

# Infectious Disease and Maternal Factors Associated with Stunting among Children in Mimika, Central Papua: A Case–Control Study

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## ABSTRACT

Child stunting persists as a critical nutritional challenge in Indonesia, with a disproportionately high burden in its eastern provinces, where infectious diseases are endemic. This study aimed to identify the determinants of stunting among children aged 24–59 months in Mimika District, Papua Tengah. A retrospective case–control study was carried out in the service area of the Pasar Sentral Primary Health Center. The analysis included 330 children aged 24–59 months, including 110 stunted cases and 220 controls, who were recruited from the same community health posts; controls were selected using simple random sampling with a 1:2 case-to-control ratio. Information was obtained through structured interviews with caregivers and the verification of health records, including maternal and child health books and the electronic community-based nutrition recording system (e-PPGM). The associations between potential risk factors and stunting were evaluated using chi-square tests, followed by multivariable logistic regression analysis. A history of infectious disease had the strongest association (aOR 4.81; 95% CI 2.69–8.58). Additional factors associated with stunting were household income below the provincial minimum wage (aOR 3.52; 95% CI 1.98–6.26), low maternal education (aOR 2.92; 95% CI 1.63–5.23), low birth weight (aOR 2.78; 95% CI 1.37–5.64), incomplete immunization (aOR 2.21; 95% CI 1.24–3.94), lack of exclusive breastfeeding (aOR 2.32; 95% CI 1.29–4.16), incomplete antenatal care visits (aOR 1.96; 95% CI 1.10–3.49), and maternal anemia during pregnancy (aOR 1.85; 95% CI 1.04–3.30). Integrated strategies focusing on infection prevention, maternal and child health services, and household living conditions are needed to reduce stunting in malaria-endemic areas.

Keywords: Stunting; infectious disease; low birth weight; maternal health; socioeconomic factors; Papua

## INTRODUCTION

Globally, linear growth failure, as reflected by stunting, remains a fundamental marker of chronic undernutrition during early childhood. The 2023 Joint Malnutrition Estimates indicated that approximately 148.1 million children under five years were stunted globally in 2022, with the highest burden in South Asia and sub-Saharan Africa <sup>1</sup>. In Indonesia, the 2023 Indonesian Health Survey (Survei Kesehatan Indonesia, SKI) recorded a national stunting prevalence of 21.5%, placing the country among those with significant child undernutrition in Southeast Asia <sup>2</sup>. Beyond physical consequences, childhood stunting is associated with long-term outcomes including impaired cognitive development, reduced adult economic productivity, and increased noncommunicable disease risk <sup>3</sup>.

Papua Province, and Mimika District in particular, faces a concurrent burden of stunting and infectious disease. According to the 2022 Indonesian Nutritional Status Survey (SSGI), stunting prevalence across the four Papuan provinces reached 34.6%, exceeding the national average of 21.6%, with Mimika region recording 33.0% <sup>2, 4</sup>. At the same time, Mimika is one of the highest malaria-endemic districts in Indonesia, reporting 77,379 cases in 2022, with *P. falciparum* and *P. vivax* co-endemic in the lowland areas <sup>5</sup>. The district's large-scale mining operations have introduced sustained economic immigration, placing non-immune populations in a perennial malaria transmission environment <sup>6</sup>. Among the consequences of malaria in pregnancy is an increased risk of low birth weight (LBW) through placental dysfunction and impaired nutrient transfer pathway documented in Jayapura and Keerom, where *P. vivax* was the predominant species involved <sup>7</sup>. LBW is an established risk factor for stunting during childhood <sup>3, 8</sup>.

