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Diet Quality, Nutrient Intake, and Estimated Iron and Zinc Bioavailability in Stunted and Normal Toddlers in Bogor Regency, Indonesia: A Comparative Study

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ABSTRACT

There are still limited studies assessing nutrient intake, especially micronutrients, among stunted children under five. Indonesia also does not yet have official indicators to evaluate diet quality in young children. This study aimed to analyze the differences in diet quality, macro-and micronutrient adequacy, and estimated bioavailability of zinc and iron in stunted and normal toddlers. Using a comparative cross-sectional design, the study was conducted at Purwasari and Kampung Manggis Community Health Centers from August 1 to 26, 2025, involving 60 stunted and 60 normal children. Diet quality was assessed using an Indonesian-adapted Healthy Eating Index (HEI 2–5 years). The results showed significant differences between stunted and normal toddlers in maternal education (p=0.001), paternal education (p=0.043), paternal occupation (p=0.045), parity (p=0.028), per capita income (p=0.006), birth weight (p=0.003), and history of infectious diseases (p=0.019). Diet quality components that differed significantly included vegetables and green vegetables (p=0.031), fruits and fruit juices (p=0.009), and dietary diversity (p=0.003), with normal toddlers demonstrating higher scores. Normal toddlers also had significantly higher adequacy of macronutrients and micronutrients ($p<0.05$). Estimated iron and zinc absorption were significantly lower among stunted toddlers (iron p=0.019; zinc p=0.010), although overall iron and zinc bioavailability categories did not differ significantly between groups. Stunting among Indonesian toddlers is associated with unfavorable socioeconomic conditions, lower birth weight, history of infectious diseases, needs improvement diet quality, and reduced estimated micronutrient absorption. Interventions should prioritize improving dietary quality, increasing vitamin C intake to enhance iron absorption, and limiting dietary inhibitors such as tea, alongside broader strategies addressing household socioeconomic factors and child health.

Key Messages:

- Socioeconomic factors, including parental education, occupation, and household income, differed between stunted and normal toddlers.
- Low birth weight and prior infectious diseases were more common in stunted toddlers.
- Stunted toddlers had lower diet quality. Adequacy of energy, macronutrients, key micronutrients, and estimated iron and zinc absorption were lower in stunted toddlers.

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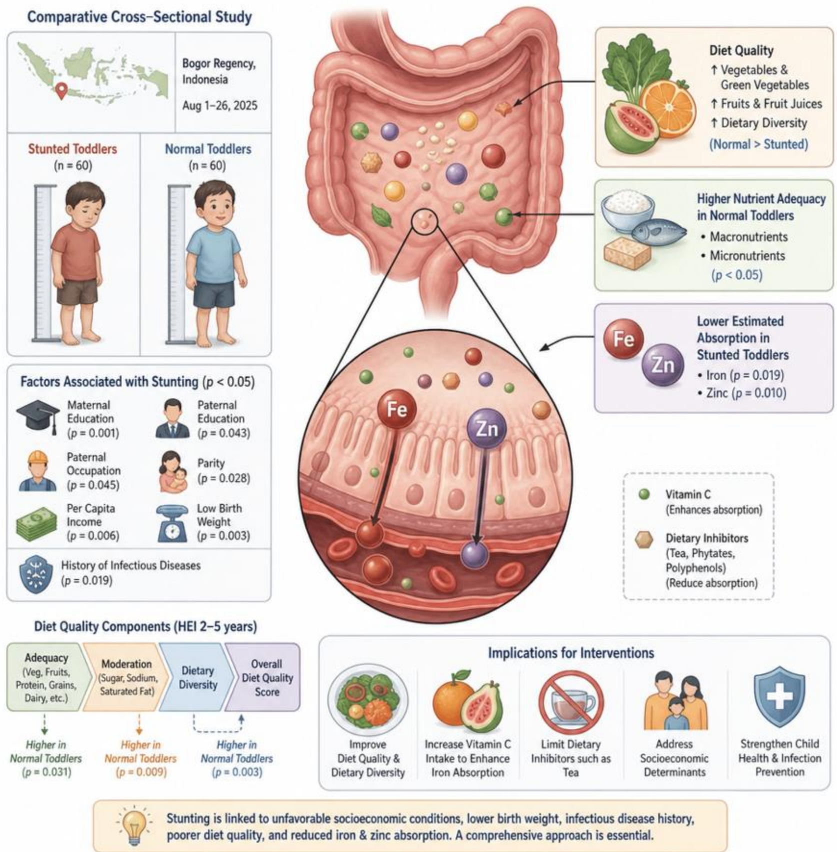
GRAPHICAL ABSTRACT



INTRODUCTION

Linear growth is the best indicator for assessing a child's overall well-being and provides an accurate picture of inequality in human development. This is tragically reflected in the millions of children around the world who fail to reach their linear growth potential due to poor health, malnutrition, and inadequate care (1). Adequate nutrition during childhood has an impact on children's growth and physiological development, health, and well-being. At this stage, a balanced diet is very important to support growth, development, and the formation of personality and eating habits (2).

