Jambura Medical and Health Science Journal, Vol.5 No.1 (February 2026)
p-ISSN 2830-0580 | e-ISSN 2830-4608

ORIGINAL ARTICLE **Open Access**

Relationship between Micronutrient Intake and Malaria Infection: A Cross-Sectional Study

Putriani Bua[1,*], Margaretha Solang[1,2], Cecy Rahma Karim[3], Sunarto Kadir[4] , Netty Ino Ischak[5]

[1]Public Health Program Study, Postgraduate School, Gorontalo State University, Gorontalo, Indonesia
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Gorontalo State University, Gorontalo, Indonesia
[3]Department of Nutrition, Faculty of Medicine, Gorontalo State University, Gorontalo, Indonesia
[4]Department of Public Health, Faculty of Sports and Health Science, Gorontalo State University, Gorontalo, Indonesia
[5]Department of Chemistry, Faculty of Mathematics and Natural Sciences, Gorontalo State University, Gorontalo, Indonesia

*Corresponding Author. Email: buaputriani639@gmail.com, Telp: +6285395071201

ABSTRACT

Introduction: The incidence of malaria infection is influenced by several factors, including micronutrient intake. Micronutrient intake is essential for maintaining normal nutritional status and maintaining a healthy immune system. Vitamin A, zinc, and iron are micronutrients that function to boost the immune system. This study aims analyze the relationship between micronutrient intake and the incidence of malaria infection at the Paguat Community Health Center.

Method: This study used a cross-sectional study method with an analytical observational approach. The population in this study consisted of 37 people obtained from the medical records of the Paguat Community Health Center for the period January-July 2025, using total sampling techniques. The study used primary data in the form of questionnaires and 3x24-hour food recall interviews. The 3x24-hour food recall method was calculated using the Nutrisurvey application to determine the nutritional content of each food item. Data analysis was performed using univariate, bivariate, and multivariate methods.

JMHSJ
Jambura Medical and Health Science Journal

Published by:
Universitas Negeri Gorontalo

Mobile number:
+62852 3321 5280

Address:
Jend. Sudirman St. No.6, Gorontalo City, Gorontalo, Indonesia

Email:
jmhsj@ung.ac.id

Article History:
Received 19 November 2025
Accepted 5 January 2026
Published 28 February 2026
DOI:
https://doi.org/10.37905/jmhsj.v5i1.35441

Results: Bivariate analysis showed that micronutrient intake such as vitamin A (*P*-value = 0.680) and iron (*P*-value = 0.080) had no significant association with malaria infection. Meanwhile, zinc micronutrient intake (*P*-value = 0.030) had a significant association with malaria infection. Based on multivariate analysis, *P*-value of 0.025 ($P < 0.05$) was obtained, with a confidence interval (95% CI: 0.035–0.798). Zinc micronutrient intake has a significant effect on the incidence of malaria infection.
Conclusion: The analysis shows no statistically significant relationship between vitamin A and iron intake with malaria infection. Zinc intake is statistically significantly associated with malaria infection.

Keywords: *Anopheles sp*., malaria, nutritional status, *Plasmodium sp.*

Introduction

Malaria is a disease caused by parasites of the genus Plasmodium.[1] *Plasmodium sp.* protozoan parasites are transmitted to humans through the bite of female Anopheles mosquitoes. Malaria is the most life-threatening parasitic disease worldwide, despite various control strategies that have been implemented. Malaria causes deaths or more each year, and children under five years of age are the most vulnerable population to these deaths.[2]

The World Health Organization (WHO) in 2020 stated that in 2019, there were approximately 229 million cases of malaria worldwide, with 94% occurring in Africa. These malaria cases are estimated to have caused 409,000 deaths globally, with 67% occurring in children. Malaria has a negative impact on women's health during pregnancy, childbirth, and the postnatal period.[3] Malaria is also endemic in India and many countries in Southeast Asia.[4] Indonesia is one of the countries in Southeast Asia with the second highest number of malaria cases after India.[5] Although Indonesia's annual parasite incidence declined from 2010 to 2014, progress stagnated between 2015 and 2019.[6]

Malaria is largely concentrated in Eastern Indonesia, with 27 districts and cities showing high endemicity.[6] In 2019, Papua Province accounted for 86% of the highest malaria cases in Indonesia. Papua consistently has the highest incidence of malaria in the country.[7]

