RESEARCH ARTICLE

Water source most suitable for rearing a sensitive malaria vector, *Anopheles funestus* in the laboratory [version 1; referees: 2 approved]

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Abstract

**Background:** The insecticide susceptibility status of *Anopheles funestus*, one of the main malaria vectors in the Afrotropical regions, remains under-studied due to the difficulty of working with this mosquito species. Collecting their larvae in natural breeding sites, rearing and maintaining them in normal laboratory conditions have been a difficult task. Forced-egg laying technique has been a very good tool to generate eggs from adult mosquitoes collected from the wild but rearing these eggs to obtain satisfying portion as adults has always been the problem. In this study, we optimized the development of mosquito species larvae under standard laboratory conditions for desired production of adult mosquitoes that can be useful for insecticide susceptibility tests.

**Methods:** A forced-egg laying technique was used to obtain eggs from gravid female *Anopheles funestus* collected from Kpome locality in Benin. Eggs were reared in three different water samples (water from the borehole, and two mineral water namely FIFA and Possotômê) and larvae were fed with TetraMin baby fish food. The physico-chemical parameters of the waters were investigated prior to use for egg incubation.

**Results:** In contrast to mineral water that had no contamination, the borehole water source was contaminated with lead (2.5mg/L) and nitrate (118.8mg/L). Egg hatching rates ranged as 91.9 ± 4.4%, 89.1 ± 2.5% and 87.9 ± 2.6% in FIFA, Possotômê and borehole water respectively. High emergence of larvae to adult mosquitoes was recorded as in FIFA (74.3%) and Possotômê (79.5%) water. No adult mosquito was obtained from larvae reared in borehole water.

**Conclusions:** This study gave insight on the water sources that could be good for rearing to mass produce *An. funestus* in the laboratory. More analysis with other local mineral water sources in our environments could be considered in the future, hopefully giving better outputs.
Introduction

*Anopheles funestus* remains a main malaria vector, and is thereby also responsible for malaria morbidity and mortality in Sub-Saharan Africa. Breeding of this mosquito species like other mosquitoes also requires an aquatic environment where larvae emerge to adult mosquitoes. Water is an important component of the ecosystem of this insect, and the quality of the water is an important determinant in egg laying, for adequate growth and development at larval stages until adults. *An. funestus*, unlike the other known malaria vector, *An. gambiae*, in Sub-Saharan Africa breeds in natural/artificial permanent and semi-permanent water bodies with floating or emerging vegetation like edges of swamps, in weedy and grassy parts of rivers, streams, furrows, ditches and ponds with low salinity and little richness in organic matter. There are reports that *Anopheles* mosquitoes breed in clear waters with temperatures between 22°C and 32°C. However, decreased oxygen levels caused by water flow and flooding are always responsible for physical damage of mosquito larvae. In addition, breeding water with a pH range of 6.08 to 7.02 is good for weakening the egg shell, so that first instar larvae can emerge. Generally, these chemical properties of larval habitat, including ammonia, nitrate and sulphate concentration, influence larval development and their aquatic survival. Insecticide susceptibility studies are important for checkmating the effectiveness of control tools used to control malaria vectors. Achieving success in this field requires a good understanding of the bio-ecology of the vector. This will guide us to organize suitable conditions to maintain mosquito samples collected from fields in the laboratory. *An. funestus* is a difficult mosquito species to handle: not only because its larvae are rarely found during field survey, but also because of their inability to survive in normal laboratory conditions. Unfortunately, there are reports that *An. funestus* is involved in malaria transmission across Africa. It is therefore necessary to find all means to study this malaria vector. Forced-egg laying technique has been a very helpful tool to generate a first filial generation of *An. funestus* mosquitoes from adults collected on the field. As much as this field tool has been of help, obtaining the desired quantity of *An. funestus* when rearing its larvae under laboratory conditions for susceptibility testing has been a big challenge. Sometimes, we also have the problem of recording a high mortality and low hatching rate of field mosquitoes under suitable laboratory conditions because of their high sensitivity. From our experience, one can lose all laboratory colonies of *An. funestus* at once (even if run to hundreds of mosquitoes), although they are kept at the right humidity of 80% and temperature range of 25 to 27°C. This can occur if contaminated water is used for rearing. After these observations, it became necessary to rear *An. funestus* larvae generated from forced-egg laying technique with different water sources but under the same laboratory conditions. This will inform us with the most suitable water source to obtain the best quantity of F₁, *An. funestus*, needed to facilitate insecticide susceptibility studies in Africa.

