Original Article

Nutrition-specific and nutrition-sensitive factors associated with childhood stunting: A case-control study in rural West Kalimantan, Indonesia

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Abstract

Stunting remains a major public health problem in Indonesia, and Kubu Raya Regency in West Kalimantan has persistently recorded stunting prevalence above provincial and national levels. The aim of this study was to identify nutrition-specific and nutrition-sensitive factors associated with stunting among children under five in this high-burden rural setting. A 1:1 matched case-control study was conducted in three villages within the catchment area of Sungai Ambawang Public Health Center from August to December 2022. Sixty-seven stunted children and 67 non-stunted children aged 0–59 months were matched by sex and age. Exposures were ascertained by structured caregiver interviews, anthropometric measurements, and record reviews; household food insecurity was measured using the Household Food Insecurity Access Scale. Data were analyzed using unconditional multivariable logistic regression with the matching variables retained as covariates, and Firth penalized logistic regression was used in a sensitivity analysis to assess potential sparse-data bias. Exclusive breastfeeding (Firth-adjusted odds ratio (aOR): 0.06; 95% confidence interval (CI): 0.02–0.25) and at least six antenatal care visits (aOR: 0.18; 95%CI: 0.06–0.54) were independently associated with lower odds of stunting. In contrast, acute infection (Firth aOR: 27.47; 95%CI: 5.22–144.50), moderate (aOR: 5.84; 95%CI: 1.19–28.76) and severe (aOR: 11.11; 95%CI: 2.31–53.37) household food insecurity were associated with higher odds of stunting. Stunting was associated with infant feeding practices, antenatal care, reported infection, and household food insecurity. These findings may inform local priorities within the national stunting strategy, although the observational design precludes causal inference.

Keywords: Stunting, exclusive breastfeeding, food insecurity, case-control study, Indonesia

Introduction

Stunting, defined as a length- or height-for-age z-score (HAZ) <−2 standard deviations (SD) of the World Health Organization (WHO) Child Growth Standards median, remains the most common form of undernutrition among young children worldwide [1]. In 2024, an estimated 150.2 million children under five (23.2%) were stunted, and Asia accounted for roughly half of them [1]. The consequences extend well beyond impaired linear growth. Maternal and child undernutrition, including fetal growth restriction, stunting, wasting, micronutrient deficiencies, and suboptimal breastfeeding, has been estimated to contribute to approximately 45% of deaths

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among children younger than five years [2]. Furthermore, stunting is associated with impaired cognitive development and a reduced likelihood of achieving full developmental potential [2]. The determinants of stunting operate at multiple levels. The United Nations Children's Fund (UNICEF) Conceptual Framework on Maternal and Child Nutrition organizes them into immediate determinants (diets and care), underlying determinants (the foods, feeding and care practices, and services available to households), and enabling determinants (governance, resources, and social norms) [3]. This hierarchy corresponds to the programmatic distinction between nutrition-specific interventions, which address immediate causes, and nutrition-sensitive interventions, which act on the underlying and enabling conditions in which those causes arise [4]. Indonesia illustrates both the scale of the problem and the difficulty of resolving it. National stunting prevalence fell from 21.5% in 2023 to 19.8% in 2024 [5], moving the country from the "high" into the "medium" band of the WHO-UNICEF population prevalence thresholds [6] but leaving it short of the 14% national target [7]. That national average conceals wide subnational variation. West Kalimantan Province recorded 29.8% in 2021 [8] and 26.8% in 2024; despite this decline, prevalence remained within the "high" band and above the national figure [5,6]. Within the province, Kubu Raya Regency recorded the highest regency-level prevalence in 2021, at 40.35% [8], and although this had fallen to 30.2% by 2024, the regency remained in the "very high" band and more than ten percentage points above the national average [5,6].

Less is known about the combination of factors associated with stunting in specific high-prevalence localities. The Indonesian evidence base rests largely on cross-sectional analyses, many of which are secondary analyses of nationally representative surveys, while systematic reviews of this evidence draw predominantly on cross-sectional and, less frequently, longitudinal designs [9,10]. Such work is well suited to identifying associations at the national level, but may not capture the combination of factors relevant to a particular regency or district. Furthermore, reviews of the Indonesian literature note that several determinant domains, including food systems, sanitation, water, and environmental conditions, remain sparsely studied [9]. Despite the high prevalence of stunting in Kubu Raya, the published evidence for the regency is limited. Local evidence includes a recent multivariable analysis in the regency, which was restricted to children aged 24–59 months and retained absence of exclusive breastfeeding as its sole independent predictor [11]. Two important questions therefore remain unresolved. First, the previous study did not include children younger than 24 months, although the first 1000 days, from conception to the second birthday, are the period in which most linear growth faltering occurs [2]. Including children younger than 24 months extends coverage to an important period of postnatal growth. Second, it did not establish whether nutrition-sensitive conditions remain associated with stunting after adjustment for nutrition-specific factors. This distinction matters because nutrition-specific factors mainly reflect feeding and care behavior, whereas nutrition-sensitive factors reflect structural conditions, such as household resources and access to food and services, that determine whether those practices can be maintained [3,4]. Examining these domains separately may therefore attribute differences in child nutrition to individual behaviors when they may partly reflect underlying constraints on access. Household food insecurity illustrates this concern. It is seldom measured in localized studies using a validated instrument such as the Household Food Insecurity Access Scale [12], despite its relevance to understanding constraints on household food access and their potential effects on children's diets. To our knowledge, no published study in the Sungai Ambawang area has examined nutrition-specific and nutrition-sensitive determinants together within a single multivariable model.

This study addresses that gap using an individually matched case-control design in a defined health center catchment area. In settings where the eligible population within a single health center catchment area is limited, a case-control design allows efficient use of available cases. Case status can be ascertained from anthropometric measurements recorded in routine nutrition surveillance rather than caregiver reports. Each stunted child was matched with a non-stunted child of the same sex and similar age to improve comparability with respect to these two growth-related variables, which were subsequently retained as covariates in the analysis. The aim of this study was to identify the nutrition-specific and nutrition-sensitive factors independently associated with stunting among children aged 0–59 months in three villages within the catchment area of Sungai Ambawang Public Health Center, and to situate them within the pillars

of Indonesia's national stunting strategy to inform local program priorities in a regency with persistently high stunting prevalence. Identifying locally relevant associations can help the Sungai Ambawang Public Health Center and the regency government decide which existing program components to prioritize and deliver together, rather than relying on national averages.

