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Dietary Protein Intake and Blood Pressure Among Vocational High School Students: A Cross-Sectional Study

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ABSTRACT

Background: Hypertension in adolescents represents a growing and increasingly recognized public health concern, principally because elevated blood pressure established during early life frequently persists into adulthood, thereby substantially augmenting the long-term risk of cardiovascular disease widely influenced by dietary habit. Whilst the influences of dietary sodium, refined carbohydrates, and saturated fats on blood pressure regulation are widely recognized in the literature, the specific role of dietary protein intake in adolescent blood pressure remains insufficiently investigated.

Aims: This study aimed to determine the nature and magnitude of the association between dietary protein intake and blood pressure among vocational high school students in Indonesia.

Participants and Methods: A cross-sectional analytical study involved 88 vocational high school students, selected via proportionate stratified random sampling. Dietary protein intake was assessed employing a validated Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ), and raw dietary data converted into nutritional quantitative values via Nutrisurvey 2007. Blood pressure was measured in accordance with a standardized protocol involving both oscillometric and aneroid sphygmomanometers. Spearman's rank correlation coefficient was employed to examine the association between dietary protein intake and blood pressure, with statistical significance set at $p < 0.05$.

Results: The majority of participants (n = 59; 67.0%) exhibited protein intake levels exceeding the nationally recommended dietary allowance. Overall, blood pressure values across the study sample remained within the normotensive range, with a mean systolic blood pressure of 110.0 mmHg and a mean diastolic pressure of 71.43 mmHg. Bivariate correlation analysis revealed a significant negative correlation between dietary protein intake and systolic blood pressure ($r = -0.217$; $p = 0.042$), as well as a significant negative correlation between protein intake and diastolic blood pressure ($r = -0.234$; $p = 0.028$), indicating that higher protein intake was weakly associated with lower blood pressure values in this cohort.

Conclusions: A statistically significant, albeit weak, negative correlation was identified between dietary protein intake and both systolic and diastolic blood pressure among the study participants. These findings suggest that higher dietary protein consumption may be inversely associated with blood pressure levels in adolescents, a relationship that warrants further investigation through prospective longitudinal designs. Given the inherent limitations of the cross-sectional study design employed, causal inferences cannot be drawn from the present findings, and confounding by other dietary and lifestyle variables cannot be excluded.

Keywords: Dietary Protein; Blood Pressure; Vocational High School Students; Adolescents; Hypertension; Adolescent Nutrition.

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1 INTRODUCTION

Hypertension in adolescents constitutes a growing public health concern, largely because elevated blood pressure at a young age frequently persists into adulthood and thereby increases the risk of future cardiovascular disease. Hinton *et al.* (2020) highlighted this trajectory, reporting that early-onset hypertension ultimately affects one in eight adults aged 20 to 40 years. This trend is particularly evident in Indonesia; for instance, Pidor *et al.* (2023) reported that 54.3% of high school students in Oebobo, Kupang City, exhibited abnormal blood pressure. This prevalence is likely to rise with unfavorable lifestyle determinants, including physical inactivity, dietary patterns, psychological and emotional well-being, and environmental health. While the effects of sodium, carbohydrates, and fats on blood pressure are widely recognized, the specific role of dietary protein is attracting renewed scientific interest. Amino acids derived from both plant and animal sources are crucial for maintaining vascular integrity, as they help optimize endothelial function, promote peripheral blood flow, and reduce vascular resistance.

Although epidemiological evidence suggests that dietary protein may protect against elevated blood pressure in youth, the scientific consensus remains limited. Nabil and Lestari (2024) identified a significant association between protein intake and blood pressure among high school students in Medan, Indonesia. In contrast, a comprehensive umbrella review by Boeing *et al.* (2024) deemed the overarching evidence inconclusive, attributing this ambiguity to

substantial methodological limitations across existing studies. These include variable quality of primary research, a considerable risk of measurement bias arising from reliance on self-reported dietary data rather than objective biomarkers, and macronutrient replacement bias in randomized trials, that obscures the independent physiological effects of protein. Consequently, considerable uncertainty persists regarding the true impact of total, animal-derived, and, in particular plant-derived proteins on blood pressure.

