Diversity of malaria in rice growing areas of the Afrotropical region

P. Carnevale1, P. Guillet2, V. Robert2, D. Fontenille2, J. Doannio1, M. Coosemans3, J. Mouchet2

1 Institut Pierre Richet, Bouaké, Côte d’Ivoire; 2 Institut de Recherches pour le Développement, Paris, France; 3 Institut de Médecine Tropicale Prince Léopold, Anvers, Belgique.

Abstract. It is well known that in many instances the rice agrosystem perfectly fits the ecological requirements of pathogens or vectors and in fact, malaria, schistosomiasis and Japanese encephalitis are important vector-borne diseases associated with rice production in developing countries (IRRI, 1987). In spite of these fears, rice cultivation has been on the increase in the African region in response to demographic and economic pressures. However, although rice fields provide suitable breeding places for Anopheles mosquitoes and rice cultivation leads to an increase in the biting rates, the species which are adapted to these sites are not the same in all parts of Africa. Several examples illustrate this phenomenon: An. funestus in the rice fields of Madagascar, An. pharoensis in saline water rice fields in the delta of the Senegal river, An. arabiensis in northern Cameroon and Burundi, An. gambiae Mospi form in the Kou Valley (Burkina Faso) and An. gambiae Savanna form in the rice fields of Kafine near Bouaké (Côte d’Ivoire).

The vectorial capacities of these species are not the same and malaria inoculation rates are not necessarily increased in the rice land agroecosystem. The consequences for malaria of introducing rice cultivation should be studied on the situation before its introduction: it could be worsened in unstable malaria areas but not in stable malaria areas. Therefore, sound epidemiological and entomological knowledge are needed before causing any environmental modifications for agricultural purposes and there should be regular monitoring to avoid any outbreak.

Key words: malaria, Anopheles, rice field, environmental change.

Due to demographic pressure, there have recently been more and more large scale environmental modifications for agricultural purposes such as rice culture or fish farming. However, what may appear as the same modification such as rice fields could lead in different areas to quite different entomological and hence epidemiological consequences (Robert et al., 1989a).

Anopheles are well known to be very adaptable to increasing ecological and environmental changes because of their high level of genetic diversity and plasticity (White, 1982; Coluzzi, 1994; Favia et al., 1997; Molyneux, 1998).

The different influences of introducing rice cultivation into various countries could be taken as an instructive example. A rice field is a sheet of water in a permanent state of change and it is interesting to notice how different Anopheles species can adapt themselves to the various ecological circumstances provided by all stages of rice culture (nursery, watering, planting, growing, tillering, maturation, harvesting, land fallow).

Through some examples we try to highlight the major differences observed in different ecological and geographical settings.

Invited contribution to the Malarialogy Centenary Conference "The malaria challenge after one hundred years of malarialogy" held in Rome at the Accademia Nazionale dei Lincei, 16-19 November 1998.

Correspondence: Professor Pierre Carnevale, Institut Pierre Richet, OCCGE, BP 1500, 01 Bouaké, Côte d’Ivoire, Tel ++225 633746, e-mail: carnevale@ird.ci
ruary to May. This increase of malaria at the end of the rainy season is linked to *An. funestus* from rice fields and is fully predictable, knowing the ecology of *Anopheles* in these areas.

It has to be remembered that the Madagascar highlands were considered as malaria free up to about 1880. A severe epidemic occurred in 1878 and malaria remained present. The first outbreak followed the development of irrigated rice farming and this can be considered as one of the first examples in Africa of a malaria epidemic due to man-made environmental change. Malaria was then 'under control' due to chemotherapy, vector control, etc., but for many reasons pressure against malaria decreased and even stopped, allowing a deadly return of malaria.

Thus rice has allowed the development of *An. funestus*, a main vector of malaria and therefore rice cultivation is considered as a 'source of life and death' (Laventure et al., 1996).

**Burundi**

Rice fields were created in areas where malaria is unstable. It appeared that the presence of flooded or flooded areas determined the level of endemicity in a region (Coosemans et al., 1984; Coosemans, 1985).