Gorontalo Province is one of the provinces with a fairly high incidence of malaria. One of the areas affected by malaria from 2023 to 2025 is Pohuwato Regency. A sharp increase in malaria cases, particularly in mining areas, was the main factor in determining this status. Based on epidemiological investigations, it was revealed that there was malaria transmission that met the criteria for an outbreak. Since 2023, the early warning system in use has indicated the potential for a malaria outbreak in Pohuwato Regency. The number of malaria cases in

Pohuwato has increased, with 814 cases recorded throughout 2023, 824 cases in 2024 accompanied by two deaths, and 170 new cases reported as of February 2025. Of the total 170 malaria cases recorded in 2025, approximately 56% originated from the mining area in Hulawa Village, 18% from the mine in Puncak Jaya Village, and the remaining 10% from Karya Baru Village.[8]

The results of a survey conducted by an emergency response team led by the Deputy Regent of Pohuwato in 2025, in an epidemiological investigation and vector survey, identified the habitat of Anopheles mosquitoes, the main vector for the spread of malaria, showing that one breeding site can reach several villages within a 2 km radius. These malaria cases occurred in the productive age group, namely 19 to 59 years old, with 95% of sufferers being men who work as miners, especially people who are active around mining sites.

Based on interviews with malaria officials, Paguat is one of the areas that has reported a spike in malaria cases. This was conveyed through an interview with one of the malaria officers at the Paguat Community Health Center, who stated that they have been receiving malaria patients since 2023. Malaria cases have become a concern due to mining activities that cause malaria infections, especially in the Paguat Community Health Center's working area.

Malaria infection is not only influenced by humans, mosquito, parasite, and environmental factors, but also by an individual's nutritional status. A person's nutritional status can be defined as the result of the intake of nutrients received and nutritional needs and their utilization to maintain nutrient reserves in the body.[9] An individual's nutritional status is influenced by various factors, including the intake of micronutrients through an individual's diet. Micronutrient intake consists of several vitamins and minerals such as vitamin A, iron, and zinc. Micronutrient intake is important for maintaining normal nutritional status so that the immune system is well maintained. Micronutrients such as vitamins and minerals function to boost the body's immunity through several mechanisms.[10] Research shows that an inappropriate diet can increase a person's risk of experiencing nutritional deficiency or excess.[11] Micronutrients include vitamin A, zinc, and iron, and their deficiency is often associated with a higher susceptibility to diseases such as malaria. Micronutrient deficiency has been linked to various infections, including malaria-related morbidity.[12]

Studies show that vitamin A in the form of retinol is used for immune cell development. Vitamin A is necessary for the development and function of T cells, a type of white blood cell that plays an important role in the immune response to malaria.[10] Vitamin A deficiency can impair the ability of T cells to kill malaria parasites.[12]

Iron has a complex relationship with malaria because it affects infection through several opposing mechanisms. Iron deficiency can decrease erythropoiesis and reticulocyte production, thereby inhibiting the growth of Plasmodium, particularly *P. vivax*, which selectively infects red blood cells.[13] Morevoer, Zinc is an essential micronutrient required by the body. Zinc deficiency significantly affects antibody levels in varying malaria statuses and age groups.[14]

Nutrient deficiencies can cause disturbances in the immune response, where nutrients modulate metabolic processes that include the activation or inhibition of enzymes or immunoregulatory mediators that can result in changes in cellular immune function, especially in T lymphocyte-derived cells.[15] Many micronutrients and macronutrients that are essential for humans are also essential for parasites, making the host's nutritional status relevant not only to an adequate immune response but also to the development of the organism itself.[16] Intake of micronutrients such as vitamins and minerals functions to enhance immunity through several mechanisms.[10]

Thus, micronutrient and macronutrient deficiencies can affect an individual's immunity, making them more susceptible to disease or increasing the severity of disease in individuals. Therefore, this study aims to analyze the relationship between micronutrient intake and malaria infection incidence at the paguat community health center.

Methods

This study used a quantitative method with a cross-sectional study design. The study was conducted in the working area of the Paguat Community Health Center, Pohuwato Regency, Gorontalo Province. Data collection was carried out over a period of 2 months, from September to October 2025. The Health Research Ethics Committee of Gorontalo State University approved this study with number 162A/UN47.B7/KE/2025.