Diet is an important factor in preventing growth disorders in toddlers; therefore, providing quality food is highly recommended to support optimal growth (3). However, there is still uncertainty regarding the quality and quantity of food intake needed to support healthy growth and development (3). One approach to assessing food intake comprehensively is to measure diet quality, which has been shown to be associated with child growth and is closely related to dietary diversity (4). Diet quality is a multidimensional concept that includes adequacy, moderation, and diversity of the diet, where dietary diversity is only one component among others and does not fully represent overall diet quality (5) However, most previous studies have been limited to using dietary diversity indicators as a proxy for diet quality (6). This approach is not entirely adequate because it does not consider the suitability of consumption patterns with the National Nutrition Guidelines, making it less capable of comprehensively describing diet quality in toddlers in various regional contexts (7). Therefore, understanding diet quality is crucial for improving food intake, which impacts children's development and growth (8). Good diet quality, in accordance with nutritional guidelines, is associated with increased height and weight (9).

In fact, the amount of nutrients consumed does not always reflect the amount of nutrients that are actually available and can be absorbed by the body. Factors that inhibit and enhance absorption in the diet play an important role in determining estimates of bioavailability and estimates of absorbed nutrients, which ultimately affect children's nutritional status and growth (10). Beyond diet quality, the effectiveness of nutrient utilization in the body is influenced by estimates of nutrients that are actually available for

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absorption, an aspect that has been rarely investigated in child nutrition studies in Indonesia. Malnutrition in children in Indonesia is related to inadequate intake of macronutrients (11). In addition, children in Indonesia are at risk of micronutrient deficiencies, such as zinc, iron, vitamin A, and calcium (11–13). Low nutrient intake generally occurs in rural and urban areas and is associated with short stature for age (12). In addition, nutrient intake and enhancer inhibitor factors also affect the bioavailability of micronutrients, especially zinc and iron. The diet in developing countries is generally based on cereals that are high in phytate and low in animal products (14). Zinc bioavailability is found in animal foods, while plant foods such as rice and legumes contain phytate, which can inhibit zinc absorption (15). Iron is found in animal-based foods, with the remainder found in plant-based foods. There are many foods that inhibit iron absorption, including tannins from tea and coffee, oxalic acid from leafy vegetables, phytic acid, and phosvitin (16). These conditions may contribute to micronutrient deficiencies, impaired immune function, increased susceptibility to infection, and ultimately suboptimal linear growth in children (17).

Due to these limitations, previous studies have not comprehensively integrated diet quality assessment based on nutritional guidelines with bioavailability estimates and nutrient absorption estimates, particularly in Indonesian toddlers. Therefore, the unique contribution of this study lies in the combined analysis of diet quality using a adapted Healthy Eating Index (HEI) and estimates of bioavailability and absorption of zinc and iron in Indonesian toddlers, which is expected to provide a more complete picture of differences in diet quality, nutrient bioavailability, and linear growth among stunted and normal children. Accordingly, this study aimed to analyze the differences in diet quality, macro- and micronutrient adequacy, and estimated bioavailability of zinc and iron between stunted and normal toddlers.

METHODS

This study used a comparative cross-sectional study design. The research locations included the Purwasari Community Health Center, which covers the villages of Sukadamai, Purwasari, and Petir, and the Kampung Manggis Community Health Center, which covers the villages of Dramaga, Neglasari, and Sinarsari, Dramaga District. The research locations were selected purposively based on considerations of the increasing prevalence of stunting in Bogor District, from 24.9% in 2022 to 27.6% in 2023 (18,19). Both health centers are included in the stunting intervention area according to the Regent's Decree 2024 (20). This study was conducted from August 1 to 26, 2025, and has received Ethical Approval from the Research Ethics Committee Involving Human Subjects at Bogor Agricultural University, Number 1838/IT3.KEPMSM-IPB/SK/2025. The sample consisted of 60 stunted toddlers and 60 normal toddlers. The minimum total sample size was 120 toddlers.

Data collected in this study comprised primary and secondary data. Primary data included household characteristics and dietary intake obtained through interviews, while secondary data on birth weight, birth length, gestational age, and history of infectious diseases were obtained from Maternal and Child Health (MCH) handbooks and verified with maternal reports. The dependent variable is the incidence of stunting, measured using a stadiometer to obtain height-for-age indices with a threshold score of Z-score ≥ -2 SD classified as non-stunted and a score of Z-score < -2 SD classified as stunted. The nutritional status of children under five was determined through anthropometric measurements, including height and weight. Height was measured using a stadiometer with an accuracy of 0.1 cm, while body weight was measured using a scale with an accuracy of 0.1 kg. All measuring equipment was calibrated daily prior to data collection, and anthropometric measurements were consistently conducted by the same trained enumerators across all data collection days to reduce inter-observer variability.