Furthermore, despite these methodological concerns, evidence derived from high-risk local demographic groups remains scarce. This literature gap is particularly evident in Kupang City, where adolescent hypertension has escalated into a serious localized health threat. Recent data from the East Nusa Tenggara Provincial Health Office (2019) revealed that Kelapa Lima Subdistrict exhibited the highest estimated incidence of hypertension among individuals aged 15 and older in the region. Sekolah Menengah Kejuruan (SMK) Negeri 6 Kupang, a vocational secondary school specializing in technology and business administration, is situated within this highly affected area. The gravity of this local situation was corroborated by preliminary screening at the institution, which revealed that, among ten randomly selected students, six were hypertensive and one was prehypertensive. The baseline distribution of categorical blood pressure in this population has also been reported, which prompted further systematic investigation into dietary factors, including protein intake.

Investigating this setting addresses a critical knowledge gap, as empirical evidence focusing on vocational high school students remains remarkably scarce. These adolescents represent a uniquely vulnerable demographic, facing heightened cardiovascular risks driven by intense academic pressure and the prolonged sedentary periods inherent to technology and administration curricula. Additionally, analyzing this specific demographic offers a valuable opportunity to map out the evolving protein intake trends currently emerging among adolescents in Indonesia. Therefore, given the conflicting scientific literature and the exceptionally high local prevalence of abnormal blood pressure, this study aimed to determine the association between protein intake and blood pressure among vocational high school students. Ultimately, the findings are expected to inform targeted, evidence-based interventions to prevent hypertension and promote healthier lifestyles within both educational and familial settings.

2 Participants and Methods

2.1 Study Design and Population

This study employed an analytic correlational design with a cross-sectional approach. The research was conducted at SMK Negeri 6 Kupang, a vocational high school located in Kelapa Lima Subdistrict of Kupang City, East Nusa Tenggara, Indonesia. This location was selected owing to the subdistrict's high reported incidence of hypertension and the school's profile as a representing setting of modern adolescent lifestyle. The study population comprised all active students in grades X, XI, and XII enrolled in the 2025/2026 academic year. Data were collected on August 2025 and involved a total of 88 students as participants. The sample size was determined using Fisher's z-transformation formula for correlation studies (Hulley *et al.*, 2013):

$$N = \left(\frac{Z_{1-\alpha} + Z_{1-\beta}}{0.5\, In\, \left(\frac{1+r}{1-r}\right)} \right)^2 + 3$$

Assuming a two-sided significance level (α) of 0.05 ($Z_{1-\alpha/2}$ = 1.96), a statistical power (1-β) of 0.80 ($Z_{1-\beta}$ = 0.84), and an anticipated correlation coefficient (r) of 0.30, the calculation yielded a minimum required sample size of 85 participants.

2.2 Sampling Procedure

Participants were selected using proportionate stratified random sampling, whereby students were randomly recruited from each grade level in proportion to the size of the respective subpopulation. Eligible participants were active students at SMK Negeri 6 Kupang who were willing to participate and provided written informed consent. Participants were excluded if they (1) reported a family history of, or had received prior physician's diagnosis of, cardiovascular disease, chronic kidney disease, or diabetes mellitus; or (2) were currently taking antihypertensive medication or any other prescription drugs or supplements known to influence blood pressure. Students who were absent during data collection or who submitted incomplete questionnaires were considered dropouts.

This study received ethical approval from the Health Research Ethics Committee of Faculty of Medicine and Veterinary Medicine, Universitas Nusa Cendana (Approval No. 35/UN15.21/KEPK-FKKH/2025) on July 8, 2025. All procedures adhered to the principles of the Declaration of Helsinki. Prior to participation, the study's objectives, procedures, and participants' rights were thoroughly explained, and written informed consent was obtained. Data collection followed a standardized protocol comprising (1) eligibility screening, (2) completion of a questionnaire on participant characteristics, including demographic and lifestyle factors, (3) a face-to-face interview for dietary assessment, and (4) blood pressure measurements. All procedures were carried out by trained researchers.

2.3 Data Collection

Habitual dietary protein intake data over the preceding one-month period was assessed through interviews using a Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) (Fayasari, 2020). The validity of this instrument among Indonesian adolescents was previously demonstrated by Saputri (2025), who reported a strong correlation (r = 0.643) with a 3-day estimated food record. Data were collected by trained research assistants standardized in SQ-FFQ administration, portion size estimation, and blood pressure measurement to ensure consistency and minimize inter-observer variability. To convert dietary data into nutritional intake, Nutrisurvey 2007 software was employed. This application systematically calculates nutrient values by referencing an integrated food composition database, enabling estimation of total protein intake (in grams) based on the reported frequency and portion sizes of each food item consumed. Average daily protein intake (in grams) was calculated and expressed as a percentage of the age-specific Recommended Dietary Allowance (*Angka Kecukupan Gizi*, AKG), and was categorized as insufficient (< 80%), adequate (80–110%), or excessive (>110%).