Child growth is shaped by complex interactions among biological, environmental, and socioeconomic factors. The UNICEF framework categorizes stunting determinants into immediate (inadequate diet, infectious diseases), underlying (household food security, care practices, health service access), and basic levels (structural socioeconomic conditions) <sup>3</sup>. Infectious diseases, including malaria, acute respiratory infections (ARIs), and diarrhea, are consistently associated with impaired linear growth <sup>9, 10, 11</sup>. Maternal health conditions, particularly anemia during pregnancy, are also linked to poor fetal growth and adverse birth outcomes <sup>12</sup>. From a socioeconomic perspective, low household income and limited maternal education may restrict access to adequate nutritional and maternal health services <sup>13</sup>. These conditions may also influence exclusive breastfeeding <sup>14</sup> and reduce the coverage of complete basic immunization, which plays an important role in preventing recurrent infections <sup>15</sup>. Maternal age, categorized as high risk (<20 years or >35 years), has also been

identified as an important determinant because biological immaturity or declining reproductive capacity can affect pregnancy outcomes<sup>16</sup>. In Mimika, these factors are further compounded by geographic remoteness, limited access to primary health services, and a heterogeneous population with varying levels of health service utilization<sup>6</sup>.

Prior research from Papua has begun to delineate the malaria–growth relationship in this specific context. A study by Sahiddin et al. (2024) in Jayapura revealed that malaria exposure during early life was associated with stunting in bivariate analysis, with an increased risk observed for both malaria during pregnancy and malaria in children under one year of age. A subsequent study by Felle and Sahiddin<sup>17</sup> using Mantel–Haenszel analysis reported no significant confounding variables (changes in coefficients <10% for all tested variables) in the relationship between maternal malaria and stunting, suggesting that maternal malaria remained an independent risk factor. However, these studies were conducted in Jayapura and focused primarily on malaria-related variables. Studies integrating infectious disease exposure, maternal factors, and socioeconomic conditions within a single multivariable analytical framework remain limited. Furthermore, the epidemiological context of Mimika District, which has different malaria endemicity patterns and a more heterogeneous population, has received relatively little attention in previous research.

Prior studies from Papua have examined the malaria–stunting relationship in specific settings. Sahiddin, Ishak<sup>18</sup> demonstrated in a case-control study in Jayapura that malaria exposure during early life was independently associated with stunting, with elevated odds for both maternal malaria and malaria in children under one year. Felle and Sahiddin<sup>17</sup> subsequently confirmed, using Mantel–Haenszel analysis, that maternal malaria remained an independent risk factor after adjustment for potential confounders. Both studies, however, were conducted in Jayapura and Keerom and focused primarily on malaria-related variables, without examining maternal health and household socioeconomic factors within a single multivariable framework. The epidemiological and socioeconomic context of Mimika District has received comparatively little attention in this literature.

This study therefore examined the determinants of stunting among children aged 24–59 months in Mimika District, Papua Tengah Province, integrating infectious disease history, maternal health, and household socioeconomic factors within a single multivariable analytical framework. Findings aim to inform maternal and child health interventions in regions where malaria and undernutrition remain concurrent public health challenges.

## MATERIALS AND METHODS

### Study design

A retrospective unmatched case–control design was used in this study. Children aged 24–59 months were recorded as stunted in the electronic Community-Based Nutrition Recording and Reporting System (e-PPGM) of Pasar Sentral Primary Health Center. Stunting was defined as a height-for-age Z score (HAZ) less than 2 standard deviations, according to the 2006 WHO Child Growth Standards. The controls were children from the same catchment area and age range identified from the same e-PPGM records at community health posts (posyandu), with HAZ values  $\geq -2$  SD. This design allowed estimation of associations between potential determinants and stunting, presented as odds ratios.

### Study setting

The study was conducted in the catchment area of the Pasar Sentral Primary Health Center, Mimika District, Papua Tengah Province, Indonesia. This health center manages 21 community health posts across urban and peri-urban locations. Mimika District has high malaria endemicity and, according to the 2022 Indonesian Nutritional Status Survey (SSGI), a stunting prevalence above the national average. Data collection occurred from January to May 2025. Exposure information was obtained retrospectively through structured interviews with mothers or primary caregivers and a review of community health post records and Maternal and Child Health (MCH) books.