Materials and methods

Mosquito collection

Blood fed *An. funestus* resting indoors were collected in selected rooms at Kpome, a village (6°55’N, 2°19’E) located in the South of Benin. Collection was carried out between 06:00 and 10:00 am using electric aspirators. The collection period corresponds to the dry season in southern Benin when *An. funestus* densities are likely to be higher. Mosquitoes collected were morphologically identified as *An. funestus* group using the key of Gillies and Meillon (1968), kept in small cups and transferred to the laboratory (Insectariums of the International Institute of Tropical Agriculture of Benin) for rearing of the F₁ to produce the F₂ generation.

Mosquito rearing in the laboratory

In the insectary (T=25°C, RH=70–80% and L/D=12:12), blood fed, semi-gravid and gravid females were kept in the small paper cups for 5 to 6 days after collection until fully gravid stage. Gravid females were then introduced individually and gently into 1.5ml Eppendorf tubes containing cotton soaked in water and surmounted by a filter paper (Wattman 3 mm/2 cm diameter) (Figure 1). Each Eppendorf tube was checked daily to identify females of *An. funestus* that have laid eggs, mosquitoes were gently removed from the tubes and transferred to a new Eppendorf tubes containing cotton and silica gel and stored at −20°C for subsequent experiments. Twenty-four hours post-oviposition, eggs from a single mosquito were divided into 3 batches and were allowed to hatch in small cups for larvae emergence, which were later transferred into rearing bowls containing 3 different types of water (Borehole water collected in Calavi and local mineral water namely FIFA and Possotômè) (Figure 1). Water of each larvae bowl was changed every two days in order to reduce mortality and larvae were fed daily with Tetramin™ baby fish food. The larvae were monitored daily during the four larval stages of the mosquito up to the adult stage (F1 *An. funestus*). Each experiment was repeated at least 8 times with each type of water. The growth and development yield was evaluated based on:

(i) eggs hatching duration,
(ii) larvae rearing duration corresponding to duration from oviposition till the first pupae stage,
(iii) larvae mortality rate
(iv) adult emergence rate.

Sheets were established to collect data manually on these parameters, such as the number of eggs incubated in each type of water, the number of hatched eggs, larvae and pupae mortality and number of daily emerged adult mosquitoes.

Physico-chemical parameters of breeding water

Each water sample was analyzed for physico-chemical parameters in the laboratory of water and food quality of Agriculture Environment and Health (AgroEcoHealth) platform of IITA-Benin. Temperature and pH of each water sample were determined using the pH meter WAG WE30200 (Wagtech Projects, Berkshire, UK). Conductivity and Total dissolved solid (TDS) were also determined using the conductivity/TDS meter WAG WE30210 (Wagtech Projects, Berkshire, UK). Before analysis, electrodes of these materials were sensitized, calibrated and rinsed with deionized water. Water samples were then analyzed, and all parameters were read and recorded.
The quantity of nitrate, nitrite and chloride was determined using the Photometer 7100: WAG-WE10441 (Wagtech Projects, Berkshire, UK). Three replicates of each water sample were introduced into beakers and the reagents were added as recommended by the manufacturer (Wagtech Projects, Berkshire, UK). The mixture was incubated to stand for 10 min (Nitrate and nitrite) and for 2 min (chlorine) to allow the appearance of color. Each beaker was then inserted into the photometer and concentrations were directly displayed and recorded.

Calcium and fluorine were quantified using the W-22XD.23XD HORIBA multi-probe (HORIBA, ltd Japan). The electrodes were also calibrated and rinsed with sterile deionized water and then with the water samples to be analyzed. The quantities of calcium and fluorine were recorded after homogenization of the samples.

