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Research article

Susceptibility to malaria in fulani, Bariba, Otamari and gando individuals living in sympatry in Benin: Role of opsonizing antibodies to Plasmodium falciparum merozoites

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ABSTRACT

Objectives: Fulani in Africa are known to be less susceptible to *Plasmodium falciparum* (*Pf*) malaria. This study explored a potential involvement of antibody-mediated merozoite phagocytosis mechanism in this natural protection against malaria.

Methods: Before the start of the malaria transmission season (MTS) in Benin, the functionality of antibodies against *Pf* merozoites was determined by the opsonic phagocytosis (OP) assay in plasma samples from Fulani, Bariba, Otamari and Gando groups. These individuals were actively followed-up for malaria detection from the beginning to the end of MTS. *Anti*-GLURP Immunoglobulin G antibody quantification, malaria Rapid Diagnostic Test (RDT) and spleen palpation were performed before and after MTS.

Results: In Bariba, Otamari and Gando, but not in Fulani, plasma from adults promoted higher levels of OP than the children ($P = 0.003$; $P = 0.012$; $P = 0.031$ and $P = 0.122$). A high proportion of Fulani children had higher OP and *anti*-GLURP ($P < 0.0001$) antibody levels as compared to non-Fulani children; whereas this was not observed for Fulani adults ($P = 0.223$). High OP levels before MTS were significantly related to negative RDT after MTS ($P = 0.011$).

Conclusion: Our results highlight the ability of opsonizing antibodies to potentially enhance natural protection of young Fulani individuals against Pf malaria in Benin.

1. Introduction

Differences in malaria resistance among distinct population groups have been investigated for a long time, and both genetic and immune parameters have been explored. The Tharu from Nepal were shown to be resistant to malaria due to a very high significant frequency of a deletion in the gene coding for the alpha globin, responsible for alpha thalassemia [1,2]. Also, the Melanesians from

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Papua New Guinea present high prevalence rates of ovalocytosis, which prevents parasite invasion in human red blood cells [3,4]. More directly linked to the present study, a Fulani resistance to malaria infections has been shown in, Burkina Faso [5–7], Mali [8–10], and Sudan [11–13]. In these studies, malaria resistance was defined as experiencing a lower number of uncomplicated and severe malaria attacks, a lower prevalence rate of malaria infections, a lower parasite density in asymptomatic carriers, a particular carriage of Fc gamma receptor (FcgR) polymorphisms, a higher IgG and IgM levels (specific or not to *P. falciparum (Pf)*). Even, compared to other ethnic groups living in sympatry, Fulani have a higher prevalence of splenomegaly [14,15]. Splenomegaly (enlargement of the spleen) due to malaria infection results from hyperstimulation of the immune system in reaction to repeated infections. Indeed, repeated Pf infections lead to a strong stimulation of B cells and to a hyperproduction of antibodies against *Pf* infection, in particular the IgM. The hyperproduction of antibodies leads to enlargement of the spleen [16,17].

Moreover, strong presumptions of constitutional characters responsible for human resistance to malaria have been stated for three decades [18]. This may raise questions about other factors than those already evidenced, which could be responsible for the Fulani resistance to malaria, such as immune mechanisms.

High antibody levels against whole merozoites and merozoite-associated antigens (e.g., AMA1, MSP1, MSP2, MSP3 and GLURP) have been associated with a reduced risk of *Pf* malaria infections [19,20].

Antibodies act on *Pf* either directly by agglutinating the parasites and therefore preventing their reinvasion of red blood cells or indirectly by binding to Fc gamma receptors (FcgR) expressed at the surface of immune cells and, therefore, triggering cell activation signals and immune response such as opsonic phagocytosis (OP) [21]. Studies exploring the antibody functionality using OP assays have shown positive correlation between IgG-mediated merozoite phagocytosis (by neutrophils and monocytes) and malaria immunity against *Pf* asexual blood stages [22,23]; [24–26].

In the present study, we explored the ability of antimerozoite antibodies to mediate *in vitro* OP by monocytic THP-1 cell line using plasma samples (collected before malaria transmission season) from Fulani, Bariba, Otamari and Gando ethnic groups. The overall aim was to assess the role played by OP in the Fulani natural protection against malaria.

2. Material and Methods

2.1. Study approval

The BAObAB project was reviewed and approved by the ethics committee of the Research Institute of Applied Biomedical Sciences (CER-ISBA/Institut des Sciences Biomédicales Appliquées) in Benin (No 61/CER/ISBA/15). All study participants were informed about the study before the beginning of the study. Individual written informed consent was obtained from adults or from the parents or guardians of children using a consent form translated in the people's native language.

