October – December, 2025
Original Article
DOI: http://dx.doi.org/10.30867/action.v10i4.2682
Pages: 958 – 968
AcTion:
Aceh Nutrition Journal
p-issn 2527-3310; e-issn 2548-5741

High simple carbohydrate intake and its impact on growth biomarkers and stunting risk in early childhood

Asupan karbohidrat sederhana yang tinggi dan dampaknya terhadap biomarker pertumbuhan serta risiko stunting pada anak usia dini

Yessi Alza[1*], Lily Restusari[2], Aslis Wirda Hayati[3], Agustina Indri Hapsari[4], Dewi Purwaningsih[5]

[1] Department of Nutrition, Poltekkes Kemenkes Riau, Pekanbaru, Indonesia.
E-mail: yessi@pkr.ac.id
[2] Department of Nutrition, Poltekkes Kemenkes Riau, Pekanbaru, Indonesia.
E-mail: lilyrestusari@gmail.com
[3] Department of Nutrition, Poltekkes Kemenkes Riau, Pekanbaru, Indonesia.
E-mail: aslis@pkr.ac.id
[4] Poltekkes Kemenkes Bandung, Indonesia.
E-mail: agustinaindrihapsari@gmail.com
[5] Dinas Kesehatan Kabupaten Batang, Indonesia.
E-mail: dewpurwa99@gmail.com

***Correspondence Author:**
Department of Nutrition, Poltekkes Kemenkes Riau, Pekanbaru, Indonesia.
E-mail: yessi@pkr.ac.id

Article History:
Received: July 20, 2025; Revised: August 15, 2025; Accepted: October 16, 2025; Published: December 13, 2025.

Publisher:
Politeknik Kesehatan Aceh
Kementerian Kesehatan RI

Abstract

Stunting in early childhood remains a major public health issue in developing countries, including Indonesia. In addition to undernutrition, excessive intake of simple carbohydrates may disrupt the endocrine pathways crucial for linear growth. This study examined the association between simple carbohydrate consumption and growth biomarkers insulin-like growth factor 1 (IGF-1), leptin, and growth hormone as predictors of stunting risk in children aged 12–36 months of age. A cross-sectional observational study was conducted with 250 children from urban and rural settings. Dietary intake was assessed using a validated 24-hour recall, and biomarker levels were measured using ELISA. The results showed an average daily energy intake of 1,350 kcal, with 65% derived from carbohydrates, predominantly simple sugars and refined starches. Stunted children exhibited significantly lower concentrations of IGF-1, leptin, and growth hormone ($p < 0.01$), with strong inverse correlations between simple carbohydrate intake and biomarker levels ($r = -0.45$ for IGF-1; $r = -0.38$ for growth hormone [GH]). Multiple regression analysis confirmed that a higher intake of simple carbohydrates significantly predicted lower biomarker levels and reduced height-for-age z-scores (HAZ). These findings highlight the importance of dietary quality, emphasizing the need to reduce simple carbohydrate intake to support hormonal balance and optimal linear growth in early childhood.

Keywords: Stunting, Simple Carbohydrates, IGF-1, Growth Hormone, Early Childhood

Abstrak

Stunting pada anak usia dini masih menjadi masalah kesehatan masyarakat di negara berkembang, termasuk Indonesia. Selain kekurangan gizi, asupan karbohidrat sederhana berlebih diduga turut mengganggu jalur endokrin penting bagi pertumbuhan linear. Penelitian ini bertujuan menganalisis pengaruh konsumsi karbohidrat sederhana terhadap biomarker pertumbuhan, insulin-like growth factor 1 (IGF-1), leptin, dan growth hormone, sebagai prediktor risiko stunting pada anak usia 12–36 bulan. Desain penelitian menggunakan observasional potong lintang dengan 250 anak dari wilayah perkotaan dan pedesaan. Asupan makanan dikaji melalui recall 24 jam terstandar, sedangkan kadar biomarker diukur menggunakan metode ELISA. Hasil menunjukkan rata-rata energi harian 1.350 kkal, dengan 65% berasal dari karbohidrat, terutama gula sederhana dan pati olahan. Anak stunting memiliki kadar IGF-1, leptin, dan growth hormone lebih rendah signifikan ($p < 0.01$), dengan korelasi negatif kuat antara konsumsi karbohidrat sederhana dan biomarker pertumbuhan ($r = -0.45$ untuk IGF-1; $r = -0.38$ untuk growth hormone). Analisis regresi menunjukkan konsumsi karbohidrat sederhana berlebih secara signifikan memprediksi penurunan biomarker serta skor z tinggi badan menurut umur (HAZ). Temuan ini menegaskan pentingnya kualitas diet, bukan sekadar kecukupan kalori, untuk mencegah stunting.

Kata Kunci: Stunting, Karbohidrat Sederhana, IGF-1, Hormon Pertumbuhan, Anak Usia Dini

Introduction

Stunting in early childhood remains a major public health issue in developing countries including Indonesia. The Global Nutrition Report and Indonesia's 2023 Basic Health Research report state that approximately 149 million children under five years of age are stunted worldwide, with a national prevalence of 24.4%, underscoring the urgency of effective nutritional interventions (Global Nutrition, 2023; Kemenkes, 2023). Beyond impairing physical growth, stunting has long-term consequences, including reduced cognitive capacity, lower productivity, and a higher risk of chronic diseases in adulthood (Soliman et al., 2021; De Onis & Branca, 2016).

