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REVIEW ARTICLE

Integrated Strategies for the Control and Prevention of Dengue Vectors with Particular Reference to *Aedes aegypti*

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ABSTRACT

Dengue fever (DF) is one of the most threatening vector borne diseases, affecting both humans and animals, causing severe epidemics and has brought the world to take serious steps for its control and prevention. DF is a viral disease transmitted by *Aedes* mosquitoes. Unfortunately, due to unavailability of vaccine and lack of effective treatment, emphasis is given on its vector control. The only option left for its eradication is to restrict mosquito breeding. This can be achieved by chemical, biological and environment management methods. Use of botanicals is also an alternate and probably most effective approach for controlling DF vector. Community based eradication campaigns including educating people about its prevention and control measures and personal prophylaxis also play a vital role to prevent its occurrence. Likewise, use of nanotechnology and micro-emulsion, use of pheromones, insect sterilization techniques have also shown promising results in vector control. Utilization of only one method cannot control this dangerous disease but combination of all above interventions, discussed in the present paper, may prevent the DF vector and ultimately might help in the eradication programs of this disease.

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INTRODUCTION

Dengue fever (DF) is caused by one of the four serotypes (DEN-1, DEN- 2, DEN-3 and DEN-4) of genus *Flavivirus* and spread by mosquito vector mainly by *Aedes aegypti* and *Aedes albopictus* which belong to order *Diptera* and family *Culicidae*. DF mosquitoes typically bite during the day particularly in the early morning and late evening. DF first emerged in 1940 and then spread across tropics and subtropics (Kroeger and Nathan, 2006). The ecologic disruption in the Southeast Asia and Pacific theaters during and following World War II created ideal conditions for increased transmission of mosquito-borne diseases, and it was in this setting that a global pandemic of dengue began (Halstead, 1992). Reports have demonstrated that monkeys can also act as a source of transmitting DF virus to humans due to mutual sharing of same habitat. Mosquitoes that bite the monkey may acquire the virus and subsequently transfer virus to humans. So, monkeys can serve as major reservoir host for the transmission of virus to humans (Holmes and Twiddy, 2003). Clinical cases have shown that early stages are similar to those of yellow fever. Fever and other symptoms seldom remain for more than seven days. The later stages of the illness often include a widespread rash (Farrar, 2008). Out of total dengue cases about less than 5% cases can be severe and a fraction of these cases can be fatal (Morens, 2009). About 50-100 million infections are reported annually and out of this more than 500,000 people suffered from dengue hemorrhagic fever (Halstead, 2007). An estimated 19,000 deaths are attributable to DF each year. Dengue hemorrhagic fever (DHF) and dengue shock syndrome are common names of severe DF that is distinguishable from classic DF because this is associated with spontaneous hemorrhage and an increase in vascular permeability which can lead to hypovolemic shock and death. Etiology of these conditions has been debated for decades but this problem remained unresolved and untreatable (Murgue, 2010). DHF is fastest growing viral disease. During 1970s and 1980s, DHF re-emerged in most of the countries such as America and some others from which it had previously been eliminated (Gubler, 1987). After a few years of re-emergence, these countries experienced epidemics of DF, followed by hyper response and the emergence of DHF (Pinheiro and Corber, 1997).

Dengue virus transmission is due to multiple factors such as increase in population, local and international traveling and international trade of commodities (tires); changes in water resources being used, storage of waste water in open drums and lack of financial and effective resources necessary for control and preventive measures. In addition to the above mentioned factors, the rise in global temperature and humidity has also increased incidence of DF. Out of all these factors, the global warming is predominantly influencing the spread of DF vectors. As increased temperature favors development of adult mosquitoes and increase their number. During hotter summer, frequency of female mosquito biting increases and warmer winter empower mosquito's survival in previously cold areas. So, in some areas increased humidity, temperature and precipitation cause measureable increase in DF incidence (Hopp and Foley, 2003). Increased level of humidity favors long survival of eggs and female mosquito. During draught season, people used to store water in drums, container and tanks; this provides the more breeding sites to mosquitoes that results in spread of DF to cities (Gage *et al*, 2008).

The increased occurrence of DF and its high mortality rate has brought the world to take serious steps for its prevention and control. Previously, old civilized communities of different countries adapted various traditional protocols to control mosquito population. Use of burned plant materials proved to be effective to drive away mosquitoes. About 39% of Malawians burn wood dung or leaves (Ziba *et al*., 1994), 3% of rural Zimbabweans used burned plants and 15% used coils (Lukwa *et al*., 1999), 100% of Kenyans people burned plants to repel mosquitoes (Seyoum *et al*., 2002) and 55% people of Guinea Bissau used burned plants or hung them in their homes to get rid of mosquitoes (Palsson and Jaenson, 1999). From prehistoric times, Indian people have been using *Azadirachta indica*, commonly known as neem, against household and storage pests. Furthermore, they traditionally burned neem leaves in the evening to repel mosquitoes. It is reported that neem plant is effective against more than 500 species of insects. Recently, *A. indica* has attracted global attentions because of its potential as a natural source of environment friendly pesticides (Isman *et al*., 2011; Mehlhorn, 2011).

In this regard, vector control proved most successful and excellent method to decrease incidence of mosquito borne diseases. Due to the emergence of resistance against various insecticides and potential environmental issues associated with some synthetic insecticides such as DDT has indicated that additional approaches to control the proliferation of mosquito population would be an urgent priority research (Grodner, 1997).

So far, no vaccine has been developed for prophylaxis of DF because the presence of more than one viral strains make it difficult. These factors contribute towards slow progress in controlling all serotypes simultaneously (Hombach, 2007). Recently, attenuated vaccines and second-generation recombinant vaccines are under development (Webster *et al*., 2009). To evaluate the efficacy of a chimeric tetravalent vaccine, large scale trials are going on since February 2009 in Washington (NIHA, 2010). If these trials are successful, then a vaccine might be licensed within next five years. Despite all these efforts, there is no chance of vaccine availability in near future. Furthermore, because of the non availability of effective and specific treatment against DF, the supportive therapy is the only remedy to replace the heavy blood loss. In supportive therapy, the intravenous fluids are administered to counter the hemo-concentrations and platelet transfusions in case of severe thrombocytopenia (Wills and Holstead, 2008).

Because of the high cost of developing new drugs and vaccines, development of drug resistance, and concerns over drug residues associated with the continuous use of chemicals, there is a renewed interest in the use of botanicals for the safe, effective and cheap control of pests of agriculture and public health importance (Yildirim *et al*., 2012). Scientists all over the world are now actively engaged in research into the use of plants and plant-derived products to fight against dengue vector. Botanical products are effective, have no harmful effects on environment and non-targeted organisms, easily biodegradable, inexpensive and readily available in many areas of the world (Su and Mulla, 1999). Plants and plant derived products are rich in natural phytochemicals (Fan *et al*., 2011), which make them effective against different microbes and pests. Some of these chemicals have also been used successfully for controlling dengue vector because of their larvicidal, ovicidal and skin repellent effects (Shaalan *et al*., 2005).

Because of above mentioned constraints in the methods used for the control and treatment of DF, control of *Aedes* mosquitoes is the only viable option (WHO, 2009). Therefore, in this paper integrated strategies for the prevention and control of DF have been discussed in the following sections.

Effective and focused surveillance: Effective and focused surveillance is fundamental in setting the objectives and evaluating a vector borne disease control program. Unfortunately, these programs are not aimed on vector eradication. Singapore's experience with dengue demonstrated that current vector control efforts are not sustainable. For sustainable succession program, Singapore needs to adopt a vector control program which is based on carefully collected epidemiological and entomological data and there is need to strengthen disease surveillance programs (Ooi *et al*., 2006).

Surveillance programs should determine the vector density as it is easier and inexpensive method in controlling *A. aegypti* (Tun-Lin *et al.,* 1995). So, an effective surveillance focusing on vector eradication, which provides fundamental information about vector density and its breeding habitat, will be helpful in *A. aegypti* control.

Environmental management and community based eradication campaigns: Environmental management should be aimed to reduce vector breeding sites, especially in close vicinity with humans and therefore minimize human-vector contact. These changes can be made for attaining long lasting effects which include modifying building designs such as roof gutters, covering containers and other potential breeding sites to prevent *Aedes* breeding (NG, 2008).