Methods

Study design, setting, and period

An observational study with an individually matched (1:1) case-control design was conducted in three villages, Jawa Tengah, Sungai Malaya, and Mega Timur, within the catchment area of Sungai Ambawang Public Health Center, Sungai Ambawang District, Kubu Raya Regency, West Kalimantan Province, Indonesia. These three villages were selected because they recorded the highest numbers of stunted children in the catchment area during the study period. Kubu Raya recorded the highest regency-level stunting prevalence in the province in 2021, exceeding both the provincial and national averages [8], making it a priority setting for identifying locally relevant determinants of stunting. Data were collected from August to December 2022.

Population and sample

The source population comprised households with children aged 0–59 months living in the three participating villages. Case status was ascertained from secondary anthropometric data held by the public health center: cases were children with a HAZ <–2, and controls were children with HAZ ≥–2. All stunted children recorded by the public health center in the three villages during the study period were enrolled as cases (total sampling: Sungai Malaya, n=25; Mega Timur, n=24; Jawa Tengah, n=18). Each case was individually matched 1:1 to one non-stunted control, selected purposively from the same villages, by sex (exact match) and age in months. Matching was done manually at recruitment: controls were chosen to be as close as possible in age to the corresponding case; no age caliper was specified in advance, and the largest age difference between matched pairs was five months. All eligible households agreed to participate. As the number of cases was fixed by the total number of stunted children in the three villages, no a priori sample size calculation was performed.

Inclusion criteria were: (1) a child aged 0–59 months recorded in public health center data; (2) caregiver residing in Jawa Tengah, Sungai Malaya, or Mega Timur village; (3) child delivered at a health facility; and (4) possession of a Maternal and Child Health Handbook. Households unwilling or unable to participate were excluded.

Study variables

The outcome variable was stunting status (stunted versus non-stunted). Exposures comprised nutrition-specific factors (low birth weight, early initiation of breastfeeding, exclusive breastfeeding, timing of complementary feeding initiation, basic immunization status, acute infection (diarrhea and/or acute respiratory infection, ARI), maternal mid-upper arm circumference (MUAC) during pregnancy, maternal body mass index (BMI), antenatal care (ANC) visit frequency, and iron supplementation during pregnancy) and nutrition-sensitive factors (presence of siblings, maternal education, maternal working status, household income, and household food security).

Data collection procedure

Data were collected by a trained enumerator team from Universitas Muhammadiyah Pontianak through structured interviews using a questionnaire, direct anthropometric measurement, and review of the Maternal and Child Health Handbook to verify stunting status and maternal and child health history.

Child stunting status was assessed using WHO Anthro software (weight, height or length, age, and sex as inputs) to generate height-for-age z-scores against the WHO standards for child growth: HAZ <–2 SD (stunted, including HAZ <–3 SD, or severely stunted) and HAZ ≥–2 SD (not stunted) [13]. Weight was measured using a calibrated scale, and length or height was measured using a length board or stadiometer, respectively, by trained personnel.

The remaining measurements were adapted from and verified against the Maternal and Child Health Handbook. A birth weight below 2,500 g was classified as low birth weight. Maternal MUAC during pregnancy was used as an indicator of nutritional status and analyzed as a continuous variable. Maternal nutritional status was additionally assessed via pre-pregnancy or early-pregnancy BMI. Iron supplementation was categorized as adequate (≥90 tablets) or inadequate (<90 tablets) against the national antenatal supplementation target. ANC attendance was categorized as meeting (≥6 visits) or not meeting (<6 visits) the Indonesian national minimum antenatal care standard, which was raised from four to six visits in 2021 and was in force throughout the study period [14]; the WHO antenatal care approach recommends at least eight contacts [15]. Basic immunization was assessed against the national childhood immunization schedule; because all children were at least 10 months of age at data collection, complete immunization was defined as receipt of Hepatitis B0, BCG, Polio 1-4, DPT-HB(-Hib) 1-3, and Measles/MMR [16], and immunization was classified as incomplete if any required doses were missing. Acute infection was defined as caregiver-reported diarrhea and/or acute respiratory infection (ARI) in the three months preceding data collection, regardless of the number of episodes. Diarrhea was defined as three or more loose or watery stools in 24 hours; ARI was defined as cough or difficult breathing, with or without fever. Reports were cross-checked against the handbook where a record was available. Infection was based on caregiver report rather than clinical diagnosis, and the number, severity, and timing of episodes relative to anthropometric measurement were not recorded.

Exclusive breastfeeding was defined according to WHO/UNICEF criteria as receipt of breast milk only, without other liquids or solids except prescribed medicine or vitamins, during the first six months after birth [17]; complementary feeding (food introduction) was categorized by initiation before six months or at six months or later. Early initiation of breastfeeding was defined as skin-to-skin contact with breastfeeding initiated within one hour of birth. Questions about breastfeeding practices and infection history were asked in separate sections of the questionnaire, and the age at which exclusive breastfeeding ended was not recorded.

Household income was categorized relative to the 2022 regional minimum wage threshold of IDR 2,500,000. Household food insecurity was assessed using the Household Food Insecurity Access Scale (HFIAS) [12], which comprises nine occurrence questions on experiences of food insecurity over the previous four weeks, each followed by a frequency-of-occurrence question (rarely, 1–2 times; sometimes, 3–10 times; often, more than 10 times). Frequency responses were scored 0–3 and summed to a score of 0–27. Households were then classified with the HFIAS categorical algorithm, which combines occurrence and frequency across all nine questions [12]: food secure (no condition experienced, or worry about food only rarely), mildly food insecure (worry about food more than rarely, or limited food choice, without any reduction in the amount eaten), moderately food insecure (eating a limited variety or unwanted foods sometimes or often, or eating smaller or fewer meals rarely or sometimes), and severely food insecure (eating smaller or fewer meals often, or running out of food, going to sleep hungry, or going a whole day and night without eating). The Indonesian-language HFIAS has been validated against another food security measure in urban and rural households in South Sulawesi, with good internal consistency (Cronbach's α=0.84) [18]; it was not separately validated in the present study population.

