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Brief reports

Inhibition of *defensin A* and *cecropin A* responses to dengue virus 1 infection in *Aedes aegypti*

Yda Méndez, César Pacheco, Flor Herrera

Instituto de Investigaciones Biomédicas "Dr. Francisco Triana Alonso", Facultad de Ciencias de la Salud, Universidad de Carabobo, Maracay, Aragua, Venezuela

Introduction: It is essential to determine the interactions between viruses and mosquitoes to diminish dengue viral transmission. These interactions constitute a very complex system of highly regulated pathways known as the innate immune system of the mosquito, which produces antimicrobial peptides that act as effector molecules against bacterial and fungal infections. There is less information about such effects on virus infections.
Objective: To determine the expression of two antimicrobial peptide genes, *defensin A* and *cecropin A*, in *Aedes aegypti* mosquitoes infected with DENV-1.
Materials and methods: We used the F_1 generation of mosquitoes orally infected with DENV-1 and real-time PCR analysis to determine whether the *defensin A* and *cecropin A* genes played a role in controlling DENV-1 replication in *Ae. aegypti*. As a reference, we conducted similar experiments with the bacteria *Escherichia coli.*
Results: Basal levels of *defensin A* and *cecropin A* mRNA were expressed in uninfected mosquitoes at different times post-blood feeding. The infected mosquitoes experienced reduced expression of these mRNA by at least eightfold when compared to uninfected control mosquitoes at all times post-infection. In contrast with the behavior of DENV-1, results showed that bacterial infection produced up-regulation of *defensin* and *cecropin* genes; however, the induction of transcripts occurred at later times (15 days).
Conclusion: DENV-1 virus inhibited the expression of *defensin A* and *cecropin A* genes in a wild *Ae. aegypti* population from Venezuela.

Key words: *Aedes aegypti*; dengue virus; alpha-defensins; cecropins; *Escherichia coli.*

Inhibición de las respuestas de *defensina A* y *cecropina A* contra la infección del virus dengue 1 en *Aedes aegypti*

Introducción. Es esencial determinar las interacciones entre los virus y los mosquitos para disminuir la transmisión viral. Estas interacciones constituyen un sistema muy complejo y muy regulado conocido como sistema inmunitario innato del mosquito, el cual produce péptidos antimicrobianos, moléculas efectoras que funcionan contra las infecciones bacterianas y fúngicas; se tiene poca información de su acción sobre los virus.
Objetivo. Determinar la expresión de dos genes AMP (*defensina A* y *cecropina A)* en mosquitos *Aedes aegypti* infectados con el virus DENV-1.
Materiales y métodos. Se infectaron oralmente mosquitos de generación F_1 con DENV-1 y mediante el análisis con PCR en tiempo real se determinó el potencial papel de los genes *defensina A* y *cecropina A* en el control de la replicación del DENV-1 en *Ae. aegypti*. Como referencia, se infectaron mosquitos con *Escherichia coli*.
Resultados: Los mosquitos no infectados expresaron niveles basales de los ARNm de los genes *defensina A* y *cecropina A* en diversos momentos después de la alimentación. Los mosquitos infectados experimentaron una reducción, por lo menos, de ocho veces en la expresión de estos ARNm con respecto a los mosquitos de control en todo el periodo posterior a la alimentación. En contraste con el comportamiento del virus DENV-1, los resultados mostraron que la infección bacteriana produjo una regulación positiva de los genes defensina y cecropina; sin embargo, la inducción de los transcritos ocurrió tardíamente (15 días*).*
Conclusión. El virus DENV-1 inhibió la expresión de los genes *defensina A* y *cecropina A* en una población silvestre de *Ae. aegypti* en Venezuela.

Palabras clave: *Aedes aegypti*; virus del dengue; alfa-defensinas; cecropinas; *Escherichia coli*.