By adopting certain environment management practices such as removing, covering and treating larval sites show better results as compared to outdoor application of insecticide which has poor penetration at the potential breeding sites of mosquito vector. By taking long term steps of physical changes in environment, that are termed as environmental modifications, the incidence of DF can be reduced (Walker, 2002). These modifications should be done at larger scale under the great amount of financial aid and manpower. Modification at local level is of no significance and may be ineffective at alternative sites of vector breeding near human habitats (Mutero *et al*., 2004). Well targeted local modification of environment can be successful in some cases. The sustained environmental interventions are effective, inexpensive and environment friendly as compared to chemical methods (Utzinger *et al*., 2001).

Use of ovitraps in different areas such as in Singapore is also proved to be effective for control of *A. aegypti* larvae. Larvicidal ovitraps consist of a black, water-filled cylindrical container with a flotation device made up of a wire mesh and 2 wooden paddles. Eggs laid by mosquitoes on the wooden paddle hatch, larvae develop in the water under the wire mesh and ultimately resultant adult mosquito's also trapped (Lok *et al*., 1977).

Community based eradication campaigns are made with the objective of educating the public about the strategies for the elimination of breeding sites to reduce mosquito production. In this method, the public or community people are divided into different groups because all the people of community are not well educated and their level of understanding is not same. In some countries like Cuba, community involvement has been very useful for the effective eradication of *A. aegypti* mosquitoes from the environment (Vanlerberghe *et al*., 2010). However, to get maximum vector control, community involvement should be used in combination of other methods to limit vector density (Pérez-Guerra *et al*., 2009; Shriram *et al*., 2009), such as the combination of community based campaigns and chemical control have shown significant results in controlling *A. aegypti* in Cuba state (Baly *et al*., 2007).

Community participation is key to success either it is biological, chemical, or environment based strategy (Yap, 1984). Community based eradication campaigns are most economical interventions for government as compared to other campaigns. Furthermore, it is almost impossible to achieve sustainable success in controlling dengue vector, without integration of community to other control methods (Gubler, 1997) because such campaigns result in mobilizing and channeling the household behaviors, thus, eliminating vector breeding sites (Parks *et al*., 2005). However, the success of community based campaigns depends on the knowledge, the behavior of the community members and practices involved (Whiteford, 1997; Nam *et al*., 2005).

Chemical control: Chemicals have played a major role for the effective control of dengue vector for several years. In 1940s, use of insecticide resulted towards the less emphasis on biological and environmental methods of controlling vectors. Dichlorodiphenyltrichloroethane (DDT) was the first chemical used to control *A. aegypti* but development of DDT resistance was a key factor which contributed towards the re-emergence of *A. aegypti* (Curtis and Lines, 2000). Studies have also shown the development of cross resistance in *A. aegypti* to other chemicals such as organophosphates and carbamates (Rawlins, 1998; Olivares-Pérez *et al*., 2011). Recently, development of multiple resistances in *A. aegypti* has also been reported in different countries such as Latin America (Rodríguez *et al*., 2007) and French West Indies (Marcombe *et al*., 2009). Resistance of *A. aegypti* to various chemicals has been described in detail in table 1.

Table 1: Reports on insecticides resistance against *Aedes aegypti* during last decade

Class of Insecticide	Insecticide	Country	References
Organochlorine	DDT	Latin America	Rodríguez *et al.* (2007)
		Japan	Kawada *et al.* (2009)
		India	Tikar *et al.* (2009)
		Latin America	Polson *et al.* (2011)
		Colombia	Ocampo *et al.* (2011)
Organophosphates	Temephos	Brazil	Macoris *et al.* (2003)
		Thailand	Ponlawat *et al.* (2005)
		Argentina	Macoris *et al.* (2007)
		Brazil	Rodríguez *et al.* (2007)
		Argentina	Llinás *et al.* (2010)
		Brazil	Lima *et al.* (2011)
		Brazil	Fontoura *et al.* (2012)
	Malathion	India	Tikar *et al.* (2009)
		Trinidad and Tobago	Polson *et al.* (2011)
		Malaysia	Rong *et al.* (2012)
	Chlorpyrifos	India	Tikar *et al.* (2009)
		Pakistan	Khan *et al.* (2011)
	Fenthion	India	Tikar *et al.* (2009)
Pyrethroids	Permethrin	Indonesia	Ahmad *et al.* (2007)
		Mexico	Garcia *et al.* (2009)
		Malaysia	Rong *et al.* (2012)
	Cypermethrin	Brazil	Lima *et al.* (2011)
	Deltamethrin	French Guiana	Dusfour *et al.* (2011)
		Africa	Constant *et al.* (2012)
		Thailand	Phanpoowong *et al.* (2012)
Carbamates	Amidocarb and propoxur	Malaysia	Rong *et al.* (2012)

Furthermore, use of synthetic chemicals has also been limited because of their carcinogenicity, teratogenicity, residual toxicity, ability to create hormonal imbalance, spermatotoxicity, long degradation period and food residues (Khater, 2011). The toxicity of Temephos on non-targeted natural organism has been shown in many ecological systems, especially in aquatic ecology, which is the breeding habitat of many insect predators of *A. aegypti* larvae. In this study, the toxic effects of Temephos against *A. aegypti* larvae, under simulated daily water consumptions were observed (Uthai *et al*., 2011).

Another disadvantage of using chemicals is that they kill natural enemies or beneficial predators that are helpful in vector control (Bommarco *et al*., 2011). However, botanical insecticides are safe and desirable alternatives to chemical insecticides (Khater, 2012).

The application method of insecticides is also important. They can either be applied as non-residual application (effective over a short time-scale) or as a residual (persistent) application (effective over a period of weeks or months). The later application may kill even immature stages of development. Space spraying of insecticides is less effective as compared to treating water containers with insecticides which show better and long living effect (Lofgren *et al*., 1970). The use of chemicals has reduced the number of dengue cases and deaths by 53% (Suaya *et al*., 2007), but, the harmful effects of insecticide sprays on environment and natural ecosystem can never be ignored.

So, there is need to minimize the development of resistance and to study the mechanism of resistance development and to develop alternative or rotational use of insecticides to prolong their efficacy.

Use of insect growth regulators: Use of insect growth regulators (IGR) for controlling mosquito's population is also an effective method. IGR are chemical compounds that alter growth and development in insects. They interfere with the normal development resulting in insect's death before they reach their adult stage. Different new larvicidal IGR such as diflubenzuron, pyriproxyfen, methoprene and endotoxins obtained from *Bacillus sphaericus* and *Bacillus thuringiensis israelensis* are effective against *A. aegypti* (Grodner, 1997).

Kamal and Khater (2010) evaluated the biological effects of IGR, pyriproxyfen and diflubenzuron against larvae of the mosquito *A. aegypti*. Results revealed that larval treatment with these IGR caused the significant reduction in the reproductive potential of mosquito adults that emerged from these treatments. Pyriproxyfen caused a 33.2% decrease in egg production as compared to 25.5% for diflubenzuron. The reduction in egg hatchability was 40.6 and 36.2% for pyriproxyfen and diflubenzuron respectively.

IGR are divided into two general categories based on mode of action (a) Chitin synthesis inhibitors (b) substances which interfering with the action of insect hormones. Chitin synthesis inhibitors, triazine/pyrimidine derivatives, buprofezin and conventional benzoylureas, reduce the ability of insects to produce new exoskeletons at molting stage and block the synthesis of chitin. They also cause high egg mortality. Belinato *et al*. (2013) evaluated the effect of triflumuron, a chitin synthesis inhibitor, against *A. aegypti*, *A. albopictus* and *Culex quinquefasciatus* under laboratory conditions and concluded that triflumuron was effective in emergence inhibition of *Cx. quinquefasciatus* and *A. albopictus*. Triflumuron was also effective against *A. aegypti*. Exposure of *A. aegypti* populations to the triflumuron (EI_{99}) resulted in complete inhibition of adult emergence.