The independent variables are household characteristics (mother's education, father's education, father's occupation, parity, per capita income). Socioeconomic variables were defined using specific cut-off points. Parents’ education was categorized as low (no schooling or elementary school), medium (junior or senior high school), and high (diploma or higher) (19). Per capita household income was classified as sufficient (≥ IDR 547,752) or low (< IDR 547,752) (21). Dietary intake was assessed using Repeated food recall 2x24 hours on consecutive days. This approach was applied to estimate usual dietary intake, as repeated 24-hour recalls are commonly used to capture short-term variability in food consumption and are

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considered appropriate for toddlers, whose dietary patterns tend to be relatively consistent from day to day. Using consecutive-day recalls also reduced respondent burden and improved recall accuracy. All foods and beverages reported were converted into nutrient intakes using NutriSurvey software, based on the Indonesian Food Composition Table (Tabel Komposisi Pangan Indonesia, TKPI) (22).

Dietary intake data were used to determine diet quality, which was analyzed using the adapted Healthy Eating Index (HEI) for children aged 2–5 years as developed in previous studies (5). The component structure and scoring system used in this study fully adhered to the HEI instrument that has been previously developed and validated. Any adaptations in this study were limited to the use of consumption recommendations to align with the Indonesian context, without altering the construct, components, or scoring mechanism of the HEI. The HEI was adapted based on the Indonesian Balanced Nutrition Guidelines (Pedoman Gizi Seimbang, PGS) (23), particularly for the adequacy components, including cereals, vegetables, fruits, milk and dairy products, animal-source foods, legumes, oils, and fats. The moderation components, including total fat and sodium, were adjusted according to the Indonesian Balanced Nutrition Guidelines (PGS) and the Recommended Dietary Allowances (Angka Kecukupan Gizi, AKG) (23,24). Saturated fat intake was assessed using the cut-off values recommended by the World Health Organization (WHO) (25), while cholesterol intake was evaluated using cut-off values from previous studies (5), given the absence of specific cholesterol recommendations in the Indonesian AKG.

Dietary iron bioavailability was estimated by partitioning total iron intake into heme and non-heme fractions according to a previously established method (26). The estimation was based on daily intakes of animal-source foods (g/day), total dietary iron (mg/day), and vitamin C (mg/day). Heme iron was calculated as 40% of total dietary iron intake, representing the proportion of heme iron derived from animal-source foods. Non-heme iron was calculated as the difference between total dietary iron and heme iron. Heme iron bioavailability was assumed to be 23%. Non-heme iron bioavailability was estimated using the following equation (26).

$$\%\ \text{bioavailable non hame} = 1{,}7653 + 1{,}1252\ 1n\ (EFs/IFs)$$

Where *Enhancer Factors* (EFs) included daily intakes of vitamin C (mg), animal-source foods (g), and fruits and vegetables (g), plus a constant of 1. *Inhibiting Factors* (IFs) comprised daily intakes of rice (g), legumes (g), and dried tea (g), plus a constant of 1. Absorbed heme and non-heme iron were calculated by multiplying each iron fraction by its respective bioavailability. Total absorbed iron was obtained by summing both fractions. Overall iron bioavailability was expressed as the percentage of total absorbed iron relative to total daily dietary iron intake and classified according to previously described criteria (26).

Zinc bioavailability estimates are made through several structured analytical stages. The first stage begins with the identification of all food items consumed by respondents based on daily consumption recall data. Each food item is recorded in detail to ensure accuracy in determining nutritional content. Phytate content for each food item was then identified using a standardized database (27), with priority given to Indonesian data, followed by ASEAN and broader Asian regional data. This phytate content information was needed because of its role as the main inhibitor of zinc absorption. Next, the phytate and zinc content of all food ingredients was converted into mmol units. This conversion was done to enable the biochemical calculation of the molar ratio of phytate to zinc. After all units were standardized, the molar ratio of phytate to zinc (RPZ) was calculated Furthermore, absorbed zinc was estimated, and zinc bioavailability categories were determined according to previously published guidelines (27).

The data analysis comprised both univariate and bivariate approaches. Univariate analysis was conducted to present the frequency distribution of each measured variable, including household characteristics, subject characteristics, nutrient intake, and estimated bioavailability. Prior to the bivariate analysis, data normality was assessed using histograms, skewness values, and the Kolmogorov–Smirnov test. The bivariate analysis included comparative tests. The Chi-square test was applied for categorical data. For continuous variables, the independent t-test was used when the data were normally distributed, whereas the Mann–Whitney test was applied for non-normally distributed data.

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CODE OF HEALTH ETHICS

This research has received Ethical Approval from the Ethics Committee for Research Involving Human Subjects of IPB University, with the approval number 1838/IT3.KEPMSM-IPB/SK/2025.

