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Generalized linear models applied to the analysis of the effectiveness of the Sterile Insect Technique

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Abstract: *Aedes aegypti* mosquito, popularly known as the dengue mosquito, represents a serious public health problem, because it is the vector responsible for several serious diseases such as Chikungunya fever, Zika virus and Dengue, the latter of which has a higher incidence in the Brazilian population. That mosquito has a high capacity for adaptation in the most diverse types of environments, mainly in places with high population density and lack of basic sanitation, factors that favor its proliferation. The control methods used by the epidemiological surveillance agencies are divided into three modalities: mechanical control, chemical control and biological control. Among the biological control methods, the Sterile Insect Technique (SIT) technique stands out, which consists of introducing sterile males into the mosquito population. This article presents reproduction analyzes of a population of natural mosquitoes compared to a population of mosquitoes with the insertion of males sterilized by ionizing radiation, seeking to observe the impact caused by this control method. The statistical analyzes showed the Negative Binomial regression model presented a better fit to the daily egg count data, when this model was compared to the Poisson model. In addition, the introduction of irradiated males decreases the average oviposition rate by approximately 30%.

Keywords: dengue, multivariate linear regression, ionizing radiation.

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Modelos lineares generalizados aplicados à análise da eficácia da Técnica de Insetos Estéreis

Resumo: O mosquito *Aedes aegypti*, popularmente conhecido como mosquito da dengue, representa um sério problema de saúde pública, pois é o vetor responsável por diversas doenças graves, como febre Chikungunya, vírus Zika e dengue, sendo esta última de maior incidência na população brasileira. Este mosquito possui alta capacidade de adaptação nos mais diversos tipos de ambientes, principalmente em locais com alta densidade populacional e falta de saneamento básico, fatores que favorecem sua proliferação. Os métodos de controle utilizados pelos órgãos de vigilância epidemiológica são divididos em três modalidades: controle mecânico, controle químico e controle biológico. Entre os métodos de controle biológico, destaca-se a Técnica de Inseto Estéril (SIT, Sterile Insect Technique), que consiste na introdução de machos estéreis na população de mosquitos. Este artigo apresenta análises de reprodução de uma população de mosquitos naturais comparada a uma população de mosquitos com a inserção de machos esterilizados por radiação ionizante, buscando observar o impacto causado por este método de controle. As análises estatísticas demonstraram que o modelo de regressão Binomial Negativo apresentou melhor ajuste aos dados diários de contagem de ovos, quando comparado ao modelo de Poisson. Além disso, a introdução de machos irradiados diminui a taxa média de oviposição em aproximadamente 30%.

Palavras-chave: dengue, regressão linear multivariada, radiação ionizante.

1. INTRODUCTION

The *Aedes aegypti* mosquito can be found in different parts of the world, predominating in tropical and subtropical climate regions, environments which offer a favorable climate for its development. Those mosquitoes have great importance as a vector of several serious arboviruses, that presents a high impact on public health worldwide, particularly in Brazil. Therefore, there is a great demand for the development of control techniques for that biological vector that are effective and cheap to public coffers [1,2].

Aedes aegypti is a mosquito which has diurnal habits that is dark in color, darker than the common mosquito and it has white stripes all over the body, which can facilitate its recognition. They are classified holometabolic, that is, they go through the egg, larva, pupa and winged stages (adult stage), characterizing their evolutionary cycle. This cycle of *Aedes aegypti* is divided into 2 phases, the aquatic and winged phases. The aquatic phase is the period when mosquitoes are immature, i.e., they are in the egg, larva, and pupae stages. The winged phase occurs after the pupae phase in the water, where the mosquito leaves the breeding site in search of terrestrial environments. The first feeding of adults, both females and males, is essentially based on nectar and sugary substances. Generally, the males develop faster than females, so when females emerge in their winged form, they are immediately approached for copulation, requiring only one insemination for fertilizing all eggs throughout the female's life. Therefore, females start to feed on blood (hematophagy) from animals and humans because they use necessary proteins for egg maturation from blood feeding [3,4].

Brazil is considered one of the largest arbovirus reserves in the world for having an area of continental proportions, being located in a region with a tropical climate, and having a large extension of forests. The main diseases transmitted by *Aedes aegypti* in the country are Yellow fever, Chikungunya fever, Zika and Dengue, the latest one has the highest incidence and impact on Brazilian public health [5-7].