The population in this study is all patients suffering from malaria infection and having a history of malaria based on observations at the Paguat Community Health Center during the period from January to July 2025, totaling 37 people. The sample consisted of 37 people, selected using total sampling techniques.

Respondents in this study were drawn from medical records at the Paguat Community Health Center for the period January-July 2025. Initially, all respondents met the criteria for the target population through a screening process. The inclusion criteria were respondents with recorded age, gender, weight, tuberculosis (TB), and a history of malaria; respondents aged 15-64 years who had previously received malaria treatment and who had good communication skills. Exclusion criteria included patients with severe chronic illnesses such as tuberculosis; respondents experiencing acute infections (high fever and severe symptoms); patients with a history of severe anemia; and those unwilling to participate in the data collection process. The entire data collection process after determining the criteria was conducted by visiting all patients selected for the study.

The dependent variable is the incidence of malaria infection, while the independent variables are micronutrient intake (vitamin A, iron, and zinc). Data were collected using a questionnaire for the dependent variable and a 3x24-hour food recall for the independent variable, namely micronutrient intake. The objective criteria for iron, zinc, and vitamin A intake were based on recommended dietary allowance (RDA).

Data analysis was performed using SPSS software. The data analysis in this study used an ordinal measurement scale, with univariate testing in the form of frequency distribution, bivariate using Fisher's exact test because the variables did not meet the chi-square test. Multivariate analysis (binary logistics) was used to assess the most relevant variables. The significance limit chosen was $P < 0.05$.

Result

The characteristics of the sample in this study were age, gender, and occupation. Table 1 shows the frequency distribution of respondents' gender with a 95% confidence interval. There were 36 male respondents (97.3%) and one female respondent (2.7%). The frequency distribution of respondents' ages was obtained. There were six respondents aged 19-23 years with a percentage of 16.2%, three respondents aged 24-28 years with a percentage of 8.1%, nine respondents aged 29-33 years, nine respondents aged 34 38 years with a percentage of 24.3%, two respondents aged 59-63 years with a percentage of 5.4%. The table shows that the respondents in the study ranged in age from 19 to 63 years. The largest age groups were 29-33 years and 34-38 years, each with nine people (24.3%). Meanwhile, the smallest age group was 49-53 years, with one person (2.7%). The frequency distribution of respondents' occupations shows that most of them work as mine laborers, namely 33 people (89.2%). A small number work as construction workers, namely three people (8.1%), and one person (2.7%) work as a farmer.

Table 2 shows the results of the frequency distribution of micronutrient intake, with 30 people (81.1%) classified as deficient in vitamin A intake, two people (5.4%) classified as adequate, and five people (13.5%) classified as excessive. These results indicate that most respondents do not meet their daily vitamin A intake requirements. Iron intake is divided into three categories, with most respondents having exceeded intake, namely 20 people (54.1%), 10 people (27.0%) in the adequate category, and seven people (18.9%) in the deficient category. These results indicate that most respondents have sufficient or higher than adequate daily iron intake. For zinc intake, most respondents were in the deficient category, totaling 26 people (70.3%), while only 11 people (29.7%) were in the adequate category. These results indicate that most respondents did not meet their optimal daily zinc requirements.

Table 1. Respondent characteristics analysis (N=37).

Characteristics	Frequency	Percentage (%)
Gender		
Male	36	97.3
Female	1	2.7
Age (in years old)	6	16.2
19-23	3	8.1
24-28	9	24.3
29-33	9	24.3
34-38	5	13.5
39-43	1	2.7
49-53	2	5.4
54-58	2	5.4
59-63	6	16.2
Occupation		
Mining worker	33	89.2
Construction worker	3	8.1
Farmer	1	2.7

In Table 3, most respondents in this study experienced malaria infection, totaling 21 respondents (56.8%). Meanwhile, 16 respondents (43.2%) did not experience malaria. The results of the study indicate that the study population is still at risk of malaria exposure based on the observation period. The next step was to conduct a bivariate analysis to determine the relationship between the two variables. Zinc intake was obtained by calculating the total zinc intake for 3 days using a 24-hour food recall. Zinc intake was based on the Recommended Nutrient Intake in Permenkes No. 28 of 2019.

