VECTOR COMPETENCE OF NORTH AND SOUTH AMERICAN STRAINS OF *AEDES ALBOPICTUS* FOR CERTAIN ARBOVIRUSES: A REVIEW

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ABSTRACT. Since the introduction of *Aedes albopictus* into North and South America, 18 viruses in 3 families have been used in vector competence studies involving 10 North American and 4 South American geographic strains of *Ae. albopictus*. This review summarizes the results of these studies and discusses the potential of *Ae. albopictus* to become a vector of arboviruses of public health importance in areas of the Western Hemisphere where it has recently become established.

INTRODUCTION

Aedes albopictus (Skuse) was an abundant and common pest in Hawaii by the late 1890s, where it presumably was introduced from the western Pacific by sailing vessels (Perkins 1913, Joyce 1961). It was discovered in Houston, TX, in 1985 (Sprenger and Wuithiranyagool 1986) and currently is established in the Western Hemisphere in 18 of the contiguous United States, Hawaii and 4 states in Brazil (Centers for Disease Control 1989, Ferreira Neto et al. 1987; C. Moore, personal communication). It seems remarkable that almost a century passed following the establishment of *Ae. albopictus* in Hawaii before the species gained a foothold in other parts of the Western Hemisphere. Undoubtedly, this can be attributed to increased traffic in the used tire trade (Reiter and Sprenger 1987).

Public health officials are concerned about the current rapid spread of *Ae. albopictus* in the Western Hemisphere because of its known and potential vector relationship with several arboviruses of public health importance. Shroyer (1986) provided a useful review of experimental and natural associations of *Ae. albopictus* with arboviruses up to the time of the discovery of this mosquito in Houston, TX. Since then, much experimental work has been done to define the vector competence of geographic strains of *Ae. albopictus* from North and South America. The purpose of this review is to summarize these studies.

Direct comparison of data on virus infection and transmission rates from different laboratories is complicated by several variables, e.g., virus strain and passage history, titer of infectious meal, whether the infectious meal is from a viremic host or a virus suspension, incubation period and temperature, whether the transmission assay is *in vivo* or *in vitro*, and method of calculating transmission rates. An argument can be made for including uninfected as well as infected mosquitoes that refeed during the virus transmission trial when calculating the transmission rate, thereby deriving the "population" transmission rate. However, I have chosen to present, whenever possible, transmission rates that are based only on the number of infected mosquitoes that refed. Uninfected mosquitoes cannot transmit virus, and eliminating them from the calculation removes some of the bias introduced when comparing transmission rates between groups of mosquitoes with widely disparate infection rates. This disparity, in turn, often is a result of differences in the titer of the infectious meal and whether the mosquitoes fed on a viremic host or a virus suspension. The "population" transmission rate can be derived by multiplying the infection rate by the transmission rate of infected females that refed.

DISCUSSION

Eleven publications have dealt with the vector competence of North and South American strains of *Ae. albopictus* (Beaman and Turell 1991, Boromisa et al. 1987, Grimstad et al. 1989, Miller and Ballinger 1988, Miller et al. 1989, Mitchell and Miller 1990, Mitchell et al. 1987, 1990; Scott et al. 1990, Smith and Francy 1991, Turell et al. 1988). Another article is in press (Heard et al. 1991). In addition, studies have been conducted with western equine encephalitis (WEE) virus (L. Kramer, S. Presser and J. Hardy, personal communication) and chikungunya (CHIK) virus (M. Turell and J. Beaman, personal communication). Eighteen viruses in 3 families have been used in vector competence studies with North and South American strains of *Ae. albopictus* as follows:

Flaviviridae
- Genus *Flavivirus*:
  - Dengue (DEN) 1,2,3,4
  - Yellow fever (YF)

Togaviridae
- Genus *Alphavirus*:
  - Eastern equine encephalitis (EEE)

Western equine encephalitis (WEE)
Venezuelan equine encephalitis (VEE)
Ross River (RR)
Mayaro (MAY)
Chikungunya (CHIK)

Bunyaviridae
Genus *Bunyavirus*:
La Crosse (LAC)
Jamestown Canyon (JC)
Keystone (KEY)
Trivittatus (TVT)
Potosi (POT)
Oropouche (ORO)
Genus *Phlebovirus*:
Rift Valley fever (RVF)

These studies have included 10 North American and 4 South American geographic strains of *Ae. albopictus*. The North American strains are from Polk County, FL; Alsace, Evansville and Indianapolis, IN; Lexington, KY; Gentilly and New Orleans, LA; Potosi, MO; Memphis, TN; and Houston, TX. The South American

Table 1. Vector competence of North and South American strains of *Aedes albopictus* for certain flaviviruses.