Growth and development of insects are regulated by hormones: prothoracicotrophic hormones or brain hormone, ecdysteroids and juvenile hormones (Retnakaran *et al*., 1995). The juvenile hormone analogues initiate the activity of naturally occurring juvenile hormone analogues and prevent metamorphosis to the adult stage. Application of juvenile hormone analogues to early instar larvae would result in the development of supernumerary instars, whereas treatment at the later stage would result in abnormal pupation and development of intermediates and larval-pupal mosaics (Khater, 2003).

Biological control: Biological control includes the utilization of natural resources, natural enemies and biological toxins to reduce dengue vectors (Lloyd, 2003). Biological control strategy is better than using chemicals because it has no bad effect and disturbance on ecosystem. This approach includes target killing of vector by using larvivorous fish, copepods and bacterial agents. Two bacteria *Bacillus thuringiensis* (Bti) and *Bacillus sphaericus* have proved effective for the control of dengue vector. Due to its high specificity, Bti has been found to be more effective against mosquitoes which breed in relatively unpolluted water such as *A. aegypti* species (Lacey and Undeen, 1986). Bti has been used as multipurpose agent for prevention of epidemics of DF.

Polanczyk *et al*. (2003) reported that entomopathogenic bacterium *Bacillus thuringiensis israelensis* can safely be used in water for controlling of *A. aegypti*. The use and potential of *Bacillus thuringiensis israelensis* against the mosquito vector is described. Emphasis is given on the importance of using this bacterium which could contribute significantly in solving the mosquito problem without affecting the environment, humans and other invertebrate organisms in critical regions.

In an epidemic situation, the use of ultra-low volume spraying of permethrin and microbial agent Bti has shown both larvicidal and adulticidal effects against *A. aegypti* (Tidwell *et al*., 1994). Furthermore, world health organization has recommended that the use of Bti is safer for drinking-water treatment. Microbial larvicides used in drinking water and sensitive areas are not harmful to vertebrates as they do not persist or accumulate in environment and body tissues (WHO, 1999). Likewise, using larvivorous fish to overcome vector population has no harmful effect on drinking water and poses no threat to biodiversity of natural ecosystem. A successful trial has been made in Cambodia to check the effectiveness of introducing larvivorous guppy fish (*Poecilia reticulata*) into water storage containers. The trial was successful because household water containers, in which trial was done, showed a 79% reduction in *Aedes* index as compared to control houses (Seng, 2008).

A small crustacean such as *mesocyclops* if introduced in household water containers and tanks eats the newly hatched larvae of *A. Aegypti.* The use of copepod has been successfully used in Vietnam for the reduction of *A. aegypti* (walker, 2002). In Vietnam, the use of copepod *Mesocyclops* as a biological agent showed effective results in controlling dengue vector (Kay and Vu, 2005). This method has also been used successfully with community participation in Thailand where introduction of *Mesocyclops thermocyclopoides* in household containers controlled *A. aegypti* by eating its larvae (Kittayapong *et al.,* 2006).

In case of *A. aegypti*, the immature stages of the mosquito in household water containers provide a suitable target for the introduction of biological agents. But these agents should not be harmful, should be cheaper, their production should be easier on large scale and be culturally and socially acceptable to the target population. Important significance of biological control is that larvivorous fish, insects and copepods can be obtained from local resources and are inexpensive and can be maintained in households by short training (Kay *et al*., 2002). Basic cause of failure in achieving success in biological control of vector emergence is failure in maintenance of larvivorous population during the period of controlling intervention.

Use of photosensitizers: There is need to develop new and ecologically safe technologies to control mosquito populations. In this regards, use of photosensitizers is also an alternative and safer strategy. Photosensitizers are activated by artificial light sources or by illumination with sunlight. The subsequent exposure of such insects to UV/visible light leads in inducing lethal photochemical reactions and death. The most popular and effective photosensitizers are porphyrins (e.g. hematoporphyrin) and xanthenes (e.g. phloxin B) which are known to have greatest photo-insecticidal activity. These compounds are non-toxic, non-mutagenic and have low impact on the environment (Ragaei and Khater, 2004; Lukšienė *et al*., 2007; Awad *et al.,* 2008).

Lucantoni *et al*. (2011) reported that Photo-Mediated C14 meso-mono (N-tetradecylpyridyl) porphine molecule can be used as an excellent photolarvicidal agent against *A. aegypti*. This study suggests that photo-sensitizing agents can be used as an excellent alternative tool for the development of new larvicides against *A. aegypti*.

Genetic modification of vector species: Genetic modification of vector species is another option for their effective and long term control. Some researchers have practiced the genetic selection of vector strains that are unable to transmit disease (Collins *et al*., 1986; Wu and Tesh, 1990). Advancement in molecular genetics has made it possible to build such genetic constructs that block and reduce the transmission of disease and pathogens (De Lara Capurro *et al*., 2000; Ito *et al*., 2002). Some technological challenges and gaps have remained in the completion of attaining these genetic modifications in a single vector population (Alphey *et al*., 2002). An approach based on mosquitoes carrying a conditional dominant lethal gene is being developed to control the transmission of dengue viruses by vector population suppression (Valdez *et al*., 2011).

Transgenic organisms are genetically altered by artificial introduction of DNA from another organism and the artificial gene sequence is referred to as a transgene. Plants with such transgenes are called genetically modified crops that can be used for the control of mosquito population (Charles, 2001). There are many reports that demonstrate the negative impact of genetically modified crops on natural enemies which remains a controversial topic (Lövei *et al*., 2009).

Another recent advancement in controlling dengue vector is the discovery of endosymbiotic bacterium *Wolbachia*, naturally present in insect populations, which can inhibit replication of the dengue virus in *A. aegypti* mosquitoes. So, there is need to introduce these strains of *Wolbachia* into wild populations of *A. aegypti*, potentially replacing field populations in a way that could reduce or even eliminate dengue transmission (Jeffery *et al*., 2009).

Use of pheromones: Pheromones are defined as class of semi chemicals which are released by insects and other animals to communicate with other individuals of the same species. These are behavioral or signaling chemicals which play an essential role in arthropod life cycle. They provide the means whereby host and oviposition sites are located and recognized (Mordue Luntz, 2003). There are five principal uses for sex pheromones: population monitoring, mass trapping of insects, movement studies, detection of exotic pests and mating disruption. Due to some difficulties with high populations of insects, these programs should not be used alone in vector control program but it should be used as tactic within a suite of integrated insect management options (Welter *et al*., 2005).

Cabrera and Jaffe (2007) has experimentally proved that both males and females produce an aggregation pheromones which attracts opposite sex towards the swarm and it modulates the lekking behavior among *Aedes* mosquitoes which can help to use it as an alternative strategy for its control. Pheromone programs can be helpful in detection of population density of *A. aegypti* mosquitoes at a particular region or area.

Use of sterile insect technique: Reproductive competition through sterile insect technique (SIT) could be an additional powerful tool to control populations of mosquitoes. Successive releases of sterile males are helpful in reducing the number of offspring in the following generations and may help in controlling the population density of mosquito species in urban areas where it threatens the health of human populations (Dumont and Chiroleu, 2010). In different experiments favorable results were obtained in terms of vector control using SIT. Induction of sterility through irradiation causes random dominant lethal mutations in the germinal cells resulting in the death of the developing embryos after fertilization (Helinski *et al*., 2009). Oliva *et al*. (2012) reported that SIT offers a promising strategy for mosquito-borne diseases prevention and control. They studied the effect of irradiation on sexual maturation and mating success of males and concluded that sterile males could be sufficiently competitive to mate with wild females and SIT can act as an important component for suppressing a wild population of *A. albopictus*. SIT can also be helpful in controlling *A. aegypti* population like that of *A. albopictus*.

Use of nanotechnology and microemulsion: In recent times, the advanced approach of nanotechnology and microemulsion could be the effective method for mosquito's control. Very fine droplets of size 1-100 nm in diameter are used for pest and insect control. Owolade *et al*. (2008) reported that nanoparticles could be used for the development of new insecticide. In this context, Salunkhe *et al*. (2011) studied the larvicidal activities of mycosynthesized silver nanoparticles against *A. aegypti* and *Anopheles stephensi*. Likewise, some other fungus mediated gold and silver nanoparticles have also been studied against *A. aegypti* larvae (Soni and Prakash, 2012). Silver nanoparticles showed high larvicidal activity as compared to gold nanoparticles which suggested that use of fungus (*Chrysosporium tropicum*) mediated silver and gold nanoparticles is a fast, environment friendly, and excellent approach for mosquito control. This could be a new alternative approach for control of *A. aegypti*.