Human landing night catches in a village surrounded by rice fields yielded predominantly: *An. arabiensis* and also *An. funestus*, *An. pharoensis* and *An. ziemanni*. Their relative importance is variable according to local ecological conditions, rice growing areas and the rainy season. For example, the *An. pharoensis* biting rate reached >100 bites/man/night (without playing a role in malaria transmission).

*An. arabiensis* is the main species of the *gambiae* complex adapted to this biotope but is actually a poor vector with a very low infectivity rate (<1%) compensated, to some extent, by its high density, which could reach up to 58 b/m/n in villages near rice fields. It also seemed that the small admixture of *An. gambiae* (>2%) could have been responsible for the relatively high level of transmission. The parasite rate is quite variable (4 to 56%) according to the distance of villages from rice fields (being highest near the rice). The situation was so much worse in rice growing areas that vector control had to be implemented to stop malaria outbreaks occurring among a population who came from altitudes where there is no transmission and therefore little or no immunity.

**Senegal**

Rice fields were created in the delta of the Senegal river where the water is largely saline and the main species adapted to these rice areas is *An. pharoensis* c. 98%) which can tolerate salt water. But although its biting rate is high, it has little or no role as a vector of malaria (6000 specimens examined with LISA tests were all negative) and its lifespan is short average parous rate c. 58%). But this species has been incriminated in malaria transmission (Carrara et al., 1990). The other species, which were found in night catches were predominantly *An. arabiensis*, *An. gambiae* (<10%), and a few *An. melos* (Faye et al., 1995). Larvae of *An. ziemanni* were found in clean water with standing vegetation and specimens of *An. rufipes* were caught resting in houses.

These rice fields on the Senegal river delta increased the *Anopheles* biting rate but did not increase the malaria transmission and morbidity, indeed the parasite rates are very low (0.4 to 0.9%). Malaria morbidity is low (c. 10% of outpatients) but adults as well as children are sick indicating that immunity is low.

In this unstable malaria situation, large scale irrigation increasing clean water and therefore breeding sites suitable for efficient malaria vectors such as *An. gambiae* s.l. could lead to dramatic increases in malaria transmission and outbreaks and great care must be taken if any environmental modifications are made for agricultural purposes.

**Cameroon**

In northern savanna areas, rice fields were developed in Gounougou, near Garoua, with two crops/year. Cytogenetic studies showed that *An. arabiensis* is present throughout the year with an average of c. 32 bites/man/night while also in night catches were *An. funestus* (average biting rate c. 11 b/m/n) and *An. pharoensis* (c. 10 b/m/n).

Sporozoites were found in these three species. The entomological inoculation rate was estimated at c. 0.82 infective bite/man/night from mid July to mid September (Robert et al., 1992).

**Burkina Faso**

In the rice fields of the Kou valley a longitudinal study was done in villages located in the area of the 1000 ha of rice fields (2 crops/year) in the savanna area (Robert et al., 1991). The rainy season lasts from May-June to October-November. A man sleeping in a village in the middle of the rice fields ('VK4') could receive about 35000 mosquito bites/year, which constitute such a nuisance that almost everyone uses mosquito nets on a regular basis. It is interesting to compare the situation produced by rice growing with usual savanna villages in the region.

Three entomological parameters should be considered, as follows.

1. *Anopheles* species composition. In savanna villages, *An. gambiae* s.l. and secondarily *An. funestus* are found during the rainy season, the latter being found also at the beginning of the dry season. The members of the *An. gambiae* complex consist of *An. gambiae* Savanna and Mopti forms and *An. arabiensis* in variable proportions at different places and times (Robert et al., 1989b). In rice fields, *An. gambiae* is predominant (>90%) over *An. arabiensis* (3.6%) and it is almost only Mopti form which is found in the village at the center of the rice fields. It is interesting to note that the proportions of Mopti
and Savanna are quite variable depending on the location of the different villages in the rice field area, the Savanna form being more abundant in villages located at the edge of the rice area. An. gambiae s.l. is predominant during the early stage of rice growing but a high density of An. pharoensis was noticed when the rice is maturing. An. coustani was also observed. No infection was ever found in An. pharoensis in several thousand salivary glands dissected (Hervey, personal communication).

