Role of nanotechnology in agriculture with special reference to management of insect pests. Appl. Microbiol. Biotechnol. 94 (2), 287–293.

Rai, M., Yadav, A., Gade, A., 2009. Silver nanoparticles as a new generation of antimicrobials. Biotechnol. Adv. 27 (1), 76–83.

Rai, M., Kon, K., Ingle, A., Duran, N., Galdiero, S., Galdiero, M., 2014. Broad-spectrum bioactivities of silver nanoparticles: the emerging trends and future prospects. Appl. Microbiol. Biotechnol. Available from: <http://dx.doi.org/10.1007/s00253-013-5473-x>.

Rajakumar, G., Rahuman, A.A., 2011. Larvicidal activity of synthesized silver nanoparticles using *Eclipta prostrata* leaf extract against filariasis and malaria vectors. Acta Trop. 118 (3), 196–203.

Rajakumar, G., Rahuman, A.A., 2012. Acaricidal activity of aqueous extract and synthesized silver nanoparticles from *Manilkara zapota* against *Rhipicephalus (Boophilus) microplus*. Res. Vet. Sci. 93 (1), 303–309.

Raman, N., Sudharsan, S., Veerakumar, V., Pravin, N., Vithiya, K., 2012. *Pithecellobium dulce* mediated extracellular green synthesis of larvicidal silver nanoparticles. Spectrochim. Acta A Mol. Biomol. Spectrosc. 96, 1031–1037.

Raoult, D., Roux, V., 1999. The body louse as a vector of reemerging human diseases. Clin. Infect. Dis. 29 (4), 888–911.

Reiner Jr., R.C., Perkins, T.A., Barker, C.M., Niu, T., Chaves, L.F., Ellis, A.M., et al., 2013. A systematic review of mathematical models of mosquito-borne pathogen transmission: 1970-2010. J. R. Soc. Interface 10 (81), 20120921.

Roni, M., Murugan, K., Panneerselvam, C., Subramaniam, J., Hwang, J.S., 2013. Evaluation of leaf aqueous extract and synthesized silver nanoparticles using *Nerium oleander* against *Anopheles stephensi* (Diptera: Culicidae). Parasitol. Res. 112 (3), 981–990.

Salunkhe, R.B., Patil, S.V., Patil, C.D., Salunke, B.K., 2011. Larvicidal potential of silver nanoparticles synthesized using fungus *Cochliobolus lunatus* against *Aedes aegypti* (Linnaeus, 1762) and *Anopheles stephensi* Liston (Diptera; Culicidae). Parasitol. Res. 109 (3), 823–831.

Santhoshkumar, T., Rahuman, A.A., Rajakumar, G., Marimuthu, S., Bagavan, A., Jayaseelan, C., et al., 2011. Synthesis of silver nanoparticles using *Nelumbo nucifera* leaf extract and its larvicidal activity against malaria and filariasis vectors. Parasitol. Res. 108 (3), 693–702.

Santhoshkumar, T., Rahuman, A.A., Bagavan, A., Marimuthu, S., Jayaseelan, C., Kirthi, A.V., et al., 2012. Evaluation of stem aqueous extract and synthesized silver nanoparticles using *Cissus quadrangularis* against *Hippobosca maculata* and *Rhipicephalus (Boophilus) microplus*. Exp. Parasitol. 132 (2), 156–165.

Sap-Iam, N., Homklincha, C., Larpudomle, R., Warisnoich, W., Sereemaspu, A., Dubas, S.T., 2010. UV irradiation-induced silver nanoparticles as mosquito larvicides. J. App. Sci. 10 (23), 3132–3136.

Schnittger, L., Rodriguez, A.E., Florin-Christensen, M., Morrison, D.A., 2012. Babesia: a world emerging. Infect. Genet. Evol. 12 (8), 1788–1809.

Smith, C.H., Goldman, R.D., 2012. An incurable itch: head lice. Can. Fam. Physician 58 (8), 839–841.

Smith, V., 2009. Taxonomy of human lice. <http://phthiraptera.info/content/taxonomy-human-lice>.

Soni, N., Prakash, S., 2012. Efficacy of fungus mediated silver and gold nanoparticles against *Aedes aegypti* larvae. Parasitol. Res. 110 (1), 175–184.

Subarani, S., Sabhanayakam, S., Kamaraj, C., 2013. Studies on the impact of biosynthesized silver nanoparticles (AgNPs) in relation to malaria and filariasis vector control against *Anopheles stephensi* Liston and *Culex quinquefasciatus* Say (Diptera: Culicidae). Parasitol. Res. 112 (2), 487–499.

Suganya, G., Karthi, S., Shivakumar, M.S., 2014. Larvicidal potential of silver nanoparticles synthesized from Leucas aspera leaf extracts against dengue vector *Aedes aegypti*. Parasitol. Res. 2014 [Epub ahead of print].

Tolle, M.A., 2009. Mosquito-borne diseases. Curr. Probl. Pediatr. Adolesc. Health Care 39 (4), 97–140.

Toloza, A.C., Ascunce, M.S., Reed, D., Picollo, M.I., 2014. Geographical distribution of pyrethroid resistance allele frequency in head lice (Phthiraptera: Pediculidae) from Argentina. J. Med. Entomol. 51 (1), 139–144.

Traore, M.O., Sarr, M.D., Badji, A., Bissan, Y., Diawara, L., Doumbia, K., et al., 2012. Proof-of-principle of onchocerciasis elimination with ivermectin treatment in endemic foci in Africa: final results of a study in Mali and Senegal. PLoS. Negl. Trop. Dis. 6 (9), e1825.

Velayutham, K., Rahuman, A.A., Rajakumar, G., Roopan, S. M., Elango, G., Kamaraj, C., et al., 2013. Larvicidal activity of green synthesized silver nanoparticles using bark aqueous extract of *Ficus racemosa* against *Culex quinquefasciatus* and *Culex gelidus*. Asian Pac. J. Trop. Med. 6 (2), 95–101.

Veracx, A., Raoult, D., 2012. Biology and genetics of human head and body lice. Trends Parasitol. 28 (12), 563–571.

Yang, T., Liu, N., 2013. Permethrin resistance profiles in a field population of mosquitoes, *Culex quinquefasciatus* (Diptera: Culicidae). J. Med. Entomol. 50 (3), 585–593.

Zahir, A.A., Rahuman, A.A., 2012. Evaluation of different extracts and synthesised silver nanoparticles from leaves of *Euphorbia prostrata* against *Haemaphysalis bispinosa* and *Hippobosca maculata*. Vet. Parasitol. 187 (3–4), 511–520.