Heavy metals (Cadmium, Lead and Copper) were quantified using METALYSER HM 3000 (TRACE2O, Berkshire, UK) by the reverse voltammeter method. The electrodes were placed and conditioned according to the desired metal as recommended by the manufacturer. Heavy metal was quantified in 70 ml of water with appropriate reagents (buffer and standard) according to the desired metal. After 5 mins of incubation, the concentration of the metal and the corresponding graphs (in the form of a peak) were displayed on a tablet connected to the machine.

PCR-based species identification
All females used for individual oviposition were identified using PCR as belonging to the An. funestus group. DNA was extracted from a total of 94 mosquitoes using the Livak protocol, followed by PCR species identification using the protocol described by Koekemoer et al., (2002).

Data analysis
Data were inserted on excel sheets and analyzed using SPSS 17.0. Chi square test was performed to analyze the difference in hatching rate between different water samples and hatching duration according to the water types. The easy to use online software (Fischer exact test) was used to assess the difference in larvae mortality rate and adult emergence rate according to the water samples. The significance level was set at 5%.

Figure 1. Developmental cycle of wild population of An. funestus in forced-eggs laying conditions: Oviposition of An. funestus (A), Incubation and hatching of An. funestus eggs (B), rearing of aquatic stage of An. funestus (C), Adults emergence (D).
Ethical statement
The request for ethical approval was not applicable for this study, according to the International Institute of Tropical Agriculture (IITA) Ethical Committee (IITA, 08 P.O. Box 0932, Tri-Postal, Cotonou, Benin). However, there was a focus group discussion with the community and household heads where verbal and written consent was obtained for mosquito collections in the community after the study aims and objectives were explained. Mosquitoes were collected in the morning using electrical aspirators. No insecticide spray or human bait methods were used for mosquito collections during this study.

Results
Species identification
Molecular identification of 94 females used for forced-eggs technique revealed that they all belonged to An. funestus s.s.

Physico-chemical parameters of water samples
The physico-chemical parameters of the different water types used for An. funestus rearing are summarized in Table 1. These results showed that Possotômè mineral water had a pH of 7.9 whereas the pH obtained with FIFA mineral water and borehole water were 5.9 and 6.2, respectively. The total dissolved solids in Possotômè water (386 mg/l) was high compared to borehole water (131 mg/l) and FIFA water (29.9 mg/l). The same trend was observed with the total conductivity characterized by a high quantity of minerals in Possotômè water (775 μS/cm), which was significantly different to FIFA water (60 μS/cm) and borehole water (265 μS/cm) (p <0.05). Indeed, calcium and chloride concentration were higher in Possotômè mineral water (54 mg/l calcium, 110 mg/l chloride) than in FIFA mineral water (3.1 mg/l calcium, 10 mg/l chloride) and borehole water (0.00031 mg/l calcium, 12.2 mg/l chloride). Nitrate was almost absent in both mineral water (Possotômè and FIFA) but was present in high concentration of 118.8 mg/l in borehole water (Table 1). Lead was completely absent in mineral water while, it was detected in borehole water at a concentration of 2.5 mg/l. Copper was also detected in all water samples (FIFA water: 0.00679 mg/l, Possotômè water: 0.042 mg/ml and Borehole water: 0.003399 mg/l) but at nontoxic-doses. No trace of cadmium was detected in all of water samples used for rearing. Temperatures recorded from pH meter were 25°C, 25.2°C and 25.5°C in FIFA, Possotômè and borehole water, respectively.

Rearing yield of wild populations of An. funestus
A total of 355, 1124 and 830 An. funestus eggs were bred in borehole, FIFA and Possotômè mineral waters, respectively. There was no significant difference in the egg hatching duration between the borehole water (5 days) and mineral waters (4 days) (P = 0.0722). The egg hatching rate of all incubation days according to water samples were summarized in Table 2. These hatching rates varied between incubation days and ranged from 12.61 ± 0.11% to 41.21 ± 6.11% for borehole, 16% to 55.57 ± 6.46% for FIFA and from 19.6 ± 2.38% and 43.77 ± 5.01% for Possotômè. No significant difference was found in the daily hatching rates for borehole (p = 0.0637), FIFA (p = 0.1450) and Possotômè waters (p = 0.080). Overall, no significant difference in eggs hatching rate was observed between the three waters (FIFA 91.9 ± 4.4%, Possotômè 89.1 ± 2.5% and borehole 87.9 ± 2.6%) (P<0.05). Larvae mortality rates obtained were respectively, 97.36%, 17.5% and 14.06% in borehole, Possotômè and FIFA waters (Table 3). There was a significant difference in larvae mortality with borehole water and mineral waters (p<0.05). The percentage of adult mosquitoes that emerged from FIFA and Possotômè mineral waters were respectively 74.36% and 79.50%. No adult mosquitoes were recorded from borehole water (Table 3). Another observation was that the rate of emerged adults with Possotômè was slightly higher when compared to FIFA mineral water. Rearing of An. funestus larvae to adults with both mineral waters took about 10 days, while for borehole water, rearing of larvae to adult stage took as long as 15 days.