Dengue virus is represented by four distinct serotypes: DENV-1, DENV-2, DENV-3 and DENV-4. Everyone can be affected by that virus and the symptoms range from mild flu-like symptoms to more severe case, such as dengue hemorrhagic fever, which usually occurs in people who have already contracted one of those serotypes [8- 11].

According to the Epidemiological Bulletin informed in August of 2023 by the Ministry of Health, 1,530,940 probable cases of dengue were reported in the country. The cases of Chikungunya and Zika fever were 143,739 and 8,425, respectively. Such numbers are indeed alarming and show the importance of developing techniques to control *Aedes aegypti* [12]. Therefore, the controlling *Aedes aegypti* is essential to minimize the incidence of diseases related to the mosquitoes population. However, that has become a major challenge for public health and epidemiological surveillance agencies. Among the difficulties in combating the dengue mosquito, we can highlight the precarious conditions of infrastructure, lack of investments in basic sanitation and the deforestation of preserved areas, which are very recurrent situations in all corners of the country. Another factor that contributes to the difficulty of controlling this vector concerns its great ease in adapting to the most diverse types of environment, especially environments with high human population density and high concentrations of garbage. In these environments, the mosquito easily finds containers that can allocate standing water, and which are used to deposit their eggs, as well as food in abundance, given that females have hematophagous food to mature their eggs [13].

The most used control methods consist of direct attack to mosquitoes both in their larval (aquatic) and adult (winged) phases. These methods are divided into three modalities: mechanical control, chemical control, and biological control.

Mechanical control consists of the elimination of breeding sites, such as containers containing stagnant water, aiming at interrupting the mosquito's biological cycle in the pupa and larva stage. Chemical control consists of the use of chemical insecticides and larvicides, however, this method of control is not prioritized because it has a high cost and promotes environmental damage. Biological control can be divided between several techniques, such as the use of organisms capable of parasitizing or preying on the mosquito and the use of genetic engineering that promotes the use of genetically modified mosquitoes in order to prevent their reproduction and inactivation of the dengue serotypes. In addition to these biological control methods, a special method and object of study in this work is the Sterile Insect Technique (SIT). This technique was devised by American entomologist Edward F. Knipling who proposed the concept of releasing sterile, factory-produced insects to control pest populations in plantations [14-16].

The SIT consists of the sterilization of pests and disease vectors, usually males, through the induction of chromosomal aberrations, whether by chemical or physical means. Such chromosomal aberrations induce lethal dominant mutations in the sperm of male mosquitoes. This work deals with the use of ionizing radiation as a means of sterilizing mosquitoes, considering its capacity to effectively induce genetic mutations. Ionizing radiation can be directly ionizing and indirectly ionizing. Directly ionizing radiations can cause direct damage to chromosomes, that is, the target atoms (DNA) when ionized or excited start a chain of events that culminate in biological modifications, which is a dominant process for high linear transfer radiation of energy (LET) as neutrons and α-particles. The indirect action of ionizing radiation, inherent to x- and γ-ray photons, occurs when the radiation interacts with other atoms or molecules in the cell, more specifically with water molecules, producing free radicals. Free radicals are unstable molecules that have an electron that tends to quickly associate with other positively charged molecules with which it can react or oxidize. The product of this interaction is the short-lived, highly reactive H2O+ ion. When these ions decay, they form uncharged free radicals that are still reactive and when interacting with other water molecules form the so-called reactive hydroxyl radical (OH·). The reactive hydroxyl radical can diffuse for a short distance, reaching the DNA and thus causing several mutations. Mutations can occur in the repair process of somatic cells and such factors have the potential to induce important genetic changes resulting in sterility. The release of *Aedes aegypti* males sterilized in nature causes changes in the reproductive cycle of the species, taking advantage of the fact that the mating of mosquitoes occurs only once, resulting in the production of non-fertilized eggs [17,18].