(b) Anopheles biting rate. In rice field villages, An. gambiae s.l. is observed throughout the year except in January (i.e. in the dry season and the interval between the two crops). Its biting rate reaches a peak of some 160 b/mn with an average of about 65 b/mn. The yearly biting rate was about 20,000 to 25,000 bites/man. The sporozoite rate is low (c. 0.3%) as well as the average parity rate (c. 30%). An. funestus is poorly represented in night catches (<2%) with an average biting rate of 1.5 b/mn (and a maximum number in December of 11 b/mn).

(c) Malaria transmission. Two points must be kept in mind regarding the dynamics of transmission: (i) intensity: in this rice growing areas, the average inoculation rate is about 0.08 infective b/mn with an average yearly inoculation rate of about 30 infective bites/man mainly due to An. gambiae (Mopti form) and secondarily due to An. funestus (about 3.5 infective bites/man/year). In villages located in the savanna, the yearly inoculation rate varies from 55 to >250 infective bites/man according to local ecological conditions and with a more or less equal participation of An. gambiae s.l. and An. funestus; (ii) seasonality: in rice growing areas, transmission is mainly in May to July then October to December, with an inoculation rate of about 0.2 infective bite/man/night. The dry season rice crop has clearly caused increased biting of An. gambiae s.l. but not of malaria transmission which is not noticeable when An. gambiae s.l. density is at its highest (August-September).

In savanna villages, transmission occurs for some 8 months or more, during the whole rainy season, An. gambiae s.l. at the beginning and the middle of the rainy season and An. funestus during the second part of the rainy season and the beginning of the dry season.

In conclusion it should be emphasised that in this rice growing area there are far more An. gambiae but similar or even lower transmission levels than in surrounding savanna villages thus constituting an interesting "epidemiological paradox". The introduction of rice growing has not worsened the malaria situation. Parasite rates are indeed lower in the savanna but large scale use of mosquito nets, social organization and higher incomes may also be responsible.

Côte d'Ivoire

An epidemiological study was undertaken in Kafine village where 72 ha of rice fields were created in 1991 (52 for irrigated rice and 20 for rainfed rice) with 2 crops/year from January-February to June and from July to November-December. Adults of the following Anopheles species were caught in this village: An. gambiae (mainly Savanna and very few Mopti), An. funestus, An. nili, An. pharoensis, An. wellcomei, An. coustani, An. ziemanni, An. squamosus, An. maculipalpis, An. dicoicus, An. obscurus, An. brotiari. In rice fields, larvae of An. gambiae were collected during ploughing, irrigation and after planting, larvae of An. pharoensis were collected during growing, tillering and maturation of rice and larvae of An. coustani and An. squamosus during maturation and harvesting. In small ponds, only larvae of An. gambiae s.l. were collected.

The main entomological parameters observed are described in Table 1.

Table 1. Averages of the entomological parameters observed in Kafine village, Côte d'Ivoire.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>An. gambiae</th>
<th>An. funestus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average mosquito biting rate</td>
<td>313.5 b/mn/night</td>
<td>264 b/mn/night</td>
</tr>
<tr>
<td>Average Anopheles biting rate</td>
<td>264 b/mn/night</td>
<td></td>
</tr>
<tr>
<td>Average biting rate</td>
<td>313.5 b/mn/night</td>
<td></td>
</tr>
<tr>
<td>Average parity rate (%)</td>
<td>41</td>
<td>54</td>
</tr>
<tr>
<td>Average sporozoite index (%)</td>
<td>0.99</td>
<td>1.55</td>
</tr>
<tr>
<td>Average inoculation rate</td>
<td>0.86</td>
<td>0.06</td>
</tr>
</tbody>
</table>

At the beginning of the rice cropping (ploughing, irrigation etc) and until the rice grows tall, the breeding sites are very productive of An. gambiae, the density is high but the parity rate, infectivity and inoculation rates are low. When rice is earing/maturing, the adult An. gambiae s.l. population is low but its parity and infectivity rates are high, inducing high transmission. In fact, as all plots are not cultivated at the same time, parts of the rice area are always suitable breeding sites for An. gambiae s.l. and malaria transmission occurs almost all the year round with peaks linked to rainy seasons and rice cultivation.

