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# Voices from the Amazon: exploring implementor and user perceptions of non-invasive malaria diagnostics in Peru

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## Abstract

**Background** Malaria burden remains high in some Peruvian regions, especially in the Northeast Amazon rainforest state of Loreto and the tropical coastal state of Tumbes. Novel non-invasive diagnostic tools for malaria are being developed, and formative research in malaria-endemic areas with community members and health professionals who would potentially use these devices is vital for this process. This study aimed to examine the acceptability and feasibility of four new non-invasive malaria diagnostic tools in development in two regions of Peru with significant malaria burden.

**Methods** The research team conducted focus group discussions and key informant interviews in Spanish to assess acceptability and ascertain questions and concerns regarding the non-invasive diagnostic tools. Focus group discussions included a range of community members (pregnant women, parents), professionals (health, education), and community leaders in Loreto. Vector control authorities and health professionals from Loreto, Tumbes, and Lima participated as key informants.

**Results** Participants were initially enthusiastic about all non-invasive diagnostic tools. However, as discussions proceeded, high enthusiasm remained for two devices that were easy to use, acceptable for the communities they were intended for, feasible to carry in remote areas, and did not require new supplies nor generate waste: the skin scan and the skin odour test. The breath and saliva tests were considered less hygienic. They were less acceptable to community members and health professionals due to concerns of disease transmission and other environmental and cultural concerns. Health professionals felt the finger scan test and the skin odour test would help triage community members in endemic sites and would be valuable in remote regions with difficult access to health facilities or laboratories.

**Conclusions** Novel non-invasive malaria diagnostic tools can be valuable in malaria-endemic settings. As manufacturers evaluate the efficacy and effectiveness of these non-invasive diagnostic tools, international recommendations should be created to ensure their agile integration into national malaria programmes.

**Keywords** Malaria, Non-invasive diagnostic tools

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## Background

Malaria is a significant global health challenge, affecting millions of people, particularly in tropical and subtropical regions. Despite substantial progress in reducing malaria incidence and mortality over the past few decades through a combination of prevention and treatment efforts, including vector control, preventive prophylaxis or vaccination, and rapid diagnostics, the disease remains a serious threat [1]. Malaria control programmes vary worldwide, but rely on rapid and accurate diagnosis, followed by treatment. In regions with meso- or hypo-endemic transmission, like in much of Latin America, programmes rely on regular screening of asymptomatic populations to eliminate parasitemia at the population level.

Malaria cases in the Americas decreased by 64%—from 1.5 million to 0.55 million—between 2000 and 2022 [2]. However, the region continues to have an unacceptable malaria disease burden. In 2018, Peru initiated its Malaria Zero Programme, which aims to eliminate malaria by 2030 [3], and implemented active case detection using both thick smears in more accessible areas and blood-based lateral flow rapid diagnostic tests (RDTs) in remote areas, as suggested in World Health Organization (WHO) guidelines, both of which are now integral components of ongoing malaria programmes [4].

Microscopy of thin and thick blood films is generally considered the "gold standard" for malaria diagnosis, with a sensitivity and specificity of 95% and 98%, respectively (though accuracy depends on the capacity of the person reading the slides). In resource-poor settings and remote areas with limited laboratory facilities, blood-based lateral flow RDTs (sensitivity and specificity ranges of 85–95% and 95–99%, respectively) can identify *Plasmodium falciparum* and *Plasmodium vivax* species, limiting unnecessary presumptive treatment of suspected malaria infection, which can lead to treatment-resistant parasitic strains or delayed treatment for other treatable illnesses [5–7]. Microscopy costs less than $0.50 USD per test, not including the supply and personnel costs, whereas currently available RDTs cost about $0.85 USD [5].

Despite the availability of these effective and low-cost diagnostic options, less invasive technologies could overcome existing limitations and challenges associated with both microscopy and RDT use [5, 6, 8, 9]. In Peru, a major limitation associated with RDT use is HRP2/3 gene deletions [10, 11], which lowers their sensitivity. Additionally, obstacles related to cultural acceptance and risk of infection or non-compliance due to a lack of trained personnel have been well documented [6, 8, 12].

Scientists are exploring the feasibility of non-invasive diagnostic tools for malaria detection that are based on other biomarkers, such as urine, saliva, aerosolized microbes, or volatile organic compounds (VOCs) [5, 6, 9, 12]. These non-invasive diagnostic tools could facilitate more frequent sampling with greater community acceptance [6], particularly among asymptomatic individuals who otherwise may be less inclined to submit to a blood-based test [12]. Point-of-need non-invasive diagnostic tools also could facilitate care by reducing waiting times for diagnosis [7, 12]. However, further research is needed regarding the acceptability and feasibility of non-invasive diagnostic tools in malaria-endemic areas because existing research generally focuses solely on the accuracy of such tests [13, 14] or on the opinions of policy-makers and health providers [12].

This qualitative study's objective is to examine the perspectives of community members and health professionals in the Peruvian Amazon region regarding the acceptability and feasibility of theoretical non-invasive diagnostic tools for malaria detection. The goal is to inform the product development of these next-generation devices.