This article comprises the analysis of the reproduction of dengue mosquitoes considering a population of natural mosquitoes with different hematophagy feeding intervals for females and a population with the insertion of male mosquitoes sterilized by ionizing radiation (SIT technique) following the same proposed feeding intervals for the population of natural mosquitoes. We sought to understand the impact caused by this method of control on the reproduction of mosquitoes, using the daily average oviposition and comparisons between groups. The analyzes were performed using generalized linear models for counting data in the Statistical Software R. The main models proposed for the appropriate analyses were the Poisson regression model and the Negative Binomial distribution model. The data analyzed are from an experiment carried out in the Insectary of the Department of Parasitology of the Institute of Biosciences of Botucatu at São Paulo State University.

2. MATERIALS AND METHODS

2.1. Design of experiment and plan for data collection

The design of experiment was planned by Cristino to facilitate the daily counting of live and dead mosquitoes and the number of eggs laid by females [10]. The eggs of *Aedes aegypti* were available by the Insectary of the Institute of Biosciences of Botucatu/SP and the experiment was carried out looking for typical optimal summer conditions for greater egg productivity, that is, controlled room temperature around 27° Celsius, 75% relative humidity and simulations controlling ambient light (day and night periods) [10].

Ten trays were numbered and randomly arranging 100 eggs in each one, until hatching the larvae. After that, the larvae were fed with ornamental fish food and, when they reached the pupae stage, the mosquitoes were transferred to properly coded cages where the counts of the number of male and female began as they developed until the adult stage, for each cage. In adulthood, the mosquitoes were fed with a 10% solution of water and sucrose and females were fed with blood too from anesthetized mice. Twenty-five mice were used during the experiment and the entire process was duly approved by the Animal Use Ethics Committee (CEUA), according to the certification number 624-CEUA [10].

Considering the population of natural mosquitoes, the experiment lasted 45 days where intervals of 4 and 7 days were used between feedings. Data were collected daily and entered into a spreadsheet containing the cage number, the current day, the number of males and females in each cage, the number of eggs laid each day and the respective feeding time. Ten cages duly enumerated were used, where in cages 1 to 5 the females were fed with blood every 7 days and, in cages 6 to 10, the females were fed with blood every 4 days.

Considering the population of mosquitoes with the insertion of sterilized males, the experiment began, a priori, with the sterilization of mosquitoes. Sterilization was based on the technique used at the Center for Nuclear Energy in Agriculture (CENA), where male mosquitoes in the pupae stage were irradiated through a cobalt-60 source present at the São Paulo State University "Júlio de Mesquita Filho" (UNESP) from Botucatu, GE/CGR/MEV brand and Alcyon II model. Different radiation doses were tested to sterilize the mosquitoes, trying to see which would be the most effective dose to promote their sterility. Testing started at 10 Gy, with increments of 10 and 10, up to a maximum dose of 150 Gy. At each test, between 300 and 500 pupae were used where they were placed in cages to observe their development and if the male mosquitoes were properly sterilized. After the tests, it was possible to conclude that the radiation doses of 30 and 40 Gy were the most effective in the sterilization of male mosquitoes without compromising the insect's biology and sexual behavior [19,20]. After choosing the doses, approximately 140 male mosquitoes in the pupal stage were placed in two plastic containers with 250 mL of water to apply the radiation doses. Each container allocated approximately 70 pupae where the first received a dose of 30 Gy and the second a dose of 40 Gy. After sterilization, the male sterile mosquitoes (E) were placed in 8 enumerated cages following different proportions between the number of natural males (N) and females (F), as shown in Table 1.

Table 1: Proportions of sterile, natural male and female mosquitoes in each cage.

Dose	Cage	Proportions*
30 Gy	11	1 F : 1 E
	12	1 F : 1 N : 1 E
	13	10 F : 10 N : 1 E
	14	1 F : 10 E : 1 N
40 Gy	15	1 F : 1 E
	16	1 F : 1 N : 1 E
	17	10 F : 10 N : 1 E
	18	1 F : 10 E : 1 N

*E = sterile males, N = natural males, F = female mosquitoes

The cages containing only sterile male and female mosquitoes (Cage 1 and 5) were used as a control group. Adult females were fed blood from mice every 4 days [11].