### Sampling

Sample size was calculated using the Kelsey formula for unmatched case–control studies. Assumptions included a 95% confidence level ( $Z\alpha = 1.96$ ), 80% power ( $Z\beta = 0.84$ ), an exposure prevalence among controls of 0.35 on the basis of previous Papua studies, and a minimum detectable odds ratio of 2.0. The calculation yielded a minimum of 100 cases and 200 controls. After allowing for a 10% nonresponse rate, the final sample comprised 110 cases and 220 controls, totaling 330 participants. Eligibility criteria for both cases and controls included children aged 24–59 months who had resided in the health center catchment area for at least six months and whose parents or guardians provided consent to participate in the study. Children with congenital anomalies, chronic diseases that could affect growth, or incomplete medical records were excluded from the study. Controls were recruited from the same community health posts (posyandu) as the cases using simple random sampling with a case-to-control ratio of 1:2. The sampling frame for controls was constructed from the e-PPGM register

at each *posyandu* within the catchment area. Eligible controls were listed per *posyandu*, and selection was carried out using a random number table to achieve the required ratio.

### Study variables

The primary outcome was stunting status. The independent variables included three domains: child factors (history of infectious disease in the preceding three months (malaria, acute respiratory infection, diarrhea, or coinfection, which were grouped into a single composite exposure variable given their shared pathway of increasing infection burden and nutritional deterioration, and because the sample size did not permit reliable disease-specific subgroup analysis), sex, low birth weight (<2,500 g), immunization completeness, exclusive breastfeeding), maternal factors (education level, age at childbirth, anemia during pregnancy, early breastfeeding initiation, antenatal care adequacy), and household factors (income relative to Papua Tengah's provincial minimum wage, birth spacing).

### Data sources and measurement

Data were compiled from primary and secondary sources. Primary data collection involved structured interviews with mothers or primary caregivers using a prevalidated questionnaire. Secondary data included birth weight, immunization records, antenatal care visits, and anthropometric measurements extracted from the e-PPGM, Maternal and Child Health (MCH) books, and Child Growth Monitoring Cards (KMS). Information on infectious disease episodes was collected from caregiver reports of diagnoses made by health professionals during the three months preceding the interview; these reports were subsequently crosschecked against visit records from community health posts or primary health centers. Immunization completeness was determined according to the Indonesian national immunization schedule, which includes BCG, three doses of DPT-HB-Hib, four doses of polio vaccine, and the measles-MR vaccine. Exclusive breastfeeding was operationalized as the practice of feeding infants solely breast milk, with no additional foods or liquids, throughout the first six months after birth. Maternal anemia during pregnancy was defined as a haemoglobin level below 11 g/dL, as recorded in the MCH book based on laboratory results obtained during antenatal care visits. Antenatal care adequacy was classified according to the Indonesian Ministry of Health standard: complete if the mother had at least six ANC visits during pregnancy (K6), and incomplete if fewer than six visits were recorded.

Household income was classified relative to the 2024 provincial minimum wage for Papua Tengah, set at IDR 4,024,270 per month; households were categorized as either below or above this threshold. Anthropometric measurements were carried out by trained enumerators, who adhered to standardized WHO procedures. Interobserver reliability for these measurements was assessed using the intraclass correlation coefficient (ICC), with values of 0.90 or higher considered acceptable.

### Bias control

Selection bias was minimized through several methodological procedures. Cases and controls were identified using e-PPGM records derived from anthropometric measurements conducted by trained health personnel, thereby reducing the risk of misclassification of stunting status. Controls were drawn from the same community health posts (*posyandu*) as the cases to minimize potential differences in environmental exposure between groups. Information bias was addressed through the use of standardized questionnaires and enumerator training prior to data collection. Enumerators were not informed of participants' case or control status, and a unified data collection form was used throughout to prevent inadvertent unmasking. Birth weight and immunization history were verified using maternal and child health (MCH) books rather than relying solely on maternal recall. Recall bias related to infectious disease history was limited by the restriction of the reporting period to the previous three months. Potential confounding was controlled for using multivariable binary logistic regression, with all relevant variables included simultaneously in the analytical model. Internal validation through bootstrapping was not conducted; this is acknowledged as a study limitation.

### Handling of quantitative variables

Continuous variables were transformed into categorical forms using established clinical and epidemiological cutoff values. Birth weight was dichotomized into low (<2,500 g) and normal ( $\geq$ 2,500 g). Maternal age was grouped as high-risk (<20 years or >35 years) versus non-high-risk (20–35 years). Household income was classified on the basis of the 2024 Papua Tengah provincial minimum wage (IDR 4,024,270 per month): below the minimum wage versus meeting or exceeding it. Birth spacing followed WHO recommendations: short (<2 years) or adequate ( $\geq$ 2 years). Parity was categorized as high ( $\geq$ 4 children) or low (<4 children).