Nanoemulsion is a transparent mixture of oil, surfactant and water with a very low viscosity, usually the product of its high water content. Wang *et al*. (2007) conducted first attempt for the development of preparation of water soluble oil emulsion for insect control. β-cypermethrin incorporated nanomulsion and oil loaded microcapsule have also been reported for controlling insects (Moretti *et al*., 2002). Later on, Nuchuchua *et al*. (2009) evaluated the repellent effect of nanoemulsion composed of citronella oil, hairy basil oil, and vetiver oil against *A. aegypti*. They reported that the use of 5% (w/w) hairy basil oil, 5% (w/w) vetiver oil (5%), and 10% (w/w) citronella oil could improve physical stability and prolong mosquito protection time for 4.7 hours due to the combination of these three essential oils as well as small droplet size of nanoemulsion.

Use of botanicals: Scientists have proved that the phytochemicals obtained from different plants have ovicidal, larvicidal, adulticidal and repellent effects against *A. aegypti*. The use of botanicals in control of dengue is very effective and useful method and considerable work has been done in this field (for detail see Table 2).

The use of insect repellent compounds dates back to ancient times as plant oils, smokes and tars were used to repel or kill insects. The use of repellents by travelers may reduce the incidence of disease from local to temperate areas. DEET (N,N-diethyl-m-toluamide) is a broad spectrum and most efficient mosquito repellent being used on skin, but unfortunately, this may cause environmental and human health risks (Pitasawat *et al*., 2003). However, plant-based repellents are efficient and better than synthetic repellents. Nerio *et al*. (2010) reviewed some useful ideas for improvement of repellency of essential oils. A large number of essential oils producing plants have been extensively studied such as *Cymbopogon* spp, *Eucalyptus* spp, *Ocimum* spp, the Osage orange (*Maclura pomifera*) and catnip (*Nepeta*

Table: 2: Plants reported for their insecticidal, growth inhibition and repellent activity against *Aedes aegypti* (1990-2013)

Plants Scientific Names	Plants English Names	Type of Activity	References
Tagetes minuta	Southern Cone Marigold	Larvicidal	Green *et al.* (1991)
Tagetes errecta	Mexican Marigold	Larvicidal	Perich *et al.* (1994)
Lantana camara	Spanish Flag	Repellent	Dua *et al.* (1996)
Mentha piperita	Peppermint	Larvicidal and Repellent	Ansari *et al.* (1999)
Azadirachta indica	Neem	Anti-pupational and Repellent	Nagpal *et al.* (2001)
		Larvicidal and Repellent	Kumar *et al.* (2011)
Ocimum sanctum	Holy Basil	Larvicidal	Pathak *et al.* (2000)
Ferronia elephantum	Bela	Repellent	Venkatachalam (2001)
Solanum nigrum	Black Nightshade	Larvicidal	Singh *et al.* (2001)
Poncirus trifoliata	Trifoliate Orange	Larvicidal and ovicidal	Cheng *et al.* (2004)
Malus domestica	Apple	Antiviral and Antioxidant	Boyer and Liu (2004)
Fagonia indica	Fagonia	Larvicidal	Chaubal *et al.* (2005)
Arachis hypogaea	Groundnut	Larvicidal	Chaubal *et al.* (2005)
Sterculia guttata	Spotted Sterculia	Larvicidal	Katade *et al.* (2006)
Balanites aegyptiaca	Soap Berry	Larvicidal	Wiesman *et al.* (2006)
Spilanthes acmella	Toothache plant	Larvicidal	Pandey *et al.* (2007)
Spilanthes paniculata	Toothache plant	Larvicidal	Pandey *et al.* (2007)
Solanum xanthocarpum	Sun Berry	Larvicidal	Mohan *et al.* (2007)
Syzygium cumini	Jambul	Larvicidal	Kumar *et al.* (2007)
Piper cubeba	Tailed Pepper	Larvicidal	Murthy and Rani (2009)
Syzygium cumini	Jambul	Larvicidal	Murthy and Rani (2009)
Cassia fistula	Golden Shower tree	Larvicidal and Ovicidal	Govindarajan (2009)
Citrus lemon	Lemon	Antiviral and Immunoregulatory	Akhila *et al.* (2009)
Carica papaya	Papaw	Antiviral and Immunoregulatory	Lee *et al.* (2010)
Eclipta alba	False Daisy	Larvicidal and Ovicidal	Govindarajan and Karupannan (2011)
Eucalyptus sp.	Black Gum	Repellent	Mandal (2012)
Piper nigrum	Black Pepper	Larvicidal	Grzybowski *et al.* (2012)
Annona muricata	Brazilian Pawpaw	Larvicidal	Grzybowski *et al.* (2012)
Calotropis procera	Sodom Apple	Larvicidal	Bansal *et al.* (2012)
Tephrosia purpurea	Fish Poison	Larvicidal	Bansal *et al.* (2012)
Prosopis juliflora	Honey Mesquite	Larvicidal	Bansal *et al.* (2012)
Curcuma longa	Turmeric	Larvicidal and anti-pupational	Kalaivani and Nathan (2012)
Zingiber officinale	Ginger	Larvicidal and anti-pupational	Kalaivani and Nathan (2012)
Caulerpa racemosa	Sea Grapes	Larvicidal	Ali *et al.* (2013)

cataria). Many plants oils and their constituents have been commercialized as insect repellents in last ten years, such as soybean, lemon grass, cinnamon and citronella oil from *Azadirachta indica* when formulated as 2% in coconut oil, showed excellent repelling effects by providing complete protection for 12 hours from mosquitoes (Sharma, 1993).

A number of essential oils of plant origin have larvicidal effect along with reducing the development of insects, suppressing adult's emergence and also cause abnormalities during the development of insects (Shalaby and Khater, 2005; Khater and Shalaby, 2008; Khater and Khater, 2009; Khater *et al*., 2011).

Mode of action of plants and essential oils: Aromatic plants contain many compounds that can act as ovicides, larvicides, adulticides and also produce repellent effects against insects. They have capacity to change insect feeding behavior, growth rate, molting and effect behavior during mating and oviposition. Essential oils obtained from plants are lipophilic in nature and interfere with basic metabolic, biochemical, physiological and behavioral functions of insects. The rapid action against some insects is indicative of a neurotoxic mode of action, and there is evidence for interference with the neuromodulator octopamine or GABA-gated chloride channels (Enan, 2005).

Several essential oil compounds have been demonstrated to act on octopaminergic system of insects. Octopamine is circulating neurohormone - neuromodulator (Hollingworth *et al*., 1984) and its disruption results in complete breakdown of nervous system in insects. Plant volatile oils have long been known to affect the behavioral responses of pests, with the monoterpenoid components proved to be most effective to be used as insecticides or antifeedants (Palevitch and Craker, 1994).

Different botanicals have different mode of action in controlling insect population and have been found to be effective against *A. aegypti*. For example *Azadirachta indica* (neem) contains azadirachtin (C35H44O16), a nortriterpenoid molecule which is the most active constituent of neem, have various effects against insects. The effects of azadirachtin on insects include feeding and oviposition deterrence, growth inhibition, and fecundity and fitness reductions (Schmutterer, 1990). This substance interferes with synthesis of the insect molting hormone and has significant effect on insect behavior. It also leads to sterility in female insects due to its adverse effects on ovarian development, fecundity and fertility (Isman and Akhtar, 2007). *Azadirachta indica* has been found to have anti-pupational and repellent effects against *A. aegypti* (Nagpal *et al*., 2001). Likewise, different plants contain different active constituents that have different mode of action against *A. aegypti*.