Blood pressure was measured by trained researchers using a standardized protocol to ensure data reliability. Participants were seated comfortably and allowed an initial resting period. Two measurements were performed from the left arm, properly supported at heart level, with a resting interval of approximately 10 minutes between the first and second readings to prevent stress-induced fluctuations. The mean of the two readings was calculated and recorded as the final systolic and diastolic blood pressure value (in mmHg) to maximize measurement reliability. Measurements were obtained utilizing both calibrated aneroid and oscillometric sphygmomanometers. To maintain consistency, the oscillometric device served as the primary screening tool, while the aneroid sphygmomanometer was employed to verify any readings within the prehypertensive or hypertensive range. All personnel operating both devices were fully trained to ensure standardized application. Both instruments were strictly calibrated prior to the study. Although minor inter-device variation may occur, such discrepancies were minimized through standardized calibration, systematic sequencing, and adherence to established protocols (Duncombe *et al.,* 2017).

2.4 Statistical Analysis

Data analysis was performed using Jeffrey's Amazing Statistics Program (JASP) version 0.19.1.0. Data processing included editing, coding, entry, and cleaning. Descriptive statistics were employed to summarize participant characteristics, protein intake categories, and blood pressure values. Categorical variables are presented as frequencies and percentages. Continuous variables are presented as frequencies and percentages, and continuous variables as mean ± standard deviation (SD). Exploratory crosstabulation analysis was conducted to identify general patterns of blood pressure across protein intake categories. Bivariate analysis was subsequently conducted to assess the association between protein intake and blood pressure. The normality of the blood pressure data was first assessed using the Kolmogorov-Smirnov test. Based on the data distribution, Pearson's correlation was applied to normally distributed data, whereas Spearman's rank correlation was used as a non-parametric alternative. A p-value < 0.05 was considered statistically significant.

3 Results

3.1 Baseline Characteristics of the Participants

The demographic and lifestyle characteristics of the participants are presented in Table 1. The study involved 88 vocational high school students (45 males, 43 females) aged 14–16 years, proportionally distributed across grade levels. With regard to lifestyle characteristics, a minor proportion of participants reported a history of smoking (n = 6, 6.8%), and the majority were non-consumers of alcohol (n = 78, 88.6%). The majority of the participants reported a sedentary lifestyle (n = 53, 60.2%), engaging only in low-intensity activities such as walking, sitting, and routine household chores. Dietary analysis indicated that the majority of participants exhibited an excessive consumption of both protein (n = 59, 67.0%) and fat (n = 56, 63.6%). In contrast, insufficient intake of carbohydrates (n = 32, 36.4%) and sodium (n = 53, 60.2%) was observed in a considerable proportion of participants. Mean systolic and diastolic blood pressure values were within the normative range for this age group (110.0 ± 12.18 mmHg and 71.43 ± 9.83 mmHg, respectively).

3.2 Exploratory Crosstabulation Analysis

Blood pressure was classified according to the American Academy of Pediatrics guidelines (Flynn *et al.,* 2017), as presented in Table 2. Among participants with normal blood pressure, the majority (45 of 63; 71.4%) reported excessive protein intake. Excessive protein intake was likewise the most common category among participants with elevated blood pressure. Conversely, insufficient protein intake appeared more frequently among participants with hypertension; nevertheless, a notable proportion of those with stage 1 hypertension also reported excessive intake. Furthermore, three of the six participants with stage 2 hypertension fell within the excessive protein intake category.