## Methods

### Study setting

Health and immigration authorities interviewed for this study were based in the Peruvian states of Loreto, in the Northeast Amazon rainforest basin bordering Ecuador, Colombia, and Brazil; and Tumbes, in the Northwest coastal region on the Ecuadorian border; and national Ministry of Health (MOH) officials in the Peruvian capital of Lima. Focus group discussions (FGDs) with community members were carried out in Loreto, with an estimated population of 1.1 M. Loreto accounts for 80–96% of annual reported malaria cases [15, 16]. Transportation in Loreto relies on boat travel along rivers, as its capital city, Iquitos (population 400,000), is the largest city in the world that can only be reached by airplane or boat, with no road access [7] (see Fig. 1).

Zungarococha is a malaria-endemic community in Loreto, 12 kms from Iquitos, where the local health post serves a range of communities along the Nanay River and the Iquitos-Nauta highway, all with historically high rates of malaria transmission. Zungarococha's health facility has a laboratory that performs microscopic diagnosis of malaria (typically by thick smear) and is where residents receive treatment. The national malaria programme relies heavily on a network of volunteer community health workers (CHWs) who are given basic training in performing blood smears or, in very remote locations, administering blood-based lateral flow RDTs. Thick smear blood samples are transported to laboratories for diagnosis, and results are communicated to CHWs, who refer those with positive results to the nearest health centre. In more

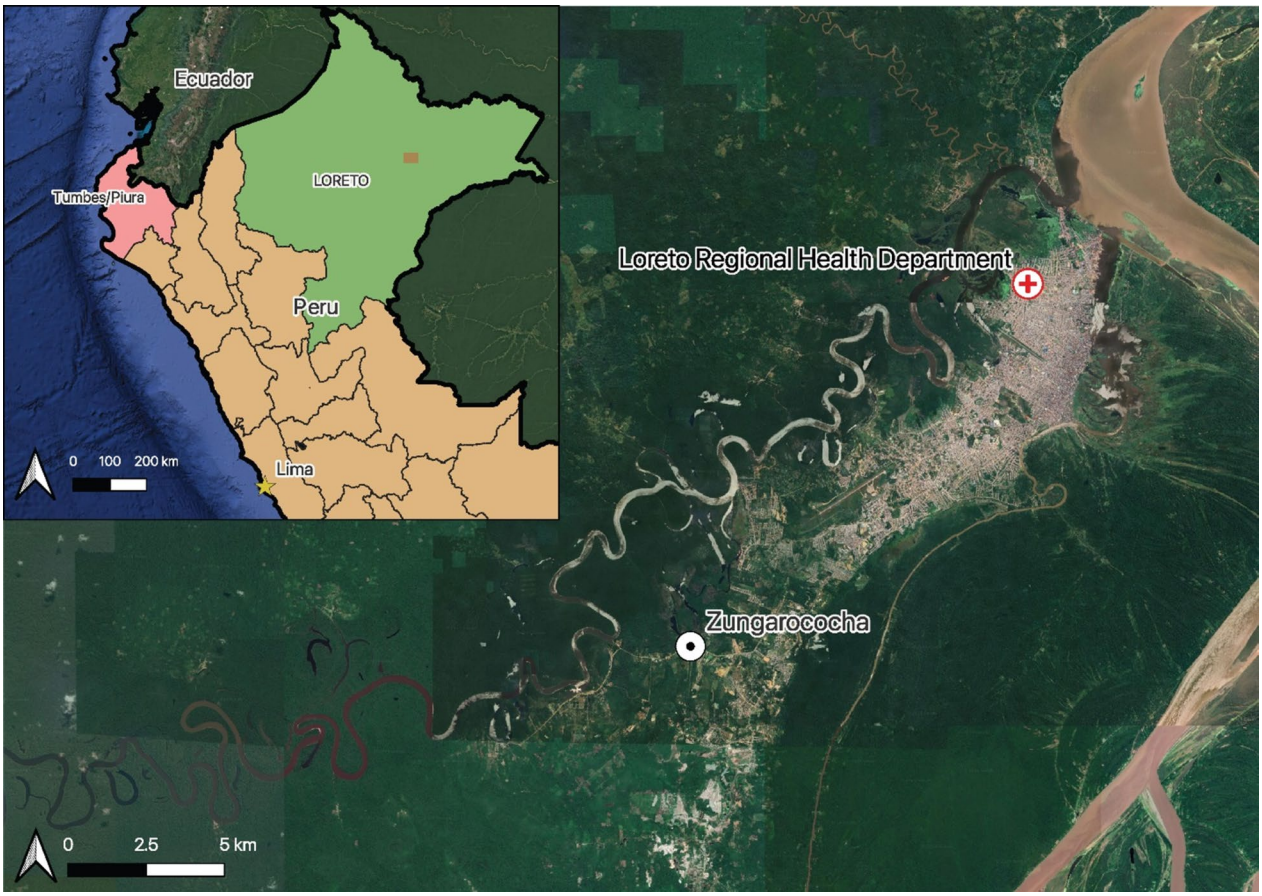


**Fig. 1** Map showing locations where focus group discussions (Zungaracocha and Iquitos city (main map) shown in red box in Loreto Department (insert upper left corner). Key informants were from the Loreto Regional Health Department responsible for the entire department (light green), Tumbes Department (pink), border crossings on the northern border, and National Ministry of Health located in Lima (yellow star)

remote locations, after a positive rapid diagnostic test, CHWs can administer anti-malaria medication following well-established protocols: mefloquine for those with *P. falciparum* (3 days), and chloroquine and primaquine (to prevent the dormant phase in the liver) for *P. vivax* cases (7 days). Approximately 25% of those diagnosed with *P. vivax* cases are re-infected within 6 months, but it is unclear whether this is due to a failure to complete the medication course, medication failure (i.e. dosage or resistance), or reinfection.