Based on Table 4, it was found that 16 respondents (53.3%) who suffered from malaria had deficient vitamin A intake, while three respondents (60.0%) had exceeded vitamin A intake. Many respondents who did not suffer from malaria were found in the group with deficient vitamin A intake, numbering 14 people (45.7%). The statistical test results showed a

P-value of 0.680 ($P > 0.05$), indicating no significant relationship between vitamin A intake and the incidence of malaria infection.

Table 2. Frequency distribution of micronutrient intake (N=37).

Micronutrient intake	Frequency	Percentage (%)
Vitamin A		
Deficient	30	81.1
Adequate	2	5.4
Exceeded	5	13.5
Iron		
Deficient	7	18.9
Adequate	10	27.0
Exceeded	20	54.1
Zinc		
Deficient	26	70.3
Adequate	11	29.7

Table 3. Frequency distribution of malaria infection incidence (N=37).

Malaria Incidence	Frequency	Percentage (%)
Positively Diagnosed	21	56.8
Negatively Diagnosed	16	43.2

Table 4. Relationship between vitamin A intake and malaria infection incidence at Paguat Community Health Center.

Vitamin A Intake	Malaria Incidence				*P-value*
	Positively Diagnosed		Negatively Diagnosed		
	n	%	n	%	
Deficient	16	53.3	14	46.7	**0.680**
Adequate	2	100.0	0	0	
Exceeded	3	60.0	2	40.0	
Total	**21**	**56.8**	**16**	**43.2**	

Fisher exact test

Based on Table 5, respondents with low iron intake had the highest proportion of malaria sufferers, namely six people (85.7%), while those who did not suffer from malaria were mostly in the group with exceeded iron intake, namely 12 people (60.0%). The statistical test results showed a *P*-value of 0.080 ($P > 0.05$), indicating no significant relationship between iron intake and malaria infection incidence.

Table 5. Relationship between iron intake and malaria infection incidence at Paguat Community Health Center.

Iron Intake	**Malaria Incidence**				***P-value***
	Positively Diagnosed		**Negatively Diagnosed**		
	n	**%**	**n**	**%**	
Deficient	6	85.7	1	14.3	**0.080**
Adequate	7	70.0	3	30.0	
Exceeded	8	40.0	12	60.0	
Total	**21**	**56.8**	**16**	**43.2**	

Fisher exact test

Table 6 shows the relationship between zinc intake and the incidence of malaria infection. Respondents with deficient zinc intake had a higher proportion of malaria patients, namely 18 people (69.2%), compared to those with adequate zinc intake, namely three people (27.3%). The statistical test results obtained a *P*-value of 0.030 ($P < 0.05$), which means that there is a significant relationship between zinc intake and the incidence of malaria infection. Zinc intake in the deficient category is associated with an increased risk of malaria. Zinc intake, as a variable related to the incidence of malaria infection, was further tested using multivariate analysis to analyze the effect of zinc micronutrient intake. A simple logistic regression analysis in the form of Binary Logistic was performed with the following results.

Table 7 shows the logistic regression analysis to predict the probability of an event occurring. The interpretation of the probability calculation from the logistic regression model obtained a value of $y = 0.981$ for the category of respondents with low zinc intake ($X = 0$). The probability of malaria occurrence is $p = 0.722$ or 72.2%. This indicates that respondents with low zinc intake have a 72.2% chance of contracting malaria. Based on the interpretation results, a value of $y = -0.748$ was obtained for the category of respondents with good intake ($X = 1$). After being entered into the logistic equation, the probability of malaria occurrence was obtained as $p = 0.321$ or 32.1%. This result shows that respondents with good zinc intake have a 32.1% chance of experiencing malaria.

Table 6. Relationship between zinc intake and malaria infection incidence at Paguat Community Health Center

Zinc Intake	Malaria Incidence				*P-value*
	Positively Diagnosed		Negatively Diagnosed		
	n	%	n	%	
Deficient	18	69.2	8	30.8	**0.030***
Adequate	3	27.3	8	70.0	
Total	**21**	**56.8**	**16**	**43.2**	

*Significant at *P*<0.05. Fisher exact test

Table 7. Multivariate analysis of zinc intake and malaria infection incidence at the Paguat Health Center.

Variable	B	S.E.	Wald	df	Sig.	Exp (B)	95% CI for Exp (B)	
							Lower	Upper
Zinc intake	-1.729	0.799	5.025	1	0.025	0.167	0.035	0.798
Constant	0.981	0.677	2.099	1	0.147	2.667		

Simple logistic regression test

Discussion

Based on the analysis results, vitamin A and iron intake did not have a significant relationship with malaria incidence. Meanwhile, the related variable was zinc intake, obtained from bivariate and multivariate tests.