Statistical analysis

Statistical analysis was performed with Stata version 19.5 (StataCorp LLC, Texas, United States). Descriptive statistics for participant characteristics included means and standard deviations or frequencies and percentages. Although cases and controls were matched 1:1 by sex and age at recruitment, the matching was done manually, without a pre-specified age caliper. All 134 children were treated as independent observations and analyzed by unconditional logistic regression, with age (continuous) and sex forced into the multivariable model regardless of significance. Unconditional logistic regression can be appropriate for matched case-control data when the matching factors are adequately controlled, although its validity and efficiency depend on the matching design and model specification [19,20,21,22]. Conditional logistic regression preserving the matched-pair structure was also examined but was not adopted, because few pairs were discordant for several exposures and the conditional model showed quasi-complete

separation, with non-estimable odds ratios for exclusive breastfeeding, low birth weight, complementary feeding timing, and household income. Bivariate associations were examined using the Pearson chi-square test for categorical exposures and, for continuous exposures, the independent-samples t-test or the Mann-Whitney U test based on Shapiro-Wilk testing; statistical significance was set at a two-sided $p<0.05$.

Age and sex were specified a priori as matching variables and were retained in every model. All other exposures were candidate variables derived from the UNICEF conceptual framework [3], and their selection into the final model was determined by the data. Exposures associated with stunting at $p<0.25$, together with the two forced matching variables, formed a 16-parameter candidate model that converged without separation. Variance inflation factors (VIF) were obtained from an auxiliary linear-probability regression using the same predictor set to assess multicollinearity. Elevated VIF values were observed for two pairs of predictors: exclusive breastfeeding with household income (VIF: 10.87 and 10.37) and low birth weight with complementary feeding timing (VIF: 7.52 and 7.78). The model was then refined by backward elimination using nested-model likelihood-ratio tests, removing the least significant candidate at each step. Maternal education ($p=0.988$), early initiation of breastfeeding ($p=0.955$), household income ($p=0.889$), iron supplementation ($p=0.834$), maternal working status ($p=0.258$), and low birth weight ($p=0.434$) were removed in turn, none shifting the remaining estimates by more than 15%; removing household income and low birth weight also resolved both collinear pairs (the VIF of exclusive breastfeeding fell from 10.87 to 1.52, and that of complementary feeding timing, which had decreased to 7.19 after the earlier elimination steps, fell to 1.15). Complementary feeding timing was not statistically significant after low birth weight was removed from the model ($p=0.109$). However, its exclusion resulted in a 21.9% change in the odds ratio for acute infection, exceeding the prespecified 15–20% change-in-estimate criterion used to assess potential confounding. It was therefore retained in the final model as a potential confounder. The final model comprised age, sex, exclusive breastfeeding, complementary feeding timing, acute infection, maternal BMI, ANC frequency, and household food security. Exposures excluded at this stage are reported at the bivariate level only. With 67 cases, the candidate model had approximately four events per parameter, whereas the final model had approximately seven. Both values are below commonly used rules of thumb [23]. Given the potential for data-driven variable selection to produce unstable estimates in a sample of this size [24], the findings should therefore be regarded as exploratory.

Model fit was assessed using the likelihood-ratio chi-square test against the null model, the Akaike and Bayesian information criteria, and the Hosmer-Lemeshow goodness-of-fit test. Discrimination was assessed using the area under the receiver operating characteristic (ROC) curve; classification accuracy, sensitivity, and specificity were calculated at a 0.5 probability threshold. Results are presented as adjusted odds ratios (aOR) with 95% confidence intervals (CIs). Because the final model produced wide confidence intervals for exclusive breastfeeding and acute infection, raising concerns about sparse-data bias and imprecision in maximum likelihood estimation, Firth penalized logistic regression [25] was fitted to the identical specification as a sensitivity analysis to assess the robustness of the estimates to bias reduction [26]. Finally, the distribution of acute infection across the other determinants retained in the final model was examined post hoc using Pearson chi-square tests; these analyses were exploratory and formed no part of the pre-specified modeling strategy.

Results

Participant characteristics

A total of 134 children under five years of age were included, comprising 67 children with stunting (cases) and 67 children without stunting (controls), individually matched by age and sex. Participant characteristics by stunting status are presented in **Table 1**. Each group included 36 boys (53.7%) and 31 girls (46.3%). The mean age was 29.91±12.47 months among cases and 31.01±12.47 months among controls. Maternal BMI averaged 24.09±4.14 kg/m² in the case group and 25.90±4.33 kg/m² in the control group, while maternal MUAC averaged 26.19±3.68 cm and 26.54±3.37 cm, respectively. Overall, 94 mothers (70.1%) had completed at least high school, and

121 (90.3%) were employed. Most children had at least one sibling (99/134; 73.9%). Household income was at or below the regional minimum wage in 64 households (47.8%). Food insecurity was reported in 108 households (80.6%), comprising 10 (7.5%) classified as mildly insecure, 34 (25.4%) as moderately insecure, and 64 (47.8%) as severely insecure.

Table 1. Characteristics of cases and controls and their bivariate associations with stunting status among children aged 0–59 months in Sungai Ambawang District, Kubu Raya Regency, West Kalimantan, Indonesia

Characteristic	Cases (n=67)	Controls (n=67)	Test statistic	*p*-value
Age, mean (SD), months	29.91 (12.47)	31.01 (12.47)	z=0.525	0.599[a]
Sex				
Boy	36 (53.7)	36 (53.7)		
Girl	31 (46.3)	31 (46.3)	χ^2=0.00	1.000[b]
Nutrition-specific determinants				
Low birth weight				
No (at least 2,500 g)	38 (56.7)	50 (74.6)		
Yes (under 2,500 g)	29 (43.3)	17 (25.4)	χ^2=4.77	0.029[b]
Early breastfeeding initiation				
Not initiated within 1 hour	25 (37.3)	16 (23.9)		
Initiated within 1 hour	42 (62.7)	51 (76.1)	χ^2=2.85	0.092[b]
Exclusive breastfeeding				
Not exclusive	44 (65.7)	24 (35.8)		
Exclusive	23 (34.3)	43 (64.2)	χ^2=11.94	0.001[b]
Complementary feeding initiation				
Before 6 months old	28 (41.8)	13 (19.4)		
At least 6 months old	39 (58.2)	54 (80.6)	χ^2=7.91	0.005[b]
Immunization status				
Incomplete	35 (52.2)	32 (47.8)		
Complete	32 (47.8)	35 (52.2)	χ^2=0.27	0.604[b]
Acute infection (diarrhea/ARI)				
None	13 (19.4)	26 (38.8)		
Present	54 (80.6)	41 (61.2)	χ^2=6.11	0.013[b]
Maternal MUAC, mean (SD), cm	26.19 (3.68)	26.54 (3.37)	z=0.940	0.347[a]
Maternal BMI, mean (SD), kg/m²	24.09 (4.14)	25.90 (4.33)	t=2.465	0.015[c]
Frequency of antenatal care				
Fewer than 6 visits	27 (40.3)	10 (14.9)		
At least 6 visits	40 (59.7)	57 (85.1)	χ^2=10.79	0.001[b]
Iron supplementation				
Fewer than 90 tablets	42 (62.7)	18 (26.9)		
At least 90 tablets	25 (37.3)	49 (73.1)	χ^2=17.38	<0.001[b]
Nutrition-sensitive determinants				
Sibling status				
No sibling	15 (22.4)	20 (29.9)		
At least one sibling	52 (77.6)	47 (70.1)	χ^2=0.97	0.325[b]
Mother's education				
Lower than high school	28 (41.8)	12 (17.9)		
High school or higher	39 (58.2)	55 (82.1)	χ^2=9.12	0.003[b]
Maternal employment status				
Not working	4 (6.0)	9 (13.4)		
Working	63 (94.0)	58 (86.6)	χ^2=2.13	0.144[b]
Household income				
At or below minimum wage	41 (61.2)	23 (34.3)		
Above minimum wage	26 (38.8)	44 (65.7)	χ^2=9.69	0.002[b]
Household food insecurity				
Secure	5 (7.5)	21 (31.3)		
Mildly insecure	4 (6.0)	6 (9.0)		
Moderately insecure	22 (32.8)	12 (17.9)		
Severely insecure	36 (53.7)	28 (41.8)	χ^2=14.19	0.003[b]