RESULTS

The total number of respondents in the study was 120 toddlers, consisting of two groups: 60 toddlers with stunting and 60 toddlers without stunting. The distribution of respondents based on the characteristics of households with toddlers with and without stunting is presented in Table 1. Based on the analysis results presented in Table 1, most mothers in the stunted toddler group had low education (71.4%), while in the normal group, more had medium education (64.2%). The test results showed that maternal education differed significantly between the stunted and normal toddler groups ($\rho<0.05$). The highest percentage of stunting was found among fathers with low education (61.5%). Conversely, among fathers with high education, there were no cases of stunting at all, with 100% of their children having normal nutritional status. The test results showed that the fathers' education levels differed significantly ($\rho < 0.05$). There was a significant difference in the variable of the father's occupation between the stunted and normal toddler groups ($\rho < 0.05$). The highest proportion of stunting was seen in the group of fathers who worked as entrepreneurs/traders/service providers (56.0%) and laborers/drivers (53.8%). More stunted toddlers came from families with non-ideal parity (66.7%), while more normal toddlers came from families with ideal parity (57.8%). The test results showed that parity differed significantly between the stunted and normal toddler groups ($\rho < 0.05$). Most stunted toddlers came from low-income families (64.3%). Conversely, families with sufficient income were more commonly found in the normal toddler group (62.5%). The test results showed that per capita income differed significantly between the stunted and normal toddler groups ($\rho < 0.05$).

Table 1 Household Characteristics of Stunted and Normal Toddlers

Variable	Nutritional Status				Total	%	*ρ- value*
	Stunted		Normal		n		
	n	%	n	%			
Mother's Highest Level of Education							
Low	35	71,4	14	28,6	49	100	0,001*
Medium	24	35,8	43	64,2	67	100	
High	1	25,0	3	75,0	4	100	
Father's Highest Level of Education							
Low	32	61,5	20	38,5	52	100	0,043*
Medium	28	42,4	38	57,6	66	100	
High	0	0	2	100	2	100	
Father's Occupation							
Entrepreneur, trader, service provider	14	56,0	11	44,0	25	100	0,045*
Civil servant/military/ private sector	3	20,0	12	80,0	15	100	
Laborers/drivers	43	53,8	37	46,3	80	100	
Parity							
Ideal	36	42,9	48	57,8	83	100	0,028*
Not ideal	24	66,7	12	33,3	36	100	
Per capita income							
Sufficient	24	37,5	40	62,5	54	100	0,006*
Low	36	64,3	20	35,7	56	100	

ρ values are based on the Chi-Square test, *significant if ($\rho<0.05$)

Table 2 presents the characteristics of stunted and normal toddlers. Among stunted toddlers, 49.5% had normal birth weight and 53.3% had low birth weight, while among normal toddlers, 50.5% were born with normal weight and 46.7% had low birth weight. The Chi-Square test results show that there is a difference between the two groups ($\rho < 0.05$). Most toddlers in both groups had normal birth length. The Chi-Square test results show that there is no significant difference between the two groups ($\rho > 0.05$). Among boys, 52.9% were stunted, while among girls, the normal group was more dominant (53.8%). Although there were variations in gender distribution, statistical tests showed that this difference was not significant between the two groups ($\rho > 0.05$). The stunted group consisted of 52.8% of infants who were born prematurely and 47.8% who were full-term, while in the normal group the proportion was the

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opposite, with slightly more full-term infants at 52.2%. However, the Chi-Square test showed that the difference was not significant ($\rho > 0.05$). A total of 54.2% of stunted toddlers had experienced infectious diseases in the last six months. Meanwhile, only 45.8% of toddlers with normal nutrition had also experienced infectious diseases in the last six months. The test results showed a significant difference in the history of infectious diseases between stunted and normal toddlers ($\rho < 0.05$).

Table 2 Characteristics of Toddlers with Stunting and Normal Toddlers

Variable	Nutritional Status				Total n	%	*ρ-value*
	Stunted		Normal				
	n	%	n	%			
Birth Weight[1)]							
Normal	52	49,5	53	50,5	105	100	0,003*
Low Birth Weight	8	53,3	7	46,7	15	100	
Mean ± SD	2905,8±426,2		3164,3±507,3				
Birth Length[1)]							
Normal	42	50,5	48	49,5	93	100	0,108
Short	18	48,1	14	51,9	27	100	
Mean ± SD	47,8±2,4		48,3±2,8				
Gestational Age[1)]							
Premature	28	52,8	25	47,2	53	100	0,924
Full Term	32	47,8	35	52,2	67	100	
Mean ± SD	37,7±1,9		37,8±1,8				
Gender[2)]							
Male	36	52,9	32	41,1	68	100	0,580
Female	24	46,2	28	53,8	52	100	
History of Infectious Diseases[2)]							
Yes	58	54,2	49	45,8	107	100	0,019*
No	2	15,4	11	84,6	13	100	

[1)]*Independent T-test*, [2)] uji *Chi-Square* * significant if ($\rho<0,05$).