Recent evidence suggests that unbalanced high-calorie diets dominated by simple carbohydrates, such as sugars and refined starches, may disrupt growth mechanisms by altering key biomarkers. Rapid glucose spikes from these foods induce chronic hyperinsulinemia, which can impair the growth hormone–IGF-1 axis, which is crucial for bone and tissue development (Cristin et al., 2023; Pei et al., 2023). Experimental studies have further indicated that this imbalance suppresses IGF-1 production, thereby inhibiting linear growth and increasing the risk of stunting (Clemmons, 2004; Suryanis, 2022).

Leptin, a hormone produced by adipose tissue, plays a central role in the regulation of growth and energy metabolism in children. High energy consumption, with a predominance of simple carbohydrates, tends to disproportionately increase the accumulation of body fat, which can lead to leptin resistance. This condition reduces the effectiveness of leptin in regulating appetite and cell growth and interferes with hormonal signals that mediate the child's energy balance and nutritional status (Friedman, 2019; Childs et al., 2021). Leptin resistance that develops at an early age can inhibit the anabolic processes necessary for optimal growth and increase the risk of growth disorders, including stunting (Rachmawati et al., 2024).

Macronutrient imbalances and excessive carbohydrate intake also affect growth hormone (GH) secretion by the pituitary gland. GH stimulates IGF-1 production in the liver and target tissues and serves as a key mediator of growth (Takahashi, 2017). Disproportionate calorie intake from simple carbohydrates can suppress GH secretion through metabolic pathways, disrupting bone growth and tissue regeneration essential for child development (Tritos & Klibanski, 2016). Thus, a balanced energy and carbohydrate intake is critical for maintaining optimal biomarker function and preventing stunting. Stunting is multifactorial and is influenced by socioeconomic status, sanitation, nutrient patterns, infections, and biological factors (Humphries et al., 2021). Among these, macronutrient imbalances, particularly those dominated by simple carbohydrates, have gained attention in child growth studies (Almeida et al., 2021; Pyne & Macdonald, 2016). Such patterns often occur in populations with limited food diversity, leading to a high calorie intake without adequate protein and micronutrients required for optimal growth (Savarino et al., 2021).

High energy intake dominated by simple carbohydrates, such as sugar and white flour, can interfere with a child's metabolism through the dysregulation of growth hormones, including insulin-like growth factor-1 (IGF-1), leptin, and other growth hormones that play an important role in anabolic and linear growth processes (Savarino et al., 2021; Shalitin & Phillip, 2003). IGF-1 is a major mediator of the effects of growth hormones that support the proliferation and differentiation of bone cells, whereas leptin plays a role in energy regulation and metabolic balance (Locatelli & Bianchi, 2014). Decreased levels of these biomarkers have been associated with impaired growth and stunting risk; however, the quantitative relationships and underlying mechanisms of macronutrient imbalances are still not adequately understood in various populations (Millward, 2017).

Previous studies have often measured energy and protein adequacy at a macro level without evaluating the proportion of macronutrient intake that can directly affect growth biomarkers. In addition, most studies are based on secondary data from large surveys or a retrospective approach, making it difficult to describe stronger cause-and-effect relationships (Freeling, 2024; McGrath et al., 2017). Another limitation is the lack of biological biomarker data that are integrated with data on macronutrient consumption patterns and child growth status simultaneously, especially in different urban and rural areas that have different food dynamics and access to health services (Harrison et al., 2020; Robertson et al., 2023).

Therefore, this study was designed to fill this gap by conducting a cross-sectional observational study in children aged 12-36 months, using a validated 24-hour recall method for the measurement of energy and carbohydrate intake, as well as an analysis of growth biomarkers (IGF-1, leptin, and growth hormone) in blood samples. This approach is expected to provide a more comprehensive picture of the effect of imbalances in high-calorie and carbohydrate energy intakes on the status of growth biomarkers as predictors of stunting risk, considering urban and rural geographical contexts.

The results of this study are expected to strengthen the scientific understanding of the biological mechanisms of growth disorders due to unbalanced macronutrient consumption patterns and become the basis for the development of more targeted nutritional intervention policies and programs. Interventions should focus on the quality and balance of macronutrients, not just on calorie adequacy, to effectively prevent stunting and support optimal child growth in the long term.

Methods

Research Design

This study used an observational design with a cross-sectional approach to investigate the relationship between an imbalance of high-calorie, calorie, and carbohydrate energy intakes and growth biomarkers as predictors of stunting risk in early childhood. This design was chosen to obtain a simultaneous picture of macronutrient consumption patterns and the status of growth biomarkers in the target population over a given period.

Research Location and Time

The research was conducted in two representative areas, namely urban and rural areas, in West Java Province, Indonesia, from May to September 2024. Location selection aims to capture variations in food consumption patterns and environmental factors that have the potential to influence growth biomarkers.

Population and Sample

The target population consisted of children aged 12–36 months who resided in the selected study areas. The sample was selected using a purposive stratified sampling method to ensure representation across different demographic and nutritional environments. A purposive approach was employed to intentionally include two contrasting settings—urban and rural —to capture potential differences in food availability, dietary practices, and environmental influences on child growth. These locations were selected based on regional nutritional surveillance data and demographic indicators from the Riau Provincial Health Office, which identified significant variability in the prevalence of stunting between urban and rural districts.