### Statistical analysis

Data were analyzed using descriptive and inferential statistics. Categorical variables are presented as frequencies and percentages; continuous variables as means with standard deviations. Bivariate associations

between each risk factor and stunting were assessed using Pearson's chi-square test, or Fisher's exact test when expected cell counts were below five. Crude odds ratios with 95% confidence intervals were calculated.

Variables with  $p < 0.25$  in bivariate analysis were entered into a multivariable binary logistic regression model using the simultaneous entry method. Adjusted odds ratios with 95% confidence intervals identified independent predictors of stunting. Model calibration was evaluated with the Hosmer-Lemeshow goodness-of-fit test ( $p > 0.05$  indicating adequate fit). Nagelkerke's  $R^2$  estimated the proportion of variance explained, and the area under the receiver operating characteristic curve (AUC) assessed discriminatory performance. All tests were two-tailed with significance set at  $\alpha = 0.05$ . Analyses were performed using SPSS version 26.0.

### Ethical approval

This study received ethical approval from the Health Research Ethics Committee of the Faculty of Public Health, Universitas Cenderawasih (approval number: 048/KEPK-FKM UC/2025). All procedures were performed following standard ethical guidelines for research involving human subjects.

## RESULTS

### Characteristics of the study participants and history of infectious diseases

A total of 330 children aged 24–59 months were included in the analysis, comprising 110 children with stunting and 220 controls. The mean height-for-age Z score among the cases was  $-2.88 \pm 0.54$ , whereas the mean among the controls was  $-0.34 \pm 1.01$ . The average birth weight was lower in the cases ( $2924 \pm 673$  g) than in the controls ( $3252 \pm 704$  g). The mean age of the children and the sex distribution were comparable between the two groups (Table 1).

**Table 1.** Characteristics of participants

Characteristics	Cases (n = 110)	Controls (n = 220)
	n (%)	n (%)
Sex		
Male	55 (50.0)	118 (53.6)
Female	55 (50.0)	102 (46.4)
Child age (months)		
Mean $\pm$ SD	40.6 $\pm$ 9.8	42.3 $\pm$ 10.4
Height-for-age Z score		
Mean $\pm$ SD	-2.88 $\pm$ 0.54	-0.34 $\pm$ 1.01
Birth weight (grams)		
Mean $\pm$ SD	2924 $\pm$ 673	3252 $\pm$ 704
History of infectious disease (past 3 months)		
None	37 (33.6)	157 (71.4)
Malaria	36 (32.7)	26 (11.8)
Acute respiratory infection	19 (17.3)	19 (8.6)
Diarrhea	11 (10.0)	17 (7.7)
Malaria + acute respiratory infection	7 (6.4)	1 (0.5)

SD = standard deviation

A history of infectious disease during the previous three months was reported in 66.4% of the children in the case group and 28.6% in the control group. Malaria was the most commonly reported infection among the children (32.7%), followed by acute respiratory infection (17.3%) and diarrhea (10.0%). Coinfection with malaria and acute respiratory infection occurred in 6.4% of the cases and 0.5% of the controls (Table 1).

### Factors associated with stunting

Bivariate analysis indicated that several child, maternal, and socioeconomic factors were associated with stunting (Table 2). A history of infectious disease had the strongest crude association (OR 4.92; 95% CI 3.01–8.04), followed by a household income below the provincial minimum wage (OR 2.98; 95% CI 1.86–4.79), low maternal education (OR 2.58; 95% CI 1.62–4.13), and maternal anemia (OR 1.80; 95% CI 1.13–2.87). Additional factors related to stunting included low birth weight, incomplete immunization status, high parity, incomplete antenatal care visits, and nonexclusive breastfeeding.