In this village, malaria transmission is mainly due to An. gambiae (Savanna) and strongly correlated with both the rainy season and rice cropping. Parasite rates are very high (about 70% for children) with no great variation during the year and malaria is typically endemic. Introduction of rice growing has not worsened the malaria situation compared to villages without rice in the same area.

A general large scale study of rice field/malaria is currently in progress in savanna and forest areas of northern and western Côte d'Ivoire to better understand the influence of different types of rice growing (one or two crops/year) on the Anopheles species composition (An. gambiae complex and An. funestus), level of insecticide resistance of malaria vectors, inoculation rates and malaria morbidity.
Conclusions

The impact of irrigated rice cultivation on composition of the mosquito population, malaria transmission (intensity and seasonality) and morbidity appeared to depend greatly on the previous local geographical, ecological and epidemiological conditions. In stable malaria areas, such as southern Burkina Faso or Côte d'Ivoire, introduction of rice growing has increased *Anopheles* biting rates but not inoculation or parasite rates and malaria has not become worse. Moreover, because of the economic improvement due to rice cultivation, there should be at community level better prevention and control of malaria. In the three unstable malaria situations considered, introduction of rice growing had two types of influence:

(i) in the delta of Senegal river, in saline water, the species selected by the rice (*An. pharoensis*) has low vectorial capacity and malaria is hypoendemic. The presence of *An. arabienensis* and a few *An. gambiae* s.l. must nevertheless be taken into consideration. In this region, due to drought, malaria transmission and immunity are now very low (Mouchet et al., 1996). Great care must be taken before embarking on large scale environmental modifications such as rice culture in fresh water which could increase suitable breeding sites for efficient malaria vectors;

(ii) at low altitudes (c. 800 m) in Burundi, introduction of rice growing has induced arrival of non immune people coming from the uplands and created breeding sites suitable for *An. arabienensis* which, even though it is a poor vector, has sharply increased malaria transmission and it became necessary, in the 1970s, to start large scale vector control (house spraying) to stop outbreaks;

(iii) in the high plateaus of Madagascar, where malaria was under control for a long time, rice fields allowed multiplication of *An. funestus*, increasing malaria transmission and morbidity, during the parts of the year corresponding to late stage matura-

We presented here a few illustrative examples of the influence of introduction of rice growing on the local epidemiology of malaria, but several other vector-borne diseases are also affected (arboviruses, schistosomiasis, etc.). Many environmental modifications for agricultural purposes are in progress or in prospect and any water management could have an impact on vector populations and vector-borne diseases, improving or worsening the local epidemiology as well as social and economic situations. In fact great changes are currently occurring, from deforestation to urbanisation which cause climatic changes and could lead to catastrophic situations if care is not taken before and during such man-made modifications. This requires sound and up to date knowledge of the ecology and epidemiology of vectors and vector-borne diseases in the field.

References


IRRI (1997). Workshop on Research and training needs in the field of integrated vector-borne disease control in rice land agroecosystems of developing countries.


ACCADEMIA NAZIONALE DEI LINCEI
in collaboration with the
Royal Society of Tropical Medicine and Hygiene
and the
Società Italiana di Parassitologia

THE MALARIA CHALLENGE
after one hundred years of malariology

Papers from
THE MALARIOLOGY CENTENARY CONFERENCE
Accademia Nazionale dei Lincei, Roma, 16-19 November 1998

Edited by Mario Coluzzi and David Bradley

Organizing Committee of the Conference
A. Ascenzi D. Bradley M. Brunori L. Bullini W. Bynum E. Capanna
Honorary Presidents of the Conference
M. Coluzzi V. Petraca E. Pozio A. Stefanelli H. Townson D. Warrell
J. de Zulueta H.M. Gilles P. Perlmann

LOMBARDO EDITORE in ROMA