<table>
<thead>
<tr>
<th>Table 1. Physico-chemical parameters of mineral/bottle waters (FIFA, Possotômè) and Borehole water.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physico-chemical parameters</strong></td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>Total dissolved solids (mg/l)</td>
</tr>
<tr>
<td>Conductivity (μS/cm)</td>
</tr>
<tr>
<td>Calcium (mg/l)</td>
</tr>
<tr>
<td>Chloride (mg/l)</td>
</tr>
<tr>
<td>Nitrate (mg/l)</td>
</tr>
<tr>
<td>Nitrite (mg/l)</td>
</tr>
<tr>
<td>Lead (mg/l)</td>
</tr>
<tr>
<td>Copper (mg/l)</td>
</tr>
<tr>
<td>Fluoride (mg/l)</td>
</tr>
<tr>
<td>Cadmium (mg/l)</td>
</tr>
<tr>
<td>Temperature (°C)</td>
</tr>
</tbody>
</table>
### Table 2. Monitoring of emerged larvae of Anopheles funestus during the hatching period indifferent water samples.

<table>
<thead>
<tr>
<th>Water samples</th>
<th>Number of replicates</th>
<th>Mean number of eggs per replicate</th>
<th>Eggshatching days</th>
<th>Meanhatching rate/day (%)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borehole water</td>
<td>8</td>
<td>44</td>
<td>1</td>
<td>0</td>
<td>0.0637</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>41.21 ± 6.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>22.01 ± 4.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>12.07 ± 1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>12.61 ± 0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>87.9 ± 2.60</td>
<td></td>
<td>0.0637</td>
<td></td>
</tr>
<tr>
<td>FIFA mineral water</td>
<td>15</td>
<td>75</td>
<td>1</td>
<td>0</td>
<td>0.1450</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55.57 ± 6.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20.33 ± 11.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>91.9 ± 4.45</td>
<td></td>
<td>0.1450</td>
<td></td>
</tr>
<tr>
<td>Possotômè mineral water</td>
<td>17</td>
<td>49</td>
<td>1</td>
<td>0</td>
<td>0.080</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>43.77 ± 5.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>25.76 ± 2.63</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>4</td>
<td>19.6 ± 2.38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>89.13 ± 2.51</td>
<td></td>
<td>0.080</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Adult productivity rate of Anopheles funestus rearing in different water samples.

<table>
<thead>
<tr>
<th>Water samples</th>
<th>Borehole water</th>
<th>FIFA mineral water</th>
<th>Possotômè mineral water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of replicates</td>
<td>8</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Mean number of larvae/replicate</td>
<td>38</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>Mortality rates (%)</td>
<td>97.36 (±5.08)</td>
<td>14.06 (±8.52)</td>
<td>17.5 (±11.78)</td>
</tr>
<tr>
<td>Emerged adult rates (%)</td>
<td>0</td>
<td>74.36 (±9.8)</td>
<td>79.5 (±11.3)</td>
</tr>
<tr>
<td>Larvae development duration (Days)</td>
<td>15</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