After multivariable adjustment, eight factors remained independently associated with stunting. Infectious disease history retained the strongest effect (aOR 4.81; 95% CI 2.69–8.58). Children in households below the minimum wage had 3.5 times greater odds of stunting (aOR 3.52; 95% CI 1.98–6.26). Low maternal education (aOR 2.92; 95% CI 1.63–5.23) and low birth weight (aOR 2.78; 95% CI 1.37–5.64) were strongly associated. Nonexclusive breastfeeding (aOR 2.32; 95% CI 1.29–4.16) and incomplete immunization (aOR 2.21; 95% CI

1.24–3.94) approximately doubled the odds. Incomplete antenatal care (aOR 1.96; 95% CI 1.10–3.49) and maternal anemia (aOR 1.85; 95% CI 1.04–3.30) remained significant but with smaller effect sizes.

**Table 2.** Factors associated with stunting among children aged 2–5 years

Risk Factors	Cases, n (%)	Controls, n (%)	cOR (95% CI)	aOR (95% CI)
Infectious disease	73 (66.4)	63 (28.6)	4.92 (3.01–8.04)	4.81 (2.69–8.58)*
Maternal anemia	53 (48.2)	75 (34.1)	1.80 (1.13–2.87)	1.85 (1.04–3.30)*
Household income below provincial minimum wage	64 (58.2)	70 (31.8)	2.98 (1.86–4.79)	3.52 (1.98–6.26)*
Low maternal education	64 (58.2)	77 (35.0)	2.58 (1.62–4.13)	2.92 (1.63–5.23)*
Low birth weight	30 (27.3)	28 (12.7)	2.57 (1.44–4.58)	2.78 (1.37–5.64)*
Incomplete immunization	57 (51.8)	73 (33.2)	2.17 (1.36–3.46)	2.21 (1.24–3.94)*
High parity	46 (41.8)	59 (26.8)	1.96 (1.21–3.18)	1.77 (0.96–3.23)
Incomplete antenatal care	53 (48.2)	73 (33.2)	1.87 (1.17–2.99)	1.96 (1.10–3.49)*
Nonexclusive breastfeeding	58 (52.7)	85 (38.6)	1.77 (1.12–2.81)	2.32 (1.29–4.16)*
Male sex	55 (50.0)	118 (53.6)	0.86 (0.55–1.37)	0.91 (0.51–1.62)
High-risk maternal age	38 (34.5)	58 (26.4)	1.47 (0.90–2.42)	1.32 (0.70–2.47)
No early initiation of breastfeeding	44 (40.0)	75 (34.1)	1.29 (0.80–2.07)	1.80 (0.99–3.28)
Short birth spacing	33 (30.0)	55 (25.0)	1.29 (0.77–2.14)	1.59 (0.83–3.04)

\*Exposure category (coded as 1): infectious disease = present; maternal anemia = present; household income = below the provincial minimum wage; maternal education = low (< senior high school); low birth weight = yes; immunization = incomplete; parity =  $\geq 4$  children; antenatal care = <6 visits; breastfeeding = nonexclusive; sex = male; maternal age = <20 or >35 years; early initiation of breastfeeding = no; birth spacing = <2 years.

### Model Performance

The final logistic regression model demonstrated satisfactory discrimination (AUC = 0.838). The Hosmer–Lemeshow test indicated good calibration ( $\chi^2 = 10.84$ , df = 8, p = 0.211). At a 0.5 probability cutoff, the sensitivity was 58.2%, and the specificity was 88.2%.

**Table 3.** Performance of the binary logistic regression model

Parameter	Value	Interpretation
Nagelkerke R <sup>2</sup>	0.42	Proportion of variation in stunting explained by the model
Hosmer–Lemeshow test	$\chi^2 = 10.84$ ; df = 8; p = 0.211	Model calibration
AUC (Area Under the Curve)	0.838	Model discrimination
Sensitivity	58.2%	Proportion of correctly classified cases
Specificity	88.2%	Proportion of correctly classified controls

Classification used a probability cutoff of 0.5.