Relationship between Vitamin A micronutrient intake and malaria infection

Based on the analysis results, there was no significant relationship between vitamin A intake and the incidence of malaria infection. Variations in vitamin A intake among respondents did not directly affect the risk of malaria. Several studies have stated that vitamin A does not provide meaningful protection against Plasmodium infection. For example, studies conducted by Sandalinas et al. state that vitamin A is not always dominant in overcoming malaria infection, because malaria infection can reduce retinol (vitamin A) levels as an inflammatory response, which does not always indicate that vitamin A directly prevents malaria.[17] In addition, it is possible that studies using respondents as samples did not categorize the samples based on the requirement of having other diseases that may affect vitamin A metabolism.[18]

The relationship between iron micronutrient intake and malaria infection incidence

The analysis results show no significant relationship between iron intake and the incidence of malaria infection. This is due to the limitations of the study, which may have prevented any relationship from being identified. In previous study, it was shown that a lack of representative or non-representative samples could be one of the influencing factors, so that the statistical model used was unable to control for other confounding factors. In addition, there are several other factors that influence the incidence of malaria infection, including environmental factors, age, genetics, and exposure to malaria infection.[19]

The relationship between zinc micronutrient intake and the incidence of malaria infection

The bivariate analysis results show that zinc micronutrient intake has a significant relationship with the incidence of malaria infection. The results of the multivariate analysis of zinc intake and the incidence of malaria infection at the Paguat Community Health Center obtained a B value of -1.729, which means it has a negative relationship. This value interprets that the better the zinc intake, the lower the chance of contracting malaria. The standard error (S.E.) shows a value of 0.0799, which means it is still within reasonable limits or the model is quite stable, not too large. This means that the smaller the S.E. value, the more stable the model estimation.

Meanwhile, the Wald value produced for zinc intake of 5.025 indicates a fairly strong or significant effect on the dependent variable (incidence of malaria infection). The value $p = 0.025$ ($p < 0.05$) illustrates that zinc intake has a significant effect on the incidence of malaria infection. The Exp(B) value of 0.167 means that respondents with adequate zinc intake have a 0.167 times greater chance of contracting malaria than respondents with low zinc intake. The confidence interval (95% CI: 0.035–0.798) does not exceed 1, which reinforces the significance of the relationship between these variables. The constant value of 0.981 ($p = 0.05$) is not significant, but it is still needed as a component of the logistic regression equation. The results of this study indicate that there is a significant relationship between zinc intake and the incidence of malaria infection; low zinc intake increases the likelihood of malaria infection. These results are consistent with the study conducted by Sakwe et al. which shows a synergistic relationship between malaria incidence and malnutrition conditions such as nutritional deficiencies.[20]

The body requires adequate nutrient intakes for all its functions to operate optimally. Several types of micronutrients play an important role in supporting the immune system. Good nutrition has great potential in preventing and controlling infectious diseases, including malaria, by providing sufficient micronutrients to strengthen the body's resistance. Thus, good nutritional status contributes to improving the body's defense mechanisms and makes individuals more resistant to malaria infection. Micronutrient deficiencies also have a major impact on reducing immunity, making individuals more susceptible to infectious diseases. Several nutrients such as carotenoids, vitamins A, C, E, selenium, and zinc are known to have immunomodulatory properties, where changes in the intake of these nutrients can affect immune function in both experimental models and humans.[21]

Zinc is a micronutrient that has significant immune modulation functions.[22] Zinc is a fundamental trace element in nutrition and is the second most abundant trace metal in the human body after iron. The total zinc content in the human body is 2–4 g, with a plasma concentration of 12–16 µM. Although it is a small plasma pool, zinc is exchangeable and moves rapidly. Adequate daily zinc intake is necessary to maintain stable conditions because, unlike iron, the body does not have a specific system for absorbing zinc. The highest concentrations of zinc are found in muscles, bones, skin, and liver.[23]

In humans, zinc deficiency is known to increase the risk of plasmodium infection and susceptibility to viral infections. Zinc plays a role in many metabolic and chronic diseases such as diabetes, cancer (esophagus, small cell oral carcinoma, breast cancer), and neurodegenerative diseases. There is also strong evidence linking zinc deficiency to several infectious diseases such as malaria, HIV, tuberculosis, measles, and pneumonia.[23]