### Discussion

Water quality is an important factor for oviposition of the female mosquito, and also influences the emergence of adult mosquitoes from larval stages. However, physico-chemical parameters such as temperature, pH, dissolved oxygen, nitrate and sulphate concentrations are likely to affect the development and survival of mosquito larvae. The different values of physico-chemical parameters obtained in this study could give a better understanding on the environmental requirements needed to produce good yield of F1 An.funestus mosquito in the laboratory from the ones collected in the wild. The pH ranges (5.9 to 7.9) recorded in the different water sources could be considered suitable for mosquito breeding. These pH were similar to that was found in breeding water samples, with pH values ranging from 4.0 to 7.8 considered favorable for normal development of An. gambiae under laboratory conditions. pH values recorded in all sampling waters might not have an effect on the eventual yield of An. funestus in this study. A previous study also revealed that mosquito larvae can thrive
well in water with neutral or slightly alkaline pH\textsuperscript{20}. The temperature of water samples (25°C) used in this study is known to be suitable for \textit{An. funestus} mosquito breeding\textsuperscript{1}.

This research also showed similarly high hatching rates of eggs with FIFA, Possotômè and borehole waters, indicating that physico-chemical compositions of the different water samples do not influence the weakening of \textit{An. funestus} egg shells. However, a high larvae mortality rate (97\%) was observed with borehole water compared to mineral water samples that produced good emergence rates. High larvae mortality rate recorded could be attributed to the high nitrate dose in borehole water (118.8mg.l\textsuperscript{-1}). This nitrate concentration in this water sample is higher than the maximum limit of 50mg/l nitrate dose authorized for human consumption\textsuperscript{11}, and could also be toxic for the larvae development. The main toxic action of nitrate on aquatic animals is the conversion of oxygen-bearing pigments (hemoglobin and hemocyanin) into the inhibited forms (methaemoglobin) which are not able to fix and carry oxygen\textsuperscript{3-24}. Therefore, the lack of oxygen can cause the death of the mosquito larvae. The high nitrate content in the borehole water could be justified by the phreatic origin of this water, because ground water has always been described to contain toxic nitrate concentrations exceeding the standard\textsuperscript{21-23}. Water sources that should be used for the breeding of aquatic stages of \textit{An. funestus} should not have similar physico-parameters as ground water. Nitrate and phosphate residues derived from chemical fertilizers used in agriculture are other potential pollutants that could be found in aquatic waters\textsuperscript{23}. Ndenga \textit{et al.}, (2012)\textsuperscript{24} was able to establish a non-significant positive correlation between the presence of nitrate at 1.8 to 3.6 mg/l and the development of \textit{Anopheles} larvae. It has also been demonstrated that the toxicity of nitrate decreased with increasing salinity of water\textsuperscript{23-25}. This could further explain the high salinity of Possotômè mineral water, which had a high conductivity and high amount of total dissolved solids. Some studies have shown that at around 15.85 g/l of sodium chloride (NaCl) in water, salinity becomes a discriminate dose that kills \textit{An. gambiae} s.s, \textit{An. coluzzii} and \textit{An. merus} larvae\textsuperscript{26}. It would always be good to assess any trace of phosphate and nitrate in rearing water before use for breeding \textit{An. funestus} in the laboratory. However, the definite effect of nitrate on larvae development should be further investigated.

Despite a relatively high salinity of 110 mg/l in Possotômè water, more than 70\% of adults were able to emerge. This correlates with the observation of Koekemoer \textit{et al.}, (2014)\textsuperscript{25}, where they reported that salinity does not affect the emergence of \textit{An. funestus} adults. Similar to egg hatching rates, rates of emergence of adult \textit{An. funestus} in FIFA and Possotômè mineral waters were statistically similar, although the larvae mortality rate was relatively low in FIFA water compared to Possotômè. No adult mosquitoes emerged from larvae reared with borehole water in this study. This could be explained by the fact that some larvae that reached pupal stage did not have enough energy to get out from their cuticle and become adults. This may be due to the lack of oxygen certainly related to high concentration of nitrate in borehole water\textsuperscript{22-24}.

\section*{Conclusions}

This study highlighted the impact of some physico-chemical factors of breeding waters on \textit{An. funestus} development under laboratory conditions. It showed that \textit{An. funestus} could develop well in FIFA and Possotômè mineral waters, which both have similar physico-chemical characteristics. However, further studies should be performed to measure other physico-chemical parameters, such as phosphate, dissolved oxygen, alkaline content. This information will be of immense help to improve \textit{An. funestus} rearing in order to obtain desired F1 progenies for more analysis.