Conclusion: Dengue Fever has now become a major global threat. To protect human life and prevent further epidemics of dengue, we need to translate our understanding and thinking to use our socio-ecological and biological systems in an effective way. Due to unavailability of vaccine in near future, we should depend on the interventions that are currently available. Use of different botanicals as mentioned in this paper has been proved to be effective and safer for the control of DF. So, we need to develop phytochemicals having long lasting effects against dengue vector and less harmful effects on environment as compared to synthetic chemicals. We need to adopt advanced techniques for vector control such as application of nanotechnology and microemulsion; use of photosensitizers and insect sterility technique can give excellent and sustainable effects.

REFERENCES

Ahmad I, S Astari and M Tan, 2007. Resistance of *Aedes aegypti (Diptera: Culicidea*) in 2006 to pyrethroid in Indonesia and its association with Oxidases and Estrases levels. Pak J Biol Sci, 10: 3688-3692.

Akhila S, AR Bindu, K bindu and NA Aleykutty, 2009. Comparirive evaluation of extracts of citrus lemon burm peel for antioxidant activity. Pharmacognosy, 1: 136-140.

Ali MYS, SR kumar and JM Beula, 2013. Mosquito larvicidal activity of seaweeds extracts against *Anopheles stephensi, Aedes aegypti* and *Culex quinquefasciatus* Asian Pac J Trop Dis, 3: 196-201.

Alphey L, CB Beard, P Billingsley, M Coetzee and A Crisanti, 2002. Malaria control with genetically manipulated insect vectors. Science, 298: 119-121.

Ansari MA, P Vasudevan, M Tandon and RK Razdan, 1999. Larvicidal and mosquito repellent action of peppermint (*Mentha piperita*) oil. Bioresource Technol, 71: 267-271.

Awad HH, TA El-Tayeb, NMA El-Aziz and MH Abdelkader, 2008. A semi-field study on the effect of novel hematoporphyrin formula on the control of *Culex pipiens* larvae. J Agric Social Sci, 4: 85-88.

Baly A, ME Toledo and M Boelaert, 2007. Cost-effectiveness of Aedes aegypti control programmes participatory versus vertical. Trans R Soc Trop Med Hyg, 101: 578-586.

Bansal SK, KV Singh, S Sharma and MRK Sherwani, 2012. Laboratory observations on the larvicidal efficacy of three plant species against mosquito vectors of malaria, Dengue/Dengue Hemorrhagic Fever (DF/DHF) and lymphatic filariasis in the semi-arid desert. J Environ Biol, 33: 617-621.

Bommarco R, F Miranda, FH Bylund and C Björkman, 2011. Insecticides suppress natural enemies and increase pest damage in cabbage. J Econ Entomol, 104: 782-791.

Boyer J and RH liu, 2004. Apple phytochemicals and their human health benefits. Nut J, 3: 1-15.

Belinato TA, AJ Martins, JBP Lima and D Valle, 2013. Effect of triflumuron, a chitin synthesis inhibitor, on *Aedes aegypti*, *Aedes albopictus* and *Culex quinquefasciatus* under laboratory conditions. Parasit Vectors J, 6:83.

Cabrera M and K Jaffe, 2007. An aggregation pheromone modulates lekking behavior in the vector mosquito *Aedes aegypti (Diptera: Culicidae*). J Am Mosq Control Assoc, 23: 1-10.

Charles D, 2001. Lords of the harvest: Biotech, big money, and the future of food. Perseus Publishing, Cambridge, MA, 348 pp.

Chaubal R, PV Pawar, GD Hebbalkar, VB Tungikar, VG Puranik, VH Deshpande and NR Deshpand, 2005. Larvicidal activity of *Acacia nilotica* extracts and isolation of D-pinitol-a bioactive carbohydrate. Chem Biodiversity, 2: 684-688.

Cheng SS, JY Liu, KH Tsai, WJ Chen and ST Chang, 2004. Chemical composition and mosquito larvicidal activity of essential oils from leaves of different *Cinnamomum osmophloeum* provenances. J Agric Food Chem, 52: 4395-4400.

Collins FH, RK Sakai, KD Vernick, S Paskewitz and DC Seeley, 1986. Genetic selection of a Plasmodium-refractory strain of the malaria vector *Anopheles gambiae*. Science, 234: 607-610.

Constant VA, GE Benjamin, K Christopher, M Jones, D Weetman and H Ranson, 2012. Multiple insecticide resistance in *Anopheles gambiae* mosquitoes, Southern Côted'Ivoire. J Emerg Infect Dis, 18: 1508-1511.

Curtis CF and JD Lines, 2000. Should DDT be banned by international treaty? Parasitol Today, 16: 119-121.

De Lara Capurro MJ, BT Coleman, KM Beerntsen and KE Myles, 2000. Virus-expressed, recombinant single-chain antibody blocks sporozoite infection of salivary glands in Plasmodium gallinaceum-infected *Aedes aegypti*. Am J Trop Med Hyg, 62: 427-433.

Dua VK, NC Gupta, AC Pandey and VP Sharma, 1996. Repellency of *Lantana camara* flowers against *Aedes* mosquitoes. J Am Mosq Control Assoc, 12: 406-408.

Dumont Y and F Chiroleu, 2010. Vector control for the Chikungunya Disease. Math Biosc Eng, 7: 313-345.

Dusfour I, V Thalmensy, P Gaborit, J Issaly, R Carinci and R Girod, 2011. Multiple insecticide resistance in *Aedes aegypti (Diptera: Culicidae*) populations compromises the effectiveness of dengue vector control in French Guiana. Mem Inst Oswaldo Cruz Rio de Janeiro, 106: 346-352.

Enan EE, 2005. Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils, Arch Insect Biochem Physiol, 59: 161-171.

Fan LS, R Muhamad, D Omar and M Rahmani, 2011. Insecticidal properties of *Piper nigrum* fruit extracts and essential oils against *Spodoptera litura*. Int J

Biol, 13: 517-522.

Farrar J, 2008. Clinical features of dengue. Imperial College Press, London, 171-191.

Fontoura NG, DF Bellinato, D Valle and JBP Lima, 2012. The efficacy of a chitin synthesis inhibitor against field populations of organophosphate-resistant *Aedes aegypti* in Brazil. Mem Inst Oswaldo Cruz Rio de Janeiro, 107: 387-395.

Gage KL, TR Burkot, RJ Eisen and EB Hayes, 2008. Climate and vector borne diseases. Am J Prev Med, 35: 436-450.

Garcı´a GP, AE Flores, I Ferna´ndez-Salas, KS Rodrı´guez, G Reyes-Solis, S Lozano-Fuentes, JG Bond, M Casas-Martı´nez, JM Ramsey, J Garcı´a-Rejo´ n, M Domı´nguez-Galera, H Ranson, J Hemingway, L Eisen and WC Black, 2009. Recent Rapid Rise of a Permethrin Knock down Resistance Allele in *Aedes aegypti* in Mexico. Negle Trop Dis 3: (10) e531.

Govindarajan M and P Karuppannan, 2011. Mosquito larvicidal and ovicidal properties of *Eclipta alba* (L) Hassk (*Asteraceae*) against chikungunya vector *Aedes aegypti* (Linn) (*Diptera: Culicidae*). Asian Pac J Trop Med, 4: 24-28.

Govindarajan M, 2009. Bioefficacy of *Cassia fistula* Linn. (*Leguminosae)* leaf extract against chikungunya vector *Aedes aegypti* (*Diptera: Culicidae*). Eur Rev Med Pharmacol, 132: 99-103.

Grzybowski A, M Tiboni, AN Mário, RF Chitolina, M Passos and JF José Fontana, 2012. The combined action of phytolarvicides for the control of dengue fever vector, *Aedes aegypti*. Revista Brasileira de Farmacognosia, 22: 549-557.

Green M, JM Singer, DJ Sutherland and CR Hibben, 1991. Larvicidal activity of Tagetus minuta (marigold) towards *Aedes aegypti*. J Am Mosq Control Assoc, 7: 282-286.

Grodner ML, 1997, http://aapse.ext.vt.edu/archives/97AAP CO_report.

Gubler DJ, 1987. Dengue and dengue hemorrhagic fever in the Americas. P R Health Sci J, 6: 107-111.

Gubler DJ, 1997. Human behavior and cultural context in disease control. Trop Med Int Health, 2: 1-2.