The Northwestern state of Tumbes (population 260,000) is a tropical coastal state with mangroves. One large freeway crosses through Tumbes, starting from its northern border with Ecuador to its southern border with the state of Piura. Malaria is non-endemic in Tumbes; there have been no autochthonous cases in the past three years. Most malaria cases are imported by military personnel returning from posts in malaria-endemic regions and migrants from various countries entering Peru from Ecuador.

Malaria control efforts in this region have focused on high-impact initiatives [17, 18], that used combined treatments for both *P. falciparum* and *P. vivax*, disseminated long-lasting insecticide-treated bed nets, implemented the massive use of blood-based lateral flow RDTs in remote locations, and initiated active case detection and other implementation strategies based on micro-epidemiology. These efforts led to a significant decrease in malaria, leading the WHO to shift from control to elimination in 2016.

### Wider study context

This study in Peru was part of a large international study conducted by FIND that also took place in Indonesia and Rwanda. In all three countries, the research teams used the same FGD and semi-structured interview (SSI) guides and codebook to present and discuss the following four types of theoretical non-invasive diagnostic devices, which included a product profile that included

the developers' estimates of performance (see Additional Files 1 and 2):

- one based on the use of a spectrophotometer placed on a finger to measure the absorption or transmission of light through the finger's skin ("finger scan test")
- two based on the detection of VOCs:
    - one through exhaled breath ("breath test")
    - one through body odour from an arm ("skin odour test")
- one based on a saliva sample ("saliva test")

These devices were not commercially available when the study took place, but to prompt discussions about these, the research team used images/visual information sheets (Additional File 1) and identified similar items to represent each test type (Fig. 2). For example, we displayed a pulsometer to simulate the finger scan test and used a no-contact thermometer to simulate the skin odour test.

#### FGD participants and data collection

The study team carried out seven FGDs (n = 64): one (n = 10) in the city of Iquitos where there is no active malaria transmission, and six (n = 53) in Zungarococha to explore community reactions to the four non-invasive diagnostic tools. The research team selected Zungarococha for FGDs because it had high rates of endemic malaria and was easily accessible. The research team used a purposive sampling process. For a single FGD representing the city of Iquitos, research staff (ASVS and EJRL) recruited participants using snowball sampling from distinct sectors of in the city. In Zungarococha, a research team member (EJRL) coordinated with the Zungarococha health post director and midwife, local school director and leaders from various community groups, a church, and a municipal authority to organize and recruit participants for FGDs. The research team carried out FGDs for pregnant women, parents of children under five, and health professionals, all in the health post.

Two FGDs with teachers and one with community leaders were conducted in classrooms at the local school. Prior to initiating each FGD, the research team individually reviewed informed consent documents, answered questions, and obtained signatures from participants who agreed to participate and to be audio-recorded. All FGDs were conducted in Spanish.

#### SSI participants and data collection

SSIs were conducted with eight participants November 11–29, 2023. The local PIs (ACM and VAPS) phoned their contacts in the Regional Health Departments of Loreto and Tumbes and asked who would be best positioned to discuss malaria and border areas. SSIs in Loreto were conducted with two medical epidemiologists managing regional health department vector-borne disease programs, a National Agrarian Health Service border inspector in the northern Amazon border, and a nurse in a health post along a border. In Tumbes, SSIs were conducted with two regional health authorities and a medical epidemiologist in the vector control programme. Finally, a national health authority in the MOH in Lima was also interviewed. All key informants signed consent forms and agreed to be audio-recorded. All SSIs were conducted in Spanish.

#### SSI topics

All key informants were asked about their experiences with malaria in their communities. VAPS and ACM then presented the four non-invasive diagnostic tools and explained how they worked. Themes discussed included: the devices' advantages and disadvantages, community response to each device, when and how the devices should be deployed, expectations of acceptable device sensitivity and specificity, whether devices need to identify *Plasmodium* species, and other comments regarding the devices.

#### Data analysis

All audio files were downloaded onto a password-protected computer and transcribed using Trint (trint.com). Spanish-speaking research staff anonymized the transcripts and performed quality control. Then, the transcripts were translated into English using the program DeepL (https://www.deepl.com/en/translator). Bilingual researchers then reviewed the translated transcripts and corrected any translation errors by comparing the English and Spanish transcripts to ensure clarity and proper translation.

All cleaned English transcripts were uploaded into Quirkos CAQDAS software (https://www.quirkos.com/index.html) for coding. When discussing device preferences in several FGDs, interviewers and participants often referred to devices as "this one" or "that one," making it difficult to capture which device they were discussing. The research team used context clues to infer which device was being discussed and added between brackets, while comments not related to the FGDs were excluded.