Table 1. Baseline Characteristics of Study Participants

Characteristics	Frequency (%)
Age (years)	
14	5 (5.7%)
15	19 (21.6%)
16	48 (54.5%)
17	14 (15.9%)
18	2 (2.3%)
Sex	
Female	45 (51.1%)
Male	43 (48.9%)
Grade	
X	30 (34.1%)
XI	31 (35.2%)
XII	27 (30.7%)
History of Smoking	
Yes	6 (6.8%)
No	82 (93.2%)
History of Alcohol Consumption	
Yes	10 (11.4%)
No	78 (88.6%)
Physical Activity Intensity	
Low	53 (60.2%)
Moderate	7 (8.0%)
High	28 (31.8%)
Carbohydrate Intake	
Insufficient	32 (36.4%)
Adequate	27 (30.7%)
Excessive	29 (33.0%)
Fat Intake	
Insufficient	10 (11.4%)
Adequate	22 (25.0%)
Excessive	56 (63.6%)
Salt Intake	
Insufficient	53 (60.2%)
Adequate	24 (27.3%)
Excessive	11 (12.5%)
Protein Intake	
Insufficient	17 (19.3%)
Adequate	12 (13.6%)
Excessive	59 (67.0%)
Systolic Blood Pressure (SBP)	110.0 ± 12.18*
Diastolic Blood Pressure (DBP)	71.43 ± 9.823*

*Note: * values expressed as mean ± standard deviation*

Table 2. Blood Pressure Classification According to Dietary Protein Intake

Blood Pressure	SBP	DBP	Protein Intake, n (%)		
			Insuf.	Adeq.	Exc.
Normal	<120	<80	9 (14.3%)	9 (14.3%)	45(71.4%
Elevated	120-129	<80	3 (20.0%)	2 (13.3%)	10 (66.7%
Stage 1 Hyp.	130-139	80-89	3 (75.0%)	0 (0.0%)	1 (25.0%
Stage 2 Hyp.	≥140	≥90	2 (33.3%)	1 (16.7%)	3 (50.0%

Note: SBP: Systolic Blood Pressure in mmHg; DBP: Diastolic Blood Pressure in mmHg; Insuf.: Insufficient; Adeq. Adequate; Exc.: Excessive; Hyp. Hypertension

3.3 Association between Protein Intake and Blood Pressure

As the Kolmogorov-Smirnov test indicated that the study variables were not normally distributed, Spearman's rank correlation was used to assess the association between protein intake and blood pressure. As summarized in Table 3, protein intake was significantly and inversely correlated with both systolic blood pressure (r_s = −0.217; p = 0.042) and diastolic blood pressure (r_s = −0.234; p = 0.028). The negative direction of the correlation indicates that higher protein intake was associated with lower systolic and diastolic blood pressure. However, the small magnitude of the coefficients indicates that the association was weak

Table 3. Spearman's Rank Correlation Analysis

Variables		Spearman's rho	*p*-value[1]
Dietary Protein Intake	SBP	-0.217	0.042
	DBP	-0.234	0.028

Note: *p*-value significant at $p < 0.05$; SBP: Systolic Blood Pressure; DBP: Diastolic Blood

4 Discussion

Blood pressure, whether decreasing or increasing, is influenced by multiple factors. With respect to age characteristics, most participants fell within the 15–17 years age range. Adolescents undergo significant physiological changes that affect blood pressure, primarily driven by puberty-related hormonal shifts. Hormones such as testosterone, growth hormone (GH), and insulin-like growth factor-1 (IGF-1) modulate sympathetic activity, renal function, and endothelial responses (Hinton *et al.,* 2020; Wójcik *et al.,* 2023). Imbalances in these pathways—characterized by enhanced sympathetic activity or Renin-Angiotensin-Aldosterone System (RAAS) activation—may promote sodium retention and reduce vasodilation, thus contributing to elevated blood pressure during this developmental stage (Frame *et al.,* 2024; Grzywa-czuba *et al.,* 2024). Although the study cohort was gender-balanced, sex-based physiological differences—such as higher muscle mass in males and the vasodilatory effects of estrogen in females—are well recognized to influence adolescent blood pressure (Visniauskas *et al.,* 2024; Yuan *et al.,* 2023).