Halstead SB, 1992. The XXth century dengue pandemic: need for surveillance and research. Rapp Trimest Stat Sanit Mond, 45: 292-298.

Halstead SB, 2007. Dengue. Lancet, 370: 1644-1652.

Helinski ME, AG Parker and BGJ Knols, 2009. Radiation biology of mosquitoes. Mal J, 8: S2-S6.

Holmes EC and SS Twiddy, 2003. The origin, emergence and evolutionary genetics of dengue virus. Infect Genet Evolution, 3: 19-28.

Hollingworth, RM. EM Johnstone and N Wright, 1984. In: PS Magee, GK Kohn and JJ Menn (eds), Pesticide Synthesis through Rational Approaches, ACS Symposium Series No. 255, American Chemical Society, Washington, DC pp: 103-125.

Hombach J, 2007. Vaccines against dengue a review of current candidate vaccines at advanced development stage. Rev Panam Salud Pública, 21: 254-260.

Hopp MJ and JA Foley, 2003. Worldwide fluctuation in dengue fever cases related to climate variability. Climate Res, 25: 85-94.

Isman MB, S Miresmailli and C Machial, 2011. Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. Phytochem Rev, 10: 197-204.

Isman MB and Y Akhtar, 2007. Plant natural products as a source for developing environmentally acceptable insecticides. In: I Shaaya, R Nauen, and AR Horowitz (eds), Insecticides Design Using Advanced Technologies. Springer, Berlin, Heidelberg, pp: 235-248.

Ito J, A Ghosh, LA Moreira, EA Wimmer and M Jacobs-Lorena, 2002. Transgenic anopheline mosquitoes impaired in transmission of a malaria parasite. Nature, 417: 452-455.

Jeffery JAL, TY Nguyen, SN Vu, TN Le, AA Hoffmann, BH Kay and PA Ryan, 2009. Characterizing the *Aedes aegypti* population in a Vietnamese village in preparation for a Wolbachia-based mosquito control strategy to eliminate dengue. Plos Negl Trop Dis, 3: e552.

Kamal HA and El Khater, 2010. The biological effects of the insect growth regulators; pyriproxyfen and diflubenzuron on the mosquito *Aedes aegypti*. J Egypt Soc Parasitol, 40: 565-574.

Kalaivani K and SS Nathan, 2012. Biological activity of selected *Lamiaceae* and *Zingiberaceae* plant essential oils against the dengue vector *Aedes aegypti* L. (*Diptera: Culicidae*). Parasitol Res, 110: 1261-1268.

Katade SR, PV Pawar, RD Wakharkar and NR Deshpande, 2006. *Sterculia guttata* seeds extractives an effective mosquito larvicide. Indian J Exp Biol, 44: 662-665.

Kawada H, M Yoshihid, A Mayumi, O Kazunori, O Shin-ya and T Mashero, 2009. Spatial distribution and Prythroid susceptibility of mosquito larvae collected from catch basins in parks in Nagasaki city, Nagasaki, Japan. Jpn J Infect Dis, 63: 19-24.

Kay BH and SN Vu, 2005. New strategy against *Aedes aegypti* in Vietnam. Lancet, 365: 613-617.

Kay BH, VS Nam and TV Tien, 2002. Control of *Aedes* vectors of dengue in three provinces of Vietnam by use of *Mesocyclops* (Copepods) and community-based methods validated by entomologic, clinical and serological surveillance. Am J Trop Med Hyg, 66: 40-48.

Khan HAA, W Akram, K Shehzad and EA Shaalan, 2011. First report of field evolved resistance to agrochemicals in dengue mosquito, *Aedes albopictus (Diptera: Culicidae*), from Pakistan. Parasite Vectors J, 4: 146.

Khater HF and AA Shalaby, 2008. Potential of biologically active plant oils for control mosquito larvae *Culex pipiens (Diptera: Culicidae*) from an Egyptian locality. Revista do Instituto de Medicina Tropical de Sao Paulo, 50: 107-112.

Khater HF and DH Khater, 2009. The insecticidal activity of four medicinal plants against the blowfly *Lucilia sericata (Diptera: Calliphoridae*). Int J of Dermat, 48: 492-497.

Khater HF, 2003. Biological control of some insects. PhD thesis, Zagazig University: Benha Branch, Egypt.

Khater HF, 2011. Biorational Insecticides for integrated pest management. In: Insecticides - Advances in Integrated Pest Management: (Farzana Perveen, ed.): Publisher: In Tech. pp: 17-49.

Khater HF, AM Hanafy, AD Abdel- Mageed,, MY Ramadan and RS El-Madawy, 2011. The insecticidal effect of some Egyptian plant oils against *Lucilia sericata* (*Diptera: Calliphoridae*). Int J Dermat, 50: 187-194.

Khater HF, 2012. Prospects of botanical biopesticides in insect pest management. Pharmacologia, 3: 641-656.

Kittayapong P, U Chansang C Chansang and A Bhumiratana, 2006. Community participation and appropriate technologies for dengue vector control at transmission foci in Thailand. J Am Mosq Control Assoc, 22: 538-546.

Kroeger A and MB Nathan, 2006. Dengue setting the global research agenda. Lancet, 368: 2193-2195.

Kumar A, N Padmanabhan and MRV Krishnan, 2007. Central nervous system activity of *Syzygium cumini* seed. Pak J Nutr, 6: 698-700.

Kumar S, N Wahab and R Warikoo, 2011. Bioefficacy of *Mentha piperita* essential oil against dengue fever mosquito *Aedes aegypti* L. Asian Pacific J of Trop Biomed, 1: 85-88.

Lacey LA and AH Undeen, 1986. Microbial control of black flies and mosquitoes. Annu Rev Entomol, 31: 265-296.

Lee PR, B Yu, P Curran and SQ Liu, 2010. Kinetics of volatile organic compounds during *papya* juice fermentation by three commercial wine yeasts. Nut food Sci, 40: 566-580.

Lima EP, MHS Paiva, A de Araújo, EVG da Silva, UM da Silva, LN de Oliveira, AEG Santana, CN Barbosa1, CC Neto, M Goulart, CS Wilding, CFJ Ayres and MAVD Santos, 2011. Insecticide resistance in *Aedes aegypti* populations from Ceará, Brazil. Parasite Vectors J, 4: 1-13.

Llinás GA, E Seccacini, CN Gardenal and S Licastro, 2010. Current resistance status to temephos in *Aedes aegypti* from different regions of Argentina. Mem Inst Oswaldo Cruz Rio de Janeiro, 105: 113-116.

Lloyd L, 2003. Best practice for dengue prevention and control in the Americas. Strategic Report 7. Environmental Health Project. Washington DC, USA.

Lofgren CS, HR Ford, RJ Tonn, YH Bang and P Siribodhi, 1970. The effectiveness of ultra-low-volume applications of malathion at a rate of 3 US fluid ounces per acre in controlling *Aedes aegypti* in Thailand. Bull World Health Organ, 42: 27-35.

Lok CK, NS Kiat and TK Koh, 1977. An autocidal ovitrap for the control and possible eradication of *Aedes aegypti*. Southeast Asian J Trop Med Public Health, 8: 56-62.

Lövei GL, DA Andow and S Arpaia, 2009. Transgenic Insecticidal Crops and Natural Enemies: A Detailed Review of Laboratory Studies. Environ Entomol, 38: 293-306.

Lucantoni L, M Michela, G Lupidi, RK Ouedraogo, O Coppellotti, F Esposito, C Fabris, G Jori and A Habluetzel, 2011. Novel, Meso-substituted cationic porphyrin molecule for photo-mediated larval control of the dengue vector *Aedes aegypti*. PLoS Negl Trop Dis, 5: e1434.

Lukšienė Z, N Kurilčik, S Juršėnas, S Radžiutė and V Būda, 2007. Towards environmentally and human friendly insect pest control technologies: Photosensitization of leafminer *flies Liriomyza bryoniae*, J Photochem Photobiol, 89: 15-21.

Lukwa N, NZ Nyazema, CF Curtis, GL Mwaiko and SK Chandiwana, 1999. People's perceptions about malaria transmission and control using mosquito repellent plants in a locality in Zimbabwe. Cent Afr J Med, 45: 64-68.