2.2. Study population

The study under BAObAB project was conducted between 2015 and 2019 in the Atacora department (northern Benin) to study the response to malaria infections of four ethnic groups living in sympatry composed of Fulani, Bariba, Otamari and Gando individuals. The Gando share their living habits and their language with the Fulani while they share their genetic background with the Bariba (Sabbagh A, personal communication). Both the Bariba and Fulani are sedentary farmers and have a nomadic tradition, living apart as an isolated society, with the consequence of a strict endogamy. Moreover, the pastoralism of Fulani was often advanced as the main reasons explaining their resistance to malaria. Lastly, the Otamari form a clan society of sedentary farmer breeders with almost a strict endogamy.

2.3. Study design

The study was conducted in four rural villages (Tamandé, Kouboro, Gorgoba and Goufanrou), distant 3–15 km from each other. The families were receiving their medical consultation at the health centers situated in Birni and Goufanrou. These villages are located in the department of Atacora where malaria is endemic with the highest prevalence rate of parasitemia in 5-year-old children in whole of Benin [27]. The population under study was composed of children (less than 8 years) and adults (21–71 years old) from Fulani, Bariba, Otamari and Gando groups. Health workers performed an active follow-up of malaria, which consisted in scheduled home visits every fifteen days. Clinical examination was also realized in case of fever whether related to malaria or not, at home or at the health center. Cross sectional visits were carried out before and after the MTS, during which a questionnaire was fulfilled in complement of clinical examination, temperature measurement and spleen palpation. A *Plasmodium* rapid diagnostic test (RDT) and a thick blood smear (TBS) examined by optical microscopy were collected to confirm malaria infection. Saliva and venous blood were collected before and after MTS for genetic and immunological analyses.

Of note, for this study, plasma samples from 243 individuals were available. These samples were collected in May 2016 before the MTS from 36 Fulani (18 children and 18 adults), 92 Bariba (45 children and 47 adults), 79 Otamari (41 children and 38 adults) and 36 Gando (16 children and 20 adults).

2.4. IgG quantification

The Enzyme Linked Immunosorbent Assay (ELISA) standard operating procedure developed by the African Malaria Network Trust

was used to assess antibody concentrations specific to GLURP malaria candidate vaccine antigen. The IgG quantification against GLURP was performed as described previously in detail [28,29].

2.5. *Plasmodium falciparum* culture and preparation of merozoites

Plasmodium falciparum line NF54 was cultured and merozoite isolation was performed as described previously [30]. Briefly, parasites were maintained in O+ human erythrocytes at 3–4% hematocrit in parasite growth medium (RPMI 1640 Gibco™ supplemented with 25 mM HEPES, 0.5% AlbuMAX, 4 mM L-glutamine, 0.02 g/L hypoxanthine, and 25 μg/mL gentamicin) at 37 °C in a humidified 5% CO_2, 2% O_2 and 93% N_2 atmosphere. The parasitemia was monitored by examination of Giemsa-stained thin blood smears, and parasite cultures were synchronized with 5% sorbitol treatment for 10 min. Synchronized trophozoite-stage parasites were harvested using a magnetic separation column (Vario MACS) and subsequently treated with 10 μM of epoxysuccinyl-L-leucylamido (4-guanidino) butane (E64) for 6–8 h to allow schizonts to mature without rupture.

Segmented schizonts were centrifuged, resuspended in 4–6 mL RPMI 1640 medium, and then filtered through a 1.2 μm/32 mm syringe filter to obtain merozoites. The filtrate was passed over a LS MACS Column twice to remove the hemozoin. Free merozoites were stained with 10 μg/mL of ethidium bromide (EtBr) for 30 min before used in OP assay.

2.6. *Opsonic phagocytosis assay measured by flow cytometry*

The OP assay was performed as described previously [26,31]. Briefly, freshly isolated Ethidium bromide-stained merozoites were

Table 1
Characteristics of participants.