Malaria parasites use zinc to protect themselves from attacks by the immune system (oxidative burst) in infected individuals, causing a decrease in zinc levels in the blood (plasma) of malaria patients.[22] According to the WHO, zinc deficiency is currently the fifth leading cause of death and morbidity in developing countries. It is estimated that about one-third of the world's population is zinc deficient. Globally, zinc deficiency contributes to approximately 18% of malaria cases. Although severe zinc deficiency is rare, mild to moderate deficiency is more common.[23] Zinc deficiency is associated with impaired immune function, resulting in increased morbidity from infection, growth disorders, and liver dysfunction. Therefore, zinc deficiency in infected humans may be a nutritional adaptation to endemic disease. Zinc deficiency is primarily related to dietary patterns; zinc is most abundant and easily absorbed from animal proteins, while consumption of vegetables and cereals reduces its absorption due to zinc binding to phytate.[22]

Zinc is found in many food groups, and its concentration and bioavailability vary greatly. Foods with the highest zinc concentrations include red meat, some shellfish, nuts, fortified cereals, and whole grains.[23] Zinc from animal sources has higher bioavailability than zinc from plant sources. People who do not consume red meat, vegetarians, and people living in developing countries who rely primarily on plant-based foods are at higher risk of zinc deficiency due to inadequate zinc intake.[24] This consumption pattern causes zinc deficiency.

Malaria, a type of infectious disease, can potentially cause nutritional immunity, which is when the host organism absorbs trace minerals during infection, limiting their availability to pathogens. Zinc is an essential trace element for both the host and the pathogen. Pathogens need zinc to survive, reproduce, and cause disease. This triggers a competitive process between the host and the invading pathogen. There are three mechanisms that allow the host to compete for zinc and create a zinc-deficient environment for the pathogen. However, some pathogens have developed tactics to overcome some of these mechanisms. At the systemic level, the distribution of zinc in the body changes. This mainly involves a small amount of free zinc that is not bound in plasma because 99.9% of zinc remains inside cells and is not directly accessible to pathogens. During infection, plasma zinc levels decrease dramatically.[25]

Study limitations

This study used a cross-sectional design, which is limited in nature and associative, and cannot explain cause-and-effect relationships. The food recall method relies on respondents' memory, which may lead to recall bias and unavoidable errors in estimating consumption portions. This study did not measure nutritional status biomarkers. The relatively small sample size affects the statistical power of the analysis. Confounding factors that could influence the variables were not considered in this study.

Conclusion

Micronutrient intake of vitamin A and iron does not have a significant association with the incidence of malaria infection. Respondents with micronutrient zinc intake have a significant association; zinc deficiency provides a greater opportunity for malaria infection compared to individuals with adequate zinc intake.

Conflicts of Interest

The authors have no conflicts of interest in reporting.

Funding sources

This study was self-funded by the researcher.

Acknowledgment

The researchers would like to thank all those who have helped.

References

1. Malik LH, Hilmi IL, Salman S. Review Artikel: Hubungan Status Gizi Dengan Malaria Pada Balita. *J Pharm Sci*. 2023:261–5.