Stratification was based on two criteria: (1) geographic location (urban vs. rural) and (2) age groups (12–24 months and 25–36 months), ensuring a balanced distribution across strata and minimizing age-related confounding in biomarker levels.

The minimum sample size was calculated using G*Power version 3.1, applying the following formula for multiple linear regression:

$$n = \frac{\left(z_{1-a/2} + z_{1-\beta}\right)^2 \cdot f^2}{effect\ size} + m$$

The sample size estimation was determined based on the study design and several statistical assumptions. A medium effect size was set at $f^2 = 0.3$, with a significance level (α) of 0.05 and statistical power (1–β) of 0.80, to reduce the risk of Type II errors. The calculation also considered a minimum of three predictor variables in the regression model. These parameters were selected to ensure adequate sensitivity for detecting meaningful associations while maintaining analytical validity. The minimum required sample size was calculated using G*Power software, which confirmed that the study design with these assumptions would provide sufficient power to detect the expected effects.

Based on these parameters, the required minimum sample size was 230 children, following recent recommendations for adequate power in multiple regression analyses (Hair et al., 2019; Stavnsbo et al., 2020). To account for incomplete responses and potential dropouts, the final sample size was increased to 250 children, proportionally allocated between the two geographic strata.

Inclusion and Exclusion Criteria

The inclusion criteria were children aged 12-36 months who were clinically healthy and had the permission of their parents/guardians who provided written informed consent. Children with chronic medical conditions or metabolic disorders that could affect growth biomarker levels were excluded from this study.

Operational Definitions of Variables

In this study, energy intake refers to the total daily caloric consumption (kcal/day), measured through a single 24-hour dietary recall interview with the child's caregiver. The data were analyzed using the NutriSurvey software (2007), which was calibrated for Indonesian food composition. Carbohydrate intake is defined as the proportion of total daily energy derived from carbohydrates, with particular emphasis on simple carbohydrates, including refined starches and added sugars, which are categorized based on their food sources.

Growth biomarkers were assessed in venous blood samples using standardized commercial enzyme-linked immunosorbent assay (ELISA) kits. These biomarkers include insulin-like growth factor 1 (IGF-1, measured in ng/mL), leptin (ng/mL), and growth hormone (mIU/L), which are physiologically involved in the regulation of linear growth.

Growth status was evaluated using height-for-age z-scores (HAZ), which were calculated based on the World Health Organization Child Growth Standards. Children were classified as stunted if their HAZ values were less than –2 standard deviations (Al Rahmad et al., 2024), as determined using the WHO Anthro software version 3.2.2.

Data Collection Procedure

Dietary intake was assessed using a structured 24-hour recall interview with parents or caregivers, conducted by trained enumerators. To enhance accuracy, visual aids (food models and local portion photos) and a multiple-pass method were used. Caregiver responses were validated by probing questions and, when needed, by brief confirmation with other household members. The recall instrument was previously validated for use in Indonesia and was analyzed using NutriSurvey 2007.

Venous blood samples (3 mL) were collected by licensed medical personnel at local health centers using sterile techniques. Samples were processed and stored appropriately, and serum biomarkers (IGF-1, leptin, and growth hormone) were analyzed using 2023-version ELISA kits, following the manufacturer's protocol in a certified laboratory with internal quality control procedures.

Data Analysis

Energy and carbohydrate intake data were processed using the 2007 version of the NutriSurvey software, which has been calibrated for local Indonesian foodstuffs. Biomarker analysis was performed using ELISA absorbance measurements on a spectrophotometer (Model Y, version 5.3). Numerical data were analyzed using SPSS version 28 for Pearson's correlation test and multiple linear regression to determine the relationship between intake variables, biomarkers of growth, and HZ status. The significance level was set at $p < 0.05$.

Code of Health Ethics

This study was approved by the Health Research Ethics Committee of Poltekkes Kemenkes Riau (Approval Number 041/KEPK-PKR/V/2024). All parents/guardians of the children were given a full explanation of the objectives, procedures, and risks of the research and signed an informed consent form prior to their participation. The privacy and confidentiality of the participant data were strictly maintained in accordance with the research ethics standards.

Result and Discussion

Respondent Characteristics

A total of 250 children aged 12–36 months were successfully recruited and included in this study, with a geographical distribution of 130 children from urban areas and 120 children from rural areas. The mean age of the children in this sample was 24.5 months, with a standard deviation of 7.2 months, indicating a fairly wide age variation that represents a critical growth stage in early life. The gender composition in the sample was relatively balanced, with a proportion of boys as high as 52% and girls as high as 48%, allowing for an unbiased analysis of biological and social variables related to growth.

Anthropometric analysis showed that the prevalence of stunting was 22.8% in children living in urban areas and slightly higher (27.5%) in those living in rural areas. Despite the difference in prevalence figures, the statistical test showed that the difference was not statistically significant (p = 0.17), indicating that the risk of stunting was not markedly different between the two locations in the context of the study. These findings indicate that stunting risk factors do not solely depend on geographical location but may be influenced by a complex combination of socioeconomic factors, nutritional consumption patterns, and access to health services that differ by region.