	Ethnic groups				*P* value
	Bariba[a] N = 92	Otamari[b] N = 79	Gando[c] N = 36	Fulani N = 36	
Children (n, %)	45 (48.9)	41 (51.2)	16 (44.4)	18 (50)	
Age (mean, ±SD)	5.1 (1.5)	5.2 (1.7)	5.2 (1.2)	5 (2.1)	
Boy (n, %)	25 (55.5)	27 (65.8)	12 (75)	10 (55.6)	**0.004**[c]
Girl (n, %)	20 (45.5)	14 (34.2)	4 (25)	8 (44.4)	
Adults (n, %)	47 (51.1)	38 (48.8)	20 (55.6)	18 (50)	
Age (mean, ±SD)	35.3 (7.3)	35.6 (9)	33.8 (8.5)	37 (13.3)	
Male (n, %)	26 (57.8)	17 (44.7)	10 (50)	6 (33.3)	**0.0005** [a]
Female (n, %)	21 (42.2)	21 (55.3)	10 (50)	12 (66.7)	**0.017** [c]
Splenomegaly before MTS (May 2016)					
Children					
Yes (n, %)	7 (15.5)	13 (31.7)	3 (18.7)	5 (27.7)	**0.036** [a]
No (n, %)	38 (84.5)	28 (68.3)	13 (81.3)	13 (72.3)	
Adults					
Yes (n, %)	2 (4.2)	3 (7.9)	1 (5)	1 (5.5)	
No (n, %)	45 (95.8)	34[a] (89.5)	19 (95)	17 (94.5)	
RDT before MTS					
Children					
Positive (n, %)	26 (57.8)	14 (34.1)	7 (43.7)	8 (44.4)	**0.048** [a]
Negative (n, %)	19 (42.2)	27 (65.8)	9 (56.3)	10 (55.6)	
Adults					
Positive (n, %)	4 (8.5)	5 (13.2)	3 (15)	2 (11.1)	
Negative (n, %)	43 (81.5)	32[a] (84.2)	17 (85)	16 (88.9)	
Splenomegaly after MTS (October 2016)					
Children					
Yes (n, %)	10 (22.2)	13 (31.7)	1 (6.2)	2 (11.1)	**0.036** [a]
No (n, %)	35 (77.8)	28 (68.3)	15 (93.8)	16 (88.9)	**0.0003** [b]
Adults					
Yes (n, %)	0 (0)	3 (7.9)	1 (5)	2 (11.1)	**0.0006** [a]
No (n, %)	47 (100)	35 (92.1)	19 (95)	16 (88.9)	
RDT after MTS					
Children					
Positive (n, %)	28 (62.2)	31 (75.6)	12 (75)	13 (72.3)	
Negative (n, %)	17 (37.8)	10 (24.4)	4 (25)	5 (27.7)	
Adults					
Positive (n, %)	15 (31.9)	15 (39.5)	5 (25)	6 (33.3)	
Negative (n, %)	32 (68.1)	23 (60.5)	15 (75)	12 (66.7)	
Rural villages					
Gorgoba	16 (17.4)	41 (51.9)	36 (100)	4 (11.1)	
Kouboro	76 (82.6)	38 (48.1)	0	6 (16.7)	
Goufanrou	0	0	0	26 (72.2)	

Statistical significance determined by Chi-square analysis between Fulani and the other groups ([a] comparison with Bariba; [b] comparison with Otamari and [c] comparison with Gando). Only significant P values (<0.05) are shown as regards the variables age, splenomegaly and RDT.

[a] Samples numbers varying (we have not information as regards splenomegaly and MTS for 1 adult).

opsonized with an optimized dilution (1:250) of decomplemented plasma for 20 min. Aliquots of 50 μl of opsonized merozoites were co-incubated with 100 000 THP-1 cells/well of a 96-well plate. The plate was incubated for 35 min at 37 °C in a 5% CO_2 humidified incubator. To stop phagocytosis, plates were centrifuged for 5 min at 400 g and 4 °C, and washed twice in fluorescence-activated cell sorting (FACS) buffer (PBS, 0.5% BSA, 2 mM ethylenediaminetetraacetic acid). Cells were fixed with 200 μl of FACS fixative (FACS buffer with 2% paraformaldehyde) and kept at 4 °C until analyzed in a Beckman Coulter cytometer (Cytoflex).

Viable THP-1 cells were gated by forward scatter and side scatter properties, and EtBr-positive events were enumerated using THP-1 cells alone [32]. The percentage of THP-1 cells containing EtBr-stained merozoites determined the level of phagocytosis, which was expressed as the phagocytosis index (PI). Data analyses were performed with Kaluza Analysis Software (version 2.1).

2.7. Statistical analysis

The OP levels were dichotomized into low and high OP values according to the median and the proportion of Fulani individuals with a high OP was compared with other groups through a Chi-square test. Differences of OP between children and adults in each group were compared by means of a Mann-Whitney *U* test and confirmed with a multivariate regression logistic model using the covariates splenomegaly, RDT results, sex, and IgG against GLURP (as a marker of malaria exposure).