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Corresponding author:
Flor Herrera, Edificio BIOMED, Final callejón Cecilio Acosta, Avda. Las Delicias, Maracay, Aragua, Venezuela
Telephone: (58-243) 242 5822, fax: (58-243) 242 5333
flormhq@gmail.com

Author contributions:
Yda Méndez conducted the experiments.
César Pacheco designed the figures and supplementary material.
Flor Herrera conceived the study and was in charge of its overall direction and the writing of the manuscript.
All authors discussed the results and contributed to the final manuscript.

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Conflicts of interest:
None declared.

In Venezuela, dengue is the most important arboviral disease affecting humans, and its incidence and prevalence rise annually (1). Until now, there is not a vaccine to avoid DENV infections and, therefore, vector control is the only way to restrain these disease risks (2).

Arboviruses such as DENV have to go through a series of critical steps that demand their interplay with different tissues, which lasts for days or weeks until transmission can occur (2-4). These tissues represent barriers that restrict virus growth through, among others, immune molecules with antipathogenic activity that belong to a very complex system of highly regulated pathways called the innate immune system of mosquitos. Toll, IMD, JAK/STAT, and RNAi are the primary immune signaling pathways (2-5).

Different strategies to diminish viral transmission have been considered, among them, the use of genetically engineered vectors and natural symbionts like *Wolbachia* (6,7). Any strategy to control dengue transmission should consider the interactions between viruses and mosquitoes, especially, their innate immune system.

Toll and IMD pathways produce effector molecules such as the antimicrobial peptides, low molecular-weight proteins well known for their action against bacterial and fungal infections, although there is less information regarding their effect on viral infections. Reports suggest that dengue virus infection is controlled by the toll pathway in mosquitoes (8) and that together with the IMD pathways they upregulate the Sindbis (9) and the DENV-2 viruses in mosquitoes (10,11). However, other studies have evidenced the inhibition of toll's innate immune response in salivary glands infected by DENV-2 with 3'UTR substitutions associated with high epidemiological fitness and enhanced production of infectious saliva (12).

In our study, we found that the expression of *defensin A* and *cecropin A* genes, two antimicrobial peptide genes mediated by the toll pathway, was significantly reduced in *Ae. aegypti* mosquitoes infected with DENV-1 suggesting that the infection progresses by suppressing the toll pathway.

Materials and methods

Mosquito collection

We collected *Ae. aegypti* mosquitoes as larvae from Maracay, Venezuela, and then obtained their F_1 generation.

Dengue virus, bacteria, and infection processes

We used a DENV-1 isolate (LAR23644) recovered from a patient in Maracay in 2007 for the infection assays. Viruses were serially passaged in *Ae. albopictus* C6/36 cells, the infected supernatants were then harvested, titered via plaque-forming assay, and frozen at -80 °C. The viral titer was 4,8 x 10^5 PFU/ml. For oral infection experiments, we mixed viral stocks 1:1 with human red blood cells washed with PBS and fed to mosquitoes (sugar starved for 24 h) via membrane feeders. Some groups of mosquitoes were fed only on human red blood cells. Immediately post-feeding, fully engorged specimens were transferred to new cages held under standard rearing conditions and provided with sucrose.

At different times after feeding, ≈30 mosquitoes were collected each time. At early times (5 and 24 hours) we checked if the virus was inactivated by some

antiviral defense mechanism present in the mosquitoes' guts while at later times (10 and 15 days), we aimed at detecting viral replication in their bodies.

To determine the percentage of virus infection, dissemination, and potential transmission in the vector, 50 individual mosquitoes' abdomen (fed with the virus similarly as before and collected 15 days later) were dissected to check for infection, their legs and wings for dissemination, and their salivary glands for potential transmission. It is known that the only way to measure transmission is by analyzing the saliva of the mosquitoes, for which the viruses in these last tissues are potentially transmittable (13). Prior to their lysis, all the tissues were washed three times with 200 µl of PBS to discard any contamination. Mosquitoes were stored at -80 °C.

Similar infections were carried out with *E. coli* cultured in OD_{600} 0.8, pelleted, washed, and resuspended in PBS. The bacteria culture was mixed with human red blood cells in equal proportions, and then we applied the methodological procedure used for viral infection.