Table 3 presents the average adapted Healthy Eating Index (HEI) scores of stunted and normal toddlers. Overall, toddlers with normal nutritional status tended to have higher mean scores across most HEI components compared with stunted toddlers. Significant differences between the two groups were observed for vegetables and green vegetables, fruits and fruit juices, and overall dietary diversity ($p < 0.05$), with normal toddlers demonstrating higher scores in these components. No significant differences were found between stunted and normal toddlers for other adequacy components, including cereals, milk and dairy products, meat and eggs, legumes, as well as oils and fats ($p > 0.05$). Similarly, moderation components snacks, total fat, saturated fat, cholesterol, and sodium did not differ significantly between the two groups ($p > 0.05$).

Table 3 Average adapted HEI Score in Stunted and Normal Toddlers

HEI components	Score range	Nutritional status		*ρ -value*
		Stunted Mean±SD	Normal Mean±SD	
Adequacy				
Cereals[2)]	0-10	2,33±2,86	3,20±3,31	0,205
Vegetables and green vegetables[2)]	0-10	0,16±0,77	0,35±1,40	0,031*
Fruits and fruit juices[2)]	0-10	0,10±0,57	0,56±1,95	0,009*
Milk and dairy products[1)]	0-10	4,37±4,50	5,02±4,39	0,428
Meat and eggs[1)]	0-10	8,54±2,78	8,93±2,35	0,402
Legumes[2)]	0-10	2,04±2,96	2,37±2,73	0,294
Oils and fats[2)]	0-10	0,20±1,32	0,29±1,11	0,096
Moderation				
Snacks (sugar, candy, chocolate)[1)]	0-10	5,91±3,91	6,97±3,53	0,121
Total fat[1)]	0-10	5,72±2,98	4,79±3,25	0,103
Saturated fat[1)]	0-10	4,89±4,20	3,75 ±4,11	0,128
Cholesterol[1)]	0-10	8,50±3,02	7,95±3,20	0,356
Sodium[1)]	0-10	8,08±3,16	8,33±2,86	0,638
Diversity[1)]	0-10	8,54±1,81	9,41±1,73	0,003*

[1)]*Independent T-test*, [2)] uji *Chi-Square* * significant if ($\rho<0,05$).

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Table 4 presents the average scores for macro and micro nutrient adequacy in stunted and normal toddlers. All macro and micro nutrient components show better average TKG (Nutritional Adequacy Level) in normal toddlers compared to stunted toddlers, and all components have statistically significant differences (p<0.05) between the stunted and normal groups. The text continues here (Figure 1).

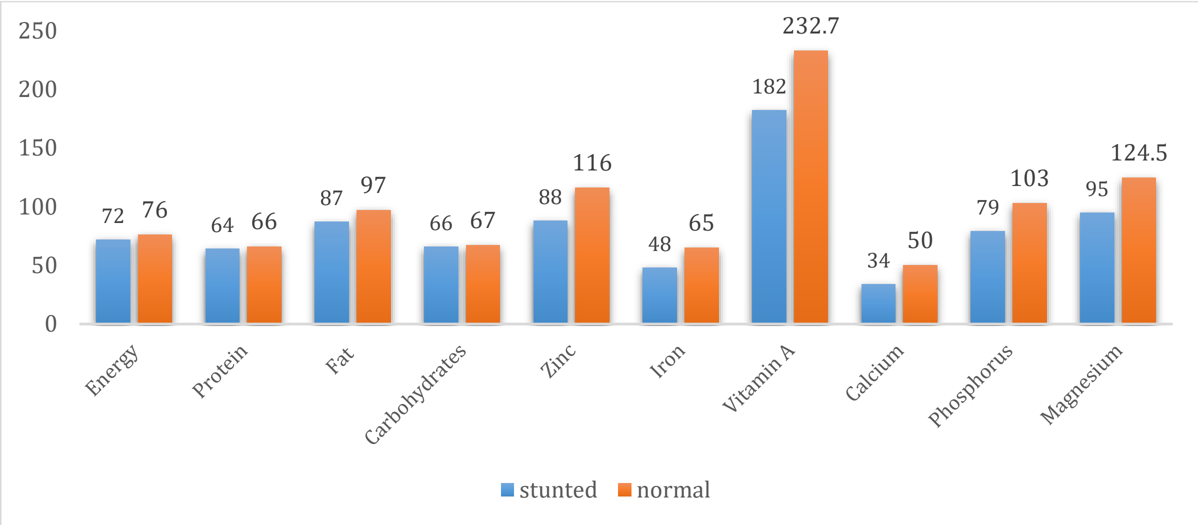

Figure 1 Average Adequacy of Macro and Micro Nutrient in Stunted and Normal Toddlers

Table 5 presents the estimated iron and zinc bioavailability among stunted and normal toddlers. The majority of toddlers in both groups had low estimated iron bioavailability. The proportion of stunted toddlers with low estimated iron bioavailability (53.8%) was slightly higher than that of normal toddlers (46.2%). The Mann–Whitney test indicated no significant difference in estimated iron bioavailability between the two groups (p>0.05). Most toddlers in both groups had high estimated zinc bioavailability (stunted: 49.1%; normal: 50.9%). The low estimated zinc bioavailability category was rarely observed, with only one stunted toddler classified in this category. Statistical analysis showed no significant difference in estimated zinc bioavailability between stunted and normal toddlers (p>0.05).