Then, the proportion of children and adults among groups with a high OP were compared using Chi-square test and confirmed with a multivariate regression ordered logit model using the same covariates while the potential involvement of antibodies against GLURP in the resistance of Fulani to malaria was tested by comparison of their levels before and after MTS between ethnic groups. Finally, OP values were related to results of RDT and splenomegaly after MTS by Chi-square test. The statistical analysis was carried out using the Stata software version 13 and $P = 0.05$ was the significant level of statistic tests.

3. Results

3.1. Characteristics of participants

The study population was divided into four groups: Fulani, Bariba, Otamari and Gando (Table 1). There was a higher percentage of boys in Gando than in Fulani group ($P = 0.004$). Even, there were more males in Bariba and Gando compared to Fulani group ($P = 0.0005$ and $P = 0.017$, respectively). With respect to splenomegaly, Fulani children presented significantly more splenomegaly than Bariba children before MTS ($P = 0.036$). No difference was found between adults in term of splenomegaly before MTS (May 2016) while after MTS (October 2016), Fulani adults presented more splenomegaly than Bariba adults ($P = 0.0006$). Children from Bariba and Otamari presented more splenomegaly ($P = 0.036$ and $P = 0.0003$, respectively) after MTS. There were more Bariba children with a positive RDT before MTS ($P = 0.048$) compared to Fulani children. Overall, there were more positive RDT in children after than before MTS in Fulani, Gando and Otamari ($P_{\text{chi square}} < 0.001$) and more positive RDT in adults after than before MTS in Fulani, Bariba, Otamari and slightly in Gando ($P_{\text{chi square}} < 0.001$ and $P_{\text{chi square}} = 0.07$, respectively).

Most of Fulani lived in the rural village of Goufanrou while most of Bariba lived in Kouboro. All the Gando lived in Gorgoba. However, the Otamari were distributed equitably Gorgoba and Kouboro (Table 1).

3.2. Merozoite – phagocytosis levels according to ethnic groups and age

OP data were divided into two levels (high or low) based on the median values. Fulani presented a higher proportion (61%) of individuals in the high OP group compared to Gando (53%) ($P = 0.020$) and Otamari (37%) ($P = 0.0001$) (Fig. 1).

Adults presented higher OP values than children ($P = 0.0001$, $P = 0.008$ and $P = 0.049$, respectively) in Otamari, Bariba and Gando groups (Fig. 2 A, B, C). The results obtained by logistic models confirmed those observed in univariate analyses (Table 2A). There was

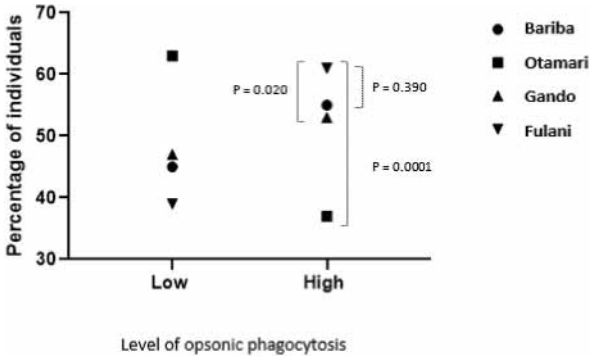

Fig. 1. Comparison of OP values between Fulani, Bariba Otamari and Gando. The proportions of individuals with a low and a high level of opsonic phagocytosis (OP) were compared in each ethnic group. Chi-square test was used to compare distribution of low and high OP between Fulani and other ethnic groups.

no difference in OP between children and adults among Fulani (P = 0.692; Odds ratio = 4.12, 95% CI = 0.68: 24.82, P = 0.122) (Fig. 2D and Table 2A).

Higher proportions of low OP values were observed for children from Bariba, Otamari and Gando (58%, 78% and 69%, respectively) while an inverse imbalance was found for Fulani children, with 39% of low OP values (Fig. 3B). Compared to other children, there were a higher proportion of high OP values in Fulani than in Bariba, Otamari and Gando (P = 0.007, P = 0.0001 and P < 0.0001, respectively) (Fig. 3 A, B). The ordered logit model presented in Table 2B (model 1) confirmed the high OP values associated with Fulani children (Coef = 0.14, 95% CI = 0.05; 0.23, P = 0.001).

No difference in OP values was observed in adults between ethnic groups in univariate or multivariate analysis (Fig. 3C, D and Table 2B). The distribution pattern of the OP values categorized into low and high OP was similar for each ethnic group, in favor of a prevalent proportion of high OP values (from 53% to 70%) (Fig. 3D).