Virus and strain	Mosquito strain	Infection *n*	Infection %	Transmission *n*	Transmission %	Reference
DEN-1						
PR-1620	Houston	292	23–100	24	88	Mitchell et al. 1987
YARU 40130	Houston	21	71	8	38	Boromisa et al. 1987
YARU 40130	Memphis	29	100	15	20	Boromisa et al. 1987
YARU 40130	New Orleans	27	100	16	6	Boromisa et al. 1987
PR-1620	Cariacica City	29	52	14	71	Miller and Ballinger 1988
DEN-2						
PR-1615	Houston	333	3–92	23	74	Mitchell et al. 1987
	Cariacica City	26	38	10	70	Miller and Ballinger 1988
DEN-3						
MOZ-1557	Houston	241	22–64	15	53	Mitchell et al. 1987
	Cariacica City	27	19	4	75	Miller and Ballinger 1988
DEN-4						
PR-1632	Houston	280	7–76	19	42	Mitchell et al. 1987
	Cariacica City	26	35	8	25	Miller and Ballinger 1988
YF						
TRIN-788379	Houston	146	30–70	67	0–55	Mitchell et al. 1987
TRIN-788379	Cariacica City	35	57	20	15	Miller and Ballinger 1988
PERU-1899/81	Cariacica City	33	36	8	38	Miller and Ballinger 1988

Table 2. Vector competence of North and South American strains of *Aedes albopictus* for certain alphaviruses.

Virus and strain	Mosquito strain	Infection *n*	Infection %	Transmission *n*	Transmission %	Reference
EEE ME 77132	Houston	10	100	20	25–57	Scott et al. 1990
WEE BFS 1703	Houston	74	83–100	24	75–83	Kramer et al. pers. comm.
VEE, 1A (Trinidad Donkey)	Houston	127	54	26*	19	Beaman and Turell 1991
	Alsace, IN	91	74	31*	13	Beaman and Turell 1991
	Sao Paulo	189	70	33*	58	Beaman and Turell 1991
	Santa Teresa	168	62	32*	63	Beaman and Turell 1991
MAY TR 4625	Sao Paulo	181	9–85	17	45–50	Smith and Francy 1991
RR Rarotonga	Houston	317	13–100	168	33–78	Mitchell et al. 1987
CHIK	Houston	218	20–76		Yes**	Turell, pers. comm.
	Gentilly, LA	226	47–89		Yes**	Turell, pers. comm.
	Polk Co., FL	120	22–92		Yes**	Turell, pers. comm.
	Sao Paulo	189	32–72		Yes**	Turell, pers. comm.

* Mosquitoes with disseminated infections.
** Transmission demonstrated but rates were not determined.

Table 3. Vector competence of North and South American strains of *Aedes albopictus* for California serogroup viruses and other Bunyaviridae.

Virus and strain	Mosquito strain	Infection		Transmission		Reference
		n	%	*n*	%	
LAC GW-1978	Houston	80	93–98	75*	47	Grimstad et al. 1989
	Evansville	9	89	6*	33	Grimstad et al. 1989
	Indianapolis	10	80	6*	17	Grimstad et al. 1989
JC 800245	Houston	30	97	26*	8	Grimstad et al. 1989
KEY B64-5587	Houston	37	92	31*	0	Grimstad et al. 1989
TVT CMWA	Houston	50	28	12*	0	Grimstad et al. 1989
POT 89-3380	Lexington	140	11–45	14	21	Mitchell et al. 1990
POT 89-3364	Potosi	361	83–100	274	0–28	Heard et al. 1991, in press
ORO TR-9760	Sao Paulo	120	2–12	5	0	Smith and Francy 1991
RVF ZH-501	Houston	275	3–89	66*	15	Turell et al. 1988

* Mosquitoes with disseminated infections.

Table 4. Vertical transmission of certain arboviruses by North and South American strains of *Aedes albopictus*.

