Parassitologia 41: 273-276, 1999

Diversity of malaria in rice growing areas of the Afrotropical region

P. Carnevale[1], P. Guillet[2], V. Robert[2], D. Fontenille[2], J. Doannio[1],
M. Coosemans[3], J. Mouchet[2]

[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* Mopti 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 riceland agroecosystem. The consequences for malaria of introducing rice cultivation depend 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.

Madagascar

Rice fields were developed in the 'Hauts Plateaux' (where there is an unstable malaria situation) with one crop a year (from October to April, during the rainy season) and it was found that: (i) species found as larvae in the rice areas are *An. pharoensis, An. flavicosta, An. funestus, An. arabiensis, An. rufipes, An. maculipalpis, An. pretoriensis, An. mascarensis, An. coustani, An. cydippis* and *An. squamosus*; their importance is variable according to the stage of growth of the rice. During the first stages, from October to January (nursery, planting, growing), rice fields are suitable breeding sites for *An. arabiensis* which is, in this area, a poor vector (sporozoite rate <0.5%) because it is mainly zoophilic and exophilic. However, during the second part of the rice culture, rice fields are suitable for *An. funestus*, which is a very good vector, and malaria is thus intensively transmitted, from February to May; (ii) rice fields constitute the main breeding site for *An. funestus* at some stage of the rice culture (Marrama *et al.*, 1995). It is most abundant when rice is in the tillering and maturation stage and secondarily when the land is fallow. During maturation, the vegetation is well developed and the quantity of water in the field is at its highest; fallow land with its standing vegetation is very productive of *An. funestus*. Land stays in this condition for several months (between 2 crops); it constitutes the main producer of *An. funestus*.

Five percent of outpatients have malaria in October-January but this increases to 25-30% from Feb-

---

Invited contribution to the Malariology Centenary Conference "The malaria challenge after one hundred years of malariology" 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 chemoprophylaxis, 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 irrigated 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 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 mmunity.

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 ts biting rate is high, it has little or no role as a vecor of malaria (6000 specimens examined with ELISA 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. melas* (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:

(a) *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 (Hervy, 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/m/n with an average of about 65 b/m/n. 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/m/n (and a maximum number in December of 11 b/m/n)

(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/m/n 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 than 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. domicolus, An. obscurus, An. brohieri*. 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.

I. Average mosquito biting rate: 313.5 bites/man/night
II. Average *Anopheles* biting rate: 264 bites/man/night

	An. gambiae	*An.funestus*
III. Average biting rate (bites/man/night)	221	13.5
IV. Average parity rate (%)	41	54
V. Average sporozoitic index (%)	0.99	1.55
VI. Average inoculation rate (infective bites/man/night)	0.86	0.06

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. arabiensis* 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. arabiensis* 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 plateaux 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 maturation/harvesting of rice and fallowing of the land. The recent malaria outbreak was controlled by classical house spraying.

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

Carrara G, Petrarca V, Niang M, Coluzzi M (1990). *Anopheles pharoensis* and transmission of *Plasmodium falciparum* in the Senegal river delta. Med Vet Entomol 4: 421-424.

Coluzzi M (1994). Malaria and the afrotropical ecosystems. Impact of man-made environmental changes. Parassitologia 36: 223-227.

Coosemans M (1985). Comparaison de l'endémie malarienne dans une zone de riziculture et dans une zone de culture du coton dans la plaine de la Rusizi, Burundi. Ann Soc Belge Méd Trop 65: 187-200.

Coosemans M, Wéry M, Storme B, Hendrix L, Mfisi B (1984). Epidémiologie du paludisme dans la plaine de la Ruzizi. Ann Soc Belge Méd Trop 64: 135-158.

Favia G, della Torre A, Bagayoko M, Lanfrancotti A, Sagnon N'F, Touré YT, Coluzzi M (1997). Molecular identification of sympatric chromosomal forms of *Anopheles gambiae* and further evidence of their reproductive isolation. Insect Mol Biol 6: 377-383.

Faye O, Fontenille D, Gaye O, Molez J-F, Konate L, Hebrard G, Hervé J-P, Trouillet J, Diallo S, Mouchet J (1995). Paludisme et riziculture dans le delta du fleuve Sénégal (Sénégal). Ann Soc Belge Méd Trop 75: 179-189.

IRRI (1987). Workshop on Research and training needs in the field of integrated vector-borne disease control in riceland agroecosystems of developing countries.

Laventure S, Mouchet J, Blanchy S, Marrama L, Rabarison P, Andrianaivolambo L, Rajaonarivelo E, Rakotoarovory I, Roux J (1996). Le riz source de vie et de mort sur les plateaux de Madagascar. Cah Santé 6: 79-86.

Marrama L, Rajaonarivelo E, Laventure S, Rabarison P (1995). *Anopheles funestus* et la riziculture sur les plateaux de Madagascar. Cah Santé 5: 415-419.

Molyneux DH (1998). Vector-borne parasitic diseases - an overview of recent changes. Int J Parasitol 28: 927-934.

Mouchet J, Faye O, Julvez J, Manguin S (1996). Drought and malaria retreat in the Sahel, West Africa. Lancet 348: 1735-1736.

Robert V, Gazin P, Carnevale P (1989a). De la difficulté de prévoir les répercussions sanitaires des aménagements hydroagricoles: le cas du paludisme dans la rizière de la Vallée du Kou. In: Le risque en agriculture (Eldin M, Milleville P, eds). Paris, ORSTOM Coll (à travers le champs), pp 541-543.

Robert V, Ouédraogo V, Carnevale P (1991). La transmission du paludisme humain dans un village du centre de la rizière de la Vallée du Kou, Burkina Faso. Le Paludisme en Afrique de l'Ouest. ORSTOM Coll Etudes et Thèses, pp 5-16.

Robert V, Petrarca V, Carnevale P, Ovazza L, Coluzzi M (1989b). Analyse cytogénétique du complexe *Anopheles gambiae* dans la région de Bobo-Dioulasso (Burkina Faso). Ann Parasitol Hum Comp 64: 290-311.

Robert V, Van den Broek A, Stevens P, Slootweg R, Petrarca V, Coluzzi M, Le Goff G, Di Deco MA, Carnevale P (1992). Mosquitoes and malaria transmission in irrigated rice-fields in the Bénoué valley of northern Cameroon. Acta Trop 52: 201-204

White GB (1982). Malaria vector ecology and genetics. Br Med Bull 38: 207-212.

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
M. Coluzzi
V. Petrarca
E. Pozio
A. Stefanelli
H. Townson
D. Warrell

Honorary Presidents of the Conference

J. de Zulueta
H.M. Gilles
P. Perlmann

LOMBARDO EDITORE in ROMA