Detection and typing of dengue viruses in Aedes aegypti

RNA extraction, detection, and typing of dengue viruses in pools of whole bodies or in dissected samples *of Ae. aegypti* were performed according to Urdaneta, *et al.* (14).

Quantitative RT-PCR* (qPCR) *for measuring gene expression

Gene expression was determined by relative quantification relating the qPCR signal of the *defensin A* or *cecropin A* gene transcript in a mosquito group fed on virus or bacteria mixed with human red blood cells and that of a control group (calibrator) fed only on human red blood cells. qPCR was conducted in a reaction volume of 25 µl in a 96-well plate containing 0.5 µg of template based on the initial RNA concentration and 200 nM forward and reverse primers using real-time Go Taq qPCR™ (Promega Corporation, USA) on a 7500 Real-Time PCR System™ (Applied Biosystems, Massachusetts, USA) using the following program: 2 minutes of preincubation at 95 ºC followed by 40 30-s cycles at 95 ºC and one minute at 60 ºC. The designed specific primers used were: *Defensin A* gene (sense: 5'-AACTGCCGGAGGAAACCTAT-3'; antisense: 5'-TCTTGGAGTTGCAGTAACCT-3') and *cecropin A* gene (sense: 5'-CGAAGTTATTTCTCCTGATCG-3'; antisense: 5'-AGCTACAACAGGAAGAGCC-3'). To normalize the data, we used the *α-tubulin* gene (sense: 5'-GCGTGAATGTATCTCCGTGC-3'; antisense: 5'-AGCTACAACAGGAAGAGCC-3') s an endogenous reference.

We assessed *α-tubulin, defensin A*, and *cecropin A* primer pairs and we found the following for each: The observed efficiency was near to 100% (figure 1S), the amplification specificity was displayed through the production of a unique peak in the melt-curve analysis (figure 2S), which was corroborated by sequencing the PCR products from each gene in both directions using the PCR primers (data not shown). The sequencing reactions were performed with the ABI PRISM BigDye Terminator™, version 3.1 Cycle Sequencing Kit on an Applied Biosystems genetic analyzer, Model ABI 3130XL. Therefore, the $2^{-\Delta\Delta Ct}$ method of relative quantification was used to appraise relative gene expression.

We used the control and virus-infected pool samples (≈30 mosquitoes/pool) at different times after feeding (5 h, 24 h, 10 days, and 15 days) in the qPCR reaction (a total of 8 pools: ≈240 mosquitoes). The control values were

very close at all times, so we took their average as the calibrator. Each qPCR experiment was repeated three times with three replicates of each one. Similar experiments were carried out with *E. coli.* The average and standard deviation (SD) of the C_Ts from the three replicates were determined and the average was only approved if the SD was <0.38 (15). Repeatability and reproducibility were calculated by a percent coefficient of variance (% CV) within and between assays respectively (tables 3S).

We calculated N-fold copy numbers of the *Ae. aegypti defensin A* and *cecropin A* gene transcripts relative to the control in each assay using geometric means for the three experiments.

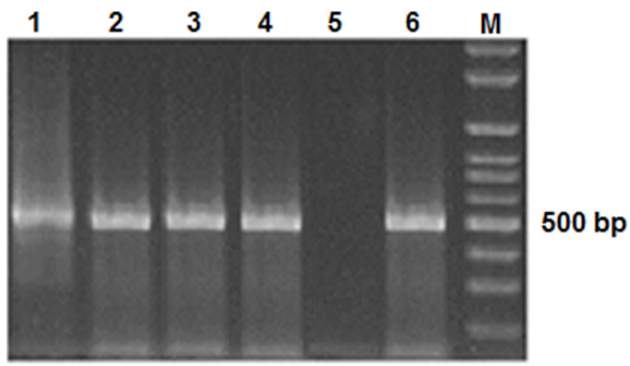
Results

Stability and replication of DENV-1

We determined whether the DENV-1 was stable at early post-infection (dpi) times (5 and 24 hours) and replicated at later ones (10 and 15 days) in the mosquitoes using RT-PCR amplification followed by agarose gel electrophoresis analysis of the products. Figure 1 shows the presence of DENV-1 with the cDNA band at the 482 bp position at all time points under study. The replication was further corroborated in the dissected samples of 50 individual mosquitoes with 70% and 100% viral infection and a dissemination efficiency 15 days post-infection. Regarding the virus present in the salivary glands, it also replicated (45%) and evidenced potential transmission efficiency (Table 9S).