Virus and strain	Mosquito strain	Route mothers infected	F_1 infections		Reference
			n	Ratio	
DEN-1 PR-1620	Anchieta	Inoc.	546	1:182	Mitchell and Miller 1990
	Santa Teresa	Inoc.	1,558	1:390	Mitchell and Miller 1990
	Sao Paulo	Inoc.	408	<1:408	Mitchell and Miller 1990
DEN-4 PR-1632	Anchieta	Inoc.	1,884	<1:1,884	Mitchell and Miller 1990
	Santa Teresa	Inoc.	1,906	1:1,906	Mitchell and Miller 1990
	Sao Paulo	Inoc.	1,819	<1:1,819	Mitchell and Miller 1990
YF, TRIN 788379	Houston	Inoc.	6,180	<1:6,180	Miller et al. 1989
EEE ME-77132	Houston	Oral	1,657	<1:1,657	Scott et al. 1990
POT 89-3380	Lexington	Inoc.	6,635	<1:6,635	Mitchell et al. 1990
		Oral	1,196	<1:1,196	Mitchell et al. 1990
POT 89-3364	Potosi	Oral	5,145	<1:5,145	Heard et al. 1991, in press

strains are from Anchieta, Cariacica City and Santa Teresa, Espirito Santo State, Brazil; and São Paulo State, Brazil.

Flaviviridae: Because of concern that *Ae. albopictus* might become involved in the transmission cycle of dengue (DEN) viruses in the Americas, vector competence studies with these viruses have received high priority (Table 1). *Per os* infection rates and transmission rates indicate that a North American strain (Houston) and a South American strain (Cariacica City) of *Ae. albopictus* are competent experimental vectors of each DEN serotype. The DEN-1 virus transmission rates reported for Houston *Ae. albopictus* ranged from 38% (Boromisa et al. 1987) to 88% (Mitchell et al. 1987). This difference

Table 5. Susceptibility of *Aedes albopictus* to oral infection with arboviruses and ability to transmit by bite.

	Ae. albopictus strains from			
	Hawaii and areas outside W. Hemisphere[1]		North and South America	
Viruses	Infect.	Trans.	Infect.	Trans.
Chikungunya	+	+	+	+
Dengue 1, 2, 3, 4	+	+	+	+
Eastern equine encephalitis	+	+	+	+
Jamestown Canyon			+	+
Japanese encephalitis	+	+		
Keystone			+	−
La Crosse			+	+
Mayaro			+	+
Nodamura	+	?		
Oropouche			+	−
Orungo	+	+		
Potosi			+	+
Rift Valley fever			+	+
Ross River	+	+	+	+
San Angelo	+	+		
St. Louis encephalitis	+	+		
Trivittatus			+	−
West Nile	+	+		
Western equine encephalitis	+	+	+	+
Venezuelan equine encephalitis			+	+
Yellow fever	+	+	+	+

[1] Information from Shroyer (1986).

probably is due, in part, to differences in the *in vitro* transmission assay used in the 2 laboratories. Boromisa et al. (1987) diluted their feeding suspensions containing mosquito salivary secretions and froze them before injecting them into uninfected mosquitoes for virus amplification, whereas Mitchell et al. (1987) injected fresh suspensions containing salivary secretions shortly after collection and without further dilution. Also, the DEN-1 virus strains used in the two laboratories were different, and this may have affected transmission rates.

Dutch investigators (Dinger et al. 1929) reported that *Ae. albopictus* could transmit yellow fever (YF) virus under experimental conditions; however, infection and transmission rates were not determined. It is clear from studies conducted at the Centers for Disease Control (CDC) that *Ae. albopictus* strains from North and South America are competent vectors of YF virus (Table 1). Therefore, in view of the adaptation of *Ae. albopictus* to peridomestic habitats, this mosquito has the potential to bridge the gap between jungle and urban YF cycles in the Western Hemisphere (Mitchell et al. 1987).

Alphaviridae: The vector competence of North and South American strains of *Ae. albopictus* has been assessed for 6 alphaviruses (Table 2). *Aedes albopictus* is a competent vector for each of these viruses under experimental conditions. Fortunately, 2 of the viruses, Ross River (RR) and chikungunya (CHIK), are not found in North or South America. Recently, *Ae. albopictus* has been found in Fiji (Laird 1990) where a large epidemic caused by RR virus occurred in 1979 (Aaskov et al. 1981). Results of vector competence studies with *Ae. albopictus* and RR virus (Mitchell et al. 1987, Mitchell and Gubler 1987) provide a basis for estimating the likelihood that *Ae. albopictus* may become involved in the transmission cycle in Fiji.