Table 1. Characteristics and Prevalence of Early Childhood Stunting

Characteristics	Urban (n=130)	Rural (n=120)	Total (n=250)
Age (months), mean ± SD	24.7 ±7.3	24.3 ±7.1	24.5 ± 7.2
Male	52,3%	52,5%	52,4%
Female	47,7%	47,5%	47,6%
Prevalence of Stunting	22,8%	27,5%	25,2%

The average age of the participants was 24.5 ± 7.2 months old. Normality testing using the Shapiro–Wilk test indicated that age was normally distributed (p > 0.05), justifying the use of the mean and standard deviation in reporting. The overall prevalence of stunting in the study population was 25.2%, with a slightly higher rate in rural areas (27.5%) than in urban areas (22.8%).

Furthermore, these demographic characteristics and nutritional status are important for understanding the environmental context of a child's growth and provide a basic framework for interpreting the relationship between macronutrient intake, growth biomarkers, and stunting risk. The representative distribution of the two geographic settings reinforces the external validity of this study while allowing an assessment of the variability of consumption patterns and environmental factors that may affect hormonal biomarkers and children's growth status differently. In addition, gender balance and a sufficiently wide age range also help reduce potential bias and ensure that the results can be applied more widely to the early childhood population.

Energy and Carbohydrate Intake

Analysis of food intake data obtained through the 24-hour recall method showed that the average daily energy intake of the children in this study was 1,350 kcal, with a standard deviation of 210 kcal. This value is within the range of average daily energy needs for children aged 12-36 months, and the considerable variability reflects the heterogeneity of the diet among the study subjects. Approximately 65%of the total energy intake comes from carbohydrates, with most being simple carbohydrates, dominated by the consumption of sugar and refined flour. This phenomenon indicates a significant macronutrient imbalance, given that the World Health Organization (WHO) recommends that the ideal proportion of carbohydrates in daily energy intake should be in the range of 55-60% for this age group to support optimal growth and metabolic balance (Maigoda, et al., 2023).

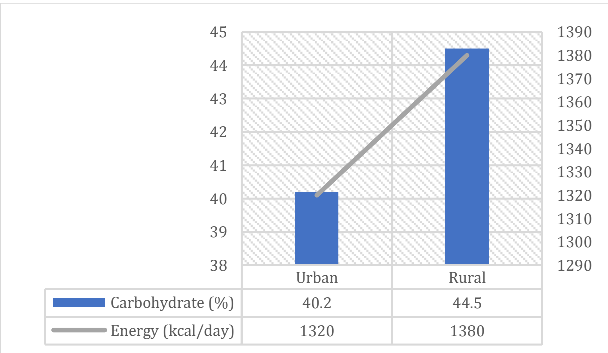

Figure 1. Carbohydrate Proportion (%) and Average Energy Intake (kcal/day) by Location

This imbalance is concerning because excessive intake of simple carbohydrates is known to cause rapid blood sugar fluctuations and an excessive insulin response, which potentially disrupts important hormonal mechanisms, such as growth hormone and IGF-1, which are essential for a child's linear growth. A high proportion of simple carbohydrates also indicates a low intake of other macronutrients, such as proteins and essential fats, which are urgently needed for healthy tissue synthesis and metabolic regulation.

Geographical comparisons showed no significant difference in the total daily energy intake between urban and rural children ($p = 0.23$), indicating comparable calorie adequacy across groups. However, a significant difference was observed in the proportion of simple carbohydrate intake, with rural children consuming a slightly higher percentage than their urban counterparts ($p = 0.04$). This disparity is likely shaped by food accessibility and consumption patterns, as rural diets are often dominated by inexpensive and readily available carbohydrate sources, such as refined flour and sugar. These results highlight that while the overall caloric requirements may be met, the quality and composition of energy intake remain critical determinants of nutritional status and health in children.

The present findings highlight that, although the average daily energy intake of children was adequate for their age group, the high contribution of carbohydrates, particularly simple sugars and refined starches, reflects a dietary imbalance with potential biological consequences for the children. Excessive intake of simple carbohydrates is associated with repeated postprandial hyperglycemia and compensatory hyperinsulinemia, which may negatively affect the growth hormone–IGF-1 axis. Previous studies have confirmed that disruption of this pathway impairs chondrocyte proliferation and linear bone growth, thereby increasing the risk of stunting (Papakonstantinou et al., 2022; Dimitriadis et al., 2021).

The significant difference in carbohydrate intake proportions between urban and rural children further underlines the role of socioeconomic and environmental determinants in shaping dietary quality. Rural children consumed a higher percentage of carbohydrates, likely due to limited food diversity and reliance on inexpensive, carbohydrate-dense staples. Similar trends have been observed in other low-resource settings, where caloric sufficiency often masks deficiencies in proteins and essential fatty acids that are critical for tissue growth and metabolic regulation (Iannotti et al., 2022; Mupunga et al., 2017; Zhao et al., 2021).

From a public health perspective, these findings emphasize that ensuring calorie adequacy alone is insufficient to address childhood stunting. Nutritional interventions should prioritize dietary quality, particularly by reducing dependence on refined carbohydrates while promoting protein-rich foods and micronutrient-dense alternatives. Community-level education and food policy reforms are essential strategies for improving access to balanced diets that support optimal growth and development of children.