3.3. Anti-GLURP IgG concentrations according to ethnic groups

Before MTS, there was a higher proportion of Fulani individuals (adults and children) with high levels of *anti*-GLURP IgG compared to Otamari (64% vs 35%, P = 0.0001) and Gando (64% vs 44%, P = 0.004) (Fig. 4A and Table 3). The same pattern was found after MTS (Fig. 4B and Table 3).

3.4. Merozoite – phagocytosis levels according to malaria transmission season

By considering the whole group of 243 individuals under study, it was observed that the OP levels before the MTS were not

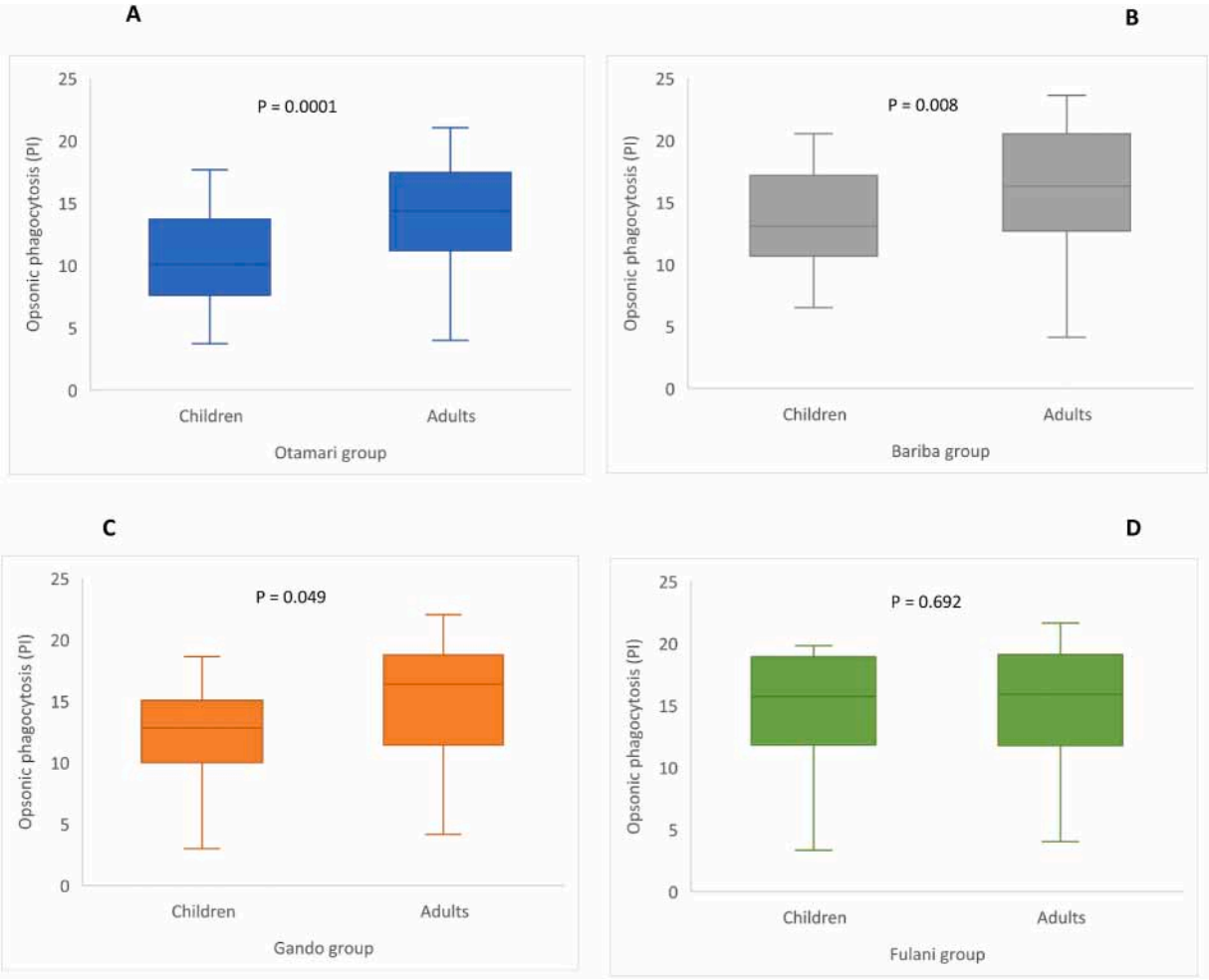

Fig. 2. Comparison of OP levels between adults and children in each ethnic group. The distribution of OP values was compared between children and adults from Fulani (D), Bariba (B), Otamari (A) and Gando (C) groups. Mann Whitney *U* test was used to compare values between adults and children in each ethnic group. THP-1 cells containing EtBr-stained merozoites determined the level of phagocytosis, which was expressed as the phagocytosis index (PI).