2.2. Count data analysis

Considering a linear model Analysis, the response variable is a linear combination of the explanatory variables. If the response variable is a count variable, thus the distribution of the response variable not present distribution equal to Normal one. So, the concept of generalized linear model was introduced by Nelder and Wedderburn (1972). In a generalized linear model, the distribution of the response variable can assume, in addition to the Normal, other distributions of the exponential family (Poisson, Negative Binomial, etc.). Their functions are related the expected value, and the vector of explanatory variables can be any differentiable function [21-23].

A generalized linear model is defined by taking Y independent random variables and its probability function in the form:

$$f(y_i;\theta_i,\phi) = \exp\left\{\frac{y_i\theta_i - b(\theta_i)}{\phi} + c(y_i,\phi)\right\}, \quad (1)$$

where θ_i is the model parameter, ϕ is a dispersion parameter that can be unitary in certain cases, and the functions $b(.)$ e $c(.)$ are known real functions. The systematic part of the model is given by

$$g(\mu_i)=\eta_i, \quad (2)$$

where $\eta_i = x_i^T\boldsymbol{\beta}$ is the linear predictor. The parameter of interest in the generalized linear model is the vector $\boldsymbol{\beta}=(\beta_{i1},\dots,\beta_{ip})^T$ which represents the unknown parameters to be estimated, p is the dimension of this vector $(p<n)$ and, the parameter of interest $(\boldsymbol{\beta})$ be estimated by the likelihood method. The vector $\boldsymbol{x}_i = (x_{i1},\dots,x_{ip})^T$ represents the values of the explanatory variables and $g(.)$consists of a monotonous and differentiable function, called a link function [21,22].

After describing the statistical model, the generalized linear models considered in that work are related to the Poisson regression model and the Negative Binomial distribution model.

The Poisson regression model is a specific generalized linear model that the response variable follows a Poisson distribution because the data are from a counting process. However, the parameter for dispersion has to be estimated because the variance must have the same value for the mean of the distribution. Its application is effective when dealing with discrete data where the data comes from a counting process, for example, to observe a number of occurrences for a fixed period of time. This model assumes only non-negative integer values for the expected value of the response variable, according to a counting data modeling. The probability function is given by

$$f(y_i/\mu_i) = \frac{\mu_i^{y_i} e^{-\mu_i}}{y_i!}, i=1, \dots, n, \quad (3)$$

where y_i and μ_i are the observed and mean values of the response variable Y_i, respectively.

This model assumes a constant variation from the mean as follows

$$E(Y_i/x_i) = var(Y_i/x_i) = \mu_i = e^{x_i'\beta}, \quad (4)$$

in which the logarithmic transformation is used as a function of the generalized linear model to establish a linear relationship between the response variable and the explanatory variables [21-24].

The Negative Binomial distribution model considers an additional dispersion parameter (φ) in the conditional variance calculation and as this parameter is characterized as non-negative, the variance can be greater than the mean. The probability function is given by

$$f(y_i;\mu_i,\phi) = \frac{\Gamma(y_i+\phi)}{\Gamma(y_i+1)\Gamma(\phi)} \left(\frac{\phi}{\phi+\mu_i}\right)^{\phi} \left(\frac{\mu_i}{\phi+\mu_i}\right)^{y_i}, i=1, \dots, n, \quad (5)$$

where Γ(.) is the gamma function and the binding function used is given by a logarithmic function. The mean value together with the variance is expressed respectively by

$$E(Y_i) = \mu_i, \quad (6)$$

$$var(Y_i) = \mu_i + \phi(\mu_i)^2. \quad (7)$$

The parameters $\boldsymbol{\phi}$ and $\boldsymbol{\beta}$ are found using iterative methods and the limiting case of this model is the Poisson distribution, when $\phi \rightarrow 0$.