Growth Biomarkers

Analysis of growth biomarker levels, including insulin-like growth factor-1 (IGF-1), leptin, and growth hormone (GH), showed the following average values: IGF-1 of 115 ng/mL with a standard deviation of 28 ng/mL, leptin of 5.2 ng/mL ± 1.7 ng/mL, and growth hormone of 7.8 ng/mL ± 2.1 ng/mL. These values are important physiological indicators that reflect hormonal and metabolic status, which are directly related to the child's growth process. IGF-1 acts as a primary mediator of the effects of growth hormones in stimulating the proliferation and differentiation of bone cells and other tissues, whereas leptin functions in the regulation of energy and hormonal signals that affect appetite and metabolism. Growth hormone itself is an anabolic hormone produced by the pituitary gland that plays a central role in linear growth and protein metabolism.

When the data were analyzed based on growth status, it was found that children who were stunted had a significant decrease in all three biomarkers compared to the group of children who were not stunted. This decrease had a strong statistical significance ($p < 0.01$ for all biomarkers), confirming the existence of a close biological relationship between chronic malnutrition and hormonal disorders underlying suboptimal growth. These findings are consistent with the literature, which states that low levels of IGF-1 and growth hormones are biomolecular indicators of linear growth disorders in children with poor nutritional status (Wong et al., 2016; Quarta et al., 2024).

In addition, Pearson's correlation analysis was conducted to explore the relationship between the proportion of simple carbohydrate intake and the levels of growth biomarkers, which showed significant results with negative values. The correlation between the proportion of simple carbohydrates and IGF-1 levels was r = -0.45 ($p < 0.001$), and with growth hormone, it was r = -0.38 ($p < 0.001$). This negative association indicates that the higher the proportion of simple carbohydrates in a child's energy intake, the lower the levels of growth biomarkers detected in the blood. This decline is likely due to dysregulation of the growth hormone axis due to the metabolic effects of excessive carbohydrate consumption, including impaired insulin sensitivity and leptin resistance, which can inhibit the synthesis and secretion of these important hormones (Könner & Brüning, 2012; Lee & Fried, 2009).

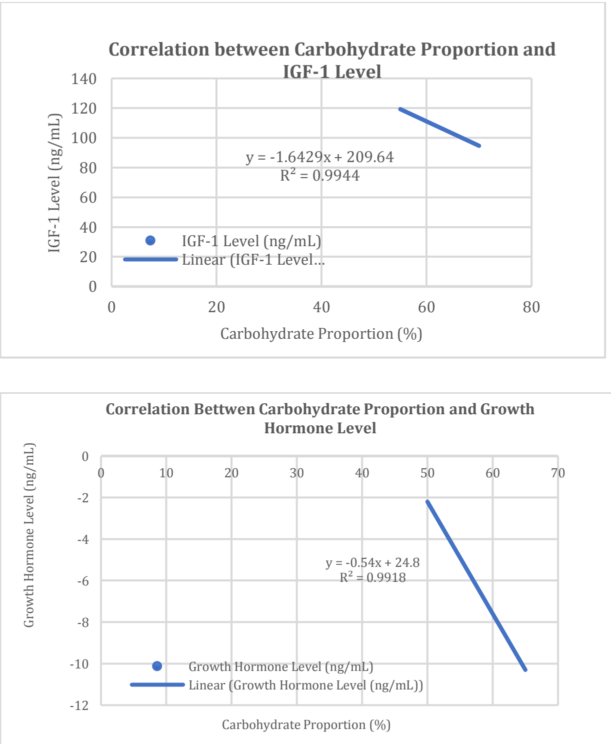

Figure 2. Correlation Graph of Carbohydrate Proportion with IGF-1 and Growth Hormone Levels in Early Childhood

These findings confirm the role of simple carbohydrates as nutritional factors that have the potential to undermine hormonal mechanisms that support optimal growth, thus contributing directly to the risk of stunting. Therefore, understanding the quality of macronutrient intake is important for preventing growth disorders and meeting daily calorie needs. This study provides in-depth empirical evidence that nutritional interventions should be directed toward limiting the consumption of simple carbohydrates and improving nutritional balance to improve the biomarker profile of child growth.

The results of this study demonstrated that stunted children had significantly lower IGF-1, leptin, and GH levels than their non-stunted counterparts. These findings reinforce the concept that growth faltering is not merely a matter of caloric insufficiency but also reflects deeper hormonal dysregulation. Low concentrations of IGF-1 and GH are widely recognized as critical indicators of impaired linear growth, consistent with previous studies showing similar patterns in malnourished children across different populations (Cammisa et al., 2025; Silverstein, 2018).

The observed negative correlations between simple carbohydrate intake and IGF-1 (r = − 0.45) and GH (r = − 0.38) further highlight the biological plausibility of dietary quality influencing the endocrine pathways essential for growth. Excessive intake of refined carbohydrates has been shown to induce repeated postprandial hyperinsulinemia, which can impair insulin sensitivity, disrupt leptin signaling, and ultimately suppress the GH–IGF-1 axis (Bayod Jaime, 2023; Bujtor et al., 2021). Such hormonal disturbances may explain the lower biomarker levels in children with high carbohydrate consumption despite adequate energy intake.

From a broader perspective, these findings underscore the importance of considering not only the quantity but also the quality of macronutrient intake in childhood nutrition policies. Reducing the reliance on simple carbohydrates and ensuring sufficient intake of proteins and essential fatty acids are crucial steps toward maintaining hormonal balance and supporting optimal growth. Therefore, interventions that improve dietary diversity, especially in resource-limited settings, may serve as an effective strategy for mitigating the risk of stunting by preserving biomarker integrity.

