Review Article

MOSQUITO-PLANT INTERACTION WITH REFERENCE TO ECO-EPIDEMIOLOGICAL IMPORTANCE: AN EXPLORATORY REVIEW

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ABSTRACT

Background: Sugar feeding behavior is a key feature of mosquitoes from evolutionary perspective that makes plant-mosquito interactions inevitable. This mosquito-plant interaction can have significant importance for vector-borne disease dynamics. In this

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context, this paper is an attempt to explore the mosquito-plant interaction focusing on the eco-epidemiological importance.

Methods: A narrative review was conducted by using electronic databases–PubMed/Medline, Google scholar, medXiriv, Wiley Online Library, Semantic Scholar- using key terms and a manual search of Google Scholar up to the year 2020. All the findings and observations in this review regarding the focused topic are based on published information as listed in the references.

Results: Plant sugars have considerable effects on survival and blood-feeding, thereby playing a crucial role in the vectorial capacity of mosquitoes. Plant sugar increases the survival of mosquitoes and contrarily reduces the biting rate, thus oppositely affecting the vectorial capacity. Mosquitoes are considered to be outdone by bees and lepidopterans when it comes to pollination, however, with the exceptions in subarctic regions, they can act as co-pollinators along with other insects. Human activities such as deforestation can affect the mosquito plant-interactions, which in turn, may force them to develop anthropophilic traits.

Conclusion: More research needs to be undertaken towards this hitherto neglected facet of mosquito ecology which can open new vistas for research and aid in the formulation of effective management strategies for the containment of mosquito-borne diseases. The knowledge thus gained from this review can help in developing and designing urban planning for sustainable urban public health.

Keywords: mosquito, plant, vector biology and competence, pollination.

INTRODUCTION

Plant-insect interaction networks are indispensable for ecosystems. Both chemical and physical mechanisms are involved in these interactions playing

important roles across many ecological situations, which obligate both plants and insects to complex adaptations.[1] Mosquito and plant interaction is also not different. Phytophagy (sugar feeding behavior) is a key feature of mosquito from evolutionary perspectives that makes plant-mosquito interactions inevitable. It has been confirmed now that consumption of plant liquids provides fuel for flight and mating and without plant liquids, mosquitoes cannot survive long.[2,3] However, procuration of vertebrate blood is essential for many female mosquitoes to complete their gonotrophic cycle, a behavior known as hematophagy.[4] There are only a couple of hundred female mosquito species amongst almost 3500 species, which are competent for vector-borne disease transmission and necessarily feed on blood.[5,6] Yet, all of the mosquito species including the disease-causing females are dependent on plant sugar mostly derived from floral nectar, honeydew, fruits etc.[7] For this obligatory phytophagy behavior coupled with hematophagy, mosquitoes are dependent both on plants and animal hosts. Therefore, this plant-mosquito interplay can have significant importance for the vector-borne disease dynamics along with other medical aspects. Moreover, like other plant-insect interactions mosquito-plant interaction also brings about aspects such as pollination, maintenance of biotic community, etc.[8,2] which are integral parts of sustainable ecosystems. This interaction is a complex paradigm which is crucial for ecological communities along with the role of plant sugar on the biological potential of disease transmission by mosquitoes. In this context, this paper is an attempt to explore the plant-mosquito interaction focusing on the eco-epidemiological importance.

METHODS

A narrative review was conducted using electronic databases– PubMed/Medline, Google scholar, Wiley Online Library, Semantic Scholar- using key terms and a manual search of Google Scholar up to the year 2020. Both not peer-reviewed and peer-reviewed journal articles searched and used were in the English language. These databases represent a varied range of disciplines allied to mosquito-plant interaction, mosquito biology, and public health. The search was initially conducted on PubMed with the relevant keywords searchable in the article titles and/or abstracts. The same approach of searching was done for other databases as well. All the findings and observations in this review regarding the focused topic are based on published information as listed in the references.