2. Kodio A, Coulibaly D, Doumbo S, Konaté S, Koné AK, Dama S, et al. Gut microbiota influences Plasmodium falciparum malaria susceptibility. *New Microbes New Infect*. 2025; 65:101586.
3. World Health Organization. World malaria report 2020 [Internet]. WHO. 2020 [cited 2025 Apr 3]. Available from: https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2020
4. Nauriyal D, Kumar D. Study of complex associations between severe malaria and malnutrition in pediatric age group. *Clin Epidemiol Glob Health*. 2022; 15:101065.
5. Ngonghala CN. The impact of temperature and decay in insecticide-treated net efficacy on malaria prevalence and control. *Math Biosci*. 2023; 355:108936.
6. Setianingsih E, Sulistyaningrum E. The impact of the malaria centre program on malaria incidence in Papua Province. *Public Health Pract*. 2025; 9:100625.
7. Fadilah I, Djaafara BA, Lestari KD, Fajariyani SB, Sunandar E, Makamur BG, et al. Quantifying spatial heterogeneity of malaria in the endemic Papua region of Indonesia: Analysis of epidemiological surveillance data. *Lancet Reg Health Asia*. 2022; 5:100051.
8. Dinas Kesehatan Provinsi Gorontalo. Tanggap Darurat KLB Malaria di Kabupaten Pohuwato: Upaya Penanggulangan dan Tantangan yang Dihadapi [Internet]. Dinkes Provinsi Gorontalo. 2025 [cited 2025 Aug 18]. Available from: https://dinkes.gorontaloprov.go.id/tanggap-darurat-klb-malaria-di-kabupaten-pohuwato-upaya-penanggulangan-dan-tantangan-yang-dihadapi/
9. Fernández-Lázaro D, Seco-Calvo J. Nutrition, nutritional status and functionality. *Nutrients*. 2023; 15(8):1944.
10. Gombart AF, Pierre A, Maggini S. A review of micronutrients and the immune system–working in harmony to reduce the risk of infection. *Nutrients*. 2020; 12(1):236.
11. Espinosa-Salas S, Gonzalez-Arias M. Nutrition: micronutrient intake, imbalances, and interventions. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023.
12. Dinga JN, Anu EF, Feumba RD, Qin HW, Ayah F, Ayiseh RB, et al. Micronutrient biomarkers and their association with malaria infection in children in Buea Health District, Cameroon. *Trop Med Infect Dis*. 2024; 9(12):303.
13. Unger HW, Bleicher A, Ome-Kaius M, Aitken EH, Rogerson SJ. Associations of maternal iron deficiency with malaria infection in a cohort of pregnant Papua New Guinean women. *Malar J*. 2022; 21(1):153.
14. Mbugi EV, Den Hartog GD, Veenemans J, Chilongola JO, Verhoef H, Savelkoul HFJ. Nutrient Deficiencies and Potential Alteration in Plasma Levels of Naturally Acquired

Malaria-Specific Antibody Responses in Tanzanian Children. *Front Nutr*. 2022; 9:872710.

15. Ibrahim KS, El-Sayed EM. Potential role of nutrients on immunity. *Int Food Res J.* 2016; 23(2):464-74.
16. Yadav CP, Hussain SSA, Pasi S, Sharma S, Bharti PK, Rahi M, et al. Linkages between malaria and malnutrition in co-endemic regions of India. *BMJ Glob Health*. 2023; 8(1):e010781.
17. Sandalinas F, Filteau S, Joy EJM, de la Revilla LS, MacDougall A, Hopkins H. Measuring the impact of malaria infection on indicators of iron and vitamin A status: a systematic literature review and meta-analysis. *Br J Nutr*. 2023; 129(1):87–103.
18. Gupta PM, Madewell ZJ, Gannon BM, Grahn M, Akelo V, Onyango D, et al. Hepatic Vitamin A Concentrations and Association with Infectious Causes of Child Death. *J Pediatr*. 2024; 265:1113816.
19. d'Avila Ferreira E, Alexandre MA, Salinas JL, de Siqueira AM, Benzecry SG, de Lacerda MVG, et al. Association between anthropometry-based nutritional status and malaria: a systematic review of observational studies. *Malar J*. 2015; 14(1):346.
20. Sakwe N, Bigoga J, Ngondi J, Njeambosay B, Esemu L, Kouambeng C, et al. Relationship between malaria, anaemia, nutritional and socio-economic status amongst under-ten children, in the North Region of Cameroon: A cross-sectional assessment. *PLoS One*. 2019; 14(6):e0218442.
21. Onukogu SC, Ibrahim J, Ogwuche RA, Jaiyeola TO, Adiaha MS. Role of nutrition in the management and control of malaria infection: a review. *World Sci News*. 2018; 107:58–71.
22. Poojary TL, Sudha K, Sowndarya K, Durgarao Y. Biochemical role of zinc in vivax malaria. *Biomedica*. 2023; 43(1):281.
23. Gammoh NZ, Rink L. Zinc in infection and inflammation. *Nutrients*. 2017; 9(6):624.
24. King JC, Brown KH, Gibson RS, Krebs NF, Lowe NM, Siekmann JH, et al. Biomarkers of Nutrition for Development (BOND)—zinc review. *J Nutr*. 2016; 146(4):858S-885S.
25. Hennigar SR, McClung JP. Nutritional immunity: starving pathogens of trace minerals. *Am J Lifestyle Med*. 2016; 10(3):170–3.