\section*{Data availability}

The raw data underlying the findings reported in this study can be found at: http://doi.org/10.17605/OSF.IO/AES4P\textsuperscript{22}.

\section*{Competing interests}

No competing interests were disclosed.

\section*{Grant information}

This work was supported by the Wellcome Trust [099864].

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

\section*{Acknowledgments}

We thank Kpome community for their cooperation during the field work. We also express our sincere thanks to Mr. Claude Gande (International Institute of Tropical Agriculture (IITA), Cotonou, Benin) for his technical assistance.

\section*{References}


Open Peer Review

Current Referee Status: ✔ ✔

Version 1

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Emmanuel Elanga Ndille
Research Institute for Development (IRD), MIVEGEC (Infectious Diseases and Vectors: Ecology, Genetics, Evolution and Control), Montpellier, France

This manuscript try to describe some qualities needed for water used for rearing Anopheles funestus mosquito species in the laboratory. The study deals with an important issue all medical entomologist faces to when trying to establish a lab stain of Anopheles funestus mosquito. Results obtained this manuscript of Tchigossou et al are very interesting and very informative. However even if the manuscript and data presented are interesting, there are some minor concerns I will like the authors to take into consideration so that their work will be more efficient.

Comments:

1) In the section Material and methods, it would certainly be interesting for authors to give an approximate size of the small cup they used to keep their mosquitoes after identification. This aspect could be important as the manuscript try to present some interesting condition for the rearing of Anopheles funestus mosquito in the laboratory

2) In the text (mosquito rearing in the laboratory) authors speak about “Calavi”. I think they should give more details on what is Calavi. Is not easy for the reader with no information about this locality to know what Calavi is.

3- In the “mosquito rearing” section, it would have been interesting for authors to be precise that the total number of eggs reared was different or the same between the 3 types of water.

4- As the present manuscript is trying to describe an experimental design to improve the rearing of Anopheles funestus in the laboratory, I think authors should ameliorate the quality of the pictures in figure 1. This will be helpful for someone who will try to reproduce what was done in the present study. Also it could be interesting for the reader if authors could give more details on “eggs incubation”

5- The two last sentences of the results section (Rearing yield of wild population of An. funestus) seem to be contradictory. Indeed, on one side authors said “No adult mosquitoes were recorded from borehole water”, on another side they said “… for borehole water, rearing of larvae to adult stage took as long as 15 days. It’s a bit difficult for the reader to understand how authors did to estimate these 15 days to obtain adult from borehole water, when it’s said by authors that with this water no adult mosquitoes were recorded? So maybe authors could clarify this last part of the “results” section.

Is the work clearly and accurately presented and does it cite the current literature?
Yes
Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

**Competing Interests:** No competing interests were disclosed.

**Referee Expertise:** Medical Entomology

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

**Author Response 14 Jan 2018**

Akadiri Yessoufou, University of Abomey, Calavi, Benin

**Answers, point by point, to the Reviewer’s comments**
The Reviewer approved our manuscript. However, he raised some minor points which we have now addressed and rectified accordingly in this revised version of the MS. The answers to his comments are as follows:

**Reviewer 1: Emmanuel Elanga Ndille,** Research Institute for Development (IRD), MIVEGEC (Infectious Diseases and Vectors: Ecology, Genetics, Evolution and Control), Montpellier, France

1) We agree with the Reviewer’s comments. The characteristics of small cup used in this study were added in the revised manuscript. Please see in the *Material and Methods* section.

2) We agree with the Reviewer’s comment. More details have been given in the revised manuscript to explain what is Calavi. Please see in the *Material and Methods* section

3) We agree with the Reviewer’s comment. This precision has been given in the revised manuscript. Please see in the *Material and Methods* section

4) As per Reviewer’s suggestion, the quality of the pictures of figure 1 has been improved.

5) “eggs incubation” means introduction of the eggs batches into water. As per Reviewer’s suggestion, this precision has been given in the revised manuscript.

6) We agree with the Reviewer’s comment. Larvae reared in this water sample reached to pupae
stage but no emergence was recorded. So, for this water sample “adult stage” was replaced by “pupae stage” in the revised manuscript. Please, see in the Results section.