ARI: acute respiratory infection; BMI: body mass index; HFIAS: Household Food Insecurity Access Scale; MUAC: mid-upper arm circumference; SD: standard deviation.

Data are presented as n (%) unless otherwise indicated. Cases and controls (67 each, n=134) were recruited via 1:1 individual matching by age and sex; the analysis treats all 134 children as independent observations (see Methods).

[a] Analyzed using the Mann-Whitney U test (age and MUAC violated the normality assumption on Shapiro-Wilk test)

[b] Analyzed using the Pearson chi-square test

[c] Analyzed using the independent-samples t-test (maternal BMI met the normality assumption)

Bivariate associations between nutrition-specific and nutrition-sensitive factors and childhood stunting

No statistically significant age difference was observed, and sex distributions were identical between groups (age: 29.91±12.47 versus 31.01±12.47 months, Mann-Whitney z=0.525, p=0.599; sex: identical proportions, χ^2=0.00, p=1.000), consistent with the matched recruitment design. Maternal MUAC also showed no statistically significant difference (26.19±3.68 versus 26.54±3.37 cm; z=0.940; p=0.347). Full bivariate results are presented in **Table 1**.

Among nutrition-specific exposures, significant associations with stunting were observed for low birth weight (χ^2=4.77, p=0.029), exclusive breastfeeding (χ^2=11.94, p=0.001), complementary feeding initiation timing (χ^2=7.91, p=0.005), acute infection (χ^2=6.11, p=0.013), maternal BMI (t=2.465, p=0.015), receiving at least six antenatal care visits (χ^2=10.79, p=0.001), and receiving at least 90 iron tablets during pregnancy (χ^2=17.38, p<0.001). Early initiation of breastfeeding was not statistically significantly associated with stunting (χ^2=2.85, p=0.092), nor was immunization completeness (χ^2=0.27, p=0.604).

Among nutrition-sensitive exposures, maternal education (χ^2=9.12, p=0.003), household income (χ^2=9.69, p=0.002), and household food security status (χ^2=14.19, p=0.003) were significantly associated with stunting, whereas sibling status (χ^2=0.97, p=0.325) and maternal occupation (χ^2=2.13, p=0.144) were not.

Distribution of stunting by household food insecurity status

The distribution of stunting status across household food insecurity categories is presented in **Figure 1**. The proportion of stunted children was 19.2% among food-secure households, 40.0% among mildly insecure, 64.7% among moderately insecure, and 56.2% among severely insecure households (χ^2(3)=14.19, p=0.003).

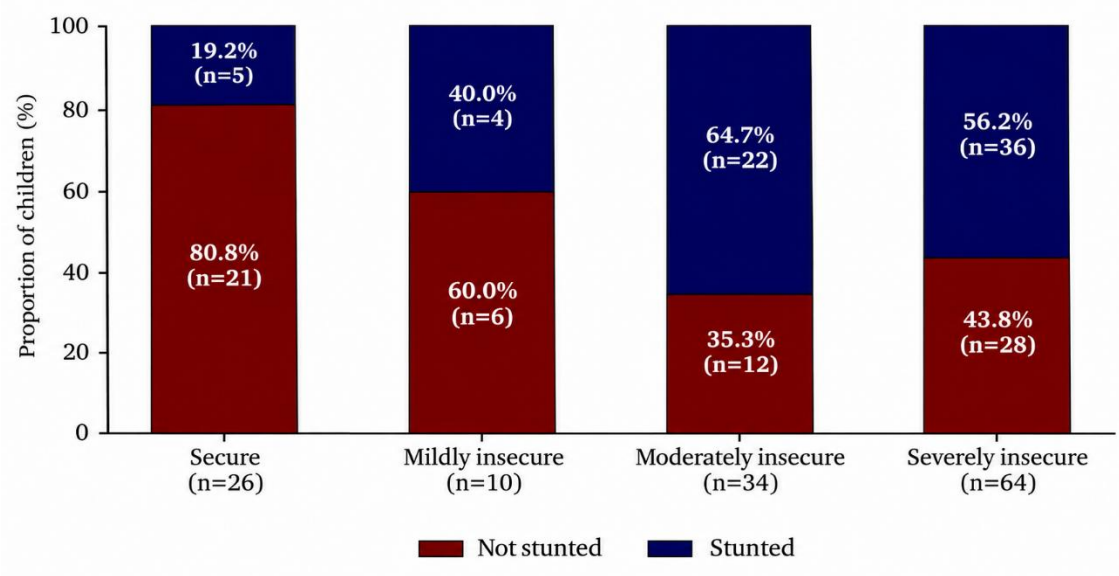

Figure 1. Distribution of stunting status across household food insecurity categories among children aged 0–59 months (n=134). Pearson chi-square test, χ^2(3)=14.19, p=0.003. Percentages are row percentages within each category.