Table 4 Estimation of Iron and Zinc Bioavailability in Stunted and Normal Toddlers

Bioavailability Estimates	**Nutritional status**				**Total n**	**%**	***ρ-value***
	Stunted		**Normal**				
	n	**%**	**n**	**%**			
Iron							
Low	49	53,8	42	46,2	91	100	0,195
Moderate	11	37,9	18	62,1	29	100	
High	0	0	0	0	0	0	
Median (Min-Max)	10 (9-11)		10 (9-14)		10 (9-14)		
Zinc							
Low	1	100	0	0,0	1	100	0,838
Moderate	5	55,6	4	44,4	9	100	
High	54	49,1	56	50,9	110	100	
Median (Min-Max)	3 (1-3)		3 (2-3)		3 (1-3)		

The ρ value based on the Mann Whitney Test is significant if (ρ<0.05).

Table 5 Estimated Nutrient Absorption in Stunted and Normal Toddlers

Estimated nutrient absorption	**Nutritional status**		***ρ-value***
	Stunted	**Normal**	
Iron			
Median	0,36	0,50	0,019*
(Min-Maks)	(0,04-1,03)	(0,10-2,03)	
Zinc			
Median	0,43	0,83	0,010*
(Min-Maks)	(0,08-1,10)	(0,21-1,83)	

The ρ value based on the Mann Whitney Test is significant if (ρ<0.05).

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Table 6 presents the absorbed iron and zinc in stunted and normal toddlers, showing that the median absorbed iron in normal toddlers (0.50 mg) was higher than in stunted toddlers (0.36 mg). The Mann Whitney test results showed a significant difference between the two groups (ρ<0.05). The median absorbed zinc in normal toddlers (0.83 mg) was higher than in stunted toddlers (0.43 mg). The Mann Whitney test results showed a significant difference between the two groups (ρ<0.05).

DISCUSSION

Highly educated mothers tend to have a better ability to understand health information and are better able to put it into practice (28,29). Fathers with higher education usually have better access to higher-paying jobs, so families led by fathers with higher education tend to have better economic conditions (30). Fathers who work in the informal sector may face income uncertainty and unstable economic conditions, which can result in inadequate nutrition for their children (31). Although fathers do not show significant differences in employment, the role of mothers in childcare and child welfare is often considered more dominant (32). The more children there are in a family, the greater the resource dilution, which is the limitation of resources such as attention, parenting time, and the availability of nutritious food that must be shared among more children (33). Low-income households tend to buy cheaper foods that are high in carbohydrates but low in nutritional content, so even though their energy needs are met, the quality of their diet (macro and micro nutrients) is often poor (34) and this will have an impact on children's growth. In Indonesia, research evidence shows that the prevalence of stunting is higher among low-income groups (35).

Low birth weight does increase the risk of stunting, but the effect is not absolute and is influenced by other factors, such as region, economic status, and health services (36). Not all low birth weight babies become stunted; some show catch-up growth in the first year if nutritional conditions, environmental factors, and postnatal health are good (37). Normal birth length can be influenced by intrauterine conditions and maternal health during pregnancy (38). In addition, even if a baby is born with normal length, the risk of stunting can still increase if the child experiences malnutrition or recurrent infections after birth (39). Although globally males are more vulnerable (40), the effect of gender on stunting is not consistent in all settings depending on the social, economic, and cultural context, as well as maternal and postnatal environmental conditions (41). Biologically, male children exhibit a faster growth trajectory from the prenatal to the postnatal period, characterized by greater energy allocation to tissue accretion but relatively lower fat reserves. From the intrauterine period, male fetuses tend to develop in a more pro-inflammatory environment, and after birth, males display relatively weaker adaptive immune responses compared with females. In addition, higher testosterone levels in males exert immunosuppressive effects and contribute to an increased basal metabolic rate (42).

Premature birth does increase the risk but is not the sole determinant of stunting. Many studies have shown that maternal factors, the postnatal environment, and catch-up growth in some prematurely born children play an important role in child growth (37,43,44). Infections can reduce appetite, decrease nutrient absorption, and increase metabolic requirements, resulting in children receiving less effective energy and protein to support linear growth; if this condition occurs repeatedly, the effects will accumulate and ultimately lead to stunting (45). On the other hand, children who have experienced stunting tend to have weaker immune function, making them more susceptible to recurrent infections (46).

The consumption of cereals, vegetables and green vegetables, fruits and juices, and nuts among both stunted and normal toddlers in this study remains far below the recommended intake levels. This finding is consistent with previous studies in Indonesia, which reported that toddlers' consumption of cereals, vegetables, fruits, and nuts is generally low and does not meet dietary recommendations (47). Similarly, earlier research found that only 45.7% of toddlers consumed green vegetables in the recommended portions (2,48). Fruits, vegetables, and green vegetables are important sources of dietary fiber and provide essential vitamins and minerals that support optimal child growth (2). Furthermore, low fruit and vegetable intake has been shown to be associated with impaired linear growth and a higher risk of stunting among toddlers (49).