Coding was primarily deductive: two research team members (LN and EO) reviewed the larger study codebook and made minor revisions to it before coding. Some

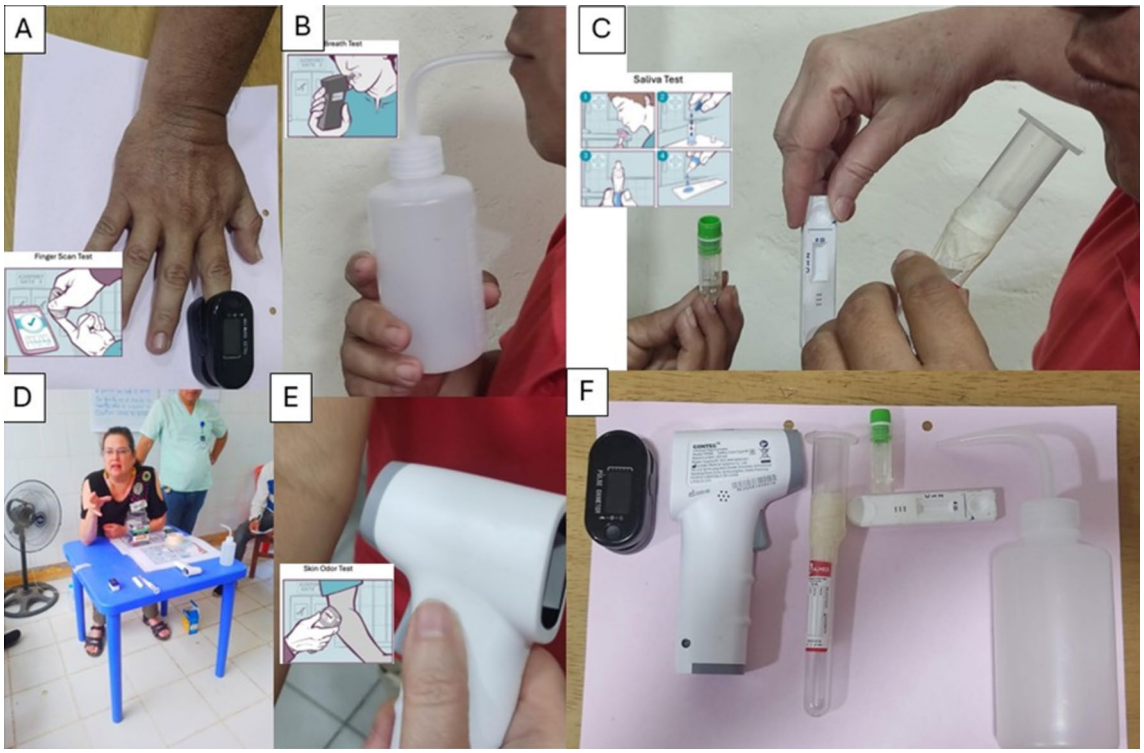


**Fig. 2** Items used as physical representations of non-invasive diagnostic tools for finger scan test (**A**) breath test (**B**); saliva test (**C**); how they were used focus group discussion (**D**); skin odour test (**E**) and composite showing all items used to represent the diagnostic tools (**F**)

data did not fit these pre-established codes during coding, so three new inductive codes were developed. LN and EO reviewed the first few SSIs together to ensure coding decisions were consistent and reliable, then split up the rest of the files (see Additional File 2).

## Results

### Population characteristics

All FGD participants were adults (defined as ≥ 18 years of age), with 73% (n = 43) female and 27% (n = 27) male overall (Table 1). Women were the majority of participants in the FGDs with teachers (11 of 15, 73%) and caregivers with children under 5 years of age (10 of 12,83%). The majority (69%) lived with a partner, reported having education beyond high school (66%), were employed

**Table 1** Summary of the demographic characteristics of FGD participants in Iquitos (n = 1) and Zungarococha (n = 6) between November 9–11, 2023

| FGDs | Gender | | Mean Age (range) | Employed | Education | | |
|---|---|---|---|---|---|---|---|
| | Men | Women | | | Primary | Secondary | Higher |
| Iquitos community | 4 | 6 | 39.4 (20–51) | 50% (5/10) | 20% (2/10) | 40% (4/10) | 40% (4/10) |
| Parents of children ages 5 and under | 2 | 10 | 29.7 (22–46) | 50% (6/12) | 17% (2/12) | 17% (2/12) | 67% (8/12) |
| Health professionals | 4 | 6 | 36.1 (27–54) | 100% (10/10) | 0% (0/12) | 0% (0/12) | 100% (12/12) |
| Teachers | 2 | 6 | 43.6 (33–61) | 100% (8/8) | 0% (0/8) | 0% (0/8) | 100% (8/8) |
| Teachers | 2 | 5 | 49.9 (41–63) | 100% (7/7) | 0% (0/7) | 0% (0/7) | 100% (7/7) |
| Pregnant women | 0 | 9 | 29.7 (18–37) | 11% (1/9) | 33% (3/9) | 56% (5/9) | 11% (1/9) |
| Community leaders | 3 | 5 | 44.8 (23–64) | 63% (5/8) | 0% (0/8) | 50% (4/8) | 50% (4/8) |

full-time (50%) or part-time (16%), and were parents (95%), with up to 8 children (mean number of children = 2.2). Ages ranged from 18 to 64, with a mean age of 38. The size of the FGDs ranged from seven to 12 people, with a mean of 9.1.