Table 2
Association between OP values, ethnic groups and age.

A. Comparison of OP values between children and adults in each ethnic group (Logistic model)	Odds ratio	95% CI	*P* value
Bariba children (reference)			
Bariba adults	4.95	1.41; 17.36	**0.012**
Otamari children (reference)			
Otamari adults	5.25	1.77; 15.60	**0.003**
Gando children (reference)			
Gando adults	6.33	1.18; 33.97	**0.031**
Fulani children (reference)			
Fulani adults	4.12	0.68; 24.82	0.122
B. Comparison of OP values between ethnic groups in children and adults (Ordered logit models: Otamari/Gando/Bariba/Fulani)	**Coef.**	**95% CI**	***P* value**
Model 1: Children			
OP values	0.14	0.05; 0.23	**0.001**
Model 2: Adults			
OP Values	0.01	−0.06; 0.08	0.763

Table 2–A presents the logit model obtained through the control variables splenomegaly, RDT results, sex, and IgG against GLURP. For each ethnic group, OP values were divided into two groups (low OP and high OP) according to the median and coded as 0 = low and 1 = high.
Table 2–B presents the ordered logit model (Ologit) obtained through the control variables splenomegaly, RDT results, sex, and IgG against GLURP. The dependent variable was represented by the ethnic groups Otamari, Gando, Bariba and Fulani coded, respectively by 0,1, 2 and 3. In bold: significant P value at the 0.05 threshold.

associated with the presence of splenomegaly after the MTS (P = 0.759) whereas they were associated with a greater number of negative RDT tests after MTS (P = 0.011; Table 4).

4. Discussion

The present study showed that plasma from Fulani children promoted higher merozoite – phagocytosis than did plasma from children belonging to Bariba, Otamari and Gando whereas there was no difference between adults from the different groups. To our knowledge, no work has previously studied associations between antibody functionality represented by OP among Fulani and non-Fulani groups.

Indeed, in Bariba, Otamari and Gando, merozoite – phagocytosis increased with age as shown in previous studies [24,26] whereas no difference appeared between adults and children from Fulani group, reflecting an important and intriguing level of merozoite – phagocytosis of Fulani children compared to Fulani adults and to children from other groups.

When comparing the levels of merozoite – phagocytosis in adults between groups, no differences were found: this may be explained by the age ranging from 21 to 71 years old and by an already acquired specific immunity against malaria unlike children who are acquiring progressively their repertoire of specific cellular and antibody responses. This last point could explain the level of merozoite – phagocytosis of Fulani children compared to other children. Indeed, high *anti*-GLURP IgG concentrations before and after MTS have been observed both in Fulani children and adults. This result agrees with those from other studies that compared IgG levels from Fulani and other ethnic groups in West and East Africa (Mali, Gambia, Burkina Faso and Sudan).

Indeed, it has been shown that the Fulani had significantly higher level anti-malaria specific IgG, IgG1 and IgG3 levels than the Dogon in Mali [12,33–35], high antibody levels against AMA1 and MSP1 [36] and a higher percentage of circulating plasma cells than the Dogon [8]. Moreover, Fulani have been shown to be more responsive to *Pf* with a high level of IgG, IgM and IgE [8,35,37]). It has been reported recently that IgM could also play a role in OP [38]. In our study, plasma samples were used in OP assays therefore we cannot exclude a possible role of IgM in the observed results even the capacity to opsonize of IgM seems lower compared to that of IgG.

Other biological factors could explain the natural protection of Fulani against malaria like the lower retention of circulating erythrocytes leading to lower circulating parasitic loads [39,40], a functional deficit of T regulatory cells [41], a strong transcriptional response in the monocytes [42] or plasma cells [41].

Indeed, Fulani have been shown to present more activated memory B-cells and plasma cells [41], with higher levels of cytokines, chemokines and a high activation of dendritic cells [43–46]) than Mossi, Rimaibé, and Dogon. Moreover, all these reasons may suggest that Fulani have more effective innate immune responses to *Pf* infection driving more effective adaptive immunity [47,48].

FcgR polymorphisms may also play a role: the FcgRIIA 131 H H genotype was found to be common in Fulani [34,45,49]) and was consistently associated with higher levels of anti-malarial IgG2 and IgG3 in comparison to levels found in Halfawi, Four, Masaleet and Hausa from Sudan [50].