Multivariable analysis of factors associated with childhood stunting

In the final multivariable model (**Table 2**), exclusive breastfeeding was strongly associated with lower odds of stunting (aOR: 0.04; 95%CI: 0.01–0.20; p<0.001) and acute infection was associated with substantially higher odds of stunting (aOR: 44.41; 95%CI: 7.16–275.39; p<0.001). Receiving at least six antenatal care visits was associated with lower odds of stunting relative to fewer than six (aOR: 0.18; 95%CI: 0.06–0.54; p=0.002). Household food insecurity showed a graded association relative to food-secure households: moderately insecure (aOR: 5.84; 95%CI: 1.19–28.76; p=0.030) and severely insecure (aOR: 11.11; 95%CI: 2.31–53.37; p=0.003) were both significant, while mildly insecure was not (aOR: 4.83; 95%CI: 0.61–38.09; p=0.135). The inverse association with maternal BMI did not reach statistical significance (aOR: 0.90; 95%CI: 0.80–

1.01; p=0.061). Age, sex, and complementary feeding initiation timing were not independently significant after adjustment. Given the large effect estimates and wide confidence intervals for exclusive breastfeeding and acute infection, the corresponding Firth penalized logistic regression estimates were reported preferentially for these two variables.

Sensitivity analysis

Firth penalized logistic regression, fitted to the identical specification (n=134), preserved the direction and statistical significance status of all associations in the final model (**Table 2**, **Figure 2**). The odds ratios for exclusive breastfeeding (aOR: 0.06; 95%CI: 0.02–0.25) and acute infection (aOR: 27.47; 95%CI: 5.22–144.50) were attenuated toward the null relative to the standard estimates of 0.04 and 44.41 while uncertainty remained substantial, consistent with potential sparse-data bias in the maximum-likelihood estimates; both associations remained statistically significant (p<0.001).

Table 2. Standard and Firth penalized multivariable logistic regression analysis of determinants of stunting among children aged 0–59 months in Sungai Ambawang District, Kubu Raya Regency, West Kalimantan, Indonesia

Exposure	Standard model		Firth penalized model	
	aOR (95%CI)	p-value	aOR (95%CI)	p-value
Age (per month)	1.03 (0.99–1.08)	0.159	1.03 (0.99–1.07)	0.187
Sex (ref: boy)				
Girl	1.45 (0.56–3.73)	0.445	1.39 (0.57–3.38)	0.471
Exclusive breastfeeding (ref: not exclusive)				
Exclusive	0.04 (0.01–0.20)	<0.001	0.06 (0.02–0.25)	<0.001
Complementary feeding initiation (ref: before 6 months)				
At least 6 months	0.43 (0.15–1.21)	0.109	0.47 (0.17–1.25)	0.128
Acute infection (ref: none)				
Present	44.41 (7.16–275.39)	<0.001	27.47 (5.22–144.50)	<0.001
Maternal BMI (per kg/m²)	0.90 (0.80–1.01)	0.061	0.91 (0.82–1.01)	0.080
Antenatal care (ref: fewer than 6 visits)				
At least 6 visits	0.18 (0.06–0.54)	0.002	0.22 (0.08–0.61)	0.004
Household food insecurity (ref: food secure)				
Mildly insecure	4.83 (0.61–38.09)	0.135	4.04 (0.60–27.08)	0.150
Moderately insecure	5.84 (1.19–28.76)	0.030	4.68 (1.07–20.45)	0.040
Severely insecure	11.11 (2.31–53.37)	0.003	8.22 (1.94–34.87)	0.004

AIC: Akaike information criterion; aOR: adjusted odds ratio; BIC: Bayesian information criterion; BMI: body mass index; CI: confidence interval; LR: likelihood ratio; ROC: receiver operating characteristic.
Multivariable logistic regression, n=134. Age and sex were forced into the model regardless of bivariate significance, as they were the matching variables at recruitment. Standard model: LR $\chi^2(10)$=71.21, p<0.001; pseudo-R^2=0.383; AIC=136.55; BIC=168.43; Hosmer-Lemeshow $\chi^2(8)$=10.49, p=0.233 (no evidence of lack of fit); area under the ROC curve=0.892; 80.6% correctly classified (sensitivity 77.6%, specificity 83.6%); mean variance inflation factor=1.40 (maximum 2.04).
Firth penalized model, fitted to the identical specification: penalized log-likelihood=−44.91; Wald $\chi^2(10)$=29.79, p<0.001. Model performance statistics describe discrimination within the matched sample, in which cases made up 50% by design; they do not indicate screening performance in the general population. For exclusive breastfeeding and acute infection, the Firth estimates are preferred because of concerns about sparse-data bias in the standard estimates.

Antenatal care attendance remained associated with lower odds of stunting (aOR: 0.22; 95%CI: 0.08–0.61; p=0.004). A gradient in household food insecurity was also observed: moderately insecure (aOR: 4.68; 95%CI: 1.07–20.45; p=0.040) and severely insecure (aOR: 8.22; 95%CI: 1.94–34.87; p=0.004) households had significantly higher odds of stunting, whereas the association for mildly insecure households was not statistically significant (aOR: 4.04; 95%CI: 0.60–27.08; p=0.150). The inverse association with maternal BMI remained non-significant (aOR: 0.91; 95%CI: 0.82–1.01; p=0.080). Age, sex, and complementary feeding initiation timing also remained non-significant. The two sets of estimates across all model terms are compared in **Figure 2**.

Post hoc distribution of acute infection

Because acute infection carried an unexpectedly large adjusted odds ratio, its distribution across the other determinants retained in the final model was examined post hoc (**Figure 3**). Infection was reported in 95 of the 134 children (70.9%): 90 had diarrhea only and 5 had both diarrhea and ARI, with no cases of ARI alone. Of the 95 reported infections, 21 (22.1%) were confirmed in the Maternal and Child Health Handbook; the remaining 74 cases had no corresponding handbook record and were based on caregiver report alone.

The proportion of children with reported infection was higher among exclusively breastfed children (92.4%) than among those not exclusively breastfed (50.0%; $\chi^2(1)=29.21$, $p<0.001$). It also varied non-monotonically across household food insecurity categories, at 73.1% among food-secure, 100% among mildly insecure, 97.1% among moderately insecure, and 51.6% among severely insecure households ($\chi^2(3)=27.04$, $p<0.001$).

In an exploratory model that added an exclusive breastfeeding × acute infection interaction to the final model, the association between infection and stunting appeared weaker among exclusively breastfed children (interaction OR: 0.04; 95%CI: 0.002–0.90; Wald $p=0.043$). However, the likelihood-ratio test for the interaction was not statistically significant ($p=0.067$), and the estimate was based on only five exclusively breastfed children without reported infection. Therefore, the interaction was not retained in the final model.