### DISCUSSION

This study revealed that several biological, maternal, and socioeconomic factors were associated with stunting. Multivariate analysis revealed that a history of infectious disease, a household income below the provincial minimum wage, low maternal education, low birth weight, incomplete immunization status, the absence of exclusive breastfeeding, incomplete antenatal care visits, and maternal anemia during pregnancy were independently associated with stunting. These findings indicate that the combined effects of child health conditions, maternal health, and household socioeconomic circumstances influence child growth in malaria-endemic settings. Similar patterns have been reported in studies from Indonesia, showing that stunting is related to child health, maternal conditions, and household socioeconomic status<sup>19, 20</sup>. Differences in findings across studies may reflect variation in study design, children's age range, operational definitions of infection exposure, and the malaria endemicity profile of each setting, and cross-study comparisons should therefore be interpreted with caution.

A history of infectious disease showed the strongest association with stunting in the present study. Recurrent infections during childhood have long been linked to impaired linear growth. A systematic review by Das, Grais<sup>9</sup> reported a bidirectional relationship between malaria and malnutrition, in which poor nutritional status increased susceptibility to infection. In contrast, malaria infection contributes to nutritional deterioration

by increasing energy catabolism and altering nutrient metabolism. Beyond energy catabolism, repeated enteric infections contribute to growth faltering through environmental enteric dysfunction (EED) a subclinical condition characterized by intestinal inflammation, villous blunting, and reduced absorptive capacity that impairs nutrient uptake independent of clinically apparent diarrhea<sup>21</sup>. Comparable findings were reported in a cohort study in Ethiopia by Gari, Loha<sup>10</sup>, which revealed that children with a history of malaria had a higher risk of stunting and wasting than children without infection did. Kang, Kreuels<sup>11</sup> reported that malaria exposure during early life may contribute to growth impairment through chronic inflammatory responses and increased metabolic demands. Evidence from Indonesia also suggests that child health conditions and family biological factors, including parental health status, contribute to the risk of stunting among children<sup>19</sup>. In Mimika, where co-infections with malaria, ARI, and diarrhea were documented in 6.4% of cases in this study, the compounded infectious burden may sustain the EED pathway over a longer period than single-pathogen exposures would.

In addition to malaria, other infectious diseases, such as diarrhea and acute respiratory infections, have been associated with impaired child growth. A multicountry longitudinal analysis by Checkley, Buckley<sup>22</sup> revealed that repeated episodes of diarrhea in early life were associated with reductions in height-for-age Z scores. Similar findings were reported by Richard, Black<sup>23</sup>, who reported that gastrointestinal infections during the first two years of life were associated with growth faltering. Some studies attribute this relationship to environmental enteric dysfunction, a chronic inflammatory condition of the intestinal mucosa that interferes with nutrient absorption and child growth. Prendergast and Humphrey<sup>21</sup> described this condition as an important biological pathway linking chronic infection exposure to stunting in children living in low- and middle-income countries. Studies from Indonesia have likewise shown that household environmental conditions, including sanitation quality and access to safe water, are associated with stunting risk<sup>24</sup>. In Mimika, access to improved sanitation and piped water remains limited across peri-urban and rural areas, conditions that sustain fecal-oral transmission and may partly explain the high diarrhea burden observed among stunted children in this study.

Household socioeconomic conditions were likewise related to stunting in the present study. Children from households with incomes below the provincial minimum wage were more likely to experience stunting than those from households with higher incomes were. Low household income restricts families' ability to maintain dietary diversity and purchase nutrient-dense foods; in Mimika, where market food prices are elevated relative to other Indonesian regions due to geographic remoteness and supply chain constraints, this limitation is particularly acute. Household economic conditions influence families' ability to obtain nutritious food and access health services. A global analysis by Danaei, Andrews<sup>25</sup> revealed that poverty, inadequate sanitation, and low maternal education are major contributors to the high incidence of stunting in low- and middle-income countries. Similar relationships between socioeconomic conditions and child nutritional status were reported by Vollmer, Bommer<sup>13</sup>, who reported that parental education and household economic status play important roles in determining child nutritional status. Recent studies in Indonesia also indicate that socioeconomic inequality remains an important determinant of stunting among young children<sup>20,26</sup>.