The fact that the merozoite – phagocytosis levels before MTS was significantly associated with a lower prevalence of *Pf* infection detected by RDT reinforces the important role that phagocytosis could play in malaria immunity as confirmed by other studies [22, 24–26]).

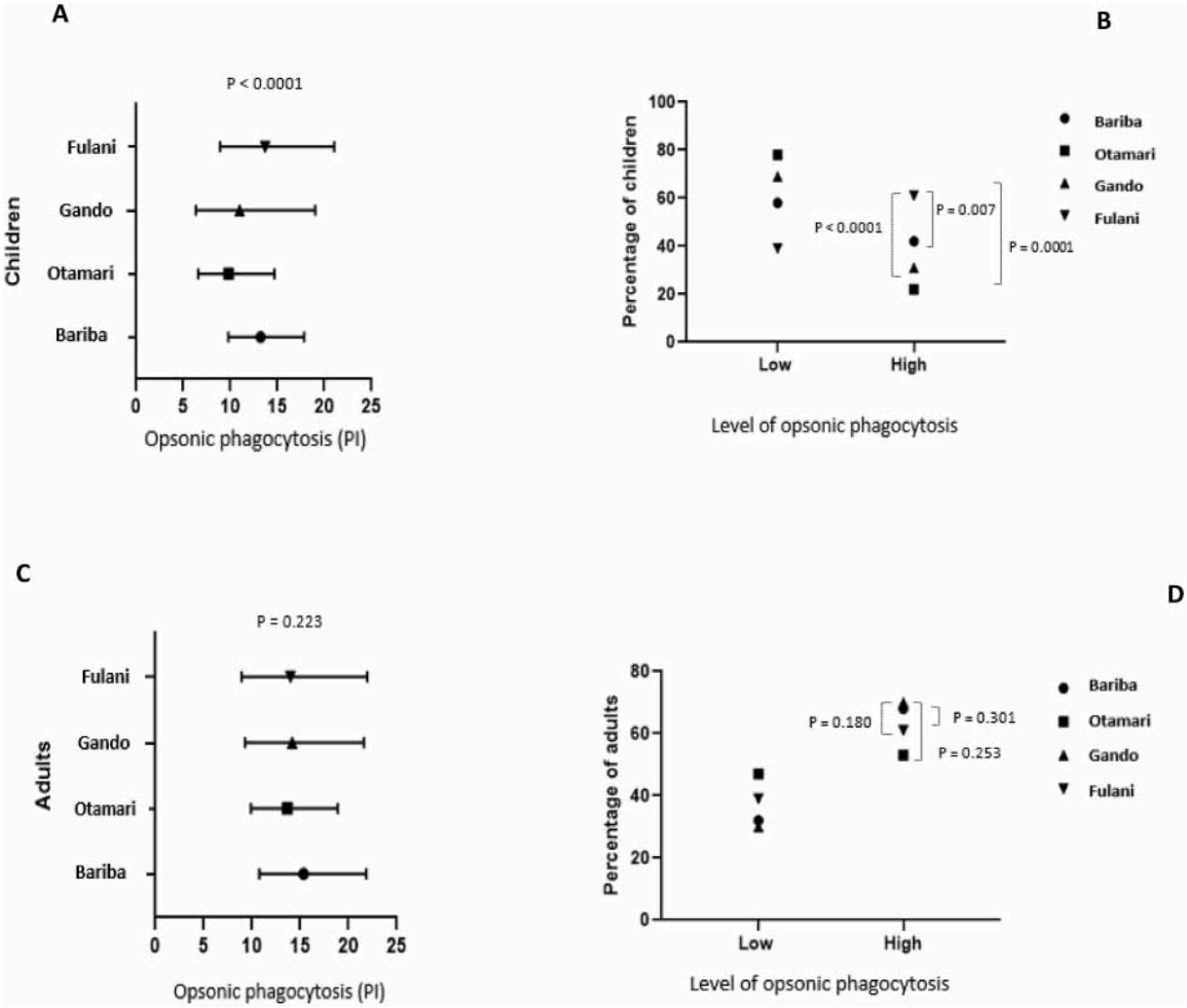

Fig. 3. Comparison of OP levels of children and adults between Fulani, Gando, Bariba and Otamari. OP levels were compared among children (A, B) and adults (C, D) in each ethnic group. Kruskal-Wallis test was used to compare the OP distribution (A, C) while Chi-square test was used to compare the proportion of individuals with high and low OP levels between Fulani and other ethnic groups (B, D).