RESULTS

Importance of Plant Sugar for Mosquito:

Sugar feeding is an elementary feature of mosquito life, necessary for their physiology.[9] Naturally occurring nutritive sugars such as glucose, fructose, sucrose, maltose, and melezitose supports long life spans; while other sugars may not have such effects.[10] Even non-carbohydrate nutrients like amino acids, salts, and vitamins, derived from nectar or other plant fluids are also essential for mosquitoes.[11] Plant meals having sugars and non-carbohydrate nutrients are found to be critical for survival, flight, mating, and blood-feeding.[9] Studies have revealed that, for some *Anopheles* mosquitoes, population size and longevity are increased in the presence of flowering plants, which indicates the effects of plant sugar on their survival (Table 1).[12] It is also reported that highly synanthropic mosquitoes may also not survive in the absence of plant sugar despite the presence of vertebrate host blood.[13] Moreover, some researchers have shown mosquitoes can get maximum longevity if provided with a continuous sugar-and-water-only diet.[14] Nevertheless, survival may depend on the quality of sugar ingested by mosquitoes.[9] Experimental results from a study have shown that sugar concentration is directly proportional to the distance of flight for some mosquitoes.[10] In the males of *Anopheles freeborni* and *Culex tarsalis*, sugar meals are digested to a great extent before the flight for the demand of energy.[15] Sugar can be also vital for preliminary stages of egg development or adult maturation.[16] Autogenous mosquitoes are often unable to develop a clutch of eggs without consuming sugar.[17] On the other hand, as a result of previous sugar feeding, a substantial reserved energy may help to increase the size of the egg clutch.[9,10]

Table 1. Plants fluids and their effects on mosquitoes

Authors	Mosquito	Plant	Main Finding
Gu *et al.*, 2011[12]	*Anopheles sergentii*	*Acacia raddiana*	The population size increased along with higher survival rates and more frequent oviposition in the presence of plant sugar.
Gary and Foster, 2004[18]	*Anopheles gambiae*	*Ricinus communis, Manihot esculenta, Lantana camara*	Plant sugar enhanced the survivorship of males and females and without consuming sugar, males failed to inseminate any females.

Authors	Mosquito	Plant	Main Finding
Asmare *et al.*, 2017[19]	*Anopheles arabiensis*	*Zea mays*	Larval survival increased significantly with nutrition from pollen.
Muller *et al.*, 2017[20]	*Anopheles coluzzii*	*Thevetia neriifolia Barleria lupilina*	High survivorship and egg production were found for mosquitoes feeding on plant sugar.
Qualls *et al.*, 2013[21]	*Aedes albopictus*	*Dracaena sanderiana*	Mosquitoes were found to survive longer, thus enabling completion of gonotrophic cycle.
Martinez-Ibarra *et al.*, 1997[22]	*Aedes aegypti*	*Hibiscus rosa sinensis Bougainvillea buttian*	Mosquitoes are dependent on environmental resources of sugar for feeding that helps in their survival.
Arum *et al.*, 2016[23]	*Aedes mcintoshi*	*Duosperma kilimandscharicum*	Vegetation influences physiology of mosquitoes and enhances longevity.
Chen and Kearney, 2015[24]	*Culex pipiens*	*Impatiens walleriana*	Mosquitoes show varying attractiveness to plant species and differential long term imbibition and survival.

Medical importance of Mosquito Plant Interactions:

Natural sources of environmental sugars (i.e., plant sugars) have a considerable effect on survival and blood-feeding, and play a crucial role in the vectorial capacity of mosquitoes.[25,12] For malaria transmission by *Anopheles sergentii*, the increased survival due to sugar consumption is crucial as female mosquitoes must be old enough to allow the maturation of sporozoites within their salivary glands to be able to transmit malaria (Table 2).[12] Vector density, an essential constituent of vectorial capacity is a result of survival and fecundity. Several studies show that sugar feeding enhances the fecundity per gonotrophic cycle.[3] For *Aedes aegypti*, sugar nutrients have been reported to positively affect the pathogen establishment. Mosquitoes that ingested sugar alone post intake of an infected blood meal, rather than sequential blood meals were found to display a much greater pathogen transmission capacity (Table 2).[26] In contrast to increased vectorial capacity, most studies revealed that sugar availability reduces mosquito biting rates and blood-feeding frequency. Therefore, vectorial capacity may get reciprocally altered with nectar availability.[25] In some instances, sugar feeding may also have negative effects on vector competence as certain factors in plant nectar may impact the growth and development of the malaria parasite within the body of the vectors.[3]