#### Familiarity with and attitudes toward malaria

All FGD participants, including individuals from non-endemic Iquitos, knew what malaria was, could describe common symptoms, knew that mosquitoes transmitted the disease, knew of communities and regions that had malaria, and could name *P. falciparum* and *P. vivax.* Many participants expressed a degree of fear or respect for the illness, including calling it *"a deadly disease" (pregnant women FGD, 36, woman).* The importance of diagnosis during pregnancy was also well recognized.

When asked directly if there was any stigma associated with having malaria, all FGD and SSI participants expressed a resounding "no." About one-third of the FGD participants had previously had malaria and enthusiastically shared their experiences. As one participant reported.

> *"There is no stigma, malaria can happen to anyone" (teacher FG, 34, man). A key informant explained, "I have had malaria five times," and there is not an issue [with stigma]" (Loreto regional health authority, 57, man).*

FGD participants expressed support for malaria screening programmes. They accepted that blood-based screening procedures were necessary, and did not express concern regarding confidentiality of their malaria status.

#### Routine malaria testing

A central component of Peru's national malaria programme has been routine school-based testing to identify asymptomatic malaria infections at roughly 3-month intervals. In addition, house-to-house screening is often carried out in response to increases in malaria transmission. These activities are usually large-scale campaigns involving entire communities that are typically performed by local health centre personnel supported by CHWs.

Despite the importance of screening, there was universal recognition that finger pricks were not popular. Stories were told, with much laughter, about what community members or school children do to avoid the regular finger pricks for the thick smears:

> *"When the nurses came to the house [to test people], my brother would run to my aunt's orchard. The nurses would then go to my aunt's house, and again he would run to the other orchard. And the nurses already knew, and they would catch him there" (parents, FGD, 30, woman).*

Other communities, such as indigenous groups, also oppose finger pricks due to concern regarding what CHWs might do with the samples:

> *"When CHWs arrive at their community, … residents go deep into the [unpopulated regions of the] rainforest" (health professionals, FGD, 54, man).*

#### Non-invasive diagnostic tools

Many FGD participants initially expressed skepticism about the described noninvasive diagnostic tools because they distrusted something new. For example, some expressed concern regarding false negative results, given their experiences with the fallibility of COVID-19 RDTs, or questioned whether these tests really could detect malaria without taking a blood sample.

Many community members explained that their confidence in the devices would increase if they saw the non-invasive diagnostic tools in action, detecting malaria cases before their own eyes. For example, they might want to observe the finger scan test used on individuals with confirmed malaria to see that the device detected it. Many expressed that if their local health professionals told them that the new non-invasive diagnostic tools were reliable, they would trust their judgement and accept their use. Indeed, after further explanation regarding how the devices worked, these non-invasive diagnostic tools were met with enthusiasm when compared to the current blood-based screening regime described above.

> *" I think it would be a useful tool to detect malaria. Perhaps children are terrified of needles, children even hide and do not want to come because they know they are going to be pricked. If there was another type of test, I would be happy, it's a benefit for me. It also makes it easier for the parent to understand" (teachers FGD, 54, woman)*
> *Below are specific reactions to each of the prototype test devices.*

#### Finger scan test

The finger scan test, along with the skin odour test, was the most popular non-invasive diagnostic tool among both community members and key informants. Overall, the finger scan test's popularity was due to its non-invasiveness, high theoretical sensitivity (90%), speed of results, ease of use, and portability. It generated

confidence in community members because the device has direct contact with skin and detects the malaria parasite in "blood," like current malaria tests.

> *"I trust anything to do with blood more than breath. Blood is stronger; in blood you can see everything and you can measure more" (teacher, FGD, 61, woman).*

Health professionals were particularly enthusiastic about the possibility of walking into a school or community and testing one individual after another, with rapid results. The health professionals explained:

> *"Because it's a small device, it means less risk [of contamination] to the medical staff going from house to house. Our staff and our population are already familiar with a small device like the pulse oximeter. It is handy and if it was positive, they would do [follow up with] the thick smear. It's 90% effective and that's also a big reason" (Tumbes regional health authority, 47, woman).*

They noted that the size and portability of such a device would be advantageous:

> *"I still pick the first one [finger scan test], because you carry it, you put it in your pocket and you go anywhere, but the other two that you mentioned [breath and saliva tests], you had to carry your personal protection equipment, your glove box, more luggage, but this [finger scan test] is something very practical. Just like the cell phone they put it here [vest pocket], so I can put it here" (health professional FGD, 27, woman).*

One concern, however, expressed by a single health professional, was that in areas with coca production and illegal drug trafficking, the finger scan test would be mistaken for a covert fingerprint reader used for law enforcement purposes.

Various participants had questions regarding the accuracy of the finger scan test. Some asked whether there may be other untested factors or diseases that might affect "blood colour," such as anemia. One individual asked whether medications or natural remedies—for example, quinine-derived teas or bark—could alter the blood colour, resulting in false negatives. Some noted that the finger scan test should be cleaned between uses (i.e., wiped with alcohol), but this was not a major concern.