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The results of the study show that stunted and normal toddlers consume meat and eggs in accordance with the recommended PGS portions (1-2 servings per day). This is in line with previous studies that most toddlers consume meat and eggs in accordance with the recommended amounts (2). Furthermore, for oils and fats in this study, both groups are still far from the recommended daily portions. This finding is in line with previous cohort studies in children, which found that consumption of oils and fats (vegetable oils, nuts & seeds, saturated fats) in children is often lower than recommended, while consumption of processed foods high in saturated fat or other energy-dense foods remains high, a condition that indicates problems with fat composition (unhealthy types of fat) as well as suboptimal fat quantity (50).

Consumption of snacks (sugar, candy, chocolate) in this study exceeded the recommended limit of more than two servings per day. This is in line with other findings reporting that 99.6% of toddlers consume more than one serving per day (2,51). These products typically contain more than 70% sucrose in their composition; sucrose is the simple carbohydrate most likely to cause caries, as it is a good substrate for pathogenic microorganisms in the mouth (2). Furthermore, in terms of moderation, total fat intake exceeds the daily AKG recommendation, and saturated fat consumption exceeds the WHO recommendation for children, which is 10% (25), Cholesterol intake is still within the recommended daily intake. Then, sodium intake is close to the maximum daily recommendation; in fact, in the normal toddler group aged 4-5 years, it has exceeded the daily consumption recommendation. These findings are consistent with previous studies stating that total fat and saturated fat consumption in toddlers is higher than recommended (2,52).

In addition, in terms of food diversity, stunted toddlers had lower diversity levels than normal toddlers, who had higher diversity scores. Previous research also reported that stunted toddlers had lower dietary diversity compared to normal toddlers, who achieved higher diversity scores (2). However, a high food diversity score does not always reflect a good diet quality (53). Diversity is only one dimension of diet quality; other indicators such as adequacy and moderation, as well as portion size, need to be considered together (54). Therefore, even if the food diversity score is high, this cannot be used as sole evidence that a person's diet quality is “good,” because a “good” diet quality also requires a balance between the components of adequacy, moderation, and diversity.

These findings are consistent with studies of toddlers aged 2–5 years in Jakarta that reported differences in energy intake between stunted and normal toddlers (55). Other studies have also shown that macronutrient intake is associated with stunting (56,57). In line with this, several studies report that stunted toddlers tend to have lower protein intake than normal toddlers (55,58). These findings are reinforced by literature that found differences in fat intake between stunted and normal toddlers (55) and that low fat intake is associated with an increased risk of stunting (59).

Previous evidence shows that low zinc intake is associated with a 7.8 times higher risk of stunting (60). Zinc deficiency can interfere with protein synthesis and cell growth, as well as worsen the overall health of children (61). Iron also plays an important role in the formation of hemoglobin, which transports oxygen throughout the body's tissues. Inadequate iron intake has been linked to an increased incidence of stunting, while adequate iron supports more optimal growth (62). In addition, vitamin A is an essential component for immune function and cell development; vitamin A deficiency can increase susceptibility to infection and adversely affect children's health (63).

This study also found that calcium intake in stunted children was lower than in children with normal nutritional status. These results are consistent with previous studies showing that low calcium consumption is associated with an increased risk of stunting in toddlers (64,65). Other literature confirms that calcium plays an important role in skeletal formation, bone mineral density, and growth hormone regulation; thus, chronic calcium deficiency can inhibit children's height growth (64).

Furthermore, the findings of this study, which show that phosphorus and magnesium intake is lower in stunted toddlers than in normal toddlers, are also in line with literature that confirms the role of essential minerals in linear growth. Phosphorus is a major component of hydroxyapatite in bones and plays an important role in mineralization and bone matrix formation. Phosphorus deficiency, especially when combined with calcium deficiency, can inhibit skeletal growth and contribute to linear growth impairment

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(66). Several case-control studies have also reported that low phosphorus intake is a significant risk factor for stunting (67).

Infection and undernutrition are interconnected in a vicious cycle that mutually reinforces one another. Infection can worsen nutritional status through reduced appetite, increased energy and nutrient requirements to support immune responses, as well as impaired absorption, increased losses, and altered metabolic utilization of micronutrients. During infection, interleukin-6 (IL-6) induces hepcidin production, which reduces iron absorption, while vitamin A may be lost through the urine and other micronutrients become sequestered in the liver and macrophages. Conversely, deficiencies of micronutrients such as vitamin A and zinc can weaken immune responses by impairing mucosal barrier function, increasing inflammation, and disrupting both cell-mediated and humoral immunity. Vitamin A deficiency compromises mucosal epithelial integrity and IgA responses, whereas zinc deficiency impairs immune cell differentiation and increases immune cell apoptosis. These conditions increase susceptibility to infection and prolong illness duration, thereby creating a vicious cycle between infection and undernutrition that ultimately contributes to impaired growth and child development (17).