Another aspect of mosquito-plant interaction is when pollen carrying mosquitoes bring pollen closer to human beings during their visit to the nearby human dwellings for rest or to bite, thereby, increasing the possibilities of allergenic pollen contamination indoors.[27]

Table 2. Effects on vectorial capacity due to plant sugar substrate

Author	Mosquito	Disease	Main Findings
Muller *et al.*, 2017[20]	*Anopheles coluzzii*	Malaria	*L. microcarpa* and *B. lupulina* plants increased transmission potential of malaria, because of increased infection rates among mosquitoes.
Gu *et al.*, 2011[12]	*Anopheles sergentii*	Malaria	The estimated vectorial capacity of *Anopheles sergentii* was 250-fold higher in sugar-rich sites than that in sugar-poor site
Gary and Foster, 2004[18]	*Anopheles gambiae*	Malaria	Plant sugar may play a crucial role in malaria vectorial capacity, through effects on survival or blood-feeding rate.
Qualls *et al.*, 2103[21]	*Aedes albopictus*	Dengue, Yellow fever, Chikungunya	With the availability of plant sugar mosquitoes survive long enough to complete the extrinsic incubation period of many arboviruses.
Kelly and Edman, 1997[26]	*Aedes aegypti*	Zika, Dengue, Yellow fever, Chikungunya	Mosquitoes have a higher rate of pathogen transmission when they feed on sugar meal after one blood meal.
Arum *et al.*, 2016[23]	*Aedes mcintoshi*	Rift Valley Fever	Increased risk of transmission of arboviruses to livestock and humans is evident for *Duosperma kilimandscharicum* sugar

Ecological importance of Mosquito-Plant interaction:

Nectars from flowers and honeydew excreted by aphids are the primary sources of environmental sugar for mosquitoes. Plant in return gets benefited for their pollination.[9] These interactions are mostly mediated by semiochemicals that guide mosquitoes to plant nectar sources. Mosquitoes have been found to play a considerable role in the pollination of flowers in subarctic regions of Northern Canada and Russia.[6] *Aedes* mosquitoes have been reported to be involved in Orchid

pollination in Alaska.[28] The attraction of female *Culex pipiens* by methylene chloride extract of flowers is reported by some scientists[29] which possibly establish the mosquitoes as a potential pollinator. This observation has been later confirmed by other scientists unequivocally.[2] Furthermore, decaying leaves, organic detritus, and microorganisms are the food of mosquito larvae.[30] The leaves of the purple pitcher plant (*Sarracenia purpurea*) are the only favorable place for the pre-adult development of certain *Wyeomyia* mosquitoes.[31] Some mosquitoes belonging to the genus *Limatus* are known to be a common colonist of the phytotelmata (a fallen part of plant).[32] Moreover, tree holes serve as breeding-habitats for several mosquitoes.[33]

DISCUSSION

Almost all mosquitoes are dependent upon plant sugar mostly as floral or extrafloral nectar and honeydew. Phytophagy is considered as one of the most primitive attributes in mosquito which later gave rise to hematophagy in the course of evolution.[34] Overlap in foraging cues may have been a contributory cause for the emergence of hematophagy from phytophagy for zoophilic mosquitoes.[35] Although, blood and sugar are interchangeable, but blood and sugar feeding activities are antagonistic and mutually exclusive to each other because of their conflicting demands.[9] The ample diversity of plants serving as a source of sugar to mosquitoes can bring them closer to human dwellings, as they include common garden plants and even indoor plants (Table 1). In a study, garden plants such as *Impatiens walleriana, Asclepias curassavica, Campsis radicans,* etc. were strongly attractive to certain species of mosquitoes and promoted long term survival in them.[24] *Ae. albopictus* was also found feeding on *Dracaena sanderiana,* the ornamental lucky bamboo plants. The increased survival in turn facilitated the development of arboviruses within them.[21] However, vectorial capacity is dependent on female density relative to humans, biting frequency, and survival rate.[3] The plant sugar directly affects survival and biting frequency but in opposing direction. Plant sugar indisputably increases the survival of mosquitoes, but tends to, reduce the biting rate. Field evidences supporting that, nonetheless, are limited.[3] A group of scientists apprehended that, improved nutritional status intensifies mosquito resistance to pathogens; thereby, reducing the disease transmission.[36] Hence, the transmission of certain mosquito-borne diseases can locally be reduced by cultivating the plants that