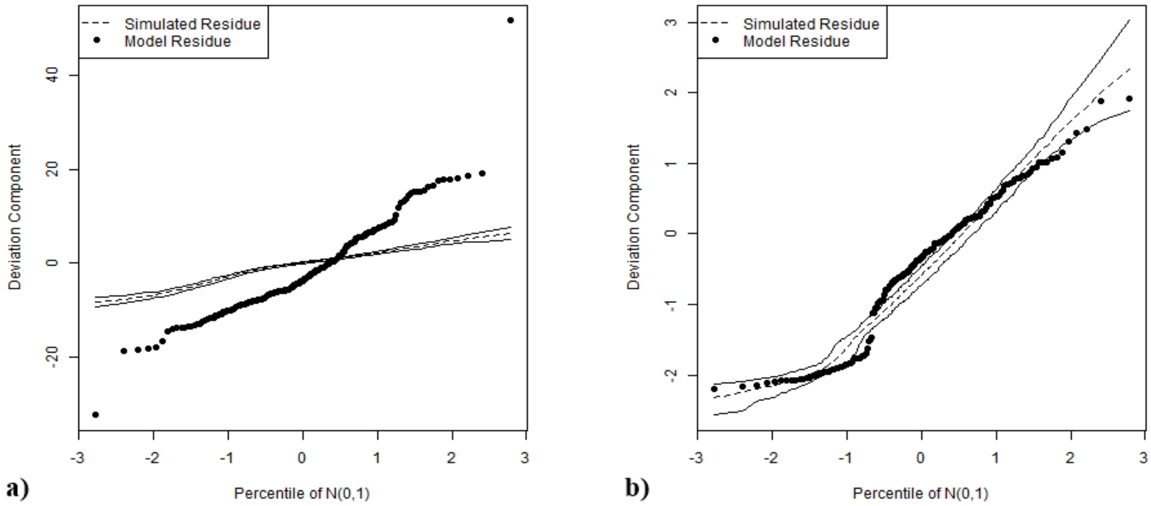
The choice of the most adequate model for data analysis was made using methods that consist in evaluating whether the proposed models present statistically significant differences, and they are well fitted to the data.

The likelihood ratio test was used in order to make comparisons regarding the goodness of fit between the two proposed models. The envelope graph of the residual quantiles was used as a method of verifying the goodness of fit of the proposed models to the data. Residuals are calculated from the value estimated by the model subtracted from the observed value for that condition. These graphs allow evaluating the behavior of the residues, that is, they allow identifying the observations that present residues outside the acceptable limits for the distribution of residues. Graphs are produced during the application of the tests which demonstrate the behavior of the residues and whether they fit within the limits considered for the distribution. If all residues are within the generated envelope without showing any systematic trend, this is an indication that the proposed model is the most adequate [21-26].

3. RESULTS AND DISCUSSION

Figure 1 shows the result after application of the residual envelope test for the population of natural mosquitoes for the blood feeding interval in was 7 days (Cages 1 to 5) and the range time was 4 days (Cages of 6 to 10).

Figure 1: Residual envelope test for **a)** Poisson Regression Model and **b)** Negative Binomial Distribution Model.



As shown in Figure 1(a), all generated residuals remain outside the confidence bands for the Poisson regression model, suggesting a lack of adjustment of the residuals and indicating Poisson model is not the most adequate to explain the experimental data. In Figure 1(b), the residuals from the Negative Binomial distribution model appear to be more adequate fit for the analysis of daily oviposition data in the population of natural mosquitoes. The parameter estimates for the Negative Binomial distribution model are shown in Table 2.

Table 2: Estimates of the Negative Binomial distribution model for the daily data of oviposition count of natural mosquitoes.

Parameters	Estimate	Standard deviation	Exp(Estimate)	Conf. Int. 95%	p-value
Intercept	0.7887	0.3059	2.2	1.09 – 4.63	0.01
Blood-Feeding Intervals	0.0840	0.2739	1.09	0.62 – 1.92	0.759
Time blood-feeding	0.1894	0.0652	1.21	1.02 – 1.39	0.004
Feed 2 vs Feed 1	0.8853	0.2986	2.42	1.26 – 4.71	0.003
Feed 3 vs Feed 1	0.5844	0.2934	1.79	0.97 – 3.34	0.046
Feed 4 vs Feed 1	1.3457	0.4823	3.84	1.43 – 11.53	0.005

Table 2 shows the variation between the feeding intervals (4 or 7 days) did not have a statistically significant difference in oviposition ($p=0.759$), thus the feeding intervals did not influence egg production by females. For the analysis of the results in the original scale of the counting data, the exponential of the parameters was applied, called the inverse link function, as shown in the column "Exp(estimative)" and, thus, it was possible to observe that after each feeding there was an increase of approximately 21% in oviposition and statistically significant due to its value of p=0.004, which shows once again that the females produced eggs even with the proposed feeding intervals. The best adjusted model is given by

$$\log(\text{ovipos}) = 0.78 + 0.08(\text{Interval}) + 0.18(\text{Day after feed in}) + 0.88(\text{feed2 vs feed1}) + 0.58(\text{feed3 vs feed1}) + 1.34(\text{feed4 vs feed1}). \quad (8)$$