The Relationship Between Intake, Biomarkers, and Stunting

Multiple linear regression analysis conducted in this study revealed that high energy intake dominated by a proportion of simple carbohydrates significantly affected the decrease in growth biomarker levels, particularly IGF-1, and negatively impacted the growth status of children, as measured using a height-to-age (HAZ) score. The regression coefficient (β) for the effect of simple carbohydrate intake on growth biomarker levels was -0.42, with a significance level of $p < 0.001$, indicating a strong and statistically significant negative relationship. This means that any increase in the proportion of simple carbohydrates in a child's daily energy intake correlates with a decrease of 0.42 units in IGF-1 levels after controlling for other disruptive variables.

Similarly, such negative effects were also reflected in the child's HAZ score, where a regression coefficient of -0.35 ($p < 0.001$) indicated that increased consumption of simple carbohydrates contributed to a significant decrease in the child's linear growth status. This regression model, which accommodates confounding variables such as age, sex, and geographic location, can explain up to 48% of the variability in IGF-1 levels and 39% of the variability in HZ scores. This relatively high level of variability indicates that simple carbohydrate intake is a major predictor of the hormonal growth model and physical growth status of children.

Table 2. Multiple Linear Regression Results for the Effect of Simple Carbohydrate Intake on IGF-1 and HAZ Score

Dependent Variable	Independent Variable	β (Coefficient)	SE	95% CI	p-value	R^2
IGF-1 (ng/mL)	Simple carbohydrate intake (%)	−0.42	0.08	−0.58, −0.26	<0.001	0.48
HAZ score	Simple carbohydrate intake (%)	−0.35	0.07	−0.49, −0.21	<0.001	0.39

Note: Models were adjusted for age, sex, and geographical location.

Controlling for these confounding variables is important to ensure that the association found is unbiased and reflects the independent effects of the intake of simple carbohydrates. For example, the age of children can affect biomarker levels and growth status, as well as the gender and environmental conditions of urban and rural areas. By including these variables in the model, this analysis provided more valid evidence that unbalanced macronutrient intake patterns play a direct role in hormonal disorders and child growth.

Biologically, these results can be explained through a metabolic mechanism in which excessive consumption of simple carbohydrates provokes sharp blood glucose fluctuations and an excessive insulin response, thereby disrupting the axis of growth hormone and inhibiting the production of IGF-1, which is essential for the proliferation of bone cells and tissues. This decrease in IGF-1 levels further inhibits linear growth, which is reflected by a decrease in HAZ in children. This study adds empirical evidence consistent with previous findings showing an association between macronutrient consumption patterns, growth hormone disorders, and the risk of stunting (Ashraf et al., 2017; Beal et al., 2018).

These findings underscore the need for a nutritional intervention approach that not only focuses on total calorie adequacy but also on the quality and balance of macronutrients, especially the restriction of simple carbohydrate consumption, to support hormonal function and optimal growth in children. Such an approach can be an effective strategy to reduce the prevalence of stunting and improve the quality of growth early on, which has a long-term impact on individual health and productivity.

Conclusion

An imbalance of high-calorie energy intake with an unbalanced proportion of carbohydrates, especially simple carbohydrates, contributes to a decrease in important growth biomarkers (IGF-1, leptin, and growth hormone) during early childhood. A reduction in these biomarkers was significantly correlated with a higher risk of stunted growth.

Therefore, effective nutritional interventions for stunting prevention should emphasize not only calorie adequacy but also the quality and balance of macronutrients in children's diets. Further research is needed to explore the molecular mechanisms and long-term relationships between dietary intake and growth biomarkers to develop optimal prevention strategies.

Acknowledgments

We sincerely thank all the children and their families who participated in this study. We also appreciate the efforts of the healthcare workers and field staff involved in the data collection and sample processing. We thank the laboratory team for their assistance in analyzing growth biomarkers. Finally, we are grateful for the valuable support and feedback from our colleagues and mentors throughout this research.

References

Almeida, C. C., Mendonça Pereira, B. F., Leandro, K. C., Costa, M. P., Spisso, B. F., & Conte-Junior, C. A. (2021). Bioactive compounds in infant formula and their effects on infant nutrition and health: A systematic literature review. *International Journal of Food Science, 2021*, Article 8850080. https://doi.org/10.1155/2021/8850080

Al Rahmad, A. H., Sofyan, H., Usman, S., & Mudatsir. (2024). The accuracy data of the toddlers' nutritional status using the "PSG Balita" app. In T. Tahlil & P. Ardia (Eds.), *The 6th Aceh International Nursing Conference* (pp. 82–86). Journal of Liaquat University of Medical and Health Sciences. https://doi.org/10.22442/jlumhs.2024.01130

Ashraf, T. S., De Sanctis, V., Yassin, M., & Adel, A. (2017). Growth and growth hormone–insulin like growth factor-I (GH-IGF-I) axis in chronic anemias. *Acta Bio Medica: Atenei Parmensis, 88*(1), 101–111. https://doi.org/10.23750/abm.v88i1.6345

Bayod Jaime, L. (2023). Molecular mechanisms of hyperinsulinemia in obesity. *Journal of Molecular Endocrinology, 70*(2), R17–R35. https://doi.org/10.1530/JME-22-0123