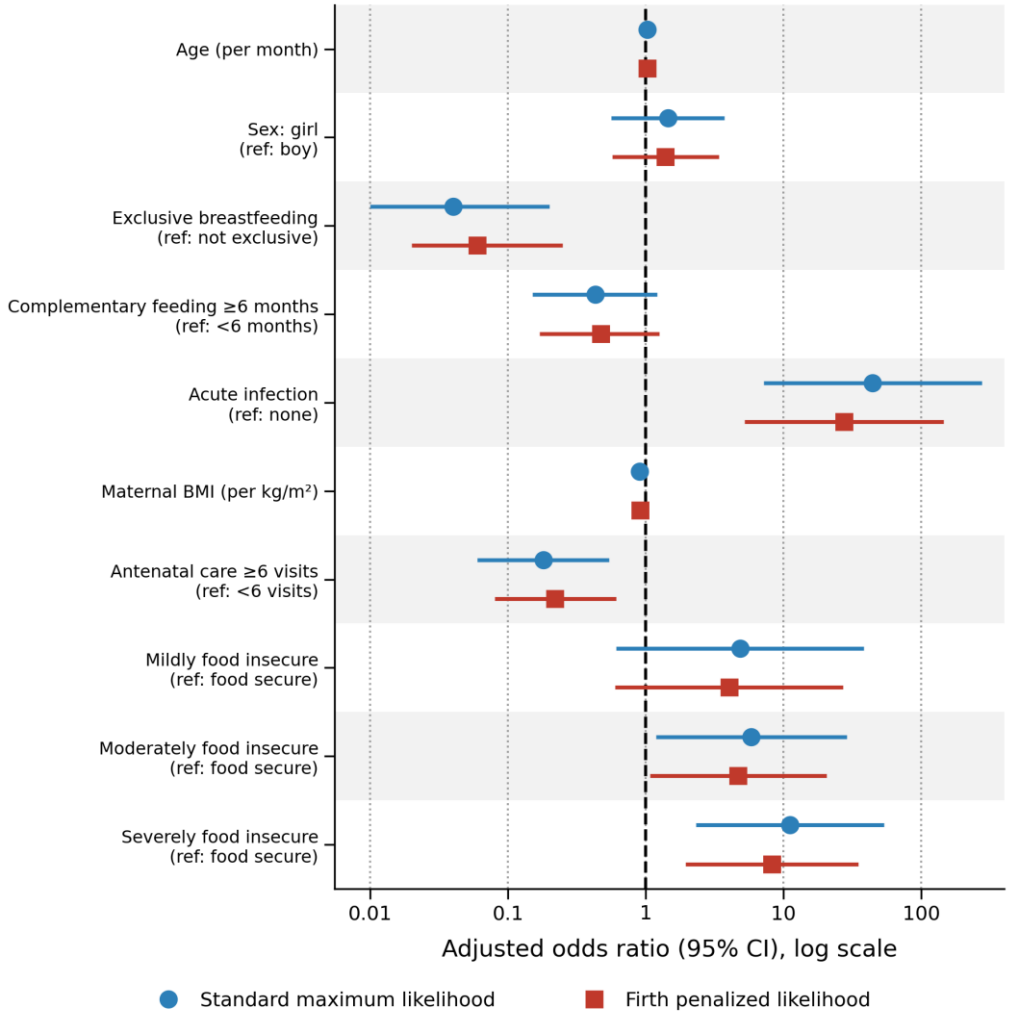

Figure 2. Comparison of standard maximum-likelihood and Firth penalized-likelihood estimates for all terms in the final multivariable model (n=134). Markers show adjusted odds ratios and horizontal lines the 95% confidence intervals, on a logarithmic scale; the dashed line marks the null value of 1.

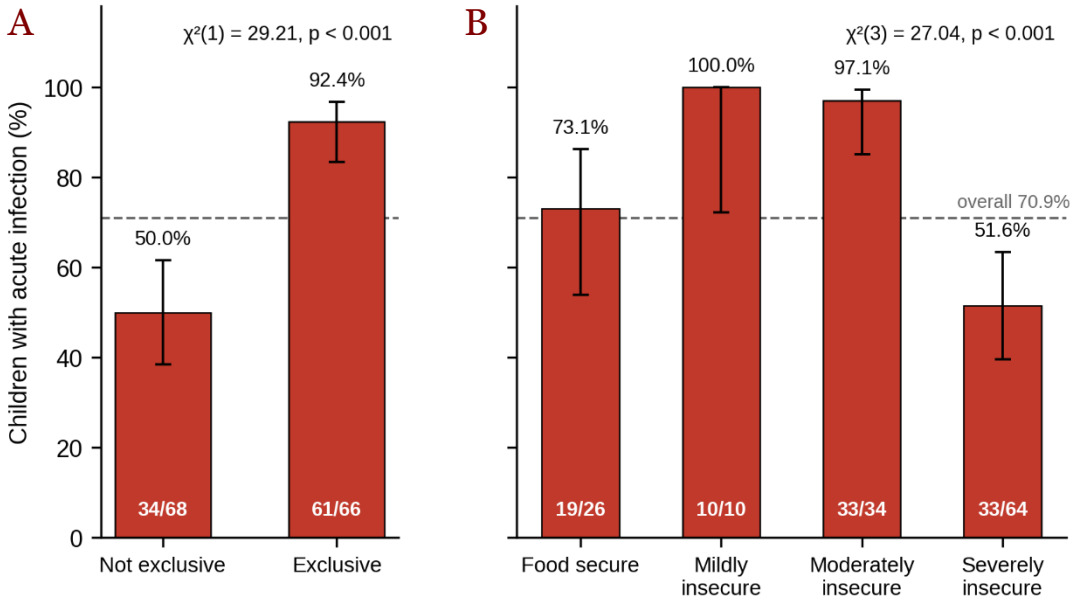

Figure 3. Post hoc distribution of acute infection in the three months preceding data collection, by exclusive breastfeeding status (A) and household food insecurity category (B) (n=134). Bars show the proportion of children with reported infection, with the number affected over the number in each group; whiskers are 95% Wilson confidence intervals. The dashed line marks the overall infection prevalence of 70.9%.

Discussion

Four factors were independently associated with stunting after multivariable adjustment: exclusive breastfeeding and adequate antenatal care attendance were associated with lower odds of stunting, while acute infection and household food insecurity were associated with higher odds of stunting. The inverse association with maternal BMI did not reach statistical significance. These findings encompass both nutrition-specific and nutrition-sensitive factors and are broadly consistent with the Indonesian evidence base [8,9], while providing local data from a regency with persistently high stunting prevalence.