Inhibition of defensin and cecropin mRNA by DENV-1

The relative expression levels of *defensin A* and *cecropin A* genes in DENV-1-infected *Ae. aegypti* mosquitoes as compared to the calibrator are shown in figure 2A with both mRNA detectable in control mosquitoes; however, a significant decrease in abundance occurred at all time points measured with at least five to eight-fold fewer amounts of *defensin* and *cecropin* mRNA, respectively, in mosquitoes infected with DENV-1.



Lanes 1-4: 5 h, 24 h, 10 days and 15 days, respectively; lane 5: Negative control; lane 6: Positive control of DEN-1 with a product size of 482 bp. Lane M: 100 bp-ladder marker.

DNA sizes are given in base pairs.

Figure 1. Detection of DEN-1 in *Aedes aegypti* by gel electrophoresis on a 2% agarose gel. DNA amplicons generated by RT-PCR of the RNA extracted from dengue viruses in *Aedes aegypti* at different times post infection.

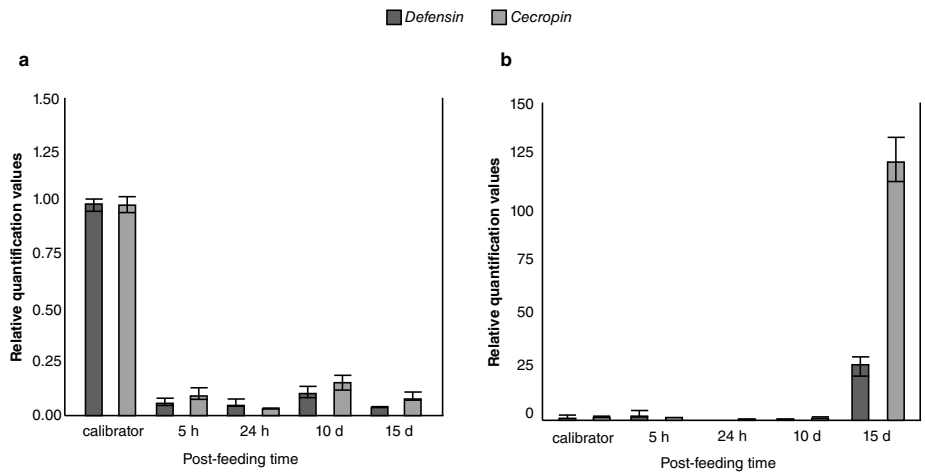


Figure 2. Comparison of immune responses to DENV-1 and *Escherichia coli* bacteria in field-collected Aedes aegypti. Averaged data from three independent real-time qPCR experiments were used to assess the expression of each of the selected immune genes in the *Aedes aegypti* mosquitoes infected with the DEN-1 virus (a) or *Escherichia coli* bacteria (b) with the host α-tubulin as an internal reference control to normalize the data. For each pathogen, the control values for both genes at all the time points were very similar. In every case, the average of all these values was used as the calibrator. The 2-ΔΔCT method was used to calculate fold change for each gene.

Induction of defensin and cecropin mRNA by bacteria

The response of the field population of *Ae. aegypti* mosquitoes to bacteria was contrary to the previously described viral response given that, as expected, the bacterial infection did not produce down-regulation in any of the genes (figure 2B); however, the induction of transcripts occurred at later times (15 days).

Discussion

There is a discrepancy regarding the reaction of mosquitoes' immune system in the presence of DENV-1. The response may be stimulation (2,8,10,11) or suppression *in vivo* (9,16-18) and *in vitro* (19, 20). Such discrepancy probably depends on the viral strain used, the genetic history of the vector, and the mode of transmission (3,21). We found a reduced expression of *defensin A* and *cecropin A* genes using the F_1 generation of wild mosquitoes infected with DENV-1. Similar results were reported with DENV-2-infected field *Ae. aegypti* populations (6).