The dispersion parameter of the Negative Binomial distribution model (φ) was approximately 0.4136. The oviposition has started 2 days after the first feeding with an average of 143 eggs per day and the 95% Confidence Interval (95% CI) equal to (136;149).

Figure 2 shows the results of the residual envelope tests applied to the oviposition data of mosquito populations with the insertion of radiation-sterilized males, considering the cages coded 11 to 18.

Figure 2: Residual envelope test for **a)** Poisson Regression Model and **b)** Negative Binomial Distribution Model.

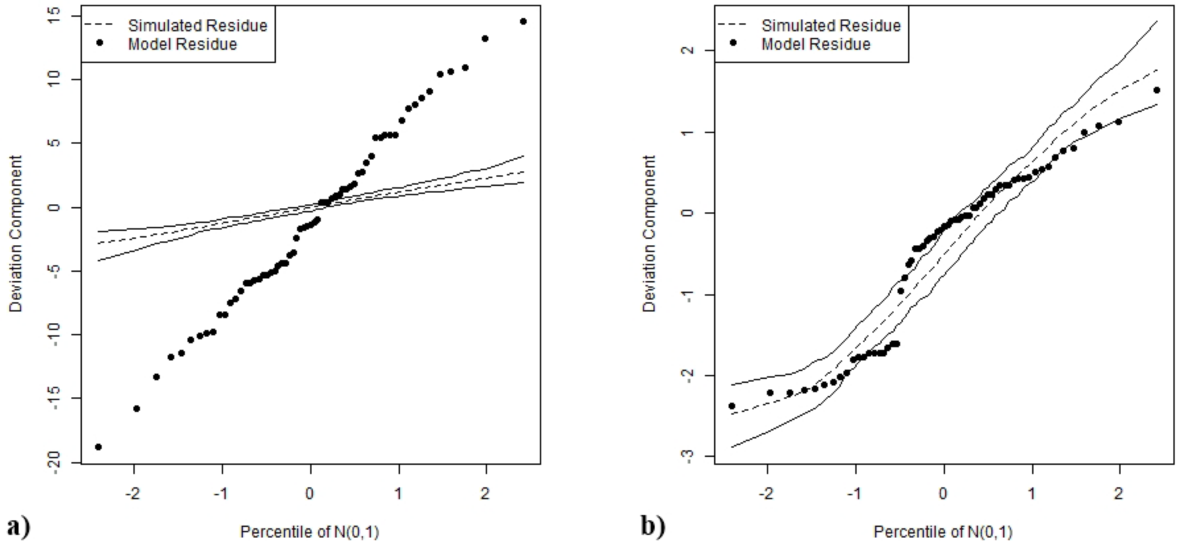


Figure 2(b) shows the tendency of the residuals to adjust to the Negative Binomial distribution model, remaining almost entirely within the envelope margins, which is the most adequate model for the data. The estimates of the model parameters are shown in Table 3.

Table 3: Estimates of the Negative Binomial distribution model for counting daily oviposition by females with the insertion of males sterilized by radiation.

Parameters	Estimate	Standard deviation	Exp(Estimate)	p-value
Intercept	0.1735	0.5602	1.1894	0.757
Dose 40 Gy vs Dose 30 Gy	0.1679	0.3933	1.1829	0.670
1F : 1N : 1E vs 1F: 1E	0.4390	0.5526	1.5512	0.427
10F : 10N : 1E vs 1F : 1E	0.0173	0.5514	1.0175	0.975
10F : 1N : 10E vs 1F : 1E	0.3901	0.5621	1.4771	0.488
Feed 2 vs Feed 1	1.8564	0.5642	6.4011	0.001
Feed 3 vs Feed 1	2.3328	0.5639	10.3074	0.001
Feed 4 vs Feed 1	2.3109	0.5639	10.0839	0.001