The nutrition-specific determinants retained in the final model were exclusive breastfeeding, complementary feeding timing, acute infection, antenatal care attendance, and maternal BMI. Exclusive breastfeeding showed the strongest inverse association with stunting, and this association remained strong under Firth estimation, supporting the robustness of its direction, although the magnitude remained imprecisely estimated. This is consistent with a study of low-income households in eastern Indonesia, where exclusive breastfeeding was associated with lower odds of stunting across household wealth strata [27], and with a recent analysis in Kubu Raya itself that retained absence of exclusive breastfeeding as the sole independent predictor of stunting among children aged 24–59 months [11]. A systematic review of Indonesian studies reports markedly higher odds of stunting in children without exclusive breastfeeding [28], and the 2024 national nutritional status survey documents the co-distribution of low exclusive breastfeeding coverage and elevated stunting prevalence across provinces [5]. The nutritional contribution of breast milk during early infancy provides a plausible explanation for this association, although underlying mechanisms were not evaluated in this study. Nevertheless, the post hoc findings did not establish whether infection mediated the observed association, particularly because reported infection was more common among children with a history of exclusive breastfeeding.

Introducing complementary food at six months or later was associated with lower odds of stunting in the bivariate analysis and maintained this direction after adjustment (aOR: 0.43; 95%CI: 0.15–1.21), although this did not reach statistical significance. The variable was retained in the final model as a potential confounder because its exclusion shifted the acute infection estimate by 21.9%. Early introduction of foods and liquids other than breast milk may displace breast milk and can expose infants to contaminated food and water, and cohort data from low- and middle-income settings link early or otherwise inappropriate complementary feeding to

undernutrition [29]. However, the direction of the association is not straightforward. A review of prospective studies found that earlier complementary feeding was generally followed by slower growth in lower-resource populations, but also that caregivers often start feeding early in response to perceived poor growth, so reverse causation is possible [30]. In this sample, complementary feeding timing was also collinear with low birth weight, limiting the precision of estimates of their independent associations. However, this collinearity did not establish whether concerns about infant growth influenced caregivers' feeding decisions.

Acute infection in the three months preceding data collection had the largest aOR in this study. The Firth estimate (aOR: 27.47) is taken as the primary result rather than the standard maximum-likelihood estimate, which may be affected by sparse-data bias when cell counts are small relative to the number of parameters [25,26]. The association is consistent with Indonesian evidence linking infectious disease history to stunting among under-fives [31], including national survey data in which recent infection was independently associated with higher odds of child undernutrition alongside inadequate water, sanitation, and housing conditions [32]. A plausible biological explanation is the long-established nutrition-infection cycle [33]: infection reduces nutrient absorption and diverts nutrients toward the immune response, while undernutrition impairs immune competence [34].

As the nutrition-infection cycle is bidirectional, the present design cannot establish temporal precedence, because infection was reported by caregivers over a three-month recall period, whereas anthropometric measurements were obtained at a single time point. The estimate must also be interpreted in relation to the other measured exposures. The post hoc cross-tabulations showed that infection was not independently distributed across the other determinants included in the model. Its prevalence was higher among exclusively breastfed children than among those not exclusively breastfed, a pattern that requires cautious interpretation, and it varied non-monotonically across household food insecurity categories. These patterns could reflect temporal ambiguity, differential caregiver recall, care-seeking behavior, or residual confounding. A shared reporting pathway is also plausible. Differences in symptom recognition or recall could link the two variables through reporting behavior, but this possibility was not directly assessed. As infection was mostly caregiver-reported and consisted almost entirely of diarrhea cases, and its timing relative to anthropometric measurement and cessation of exclusive breastfeeding was not recorded, these post hoc patterns cannot establish temporal order or a causal mechanism. The aOR therefore indicates a strong but imprecise association in this sample and should not be interpreted as a causal effect. These findings highlight the need for further evaluation of coordinated infection-prevention and nutrition services, although they do not establish the effectiveness of such an approach.

Attending at least six antenatal care visits, the minimum specified by Indonesia's national antenatal care standard [14], was independently associated with lower odds of stunting, consistent with literature identifying antenatal care frequency and quality as correlates of stunting risk in Indonesian children [9,35]. This association should not be read as a causal effect of the number of visits. Attendance is also likely to reflect access to health services, maternal health behavior, socioeconomic position, and the quality of care received, as well as receipt of interventions such as iron supplementation and nutrition counseling. The national minimum is below the eight contacts recommended by WHO [15], so the threshold applied here reflects the national visit-frequency criterion rather than the WHO contact-frequency recommendation, and this study cannot show whether moving toward the eight-contact model would give additional benefit. Antenatal care was classified here as nutrition-specific because antenatal contact delivers interventions acting directly on maternal and fetal nutritional status, although its position in the proximate-distal hierarchy is contested. A decomposition analysis of declines in stunting across sub-Saharan Africa identified utilization of maternity care as the most important distal determinant, operating largely through increased coverage of more proximate interventions, such as iron supplementation, rather than through a direct effect on child growth [36]. In this study, iron supplementation showed a strong bivariate association with stunting but was not retained in the multivariable model; this does not establish that its association was mediated by antenatal care. The association with attendance may reflect the broader antenatal service package, including nutrition counseling and iron supplementation, as well as unmeasured differences in

access and care quality. Antenatal contact remains a relevant service platform, but these data cannot distinguish the contributions of its individual components.

Maternal BMI showed a non-significant inverse association after adjustment, with a similar estimate under penalized estimation, consistent in direction with the literature linking maternal nutritional status to offspring growth during the first 1,000 days of life [37]. The confidence intervals included the null, and the available data cannot distinguish limited precision from an absence of association in this population. Maternal MUAC, the second indicator of maternal nutritional status, showed no statistically significant difference between groups.

Household food insecurity was the only nutrition-sensitive determinant retained in the final model. Maternal education and household income were associated with stunting in the bivariate analysis but not after adjustment. Household food insecurity showed a graded association with stunting that strengthened with severity, and the gradient was preserved under Firth estimation. The estimate for the mildly insecure category was imprecise, based on only 10 households, and its confidence interval included the null; these data do not establish a threshold effect.