**Competing Interests:** The authors have nothing to declare as far as the conflict of interest is concerned

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**Cyrille Ndo**  
Malaria Research Laboratory, Organization of Coordination for the Fight against Endemic Diseases in Central Africa (OCEAC), Yaoundé, Cameroon

**General comment**
This is a very interesting paper, especially for all people working with *Anopheles funestus*. This species is difficult to colonize in insectary and this has for long time prevented research on *An. funestus*. By defining water conditions that could promote or impede larval development of this species, it will henceforth be easy to generate large F1 colonies from wild collected gravid females that could be used for various experiments.

**Recommendation**
I recommend the paper to be accepted with minor revisions. Especially, the language in the abstract need to be improved.

**Reviewer’s Comments and questions**
Please check everywhere you have bold to see the change done

**Introduction**

1) … for adequate growth and **development from larval stages** until adults

2) Insecticide susceptibility studies are important for checkmating the effectiveness of control tools used to control malaria vectors. Achieving success in this field requires a good understanding of the bio-ecology of the vector. This will guide us to organize suitable conditions to maintain mosquito samples collected from fields in the laboratory.

**Comment:** For me this transition is not appropriate. I suggest the authors to say rather that 'most of experiments to study the biology of Anopheles mosquitoes, such assessment of insecticide susceptibility, use laboratory reared colonies. Is this therefore crucial to better understand suitable conditions for rearing of field collected mosquitoes'.

3) Unfortunately, there are reports that *An. funestus* is involved in malaria transmission across Africa. It is therefore necessary to find all means to study this malaria vector.

**Comment:** I suggest the authors to say rather "Since Anopheles funestus represents an important malaria vector across Sub-Saharan Africa, it is therefore necessary to find all means to study this malaria vector."

4) ............ for **insecticide** susceptibility testing........
5) Sometimes, we also have the problem of recording a high mortality and low hatching rate of field mosquitoes under suitable laboratory conditions because of their high sensitivity. **Question:** This sentence is not clear. Can the author reformulate it?

6) **Comment:** I found the end of the introduction laborious from "Sometimes, we also have the problem..... " to the end.

**Material and methods**

7) larvae rearing duration corresponding to duration from oviposition till the first pupae stage **Comment:** Most of the time, larvae rearing duration is the time from L1 to Puape

8) **Comment:** Larval mortality, not larvae mortality

**Data analysis**

9) Chi square test was performed to analyze the difference in hatching rate between different water samples and hatching duration according to the water types. **Comment:** I guess that hatching duration was expressed in days and that the authors rather compared means. I don't understand why the chi square test was used.

**Ethical statement**

10) Mosquitoes were collected in the morning using electrical aspirators. No insecticide spray or human bait methods were used for mosquito collections during this study. **Comment:** I suggest the authors to say rather "Since mosquitoes were collected using electrical aspirators, no insecticide spray or human bait methods were used for mosquito collections during this study."

**Results**

11) Nitrate was almost absent in both mineral water (Possotome and FIFA) but was present in high concentration of 118.8mg/l in borehole water (Table I). **Comment:** Nitrate was almost absent in both mineral water (Possotome and FIFA) but was present at high concentration of 118.8mg/l in borehole water (Table I).

12) **Comment and question:** I don't understand what the authors mean by egg hatching rate of all incubation days. Could they please explain or use a more clear expression?

13) There was a significant difference in larvae mortality with borehole water and mineral waters (p<0.05). **Comment:** The authors didn't mention if larval mortality was statistically different or not between the two mineral waters.

14) No adult mosquitoes were recorded from borehole water (Table 3). **Comment:** No adult mosquitoes were obtained from borehole water (Table 3).

15) Another observation was that the rate of emerged adults with Possotome was slightly higher when compared to FIFA mineral water.
Comment: Please add statistics

Discussion
16) These pH were similar to that was found in breeding water samples, with pH values ranging from 4.0 to 7.8 considered favorable for normal development of An. gambiae under laboratory conditions.9,19. 
Comment: Remove "was"

17) This research also showed similarly high hatching rates of eggs with FIFA, Possotome and borehole waters, indicating that physico-chemical compositions of the different water samples do not influence the weakening of An. funestus egg shells
Comment: Say rather "similar high..." or "comparable high...."