The specific molecular mechanism by which DENV *acts* remains uncharacterized. The virus may be able to knock down the expression of some factor needed to induce the expression of *defensin* and *cecropin* mRNA, similar to the role reported for the *Ae*FaDD protein in *Ae. aegypti* (22). Alternatively, the DENV may directly target and inhibit the transcription of both genes.

The suppression of the innate immune responses of mosquitoes found in this study was time-independent contrary to other reports using similar times: 1, 2, 7, and 14 days (17), which implies that DENV may exert continuous immunomodulatory activity in mosquitoes, or for some period of time. This is critical for defining the vector competence of local mosquitoes, as well as dengue transmission intensity in a particular area.

As expected, the bacterial infection did not produce down-regulation of the *defensin* and *cecropin* genes (23,24)*;* however, the induction of the transcripts occurred at later times (figure 2B). These data could indicate that the capacity of these wild *Ae. aegypti* mosquitoes to mount a highly effective production of defensin and cecropin to control invading bacteria would take the time probably required to inactivate bacterial growth factors.

In conclusion, DENV-1 inhibits the expression of *defensin A* and *cecropin A* genes in a wild *Ae. aegypti* population from Maracay city in Venezuela. The way the virus participates in this inhibitory mechanism and the viral effector molecules acting in it are still to be determined.

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References

1. Ramos-Castañeda J, Barreto dos Santos F, Martínez-Vega R, Galvão de Araujo JM, Joint G, Sarti E. Dengue in Latin America: Systematic review of molecular epidemiological trends. PLoS Negl Trop Dis. 2017;11:e0005224. https://doi.org/10.1371/journal.pntd.0005224
2. Liu T, Xu Y, Wang X, Gu J, Yan G, Chen XG. Antiviral systems in vector mosquitoes. Dev Comp Immunol. 2018;83:34-43. https://doi.org/10.1016/j.dci.2017.12.025
3. Sim S, Jupatanakul N, Dimopoulos G. Mosquito immunity against arboviruses. Viruses. 2014;6:4479-504. https://doi.org/10.3390/v6114479
4. Wang Y, Chang M, Wang X, Zheng AH, Zou Z. The immune strategies of mosquito *Aedes aegypti* against microbial infection. Dev Comp Immunol. 2018;83:12-21. https://doi.org/10.1016/j.dci.2017.12.001
5. Blair C. Mosquito RNAi is the major innate immune pathway controlling arbovirus infection and transmission. Future Microbiol. 2011;6:265-77. https://doi.10.2217/fmb.11.11
6. Carvalho-Leandro D, Ayres C, Guedes D, Suesdek L, Melo-Santos MA, Oliveira CF. Immune transcript variations among *Aedes aegypti* populations with distinct susceptibility to dengue virus serotype 2. Acta Trop. 2012;124:113-9. https://doi.org/10.1016/j.actatropica.2012.07.006
7. Mains J, Brelsfoard C, Rose R, Dobson S. Female adult *Aedes albopictus* suppression by *Wolbachia*-infected male mosquitoes. Sci Rep. 2016 6:33846. https://doi.org/10.1038/srep33846
8. Xi Z, Ramírez JL, Dimopoulos G. The *Aedes aegypti* toll pathway controls dengue virus infection. PLoS Pathog. 2008;4:e1000098. https://doi.org/10.1371/journal.ppat.1000098
9. Sanders HR, Foy BD, Evans AM, Ross LS, Beaty BJ, Olson KE, *et al.* Sindbis virus induces transport processes and alters expression of innate immunity pathway genes in the midgut of the disease vector, *Aedes aegypti*. Insect Biochem Mol Biol. 2005;35:1293-307. https://doi.org/10.1016/j.ibmb.2005.07.006
10. Luplertlop N, Surasombatpattana P, Patramool S, Dumas E, Wasinpiyamongkol, Saune L, *et al.* Induction of a peptide with activity against a broad spectrum of pathogens in the *Aedes aegypti* salivary gland, following infection with dengue virus. PLoS Pathog. 2011;7:e1001252. https://doi.org/10.1371/journal.ppat.1001252
11. Wasinpiyamongkol L, Missé D, Luplertlop N. Induction of *defensin* response to dengue infection in *Aedes aegypti.* Entomol Science. 2015;18:199-206. https://doi.org/10.1111/ens.12108
12. Pompon J, Manuel M, Ng G, Wong B, Shan C, Manokaran G, *et al.* Dengue subgenomic flaviviral RNA disrupts immunity in mosquito salivary glands to increase virus transmission. PLoS Pathog. 2017;13:e1006535. https://doi.org/10.1371/journal.ppat.1006535
13. Mellor PS. Replication of arboviruses in insect vectors. J Comp Path. 2000;123:231-47. https://doi.org/10.1053/jcpa.2000.0434