Beal, T., Tumilowicz, A., Sutrisna, A., Izwardy, D., & Neufeld, L. M. (2018). A review of child stunting determinants in Indonesia. *Maternal & Child Nutrition, 14*(4), e12617. https://doi.org/10.1111/mcn.12617

Bujtor, M., Turner, A. I., Torres, S. J., Esteban-Gonzalo, L., Pariante, C. M., & Borsini, A. (2021). Associations of dietary intake on biological markers of inflammation in children and adolescents: A systematic review. *Nutrients, 13*(2), 356. https://doi.org/10.3390/nu13020356

Cammisa, I., Rigante, D., & Cipolla, C. (2025). A theoretical link between the GH/IGF-1 axis and cytokine family in children: Current knowledge and future perspectives. *Children, 12*(4), 495. https://doi.org/10.3390/children12040495

Childs, G. V., Odle, A. K., MacNicol, M. C., & MacNicol, A. M. (2021). The importance of leptin to reproduction. *Endocrinology, 162*(2), bqaa204. https://doi.org/10.1210/endocr/bqaa204

Clemmons, D. R. (2004). The relative roles of growth hormone and IGF-1 in controlling insulin sensitivity. *The Journal of Clinical Investigation, 113*(1), 25–27. https://doi.org/10.1172/JCI20660

Cristin, L., Montini, A., Martinino, A., Scarano Pereira, J. P., Giovinazzo, F., & Agnes, S. (2023). The role of growth hormone and insulin-like growth factor 1 in the development of non-alcoholic steatohepatitis: A systematic review. *Cells, 12*(4), 517. https://doi.org/10.3390/cells12040517

De Onis, M., & Branca, F. (2016). Childhood stunting: A global perspective. *Maternal & Child Nutrition, 12*(S1), 12–26. https://doi.org/10.1111/mcn.12231

Dimitriadis, G. D., Maratou, E., Kountouri, A., Board, M., & Lambadiari, V. (2021). Regulation of postabsorptive and postprandial glucose metabolism by insulin-dependent and insulin-independent mechanisms: An integrative approach. *Nutrients, 13*(1), 159. https://doi.org/10.3390/nu13010159

Freeling, J. L. (2024). *The relationship of macronutrient intake with growth in children with type 1 diabetes mellitus* (Doctoral dissertation, South Dakota State University). Open PRAIRIE. https://openprairie.sdstate.edu/etd2/986

Friedman, J. M. (2019). Leptin and the endocrine control of energy balance. *Nature Metabolism, 1*(8), 754–764. https://doi.org/10.1038/s42255-019-0095-y

Global Nutrition Report. (2023). *Global nutrition report 2023: The state of global nutrition*. Global Nutrition Report. https://globalnutritionreport.org

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.

Harrison, E., Syed, S., Ehsan, L., Iqbal, N. T., Sadiq, K., Umrani, F., Ahmed, S., Rahman, N., Jakhro, S., & Ma, J. Z. (2020). Machine learning model demonstrates stunting at birth and systemic inflammatory biomarkers as predictors of subsequent infant growth: A four-year prospective study. *BMC Pediatrics, 20*(1), 287. https://doi.org/10.1186/s12887-020-02174-y

Humphries, D. L., Scott, M. E., & Vermund, S. H. (2021). Nutrition and infectious diseases. In *Nutrition and health* (pp. 492–510). Springer. https://doi.org/10.1007/978-3-030-69764-1_20

Iannotti, L. L., Gyimah, E. A., Reid, M., Chapnick, M., Cartmill, M. K., Lutter, C. K., Hilton, C., Gildner, T. E., & Quinn, E. A. (2022). Child dietary patterns in *Homo sapiens* evolution: A systematic review. *Evolution, Medicine, and Public Health, 10*(1), 371–390. https://doi.org/10.1093/emph/eoac027

Kementerian Kesehatan Republik Indonesia. (2023). *Riset kesehatan dasar (Riskesdas) 2023*. Badan Penelitian dan Pengembangan Kesehatan, Kemenkes RI. https://www.litbang.kemkes.go.id

Könner, A. C., & Brüning, J. C. (2012). Selective insulin and leptin resistance in metabolic disorders. *Cell Metabolism, 16*(2), 144–152. https://doi.org/10.1016/j.cmet.2012.07.004

Lee, M.-J., & Fried, S. K. (2009). Integration of hormonal and nutrient signals that regulate leptin synthesis and secretion. *American Journal of Physiology–Endocrinology and Metabolism, 296*(6), E1230–E1238. https://doi.org/10.1152/ajpendo.90994.2008

Locatelli, V., & Bianchi, V. E. (2014). Effect of GH/IGF-1 on bone metabolism and osteoporosis. *International Journal of Endocrinology, 2014*, Article 235060. https://doi.org/10.1155/2014/235060

Maigoda, T. C., Simbolon, D., & Al Rahmad, A. H. (2023). *Kenali stunting sejak dini* (1st ed.). PT Nasya Expanding Management. SINTA

McGrath, C. J., Arndt, M. B., & Walson, J. L. (2017). Biomarkers to stratify risk groups among children with malnutrition in resource-limited settings and to monitor response to intervention. *Hormone Research in Paediatrics, 88*(1), 111–122. https://doi.org/10.1159/000454940