#### Skin odour test

Reactions to the skin odour test were similar to those of the finger scan test, even though the mechanism for malaria detection was different (i.e., it did not measure anything in blood). Overall, the skin odour test was perceived to be easy, safe, and practical, providing rapid results without requiring additional supplies.

Two issues emerged with the skin odour test that did not come up with the finger scan test. First, because the facilitator indicated that the device could "smell" the malaria parasite in a person's odour, questions arose about other odours interfering with the functionality of the device:

> *"Because here it's usually quite hot, perhaps you could mistake odor for sweat. We could miss the diagnosis" (Tumbes regional health authority, SSI, 44, woman) and "If someone sprays perfume or something in that area, or repellent, or something that has alcohol in it... there have to be certain specifications [for its correct use]" (health professional FGD, 30, man).*

Second, participants were concerned that device's accuracy could be affected by placing the device too close or too far from the skin:

> *"This one [finger scan test] has contact and it's going to give me a more effective result. On the other hand, the other one [skin odor test] can come close to me and suddenly I don't get a good reading because of the margin of distance or because a child can move. On the other hand, this [finger scan test] is already on my body" (health professional FGD, 38, woman).*

When FGD participants and key informants were asked to select their favourite device, most votes were split between the skin scan or odour test. Enthusiasm for the finger scan test was slightly higher because respondents thought there was no way to use it incorrectly, but the skin odour test was a close second.

#### Breath test

The breath test was initially viewed favourably due to its non-invasive nature compared to a finger prick. As discussions progressed, however, concerns emerged that dampened enthusiasm for this device.

Participants raised concerns about the breath test's accuracy depending on what a person may have recently consumed:

> *"There are different factors that affect the breath and that test, for example, if a person comes in that has had alcohol or has smoked, eats chewing gum, any kind of food there's always going to be different types of odors" (health professionals FGD, 30, man).*

Although most concerns focused on whether other odours in one's breath or poor oral health might affect test accuracy, many associating the device with a breathalyzer. Some joked that there would be hesitation to use

the test because of concerns that its true purpose was to measure blood alcohol level. In both the FGDs and SSIs, people mentioned that in regions where malaria is endemic, alcohol consumption is also high.

Many participants were unenthusiastic about blowing into a device that had already been used by others, perceiving it as unhygienic:

> *"People have certain stigmas. He's already put it in his mouth, we're going to put it in someone else's mouth, that's a problem" (Loreto border inspector, 44, man).*

Even if the mouthpiece were changed with each person, the idea that other people's breath and possible viruses or diseases like tuberculosis could remain on or in the device was off-putting. Two FGD participants stated that the breath test was like a spirometer for lung function, which people use without hesitation. However, once the "shared breath" issue arose, hygiene became the focus of the conversations, with most asking how the breath test device would be cleaned and how many uses it would have.

Age was also a limiting factor, as parents mentioned that babies and young children would not be able to blow, while health workers opined that it could be ineffective for people with disabilities or who were very ill:

> *"In first grade I doubt that they can blow well, from second grade up, yes" (teachers FGD, 52, woman).*

Environmental issues also emerged in some FGDs and SSIs in Loreto related to the breath and saliva tests, because they would generate trash (mouthpieces and tubes), especially in areas without solid waste removal. Trash was not of concern in the Tumbes border region, where key informants envisioned device use within the health facilities where biomedical trash is regularly collected.

#### Saliva test

Like the breath test, the saliva test was initially viewed favourably due to its non-invasive nature and similarity to COVID-19 rapid tests. For some, its reliance on a bodily fluid made it seem more reliable than the body odour test:

> *"I think it's better because it's saliva and it comes directly from the body, it gives you confidence" (pregnant women FGD, 37, woman).*

Nonetheless, specific concerns emerged, resulting in the saliva test being the least preferred device.

The strongest unfavourable reaction came in the FGD with health professionals; one immediately exclaimed: *"this is gross!"* Discussion then focused on safety and the need for personal protective equipment (PPE) if individuals were spitting in front of them. There was concern about disease transmission from the *"spit in the air,"* such as tuberculosis or COVID-19. Some health professionals suggested the device's use should be limited to protected sites, but not in group or screening scenarios:

> *"Sure, we would have to be protected somehow. We would have to be. We're talking about bodily fluids. And most of our population, besides malaria, in the indigenous area, there's tuberculosis. So, we would need adequate protection, some patients could spit with force and splash. We would have to be protected, and the population would have to be protected as well" (Loreto border region nurse, 36, woman)*

FGD participants did not have the same reaction of disgust, but, like health professionals, commented that this device less practical due because results required a longer wait time (~ 20 min). Age limits were discussed if sputum was required, but participants felt that if saliva was all that was needed, this would be easy to obtain, even from a newborn.

One Loreto key informant provided other insights that did not emerge in the FGDs. First, devices that did not require any accessories were preferable to those that required procurement of specific supplies (i.e., mouthpiece, RDTs). These supplies often run low or are subject to supply chain issues. Second, the invasive blood-based RDT currently used by the malaria programme differentiates between *P. vivax* and *P. falciparum* and is quite affordable ($1–2 per device). He expressed that the non-invasive diagnostic tools would be more useful for screening campaigns, but final diagnosis requires identification of the infecting species to prescribe appropriate treatment.