Macoris GMD, MTM Andrighetti, L Takaku, CM Glasser, VC Garbeloto and JE Bracco, 2003. Resistance of *Aedes aegypti* from the State of São Paulo, Brazil, to organophosphates insecticides. Mem Inst Oswaldo Cruz Rio de Janeiro, 98: 703-708.

Macoris MDDG, MTM Andrighetti, VCG Otrera, LR de Carvalho, ALC Júnior and WG Brogdon, 2007. Association of insecticide use and alteration on *Aedes aegypti* susceptibility status. Mem Inst Oswaldo Cruz Rio de Janeiro, 102: 895-900.

Mandal S, 2012. Mosquito vector management with botanicals-the most effective weapons in controlling mosquito-borne diseases. Asian Pacific J Trop Biomed, 2: 336.

Marcombe S, R Poupardin, F Darriet, S Reynaud, J Bonnet, C Strode, C Brengues, A Yébakima, H Ranson, V Corbel and JP David, 2009. Exploring the molecular basis of insecticide resistance in the dengue vector *Aedes aegypti*. BMC Genomics, 10: 494.

Mehlhorn H, 2011. Nature Helps, Parasitology Research Monographs 1, Springer-Verlag Berlin Heidelberg.

Mohan L, P Sharmaand and CN Srivastava, 2007. Comparative efficacy of *Solanum xanthocarpum* extracts alone and in combination with a syntheticpyrethroid, cypermethrin, against malaria vector, *Anopheles stephensi*. Southeast Asian J Trop Med Pub Health, 38: 256-260.

Mordue LAJ, 2003, Arthropod semiochemicals: mosquitoes, midges and sealice, Biochem Soc Trans, 31: 128-133.

Morens DM, 2009. Dengue fever and dengue hemorrhagic fever. Pediatr Infect Dis J, 28: 635-636.

Moretti MDL, G Sanna-Passino, S Demontis and E Bazzoni, 2002. Essential oil formulations useful as a new tool for insect pest control. AAPS Pharm Sci Tech, 13: 1-11.

Murgue B, 2010. Severe dengue questioning the paradigm. Microbes Infect, 12: 113-118.

Murthy JM and PU Rani, 2009. Biological activity of certain botanical extracts as larvicides against the yellow fever mosquito, *Aedes aegypti* L. J Biopest, 2: 72-76.

Mutero C, V Kabutha, L Kimani and G Kabuage, 2004. A transdisciplinary perspective on the links between malaria and agro ecosystems in Kenya. Acta Tropica, 89: 171-186.

Nagpal BN, A Srivastava, N Valecha and VP Sharma, 2001. Repellent action of neem cream against *Anopheles culicifacies* and *Culex quinquefasciatus*. Current Sci, 80: 1270-1271.

Nam VS, TY Nguyen, VP Tran, UN Truong, QM Le and VL Le, 2005. Elimination of dengue by community programs using *Mesocyclops* (*Copepoda*) against *Aedes aegypti* in central Vietnam. Am J Trop Med Hyg, 72: 67-73.

Nerio LS, JO Verbel and E Stashenko, 2010. Repellent activity of essential oils: a review, Bioresource Technol, 101: 372-378.

NG LC, 2008. Singapore's dengue control programme in the face of new challenges. In: Asia-Pacific dengue programme managers meeting 5 to 9 May 2008, Singapore. Manila. World Health Organization Western Pacific Regional Office, 33-39.

NIHA, 2010. Efficacy and safety of Dengue vaccine in healthy children. Washington. Available from:http://clinicaltrials.gov/ct2/show/NCT00842530.

Nuchuchua O, U Sakulku, N Uawongyart, S Puttipipatkhachorn, Soottitantawat and U Ruktanonchai, 2009. InVitro Characterization and Mosquito (*Aedes aegypti*) Repellent Activity of Essential-Oils-Loaded Nanoemulsions. AAPS Pharm Sci Tech, 10: 1242-1246.

Ocampo C, MS Terreros, N Mina, J McAllister and W Brogdon, 2011. Insecticide Resistance status of *Aedes aegypti* in 10 localities of Colombia. Acta Trop, 118: 37-44.

Olivares-Pérez J, S Rojas-Hernández, MT Valencia-Almazan, I Gutiérrez-Segura and EJ Míreles-Martínez, 2011. Prevalence of resistant strains of *Rhipicephalus microplus* to acaricides in cattle ranch in the tropical region of Tecpan of galeana, Guerrero Mexico. Pak Vet J, 31: 366-368.

Olivia CF, O mail, M Jacquet, J Gilles, L Guy, P Maquart, S Quilici, F Schooneman, MJB Vreysen and S Boyer, 2012. The Sterile Insect Technique for Controlling Populations of *Aedes albopictus (Diptera: Culicidae)* on Reunion Island: Mating Vigour of Sterilized Males. PLoS ONE, 7: e49414.

Ooi EE, KT Goh and DJ Gubler, 2006. Dengue prevention and 35 years of vector control in Singapore. Emerg Infect Dis, 12: 887-893.

Owolade OF, DO Ogunleti and MO Adenekan, 2008. Titanium Dioxide affects disease development and yield of edible cowpea, Elect J Environ Agric Food Chem, 7: 2942-2947.

Palsson K and TG Jaenson, 1999. People's perceptions about malaria transmission and control using mosquito repellent plants in a locality in Zimbabwe. Acta Trop, 72: 39-52.

Palevitch D and LE Craker, 1994. Volatile oils as potential insecticides. Herb, Spice Med Plant Digest 12: 1-5.

Pandey V, V Agrawal, K Raghavendra and AP Dash, 2007. Strong larvicidal activity of three species of Spilanthes (Akarkara) against malaria *Anopheles stephensi*, *Anopheles culicifacies*, species and filaria vector *Culex quinquefasciatus*. Parasitol Res, 102: 171-174.

Parks W, L Lloyd, MB Nathan, E Hosein, A Odugleh and GG Clark, 2005. International experiences in social mobilization and communication for dengue prevention and control. Dengue Bull, 28: 1-7.

Pathak N, PK Mittal, OP Singh and P Vasudevan, 2000. Larvicidal action of essential oils from plants against the vector mosquitoes *Anopheles stephensi, Culex quinquefasciatus* and *Aedes aegypti*. J Int Pest Control, 42: 53-55.

Pérez-Guerra CL, E Zielinski-Gutierrez, D Vargas-Torres and GG Clark, 2009. Community beliefs and practices about dengue in Puerto Rico. Rev Panam Salud Publica, 25: 218-226.

Perich MJ, C Wells, W Bertsch and KE Tredway, 1994. Toxicity of extracts from three Tagetes species against adult and larvae of yellow fever mosquito and *Anopheles stephensi* (*Diptera: Culicidae*). J Med Entomol, 31: 834.

Phanpoowong T, U Uthai, S Thongrungkiat, N Komalamisra, R Srisawat, B Russell and L Renia, 2012. Dengue -2 virus carrying capacity of Thai *Aedes aegypti* strains with different susceptibility to Deltamethrin. Southeast Asian J Trop Med Pub Health, 43: 634-640.

Pinheiro FP and SJ Cober, 1997. Global situation of dengue and dengue haemorrhagic fever and its emergence in the America. World Health Stat Q, 50: 161-169.

Pitasawat B, W Choochote, B Tuetun, P Tippawangkosol, D Kanjanapothi, A Jitpakdi and D Riyong, 2003. Repellency of aromatic turmeric *Curcuma aromatica* under laboratory and field conditions. J Vect Ecol, 28: 234-240.

Polanczyk RA, MD Garcia and SB Alves, 2003. Potencial de *Bacillus thuringiensis israelensis* Berliner no controle de *Aedes aegypti*. Rev Saúde Pública, 37: 6.

Polson KA, SC Rawlins, WG Brogdon and DD Chadee, 2011. Biochemical mechanisms involved in DDT and pyrethroid resistance in Trinidad and Tobago strains of *Aedes aegypti*. Bull Entomol Res, 101: 435-441.