Millward, D. J. (2017). Nutrition, infection and stunting: The roles of deficiencies of individual nutrients and foods, and of inflammation, as determinants of reduced linear growth of children. *Nutrition Research Reviews, 30*(1), 50–72. https://doi.org/10.1017/S0954422416000238

Mupunga, I., Mngqawa, P., & Katerere, D. R. (2017). Peanuts, aflatoxins and undernutrition in children in sub-Saharan Africa. *Nutrients, 9*(12), 1287. https://doi.org/10.3390/nu9121287

Papakonstantinou, E., Oikonomou, C., Nychas, G., & Dimitriadis, G. D. (2022). Effects of diet, lifestyle, chrononutrition and alternative dietary interventions on postprandial glycemia and insulin resistance. *Nutrients, 14*(4), 823. https://doi.org/10.3390/nu14040823

Pei, Y.-F., Song, Z., Bu, F., Li, K., Xu, Q., Zhao, Q.-G., Ma, X.-L., Zhang, L., & Li, B. (2023). Non-linear causal association of body mass index with serum insulin-like growth factor 1: A Mendelian randomization study. *Journal of Clinical Endocrinology & Metabolism, 108*(4), e161–e170. https://doi.org/10.1210/clinem/dgad012

Pyne, V., & Macdonald, I. A. (2016). Update on carbohydrates and health: The relevance of the Scientific Advisory Committee on Nutrition report for children. *Archives of Disease in Childhood, 101*(10), 876–880. https://doi.org/10.1136/archdischild-2015-309272

Quarta, A., Quarta, M. T., Mastromauro, C., Chiarelli, F., & Giannini, C. (2024). Influence of nutrition on growth and development of metabolic syndrome in children. *Nutrients, 16*(22), 3801. https://doi.org/10.3390/nu16223801

Rachmawati, R., Iskandar, I., Al Rahmad, A. H., Fadjri, T. K., & Hidayat, T. (2024). Penguatan metode deteksi dini faktor risiko dalam keluarga sebagai upaya pencegahan stunting pada tim pendamping keluarga di desa lokus. *Jurnal PADE: Pengabdian & Edukasi, 6*(2), 121–126. https://doi.org/10.30867/pade.v6i2.2218 Jurnal Poltekkes Aceh

Robertson, R. C., Edens, T. J., Carr, L., Mutasa, K., Gough, E. K., Evans, C., Geum, H. M., Baharmand, I., Gill, S. K., & Ntozini, R. (2023). The gut microbiome and early-life growth in a population with high prevalence of stunting. *Nature Communications, 14*(1), 654. https://doi.org/10.1038/s41467-023-36135-6 Nature

Savarino, G., Corsello, A., & Corsello, G. (2021). Macronutrient balance and micronutrient amounts through growth and development. *Italian Journal of Pediatrics, 47*(1), 109. https://doi.org/10.1186/s13052-021-01061-0 SpringerLink

Shalitin, S., & Phillip, M. (2003). Role of obesity and leptin in the pubertal process and pubertal growth: A review. *International Journal of Obesity, 27*(8), 869–874. https://doi.org/10.1038/sj.ijo.0802319

Silverstein, D. M. (2018). Growth and nutrition in pediatric chronic kidney disease. *Frontiers in Pediatrics, 6*, Article 205. https://doi.org/10.3389/fped.2018.00205

Soliman, A., De Sanctis, V., Alaaraj, N., Ahmed, S., Alyafei, F., Hamed, N., & Soliman, N. (2021). Early and long-term consequences of nutritional stunting: From childhood to adulthood. *Acta Bio Medica: Atenei Parmensis, 92*(1), e2021168. https://doi.org/10.23750/abm.v92i1.11346

Stavnsbo, M., Resaland, G. K., Anderssen, S. A., Steene-Johannessen, J., Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2020). Correction to: Reference values for cardiometabolic risk scores in children and adolescents: The European Youth Heart Study. *Revista Paulista de Pediatria, 38*, e2019134. https://doi.org/10.1590/1984-0462/2020/38/2019134

Suryanis, I. (2022). Studi kejadian stunting pada anak yang ditinjau dari aspek biologi molekuler: Literature review. *HEME Health & Medical Journal, 4*(3), 214–219. https://doi.org/10.33024/hhmj.v4i3.12345 jurnal.unbrah.ac.id

Takahashi, Y. (2017). The role of growth hormone and insulin-like growth factor-I in the liver. *International Journal of Molecular Sciences, 18*(7), 1447. https://doi.org/10.3390/ijms18071447

Tritos, N. A., & Klibanski, A. (2016). Effects of growth hormone on bone. *Progress in Molecular Biology and Translational Science, 138*, 193–211. https://doi.org/10.1016/bs.pmbts.2015.10.009

Wong, S. C., Dobie, R., Altowati, M. A., Werther, G. A., Farquharson, C., & Ahmed, S. F. (2016). Growth and the growth hormone–insulin like growth factor 1 axis in children with chronic inflammation: Current evidence, gaps in knowledge, and future directions. *Endocrine Reviews, 37*(1), 62–110. https://doi.org/10.1210/er.2015-1046

Zhao, J., Zuo, L., Sun, J., Su, C., & Wang, H. (2021). Trends and urban-rural disparities of energy intake and macronutrient composition among Chinese children: Findings from the China Health and Nutrition Survey (1991–2015). *Nutrients, 13*(6), 1933. https://doi.org/10.3390/nu13061933