#### Use of non-invasive diagnostic tools

Health professionals immediately understood the value of these non-invasive diagnostic tools, expressing that they would be rapid screening devices identifying people for confirmatory testing. One health authority explained that the laboratory can process about 80 thick smears per day, creating a laboratory bottleneck for a screening campaign. Therefore, he said he would use any of these non-invasive diagnostic tools (except for the saliva RDT with a longer processing time) to quickly screen whole populations and follow up with those diagnosed with a positive result.

> *"Who wouldn't want to have an early detection system that tells you whether you have malaria or don't have it? Because often people seek medical attention*

*when it's already advanced. But with this, immediately you know and boom, you're giving pretreatment to go after the disease" (Loreto border inspector, 44, man).*

*"What I imagine right now, with the first two tools that we have seen, is doing various sweeps of the population. If I can, I start with that and I can continue it indefinitely. With a thick smear surveillance campaign, when the program stops, when it reaches its fourth control, after that, the program no longer has any money. The staff is exhausted. Then everyone comes back from the field. But with this, hey, come over here, two hundred plim, plim, plim, plim... Yes, if it can do that, wow! This is the solution, the solution to our problems" (Loreto regional health authority, 60, man).*

Key informants viewed these tests as a welcome addition for smaller health centres in endemic areas with inadequate health infrastructure:

*"I would put it in every micro-network headquarters, where we have febrile units, and in the hospital. That would make it easier for us as we do differential diagnoses. It would be easy to rule out malaria and focus on another disease" (Tumbes regional health authority, 47, woman).*

The informants in Tumbes also suggested that non-governmental organizations located near the border, which assist refugees and other people in need, could use these devices. Health professionals and authorities noted that the new devices would require approval at the MOH level and incorporation into MOH protocols.

Participants agreed they would trust health professionals and CHWs to use these devices and that crucial community partners, including teachers and bodega owners, could also be trained to use the tests. Some opined that these tests should be used when malaria is more prevalent, while others emphasized where these tests should be used in endemic malaria zones or in remote areas with fewer health resources.

### Sensitivity and specificity

Health authorities and professionals were asked what the minimum desired sensitivity or specificity of the non-invasive diagnostic tools should be, and evaluated the theoretical devices based on parameters provided by the study sponsor (Additional File 1). Most pointed out that the thick smear is less sensitive than the theoretical sensitivity of the finger scan and skin odour tests (~90% theoretical sensitivity), albeit when asked about the thick smear sensitivity, the responses ranged from 35 to 98%. Most stated that 80% sensitivity would be acceptable to them, especially if used as a screening tool to reduce the number of people who need follow-up diagnosis or treatment. Respondents were less concerned with test specificity because all positive results would require additional testing to identify the species of malaria:

*"I'm not too worried about the specificity. And even more so, I'm not worried if I treat a false negative. I'm more worried about sensitivity.... Because I want to capture everything and it doesn't matter if I give 50% more in the treatment" (Loreto regional health authority, 60, man).*

### Suggested key characteristics and questions

Health professionals mentioned other characteristics that could make the non-invasive diagnostic tools more useful, such as a long-lasting battery that could be replaced or plugged in to recharge.

*"In the communities where there is no electricity, you know, you've been here several times. Here our highways are our rivers, here we don't have highways. Access roads, here it's rivers, it's 15 days on the river. In the summer, sometimes the river goes down, you can't get out there. That is why for these areas, you have to have special considerations" (Loreto border inspector, 44, man).*

Several health authorities raised the possibility of integrating a data component to input patient name and other basic information that could be linked to the result. This would allow epidemiologists and other health authorities to easily track the number of malaria cases and ensure that those who test positive receive a diagnostic test for adequate treatment and follow-up.

Key informants and community members brought up additional questions and suggestions. Some mentioned wanting proof that the non-invasive diagnostic tools work in settings distinct from the controlled environments where they are developed, including in jungle climates, in non-White populations, in persons exposed to pesticides, and in persons with other conditions like allergies or another infectious disease (TB, dengue, COVID-19). Furthermore, they asked about how long the devices would last (i.e., number of uses), results when battery power was low, and if the devices caused adverse reactions.

## Discussion

Focus group discussions with community members and leaders, health professionals, teachers, and key informants associated with malaria programs in border areas provided mature and well-informed perspectives that

should be considered by individuals and companies developing novel non-invasives tests for malaria and other infectious diseases endemic in low- and middle-income countries. Key findings included: (1) documentation of resistance to finger sticks in many affected communities, especially in the context of large scale screening programs in otherwise healthy people; (2) preferences for devices that could be reused without disposable pieces and did not include bodily fluids, (3) devices that could not identify malaria parasites to species would be useful screening tools, but positive test results would require confirmation with existing methods; and (4) devices should include data capture and transmission.

All participants and authorities appreciated the non-invasive nature of all four diagnostic tools, compared to finger pricks for thick smears or RDTs; however, the level of enthusiasm varied across the different tools. The finger scan and skin odour tests were the most favoured by both the community participants and the health authorities. Both devices would require an initial investment that would pay for itself by reducing the resources associated with collecting, transporting, and analysing thick smears. In malaria endemic areas where routine malaria surveillance is conducted in schools and communities, these non-invasive diagnostic tools would be widely acceptable by the population and would likely improve participation in surveillance screening activities, consistent with previous studies showing that non-invasive diagnostic tools could facilitate screening campaigns by increasing the number of asymptomatic people who would consent to a test, which would facilitate access to malaria treatment for those who tested positive but were not experiencing symptoms [6, 7, 12].