The 30 Gy dose, the ratio of 1 female (1F) to 1 sterile male (1E), Cages 11 and 15, and the first blood feeding were considered as reference categories for data analysis, comparing to the other categories. The radiation doses of 30 and 40 Gy did not present a statistically significant difference in the average daily oviposition ($p=0.670$). The proportions used between natural (N) and sterile (E) male mosquitoes and females (F) also did not show statistically significant differences in oviposition mean ($p>0.05$). In the second blood feeding there was an increase of 6.4 times in relation to the amount of eggs observed in the first feeding. Considering the third and fourth blood feedings, there was an increase of more than 10 times in the average oviposition compared to the first feeding. Therefore, the results suggest that oviposition does not change with the radiation dose used in the sterilization of male mosquitoes and that is not related to the proportions of natural and sterile males inserted in the population, that is, oviposition occurs naturally.

The best adjusted model for counting data is given by

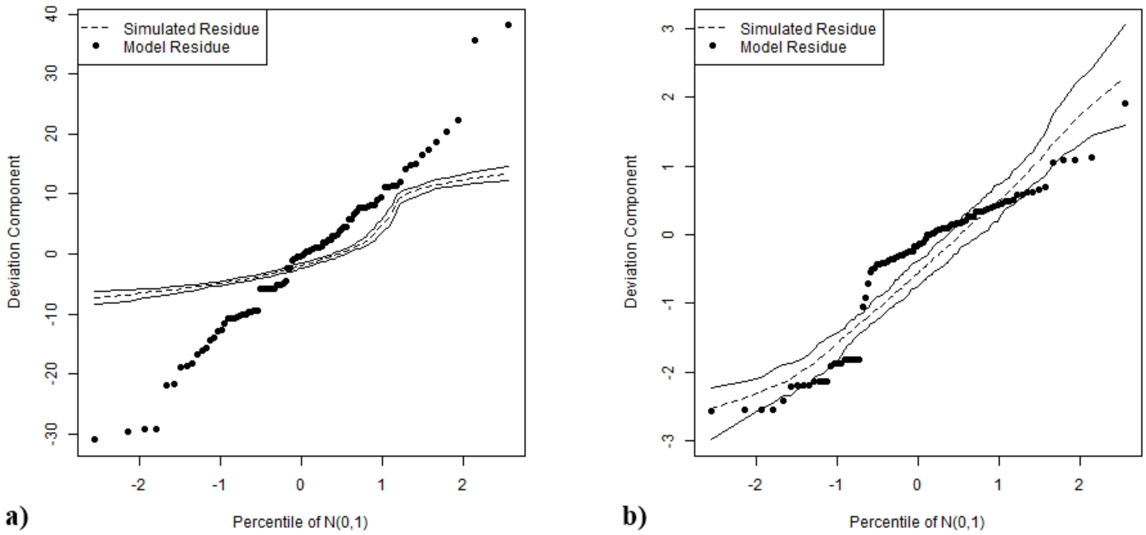
$$\log(\text{ovipos}) = 0.17 + 0.16(D{:}30\text{GyvsD:40Gy}) + 0.43(1F{:}1N{:}1\text{Evs}1F{:}1N)$$
$$+0.01(10F{:}10N{:}1\text{Evs}1F{:}1E) + 0.39(10F{:}1N{:}10\text{Evs}1F{:}1E) + 1.85(\text{feed2vsfeed1})$$
$$+2.33(\text{feed3vsfeed1}) + 2.31(\text{feed4vsfeed1}). \quad (9)$$

The dispersion parameter of the Negative Binomial distribution model (φ) was approximately 0.4166.

Nascimento *et al.* demonstrated that the introduction of sterile males decreases the hatching rate, thus interrupting the proliferation and accelerated growth of *Aedes aegypti*populations, given optimal temperature conditions and places with abundant breeding sites [25]. Ranathunge *et al.* also demonstrated that mosquito egg hatching rates are significantly lower when the SIT method is employed [26]. The studies conducted by Lima have demonstrated that the effects of ionizing radiation not only induced sterility but also incurred a biological cost on the survival of exposed individuals. This detriment potentially compromises various physiological processes, rendering them less competitive in their respective ecological contexts [27]. Furthermore, additional studies have also demonstrated the impact on egg hatching when the SIT method is employed [28, 29].