14. Urdaneta L, Herrera F, Pernalete M, Zoghbi N, Rubio-Palis Y, Barrios R, *et al.* Detection of dengue viruses in field-caught *Aedes aegypti* (Diptera: Culicidae) in Maracay, Aragua state, Venezuela by type-specific polymerase chain reaction. Infect Genet Evol. 2005;5:177-84 https://doi.org/10.1016/j.meegid.2004.09.004

15. Pfaffl MW. A new mathematical model for relative quantification in real-time RT-PCR. Nucleic Acids Res. 2001;29:2002-7. https://doi.org/10.1093/nar/29.9.e45

16. Fragkoudis R, Chi Y, Siu R, Barry G, Attarzadeh-Yazdi G, Merits A, *et al.* Semliki Forest virus strongly reduces mosquito host defense signaling. Insect Mol Biol. 2008;17:647-56. https://doi.org/10.1111/j.1365-2583.2008.00834.x

17. Colpitts T, Cox J, Vanlandingham D, Feitosa F, Cheng G, Kurscheid S, *et al.* Alterations in the *Aedes aegypti* transcriptome during Infection with West Nile, dengue and yellow fever viruses. PLoS Pathog. 2011;7: e1002189. https://doi.org/10.1371/journal.ppat.1002189

18. Chang-Hyun K, Muturi E. Effect of larval density and Sindbis virus infection on immune responses in *Aedes aegypti.* J Insect Physiol. 2013;59:604-10. https://doi.org/10.1016/j.jinsphys.2013.03.010

19. Lin C, Chou C, Hsu Y, Lien J, Wang Y, Chen S, *et al.* Characterization of two mosquito STATs, AaSTAT and CtSTAT. Differential regulation of tyrosine phosphorylation and DNA binding activity by lipopolysaccharide treatment and by Japanese encephalitis virus infection. J Biol Chem. 2004;279:3308-17. https://doi.org/10.1074/jbc.M309749200

20. Sim S, Dimopoulos G. Dengue virus inhibits immune responses in *Aedes aegypti* cells. PLoS One. 2010;5 e10678. https://doi.org/10.1371/journal.pone.0010678

21. Lambrechts L, Scott T. Mode of transmission and the evolution of arbovirus virulence in mosquito vectors. Proc R Soc B. 2009;276:1369-78. https://doi.org/10.1098/rspb.2008.1709

22. Cooper D, Chamberlain C, Lowenberger C. *Aedes* FADD: A novel death domain-containing protein required for antibacterial immunity in the yellow fever mosquito, *Aedes aegypti.* J Insect Biochem Mol Biol. 2009;39:47-54. https://doi.org/10.1016/j.ibmb.2008.09.011

23. Bartholomay L, Michel K. Mosquito Immunobiology: the intersection of vector health and vector competence. Annu Rev Entomol. 2018;63:145-67. https://doi.org/10.1146/annurev-ento-010715-023530

24. Lowenberger C. Innate immune response of *Aedes aegypti.* Insect Biochem Mol Biol. 2001;31:219-22. https://doi.org/10.1016/s0965-1748(00)00141-7