The tools that required single-use supplies (breath test and saliva test) were less acceptable due to the logistical challenges associated with unreliable supply chains and difficulties with transport to remote areas where malaria is a significant public health issue. Concerns about the disposal of packaging and materials associated with RDTs have been described before [7]; however, the clear expression of environmental concerns by all types of respondents were consistent. Product developers should minimize the use of single-use supplies that require disposal.

Additionally, there were other health-related concerns regarding the breath and saliva tests. Prior to the COVID-19 pandemic, saliva-based diagnostic tools for malaria detection were touted as superior to blood-based tests, especially for children [8, 9, 12]. These findings indicate that the pandemic may have created an aversion to saliva-based diagnostic tools by community members due to the perceived risk of respiratory virus infection. Indeed, in the health professionals FGD, some expressed that saliva sample diagnostic tools require PPE, which make them less feasible. For product developers, devices based on breath or saliva were viewed less favourably, given the concerns for disease transmission.

Further, health professionals stressed the importance of incorporating a data system, even if basic, into these devices to capture patient information and test results. Data entry and management represents a burden to current programmes, and authorities require access generated by these devices to determine health needs and priorities.

In addition, due to the initial skepticism among some community members about whether and how well these devices diagnose malaria, adequate health education and promotion about these devices and how they work would be critical. Future research should focus on the types of messages and strategies to generate trust in the devices by communities where these will be used, and device developers should keep these suggestions in mind for non-invasive malaria diagnostic tools for this region.

Health professionals and authorities were extremely enthusiastic about incorporating such devices into their budgets for malaria control. Because the new devices would require MOH approval and incorporation into MOH protocols, international health organizations, such as WHO/PAHO, would need to develop clear recommendations on their use that governments in malaria-endemic areas can rely on to facilitate their approval for use.

#### Limitations and strengths

This study's theoretical descriptions of devices did not include actual prototypes, and estimates of sensitivity and specificity parameters were provided by the study sponsor and do not reflect real world validations across the spectrum of disease (asymptomatic to severe). It is likely that the accuracy of these devices would decrease with lower parasitaemias often observed with asymptomatic infection. It is possible that some respondents would have been less enthusiastic about specific devices if those parameters had not been included in the discussion. Respondents, however, provided their expectation of minimum sensitivity and specificity independent of those provided by the team. Future studies should clearly distinguish between device performance when used as a screening or diagnostic tool.

In addition, Zungarococha is not representative of all malaria-endemic sites within Peru. Zungarococha was selected for FGDs because it had high rates of endemic malaria and was easily accessible. Other malaria-endemic communities within Loreto are only accessible by days of boat travel or by small airplanes. Many of

these sites have distinct contexts (remote and difficult access, drug trafficking, or even some terrorist activity). That said, themes saturation was obtained in the FGDs, and the key informants were knowledgeable about the malaria challenges in their regions. Understanding the malaria situation and regional context was critical for exploring how these devices would be integrated into malaria control programs. A key strength of this study is that it solicited opinions regarding non-invasive diagnostic tools before the technologies are developed. The goal is that community feedback of this kind can influence technological development to optimize community acceptance of these tools.

## Conclusion

Novel non-invasive malaria diagnostic tools can be valuable in malaria-endemic settings, particularly those with difficult terrain and limited access to health facilities and specialized laboratories. This study revealed high enthusiasm for two non-invasive diagnostics—the finger spectrophotometer and the VOC body odour test—and their integration into the malaria prevention and control program in Peru. Participants were not excited about devices that require single-use supplies, given local challenges associated with procurement and disposal of such supplies, nor devices that depend on samples of saliva and breath, due to concerns regarding disease transmission. As manufacturers evaluate the efficacy and effectiveness of these non-invasive diagnostic tools, international recommendations should be created to ensure their agile integration into national malaria programmes. Future research should also focus on how to generate trust in the devices by communities where they will be used.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12936-025-05273-1.

Additional File 1.

Additional File 2.

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**Author contributions**

V.F., S.C., E.M.-C., K.T., S.S. conceptualized the study. V.F. designed the original study protocol, which V.P.S. and A.C.M. adapted to the Peruvian context. V.F., S.C., and E.M.-C. created the visual information sheets. V.F. supervised the study and designed the data collection tools and codebook for the data analysis. S.C. provided the technical support for the study. V.P.S., A.C.M., E.J.R.L., A.S.V.S., and J.J.C.L. performed the data collection and curation. E.O. and L.N. coded and analyzed the data. L.N. drafted the manuscript, and V.P.S., A.C.M., V.F., S.C., and E.M.-C. made substantial edits. All authors read and approved the final manuscript.

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**Availability of data and materials**

No datasets were generated or analysed during the current study.

## Declarations

**Ethics approval and consent to participate**

Our study protocol was approved by the PRISMA (Protocol CE0561.23) Institutional Review Board, based in Lima, Peru, on October 31, 2024.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare no competing interests.

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## Publisher's Note