have proven to negatively affect the vectorial capacity of mosquitoes, yet at the same time providing the necessary sources of plant sugar to them.[8] Several mosquitoes are well known to feed on the larva of some lepidopterans.[37] Circulation and propagation of plant viruses have been evident in certain lepidopterans.[38] Therefore, possibilities arise that mosquitoes may get plant viruses from insects, thereby, adding new dimensions in viral disease transmission. However, further studies in this direction are required to come to any logical conclusion.

Another component of mosquito plant interaction is pollination. Hitherto, mosquitoes are considered to be outdone by bees and lepidopterans when it comes to pollination, with the exceptions in subarctic regions.[6,39] Nonetheless, it is speculated that mosquitoes can be regarded as co-pollinator or complementary pollinator together with other insects such as small moths and dipterans.[2] In a preliminary study, mosquitoes of certain species belonging to the genera Culex, Aedes and Armigeres were found to carry some allergenic pollen while probing and feeding.[27] Given the intense interactions between mosquitoes and plants, further studies in this direction are required for reconfirmation.

Human activities such as deforestation can drastically affect the mosquito plant-interactions. The scarcity of plant sugar disturbs the ecology of mosquitoes and this may lead to mosquitos' diversion towards alternative sources of food. Deforestation of natural habitats consequently decreases the abundance of animal hosts for zoophilic mosquitoes as well.[40] In addition, deforestation undertaken for human use increases human-mosquito encounters, hence, may allow the facultative zoophilic mosquitoes to select humans as a possible alternative food source.[41] This situation may force them to develop anthropophilic traits. This changing feeding behavior might have some impact on mosquito-borne disease ecology.[42] Therewithal, as a result of deforestation, the abundance of fallen-plant-parts (phytotelmata) increases to a greater extent relative to the intact forest that in turn serves as preferred habitats for mosquito larvae.[32] It is a well-documented fact that deforestation triggered the establishment of new habitats for *Anopheles darlingi* mosquitoes, and that subsequently resulted in malaria epidemics in South America.[42] Urban forestry and city-gardening are widely accepted throughout the world to reduce the effects of urbanization and in order to create a sustainable urban environment.[43] It has been witnessed that tree-holes act as important larval habitats for mosquitoes such as certain *Aedes* spp. in urban and sub-urban areas.[33] Hence,

considering the effects of plants on mosquito ecology, plantation should be judicious and ecologically compatible with the local environment. Due care should be taken to ensure that plantation programs should not facilitate to create any mosquitogenic conditions. A comprehensive study on hitherto neglected plant-mosquito interaction in reference to disease vector dynamics and plant ecology is required for better understanding and management of mosquito-borne diseases.

CONCLUSION

Mosquito-plant interaction is inevitable and crucial for mosquitoes to support their inherent phytophagous behavior, which in turn, affects their ecology and bionomics. Mosquitoes are mostly looked upon as disease-vectors owing to their haematophagy, but phytophagy also has a contributory effect on their vectorial capacity. Mosquitoes acting as generalist pollinators or co-pollinators may also have a significant role in the sustainability of the ecosystem that needs to be acknowledged. However, perusal of literature revealed that in the recent past mosquito-plant relationship with references to eco-epidemiological importance has remained unexplored or under-explored. More attention is required towards this hitherto neglected facet of mosquito ecology which can open new vistas for research and in formulation of management strategies for the containment of mosquito-borne diseases. This knowledge can also be helpful while developing and designing urban planning for sustainable urban public health. In order to achieve the objective of sustainable urban public health, vector biologists, plant science experts, disease ecologists and public health experts should be consulted while planning urban development.

Conflict of Interest: The authors have none to declare.

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