Maternal education is often identified as an important determinant of a child's nutritional status. In the present study, children whose mothers had lower levels of education were more likely to experience stunting. Mothers with higher educational attainment are more likely to apply recommended infant feeding practices, recognize early signs of growth faltering, and utilize available maternal and child health services pathways through which education translates into nutritional outcomes for children<sup>27</sup>. Evidence from Indonesia reported by Torlesse, Cronin<sup>27</sup> demonstrates that maternal education is closely related to infant and young child feeding practices as well as the use of health services. Similar conclusions were reported by Beal, Tumilowicz<sup>28</sup>, who emphasized the role of maternal and environmental conditions in shaping children's nutritional outcomes in Indonesia. Recent studies have further highlighted that maternal knowledge and education contribute to improved caregiving practices and the fulfillment of children's nutritional needs<sup>29</sup>.

Low birth weight emerged as an additional determinant. Children born at <2,500 g face a greater risk of subsequent growth impairment. Longitudinal studies have consistently documented this relationship. Victora, Adair<sup>8</sup> demonstrated that birth weight plays a key role in determining growth trajectories during early childhood. Similarly, a recent meta-analysis by Vats, Walia<sup>30</sup> reported that low birth weight substantially increases the risk of stunting among children in low- and middle-income countries.

In malaria-endemic settings, low birth weight may partly result from malaria infection during pregnancy. A cohort study by Rijken, De Livera<sup>31</sup> demonstrated that malaria during pregnancy increases the risk of low birth weight delivery through placental insufficiency and compromised nutrient transfer to the developing fetus. This mechanism is particularly relevant in regions such as Papua, where malaria during pregnancy remains an ongoing public health concern<sup>18</sup>. Indicators related to maternal and child health services were also associated with stunting in the present study. Children with incomplete immunization were significantly more likely to be stunted, which is consistent with MAL-ED multicountry findings linking recurrent infections to linear growth faltering<sup>32</sup>.

Exclusive breastfeeding during the first six months was protective against stunting, corroborating the

findings of Indonesian research by Hadi, Fatimatasari<sup>14</sup>, who reported that children who received exclusive breastfeeding had a lower likelihood of stunting than those who did not. Breast milk contains secretory IgA (sIgA) and lactoferrin, which reduce the frequency and severity of enteric and respiratory infections during early infancy by coating intestinal mucosa and limiting pathogen adherence<sup>33</sup>. Maternal anemia during pregnancy was likewise associated with stunting in the present study. Iron deficiency anemia during pregnancy is associated with adverse birth outcomes including low birth weight and intrauterine growth restriction, and maternal iron deficiency reduces fetal iron stores that are critical for postnatal erythropoiesis and tissue oxygenation<sup>34</sup>. A global analysis conducted by Stevens, Finucane<sup>12</sup> identified anemia as a pervasive issue among reproductive-age women in developing countries. Adequate antenatal care utilization was also related to child growth outcomes. Evidence from a cohort study in Kenya by Martin, Mutuku<sup>35</sup> demonstrated that mothers who adequately used maternal health services were less likely to have children with early childhood stunting.

Several limitations require consideration. The retrospective case-control design precludes causal inference regarding exposure-outcome relationships. Reliance on caregiver recall for infectious disease history may have introduced recall bias; although the recall period was restricted to three months and reports were crosschecked against health facility records, underreporting or misclassification of disease episodes cannot be excluded. The study was conducted within a single primary health center catchment area in urban and peri-urban Mimika, which may limit the generalizability of findings to rural or highland populations within the district, or to other regions in Papua with different malaria endemicity, demographic composition, and health service access. Internal validation through bootstrapping was not performed, and the stability of the model estimates across different subsamples remains untested. Interaction or stratified analyses were not performed due to sample size constraints.

## CONCLUSION AND RECOMMENDATIONS

Stunting among children in Mimika District was associated with an infectious disease history, low household income, low maternal education, low birth weight, incomplete immunization, nonexclusive breastfeeding, inadequate antenatal care, and maternal anemia. Programmatic responses should include malaria screening integrated into routine antenatal care visits, reinforcement of exclusive breastfeeding counselling at posyandu level, and targeted nutrition assistance for households with incomes below the provincial minimum wage.

## AUTHOR'S CONTRIBUTION STATEMENT

Rosmin Mariati Tingginehe: Conceptualization, data curation, formal analysis, investigation, project administration, writing – original draft. Muhamad Sahiddin: Methodology, supervision, validation, writing – review & editing. Both authors have read and approved the final manuscript.

## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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