Since birds are the principal amplification hosts for eastern equine encephalitis (EEE) and western equine encephalitis (WEE) viruses, it seems unlikely that *Ae. albopictus* will become a major vector of these viruses unless a significant degree of feeding on birds is found to occur. Also, WEE virus activity generally occurs in dry and semi-arid areas of the Great Plains and western United States, areas that are unfavorable to a mosquito that requires humid environments. Estimating the chances of *Ae. albopictus* becoming involved in the transmission cycles of Venezuelan equine encephalitis (VEE) and Mayaro (MAY) viruses is more problematic. Currently, the distribution of *Ae. albopictus* in Texas overlaps with areas that experienced epizootic VEE activity during 1971. *Aedes albopictus* is not present in areas where MAY epidemics have occurred.

Bunyaviridae: A major concern regarding the establishment of *Ae. albopictus* in the United States has been the possibility that this mosquito may become involved in the transmission cycle of La Crosse (LAC) virus. Grimstad et al. (1989) showed that 3 geographic strains of *Ae. albopictus* from the United States are competent vectors for LAC virus (Table 3), and the mosquito occurs within the range of LAC virus activity (Wesson et al. 1990). Three other California sereogroup viruses, Jamestown Canyon (JC), Keystone (KEY) and trivittatus (TVT), were included in the studies of Grimstad et al. (1989). Jamestown Canyon virus was transmitted inefficiently (8%), and none of 12 *Ae. albopictus* with disseminated TVT virus infections or 31 with disseminated KEY virus infections transmitted virus (Table 3).

Potosi (POT) virus, a new *Bunyavirus* isolated from *Ae. albopictus* collected in Potosi, MO (Francy et al. 1990; C. J. Mitchell, G. C. Smith, T. F. Tsai, and C. Frazier, unpublished data), is of interest because it represents the first recognized involvement of *Ae. albopictus* in a virus transmission cycle in the United States. Potosi virus has not been shown to infect or cause disease in humans. A serosurvey of 243 people living within 1.6 km of the tire yard from which POT virus was isolated showed no evidence of human infection with the virus (T. Tsai, personal communication). Two strains of *Ae. albopictus* have been shown to be competent vectors of POT virus (Table 3). However, neither strain appears capable of transmitting POT virus vertically (Table 4). This suggests that the virus was not introduced into Missouri via infected *Ae. albopictus* eggs in imported used tires (Mitchell et al. 1990).

Although the sample tested in virus transmission trials was small, *Ae. albopictus* does not appear to be a competent vector of Oropouche (ORO) virus (Table 3). It seems unlikely that *Ae. albopictus* would become involved in the transmission of ORO virus since *Culicoides paraensis* (Goeldi) is believed to be the main vector (Roberts et al. 1981). Currently, the distributions of *Ae. albopictus* and Rift Valley Fever (RVF) virus do not overlap; however, *Ae. albopictus* has recently been reported from tires in South Africa (Cornel and Hunt 1991). If *Ae. albopictus* expands its range into RVF endemic areas it should be considered a potential vector (Turell et al. 1988).

Vertical transmission: Relatively few attempts have been made to assess the ability of North and South American strains of *Ae. albopictus* to transmit viruses vertically (Table 4). The results of studies with POT virus are discussed above. Both DEN-1 and DEN-4 viruses have been shown to be vertically transmitted by Brazilian strains of *Ae. albopictus* following parenteral injection of virus into females. Filial infection rates ranged from 1:182 to 1:1,906 (Table 4). Vertical transmission of YF virus was not demonstrated in 6,180 progeny of infected females.

Scott et al. (1990) tested a small sample (1,657) of *Ae. albopictus* for vertical transmission of EEE virus. The negative results are consistent with those for other alphaviruses that have been studied; none has been conclusively shown to be transmitted vertically.

SUMMARY AND CONCLUSIONS

The vector competence of *Ae. albopictus* has been tested for 24 viruses (Table 5). Previous studies with *Ae. albopictus* from Hawaii and areas outside the Western Hemisphere included 15 viruses (Shroyer 1986). Studies conducted with North and South American strains of *Ae. albopictus* have confirmed results for 9 of these viruses and have added an additional 9 viruses to the list.

The greatest danger posed by *Ae. albopictus* in the Western Hemisphere, outside of Hawaii, is its potential to serve as a vector of DEN, LAC and YF viruses. However, at this time, the only virus isolated from *Ae. albopictus* collected in nature in the Western Hemisphere is the apparently innocuous POT virus. It should be emphasized that *Ae. albopictus* has yet to be implicated as the vector of any case of vector-borne disease in North or South America.

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