A comparable graded association has been reported in Indonesian nationally representative data, where the prevalence ratio for stunting was 1.24 (95%CI: 1.18–1.31) in moderately food-insecure households and 1.39 (95%CI: 1.27–1.53) in severely food-insecure households, with the association significant specifically in rural areas [38], the setting type examined here. Household food insecurity measured by the same instrument has likewise been associated with stunting in urban Indonesian populations [39], and two systematic reviews of Indonesian studies reach the same conclusion [40,41]. An international meta-analysis of cohort studies, however, reported substantial heterogeneity and no statistically significant pooled association despite most individual studies reporting positive associations [42]; this discrepancy may reflect variation in measurement instruments and follow-up windows, underscoring the need for context-specific interpretation. Notably, the crude proportion of stunted children in this sample did not rise monotonically across categories, peaking among moderately rather than severely insecure households; the uneven distribution of acute infection may contribute to this difference between crude and adjusted patterns, although its specific contribution was not isolated. Given the small mildly insecure group and this non-monotonic crude pattern, the gradient should nonetheless be interpreted with caution.

Maternal education and household income were each associated with stunting at the bivariate level but were removed during backward elimination without changing the remaining estimates by more than 15%. This does not show that they are unimportant. In the UNICEF conceptual framework, education and household resources are underlying and enabling determinants that act largely through more proximal factors [3], such as feeding practices and use of antenatal services, all of which were represented in the final model; adjusting for these proximal factors may attenuate their associations, although mediation was not assessed. Household food insecurity, which was retained in the final model, is a measure of food access that may capture constraints not fully reflected by income. Household income was also strongly collinear with exclusive breastfeeding in this sample, which limited the precision of their mutually adjusted estimates.

Case status was determined from anthropometry measured by trained personnel against WHO Child Growth Standards rather than from caregiver report, and exposure histories were cross-checked against the Maternal and Child Health Handbook where records were available. Matching on sex and age, with both retained as covariates, is consistent with an approach for analyzing originally matched data by unconditional methods [19,20,21,22]. The final model showed no evidence of lack of fit, good discrimination, 80.6% correct classification, and no evidence of substantial residual multicollinearity, and the Firth sensitivity analysis showed that the statistically significant associations persisted under bias-corrected estimation. However, the discrimination and classification statistics were derived from a sample with 50% cases by design and therefore reflect apparent model performance in the matched sample rather than predictive performance in an independent population.

Several limitations qualify these findings. Breastfeeding history, complementary feeding timing, and infection episodes were ascertained retrospectively by caregiver report, raising the possibility of recall bias, potentially differential between caregivers of stunted and non-stunted

children. Acute infection was not assessed by clinical examination, and only 21 of the 95 reported infections were corroborated in the Maternal and Child Health Handbook. The number, severity, and timing of episodes were not recorded, precluding assessment of temporal order. Controls were selected purposively, and cases comprised all recorded stunted children in the three selected villages, which limits generalizability beyond the three study villages. Selection bias may also have operated through the inclusion criteria: children were required to be registered at the public health center, to have been delivered at a health facility, and to have a Maternal and Child Health Handbook. Consequently, children with more limited access to health services, who may differ in both exposures and stunting risk, were likely under-represented. The findings may therefore not represent all children aged 0–59 months in Kubu Raya.

The sample of 134 constrained precision throughout. No a priori sample size calculation was performed, the number of events per model parameter was low, and variables were selected in a data-driven way, which together create a risk of overfitting and of unstable variable selection [23,24]. Several estimates therefore had wide confidence intervals even after Firth correction, and household income and low birth weight were excluded from the final model amid collinearity with other predictors. No age caliper was pre-specified, and although the matching factors were adjusted for, the pair structure itself was not modeled. The Indonesian HFIAS has been validated in another province [18] but not in the study population. Causal inference is constrained by the observational design. Finally, water, sanitation, and hygiene conditions, which are established correlates of stunting in Indonesia and other settings [32,43], were not measured; therefore, residual confounding cannot be excluded.

The factors associated with stunting in this study relate to modifiable targets addressed by Indonesia's national stunting strategy. The findings are consistent with existing intervention priorities, including sustained lactation counseling and community-based support at the integrated health post and health center level, reinforced by convergent findings from a separate Kubu Raya analysis [11]; improving antenatal care coverage toward the national minimum of six visits and, ultimately, the eight contacts recommended by WHO, given that antenatal care also provides opportunities for iron supplementation and nutrition counseling; and strengthening infection prevention and prompt case management. An important contribution of the present study is the local evidence that household food insecurity remained associated with stunting after adjustment for these nutrition-specific factors. This finding highlights the importance of addressing household food access, alongside feeding practices, in local stunting prevention programs in Sungai Ambawang. The co-occurrence of infection with feeding-related determinants also provides a rationale for evaluating the integration of infection prevention and routine nutrition services in this setting, although this observational study cannot establish whether such integration would be more effective than delivering these services through separate programs. Future research should prioritize a larger, probability-sampled study with prospective ascertainment of infection, and direct measurement of water, sanitation, and hygiene conditions.

Conclusion

In this high-burden rural regency, nutrition-specific and nutrition-sensitive factors were associated with stunting in the same adjusted model: exclusive breastfeeding and attending at least six antenatal care visits were associated with lower odds of stunting, while acute infection and household food insecurity remained associated with higher odds after adjustment for the other covariates. However, these findings are based on a small, purposively sampled case-control study, with imprecise estimates that cannot establish causality or population-level effects. They are best used to inform locally targeted hypotheses and program priorities in Sungai Ambawang, where they provide a rationale for evaluating coordinated delivery of existing stunting interventions, with attention to household food access as well as feeding and health services. A larger, probability-sampled study with prospective ascertainment of infection is the most important next step.

Ethics approval

This study adhered to the ethical principles of the Declaration of Helsinki and received approval from the Health Research Ethics Committee of the Faculty of Health Sciences, Universitas

Muhammadiyah Pontianak (approval No. 013/KEPK-FIKES/UM PONTIANAK/2022). Written informed consent was obtained from each participating caregiver prior to data collection.

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Competing interests

All the authors declare that there are no conflicts of interest.

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Underlying data

Derived data supporting the findings of this study are available from the corresponding author on request.

Declaration of artificial intelligence use

Artificial intelligence (AI) tool, Claude model claude-opus-5 (Anthropic PBC, San Francisco, CA, USA), was used for manuscript writing support, including drafting manuscript outlines and structure from author-supplied material and sources; restructuring, condensing, and language refinement of author-drafted text throughout the manuscript; formatting the manuscript according to journal requirements; and retrieval, formatting, and cross-checking of the reference list. Figures were generated using Python (Matplotlib) based on summary statistics and regression output produced by the authors. AI tools were not used for study design, data collection, data preprocessing, or statistical analysis; all modeling was performed by the authors in Stata, and no result reported here was produced by AI. Authors confirm that all AI-assisted processes were critically reviewed by the authors to ensure the integrity and reliability of the results. The authors were solely responsible for the final decisions and interpretations presented in this article.

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