18) Question: Can the authors use the term "larval mortality" rather than "larvae mortality"?

19) This nitrate concentration in this water sample is higher than the maximum limit of 50mg/l nitrate dose authorized for human consumption21, and could also be toxic for the larvae development. 
Comment: Say rather "This nitrate concentration in this water sample is higher than the maximum limit of 50mg/l nitrate dose authorized for human consumption21, and could also be toxic mosquito larvae."

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 14 Jan 2018

Akadiri Yessoufou, University of Abomey, Calavi, Benin

Answers, point by point, to the Reviewer’s comments
The Reviewer approved our manuscript. However, he raised some minor points which we have
now addressed and rectified accordingly in this revised version of the MS. The answers to his comments are as follows

**Reviewer 2: Cyrille Ndo**, Malaria Research Laboratory, Organization of Coordination for the Fight against Endemic Diseases in Central Africa (OCEAC), Yaoundé, Cameroon

**Introduction**

1) We agree with this correction and we have already incorporated the change in the revised manuscript. Please see in the Introduction section.

2) As per Reviewer’s suggestion, we have now rectified the sentence accordingly. Please see in the Introduction section.

3) As per Reviewer’s suggestion, we have now reformulated the sentence. Please, see in the Introduction section 4) As per Reviewer’s suggestion, we have now introduced the word “insecticide” in appropriate place. Please see in the Introduction section.

5) As per Reviewer’s suggestion, we have now reworded the sentence. Please see last paragraph of introduction section: “Sometimes, we recorded high mortality rate even when *An. funestus* mosquitoes are kept under recommended laboratory conditions.”

6) As per Reviewer’s suggestion, we have now reformulated the last sentence of the introduction: “Sometimes, we recorded high mortality rate even when *An. funestus* mosquitoes are kept under recommended laboratory conditions. This observation prompted us to rear *An. funestus* larvae generated from forced-egg laying technique with different water sources but under the same laboratory conditions. Therefore, the aim of this study was to determine the most suitable water source which will permit to obtain the best quantity of *F₁ An. funestus* for laboratory experiments.”

**Material and methods**

7) We agree with the Reviewer’s comment. “larvae rearing duration is the time from L1 to pupae”. We have now corrected this sentence in the revised manuscript.

8) We agree with the Reviewer’s comment. “larval mortality” has been replaced by “larval mortality” throughout the revised manuscript.

**Data analysis**

9) We agree with the Reviewer’s comment. Chi square test was used to analyze the difference in hatching rate (means) between different water samples only not to compare duration (days). This statement has been corrected in the revised manuscript.

**Ethical statement**

10) As per Reviewer’s suggestion, we have now corrected the sentence. Please see in the Material and Methods section

**Results**

11) As per Reviewer's suggestion, we have now corrected the sentence. Please see in the Results section

12) The tests have been repeated several times (see table 2: number of replicate). We have now corrected the sentence to better explain the idea: “The eggs hatching rate of all repetitions (experiments) of each water sample are summarized in Table 2”

13) We agree with Reviewer’s comment. Larval mortality is not statistically different between the two mineral waters (P = 0.3573). We have now mentioned this in the revised manuscript.

14) As per Reviewer’s suggestion, we have now replaced “recorded” by “obtained” in the revised manuscript. Please see in the Results section.
15) We agree with Reviewer’s comment. We have now corrected the sentence and added statistics to this statement in the revised manuscript (P = 0.1823).

Discussion
16) As per Reviewer’s suggestion, we have removed ‘was’ from the sentence in the revised manuscript. Please see first paragraph of the Discussion section.

17) As per Reviewer’s suggestion, we have now corrected the sentence in the revised manuscript. Please see in the Discussion section.

18) We agree with the Reviewer’s comment. “larvae mortality” has been replaced by “larval mortality” throughout the revised manuscript.

19) We agree with the Reviewer’s comment. The comment has been addressed in the manuscript and the sentence has been modified as suggested.

Competing Interests: The authors have nothing to declare as far as the conflict of interest is concerned.