Figure 3 shows the residual envelope for choosing the most suitable model to be used in the analysis of the mean oviposition of mosquito populations with the insertion of males sterilized by ionizing radiation compared to the populations of natural mosquitoes.

Figure 3: Residual envelope test for **a)** Poisson Regression Model and **b)** Negative Binomial Distribution Model.



The cages coded 6 to 10, with natural mosquitoes where females were blood fed every 4 days and cages from 11 to 18, with sterile male mosquitoes, females were also fed every 4 days. The most suitable model for the analysis was the Negative Binomial distribution, as shown in Figure 3(b), where the residuals showed a tendency to fit the envelope. Estimates of the model parameters are shown in Table 4.

Table 4: Estimates of the Negative Binomial distribution model for counting daily oviposition by females with insertion of males sterilized by radiation compared to a population of natural mosquitoes.

Parameters	Estimate	Standard deviation	Exp(Estimate)	p-value
Intercept	2.1862	0.3683	8.9022	0.001
Dose 30 Gy vs Natural	-1.2683	0.3681	0.2813	0.001
Dose 40 Gy vs Natural	-1.0046	0.3678	0.3661	0.001
Feed 2 vs Feed 1	1.3302	0.4261	3.7819	0.001
Feed 3 vs Feed 1	1.7650	0.4259	5.8416	0.001
Feed 4 vs Feed 1	1.6992	0.4259	5.4693	0.001

The females mosquitoes have started the oviposition process 2 days after the first feeding. The best adjusted model for counting data is given by

$$\log(\text{ovipos}) = 2.18 - 1.26(D{:}30\text{GyvsNat.}) - 1.00(D{:}40\text{GyvsNat.}) + 1.33(\text{feed2vsfeed1}) + 1.76(\text{feed3vsfeed1}) + 1.69(\text{feed4vsfeed1}) \quad (10)$$

The dispersion parameter of the Negative Binomial distribution model (φ) was equal to 0.4643. When making the comparisons between the oviposition of the natural mosquito's population and the population with the insertion of sterilized males by radiation process, we can obtain:

i) The populations with the presence of males sterilized 30 Gy has decreased in the average oviposition of approximately 28.13%;
ii) The population with males sterilized 40 Gy has decreased in the average oviposition of approximately 36.61%.

From the second blood feeding, mean oviposition increased 2.9 times compared to the first feeding and the third and fourth feeding have increased almost 4 times the amount in the first blood feeding.

According to Cristino, there is a certain preference of females for males sterilized with a dose of 30 Gy, which are quite competitive with respect to natural males [10].

4. CONCLUSIONS

The Statistics is a valuable analytical tool in many areas. In this work, that tool was used to analyze the effectiveness of the SIT to control arboviruses, minimizing the negative impact that these diseases cause on the public health system.

Considering the analysis of populations of natural mosquitoes, it was possible to conclude that the modification of blood feeding intervals does not cause statistically significant effects on the average daily oviposition, that is, oviposition will still occur in situations even the female mosquito does not have access to blood supply within a short time. This highlights the difficulty of controlling this vector, especially in regions with high population density, where mosquitoes easily find blood food in abundance.

The populations of sterile males do not present statistical differences using the two radiation doses, as well as the proportions between natural and sterilized males did not present statistically significant differences on mean oviposition. At first there was not possible to observe any impact on the average oviposition of females. Furthermore, the radiation doses 30 and 40 Gy did not present statistical differences, although they were effective for the sterilization of mosquitoes without compromising the biology and sexual behavior of the male mosquito, according to the technique used at the Center for Nuclear Energy in Agriculture (CENA) of the University of São Paulo (USP).

Finally, the comparisons between populations of natural mosquitoes and sterilized ones have showed the results of ionizing radiation control method have caused a significant decrease in the average daily oviposition. In addition to the fact that the eggs produced by the females are not fertilized, there is also a decrease in the number of eggs, therefore the SIT method can be an important ally in combating the dengue mosquito population.

The insertion of sterilized male population in the environment does not entail any risk of disease in humans because their food is not blood instead, which is an exclusive characteristic of *Aedes aegypti* females mosquitoes.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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