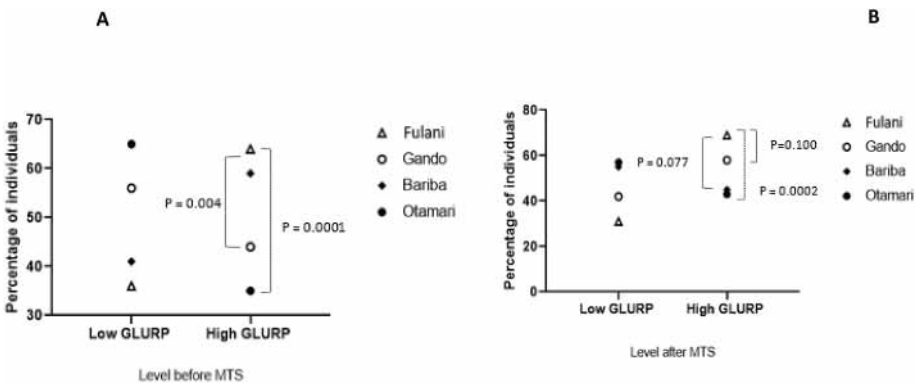

Fig. 4. *Anti*-GLURP IgG concentrations before and after MTS among ethnic groups. The proportions of individuals with low and high *anti*-GLURP IgG concentrations (below and over the median value) were compared in each group before (A) and after (B) the malaria transmission season. Chi-square test was used to compare the proportion of high and low *anti*-GLURP IgG levels between Fulani and other ethnic groups.

Table 3
Comparison of IgG levels against GLURP between ethnic groups before and after MTS.

	Bariba	Otamari	Gando	Fulani	*P*-value[a]
Children					**0.001**[b]
Log *anti*-GLURP IgG before MTS (mean ± SD)	3,15 (0,60)	2,71 (0,72)	3,02 (0,57)	3,12 (0,77)	**0.007**[c]
Log *anti*-GLURP IgG after MTS (mean ± SD)	2,90 (0,80)	2,89 (0,73)	2,63 (0,83)	3,18 (0,97)	**0.043**[d]
Adults					
Log *anti*-GLURP IgG before MTS (mean ± SD)	3,62 (0,49)	3,34 (0,75)	3,29 (0,50)	3,84 (0,68)	
Log *anti*-GLURP IgG after MTS (mean ± SD)	3,27 (0,76)	3,18 (0,85)	3,31 (0,66)	3,51 (0,90)	

Only significant P values (<0.05) are shown.
[a] P value determined by the Mann-Whitney *U* test between Fulani and the other ethnic groups.
[b] Fulani and Otamari (children and adults) before MTS.
[c] Fulani and Gando (children and adults) before MTS.
[d] Fulani and Otamari (children and adults) after MTS.

Table 4
Relationships between OP values before MTS and the presence of a splenomegaly or positive *Pf* RDT after MTS.

OP Values	Splenomegaly			Positive *Pf* Rapid Diagnostic Test		*P* value[a]
	No	Yes	P value	No	Yes	
Low (n, %)	105 (43.2)	17 (6.9)	0.759	58 (23.8)	64 (26.3)	**0.011**
High (n, %)	106 (45.6)	15 (6.17)		77 (31.6)	44 (18.1)	

OP values were categorized in two levels, low and high, according to the median.
[a] Statistical significance determined by Chi-square analysis.

5. Conclusion

This study showed that plasma from Fulani children from Benin promoted a better merozoite -phagocytosis activity than plasma from children belonging to other ethnic groups living in sympatry. Although small (n = 243), the sample size could be considered substantial in view of the methodological constraints imposed by the opsonic phagocytosis assay: identical effector cells in sufficient quantity, sufficient volume of parasite culture, rigorously identical conditions of realization of the assay. However, it would be interesting to replicate this study on a larger scale and in other countries.

Finally, our results highlight the ability of opsonizing antibodies to potentially enhance natural protection of young Fulani individuals against Pf malaria in Benin. This ability is potentially linked to their high antibody levels against Pf merozoite antigens such as GLURP. However, many other biological factors could be involved in the Fulani natural protection against malaria.

Author contribution statement

Abdou Khadre Dit Jadir FALL; Ikhlaq Hussain Kana; Asier Garcia-Senosiain: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Benoit Henry: Performed the experiments.

Célia Dechavanne: Contributed reagents, materials, analysis tools or data; Wrote the paper.

André Garcia; Pierre Buffet; Audrey Sabbagh: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Florence Migot-Nabias: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Michael Theisen; David Courtin: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

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.

Additional information

No additional information is available for this paper.

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