Estimates of iron bioavailability show that the majority of toddlers in both groups have low iron bioavailability. This is in line with previous research on children aged 2-6 years in Australia, where estimates of iron bioavailability were "low" with values (2.7-10.5) (10). The bioavailability of iron consumed is relatively low, which is related to low intake of components that enhance iron absorption and high consumption of components that inhibit absorption (68). In this study, the intake of foods that enhance iron absorption namely animal-source foods, vitamin C, and fruits and vegetables was higher among normal toddlers. In contrast, the intake of foods that inhibit iron absorption, such as rice, legumes, and tea, was higher among stunted toddlers. In addition, the median iron absorption in normal toddlers was higher than in stunted toddlers. When compared to the biological requirements according to the Institute of Medicine, children aged 1–3 years need about 0.54 mg/day of iron that is actually absorbed by the body, while children aged 4–8 years need about 0.74 mg/day of iron absorbed daily. These figures represent the minimum physiological requirements that must be met to support growth, cognitive development, and hemoglobin maintenance (69). Thus, most stunted toddlers in this study did not meet the minimum requirement for absorbed iron, while most normal toddlers were closer to the recommended value. This reinforces that iron absorption deficiency has the potential to worsen the effects of stunting through impaired cognitive development, immunity, and metabolism. Therefore, practical dietary strategies are needed, including recommendations to consume iron rich foods together with iron absorption enhancers, such as vitamin C rich fruits and vegetables, to optimize iron utilization in toddlers (10).

Zinc deficiency may arise from inadequate dietary intake and impaired zinc absorption. Zinc bioavailability is determined by several factors, including individual zinc status, the amount of zinc consumed, and the fraction of zinc that can be absorbed from food sources (70). Certain dietary components enhance zinc bioavailability, particularly protein, as amino acids derived from animal protein help maintain zinc solubility in body fluids and facilitate its utilization (71). This effect is attributed to amino acids released from animal proteins that keep zinc soluble and counteract the inhibitory effects of phytate in foods (72). In contrast, compounds such as phytic acid, oxalates, and polyphenols are known to inhibit zinc bioavailability by interfering with its absorption (16).

Furthermore, estimates of zinc bioavailability show that most toddlers in both groups have high zinc bioavailability. Zinc bioavailability is greatly influenced by the ratio of phytate to zinc in food. However, the phytate content in food consumed by toddlers can also be reduced by processing. For example, rice, which is the staple food of Indonesians, generally undergoes milling, washing, and soaking, which are known to reduce the phytic acid content in food. In addition, many toddlers consume tofu and tempeh, two fermented soy products, where the fermentation process naturally breaks down phytate, resulting in lower levels (73,74). Furthermore, the median zinc absorption in normal toddlers is higher than in stunted toddlers. Zinc absorption is greatly influenced by food composition, especially phytate content, the molar ratio of phytate to zinc, and the amount of zinc intake itself. In diets with adequate zinc intake and low consumption of high-phytic acid foods, the fraction of zinc that can be absorbed by the body tends to be greater. This is

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because phytic acid is a strong inhibitor of zinc absorption; the lower the phytic acid content in food, the smaller the barrier to zinc absorption, so that the amount of zinc absorbed will increase (27). Promoting animal foods thus appears the best strategy for enhancing the zinc content of toodlers diets (75).

The limitations of this study should also be considered. Blood samples were not collected; therefore, the selection of absorption algorithms was limited, and the efficiency of the estimated absorption values could not be directly evaluated. In the absence of inflammatory biomarkers, the estimated biologically available iron intake should be interpreted as an approximation rather than a precise measurement. Nevertheless, this approach remains relevant and adequate for comparative analyses between stunted and normal toddlers.

CONCLUSION

In conclusion, stunting in toddlers is a multifactorial issue significantly associated with household socioeconomic vulnerabilities (lower income and parental education), individual health history (low birth weight and infectious diseases), and suboptimal dietary quality. Compared to normal toddlers, stunted children demonstrate significantly lower macro- and micronutrient adequacy, reduced intake of vegetables and fruits, and a dietary pattern high in iron inhibitors but lacking in absorption enhancers like vitamin C and animal-source proteins. Therefore, policy-relevant strategies to reduce stunting must be integrated and multifaceted. Interventions should prioritize improving parental nutritional literacy, promoting the consumption of affordable local foods that enhance iron and zinc bioavailability, advising against tea consumption during meals, and coupling these dietary improvements with robust infection prevention efforts.

DECLARATION OF THE USE OF AI

The authors declare that no artificial intelligence (AI), AI-assisted technologies, or large language models (LLMs) were used in the conception of the study, data analysis, or the drafting, writing, and editing of this manuscript

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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