Ponlawat AJ, G Scott and LC Harrington, 2005. Insecticide susceptibility of *Aedes aegypti* and *Aedes albopictus* across Thailand. J Med Entomol, 42: 821-825.

Ragaei M and HF Khater, 2004. Laser and photobiology applications: Photosensitizers as photopesticides, Phototherapy and phototoxicity in animals. Workshop on Laser Chemistry and Applications Materials and Biomedical Research. National Research Center, Cairo, October 2-5.

Rawlins SC, 1998. Spatial distribution of insecticide resistance in Caribbean populations of *Aedes aegypti* and its significance. Pan Am J Pub Health, 4: 243-251.

Retnakaran A, K Hiruma, SR Palli and LM Riddiford, 1995. Molecular analysis of the mode of action of RH-5992, a lepidopteran-specific, non-steroidal ecdysteroid agonist, Insect Biochem Mol Biol, 25: 109-117.

Rodríguez MM, JA Bisset and D Fernández, 2007. Levels of insecticide resistance and resistance mechanisms in *Aedes aegypti* from some Latin American countries. J Am Mosq Control Assoc, 23: 420-429.

Rong LS, AT Ann, NW Ahmad, LH Lim and MS Azirun, 2012. Insecticide susceptibility status of field-collected *Aedes* (*Stegomyia*) *aegypti* (L.) at a dengue endemic site in Shah Alam, Selangor, Malaysia. Southeast Asian J Trop Med Pub Health, 43: 34-47.

Salunkhe RB, SV Patil, CD Patil and BK Salunke, 2011. Larvicidal potential of silver nanoparticles synthesized using fungus *Cochliobolus lunatus* against *Aedes aegypti* and *Anopheles stephensi* Liston (*Diptera; Culicidae*). Parasitol Res, 109: 823-31.

Seng CM, 2008. Community-based use of the larvivorous fish *Poecilia reticulata* to control the dengue vector *Aedes aegypti* in domestic water storage containers in rural Cambodia. J Vector Ecol, 33: 139-144.

Seyoum A, K Palsson, S Kunga, EW Kabiru, W Lwande, GF Killeen, A Hassanali and BG Knols, 2002. Traditional use of mosquito-repellent plants in western Kenya and their evaluation in semi-field experimental huts against *Anopheles gam*biae: ethnobotanical studies and application by thermal expulsion and direct burning. Trans Roy Soc Trop Med Hygiene, 96: 225-231.

Shaalan EAS, D Canyon, MWF Younes, HA What and AH Mansour, 2005. A review of botanical phytochemicals with mosquitocidal potential. J Environ Int, 31: 1149-1166.

Schmutterer H, 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica,* Annu Rev Entomol, 35: 271-297.

Shalaby AA and HF Khater, 2005. Toxicity of certain solvent extracts of *Rosmarinus officinalis* against *Culex pipiens* larvae. J Egyptian-German Soc Zool, 48: 69-80.

Sharma RN, 1993. The utilization of essential oils and some common allelochemic constituent for non-insecticidal pest management strategies. In: Newer Trends Essent-51. New Delhi (India): Tata McGraw Hill.

Shriram AN, AP Sugunan, SP Manimunda and P Vijayachari, 2009. Community-centred approach for the control of *Aedes* spp in a peri -urban zone in the Andaman and Nicobar Islands using temephos. Natl Med J Ind, 22: 116-120.

Singh SP, K Raghavendra, RK Singh and SK Subbarao, 2001. Studies on larvicidal properties of leaf extract of *Solanum nigrum* Linn (Family: *Solanaceae*). Current Sci, 81: 1529-1530.

Soni N and S Prakash, 2012. Efficacy of fungus mediated silvnuary and gold nanoparticles against *Aedes aegypti* larvae. Parasitol Res, 110: 175-184.

Su T and MR Mulla, 1999. Oviposition bioassay responses of *Culex tarsalis* and *Culex quinquefasciatus* to neem products containing azadirachtin. Entomol Exp Appl, 91: 337-345.

Suaya JA, DS Shepard, MS Chang, M Caram, S Hoyer, D Socheat, N Chantha and MB Nathan, 2007. Cost-effectiveness of annual targeted larviciding campaigns in Cambodia against the dengue vector *Aedes aegypti*. Trop Med Int Health, 12: 1026-1036.

Tidwell ML, DC Williams, TA Gwinn, CH Pena, SH Tedders, GE Gonzalvez and Y Mekuria, 1994. Emergency control of *Aedes aegypti* using the scorpion 20 ULV forced air generator. J Am Mosq Control Assoc, 10: 403-406.

Tikar SN, A Kumar, GBKS Prasad and S Prakash, 2009. Temephos-induced resistance in *Aedes aegypti* and its cross-resistance studies to certain insecticides from India. Parasitol Res, 105: 57-63.

Tun-Lin W, BH Kay and A Barnes, 1995. Understanding productivity, a key to *Aedes aegypti* surveillance. Am J Trop Med Hyg, 53: 595-601.

Uthai U, P Rattanapreechachai and L Chowanadisai, 2011. Bioassay and Effective Concentration of Temephos against *Aedes aegypti* Larvae and the adverse effect upon indigenous predators: *Toxorhynchites splendens* and *Micronecta* sp. Asian J Pub Health, 2: 67-77.

Utzinger J, Y Tozan and BH Singer, 2001. Efficacy and cost-effectiveness of environmental management for malaria control. Trop Med Int Health, 6: 677-687.

Valdez MRW, D Nimmob, J Betza, H Gongb, AA Jamesc, L Alphey and WC Blva, 2011. Genetic elimination of dengue vector mosquitoes. PNAS, 108: 4772-4775.

Vanlerberghe V, ME Toledo, M Rodríguez, D Gómez, A Baly, JR Benítez and P Van der Stuyft, 2010. Community involvement in dengue vector control: Cluster randomized trial. MEDICC Review, 12: 41-47.

Venkatachalam MR and A Jebanesan, 2001. Repellent activity of *Ferronia elephantum (Rutaceae)* leaf extract against *Aedes aegypti* (L). Bioresource Technol, 76: 287-288.

Walker K, 2002. A review of control methods for African malaria vectors. Environmental health project. US Agency for International Development. Washington. DC.

Wang L, X Li, G Zhang, J Dong and J Eastoe, 2007. Oil-in-water nanoemulsions for pesticide formulations. J Colloid Interface Sci, 314: 230-235.

Webster DP, J Farrar and S Rowland-Jones, 2009. Progress towards a dengue vaccine. Lancet Infect Dis, 9: 678-87.

Welter SC, CG Millar, F Cave, RA Van Steenwyk and J Dunley, 2005. Pheromone mating disruption offers selective management options for key pests, California Agric, 59: 16-22.

Whiteford LM, 1997. The ethno ecology of dengue fever. Med Anthropol Q, 11: 202-223.

WHO, 1999. Microbial pest control agent *Bacillus thuringiensis*. Finland. WHO publications. pp: 99.

WHO, 2009. In Dengue: Guidelines for diagnosis, treatment, prevention and control. 111-133 (TDR/WHO, Geneva, Switzerland).

Wiesman Z, P Bishnu and Chapagain, 2006. Larvicidal activity of saponin containing extracts and fractions of fruit mesocarp of *Balanites aegyptiaca*. Fitoterapia, 77: 420-424.

Wills B and SB Holstead, 2008. Management of dengue. Imperial College Press. London, 193-217.

Wu WK and RB Tesh, 1990. Selection of *Phlebotomus papatasi (Diptera:Psychodidae*) lines susceptible and refractory to *Leishmania* major infection. Am J Trop Med Hyg, 42: 320-328.

Yap HH, 1984. Vector control in Malaysia present status and future prospects. J Malay Soc Health, 4: 7-12.

Yildirim E, A Aslan, B Emsen, A Cakir and S Ercisli, 2012. Insecticidal effect of *Usnea longissima (Parmeliaceae)* extract against *Sitophilus granarius (Coleoptera: Curculionidae*). Int J Agric Biol, 14: 303-306.

Ziba C, L Slutsker, L Chitsul and RW Steketee, 1994. Use of malaria prevention measures in Malawian housholds. Trop Med Parasitol, 45: 70-73.