With regard to smoking history, a small proportion of participants reported having smoked. Adolescents with a history of active smoking display a threefold higher risk of developing hypertension compared to those who have never smoked (Park *et al.,* 2024). Nicotine acts as a sympathomimetic agonist, stimulating the release of catecholamines (adrenaline and noradrenaline) from the adrenal medulla and sympathetic nerve terminals, which increases heart rate. This response elevates cardiac output,

while simultaneously causing peripheral vasoconstriction through the activation of α-adrenergic receptors on vascular smooth muscle. The resulting increase in vascular resistance contributes directly to elevated blood pressure (Alhawari *et al.,* 2018; Kondo *et al.,* 2019). Regarding alcohol consumption, 10 out of the 88 students reported having consumed alcohol. Alcohol contributes substantially to hypertension by activating the sympathetic nervous system and the RAAS pathway. This activation increases heart rate, induces vasoconstriction, and promotes sodium and fluid retention, all of which elevate blood pressure (Tasnim *et al.,* 2020). Alcohol intake also stimulates excessive production of Reactive Oxygen Species (ROS) in endothelial cells and vascular smooth muscle cells. These ROS induce oxidative stress, lipid peroxidation of cell membranes, reduced bioavailability of vasodilators, and endothelial dysfunction. Consequently, the capacity of blood vessels to relax is diminished, while vasoconstriction and arterial stiffness are increased, which may lead to elevated blood pressure. Furthermore, greater alcohol consumption during adolescence is associated with a higher risk of hypertension in adulthood (Chen *et al.,* 2024). Regarding physical activity, the majority of participants engaged in low-intensity activities. This finding is noteworthy because regular physical activity improves vascular elasticity and reduces peripheral vascular resistance. This effect occurs primarily through increased release of vasodilators, especially nitric oxide (NO), which lowers vascular tone and reduces arterial stiffness (Gibbs *et al.,* 2021). In addition, physical activity improves body composition by reducing body fat, especially visceral fat. Excess visceral fat accumulated during adolescence significantly increases the risk of developing hypertension (Lira *et al.,* 2022).

Participants' dietary intake plays a crucial role in blood pressure regulation. The majority of participants had not yet achieved balanced carbohydrate intake, as both insufficient and excessive consumption may contribute to elevated blood pressure. Excessive carbohydrate intake, particularly from sources with a low biological value (BV), can lead to hyperglycemia, oxidative stress, and endothelial dysfunction, which increase vascular resistance and blood pressure. Conversely, when carbohydrate intake is significantly reduced, the body compensates metabolically through increased fat and protein oxidation, which may induce ketone production, sympathetic activation, and alterations in metabolic hormones that also raise blood pressure (Hassan *et al.,* 2015; Hulley, 2021). A majority of participants reported excessive dietary fat consumption, a significant finding because it directly contributes to elevated blood pressure. Excess dietary fat increases blood cholesterol levels and promotes the formation and accumulation of atherosclerotic plaque. This accumulation narrows the arterial lumen and increases arterial stiffness or rigidity. When arteries lose their elasticity, greater pressure is required to maintain adequate blood flow, resulting in elevated blood pressure (Hassan *et al.,* 2015; Li *et al.,* 2021). Excessive saturated fat intake is recognized to impair endothelial function. When endothelial function is disrupted, the production of NO, the primary vasodilator, is reduced, thereby increasing peripheral resistance (Khoirunnisa *et al.,* 2024). Furthermore, excessive dietary fat intake is commonly associated with increased energy intake and the accumulation of adipose tissue, especially visceral fat, which triggers activation of neurohormonal systems resulting in vasoconstriction (Laguzzi *et al.,* 2021).

Regarding salt intake, nearly all participants presented insufficient salt intake, which may have a protective effect against blood pressure elevation. In contrast, excessive sodium intake has been consistently associated with an increased risk of hypertension (Li *et al.,* 2023). Sodium contributes to elevated blood pressure by inducing fluid retention that increases cardiac output, and by activating the RAAS pathway, which leads to vasoconstriction. Furthermore, excess sodium impairs endothelial function and reduces nitric oxide availability, leading to arterial stiffness and increased peripheral resistance. (Kos *et al.,* 2023).

The distribution of protein intake revealed that the majority of participants exhibited excessive dietary protein intake, while some participants reported insufficient intake. Insufficient protein intake among the participants may stem from poor dietary patterns and reduced appetite. This finding aligns with the research of Moore and McNulty (2023), who reported a deterioration in dietary quality among adolescents. Adolescents from lower socioeconomic backgrounds tend to consume less protein due to limited food access and unfavorable eating habits (Veronika *et al.,* 2021) Insufficient protein intake in adolescents can impair linear growth, reduce muscle mass, and increase the risk of chronic energy deficiency (Putri *et al.,* 2022*)*. Descriptive dietary analysis indicated a tendency toward higher consumption of animal-based proteins—such as processed fish, chicken, and milk—compared to plant-based proteins. While literature suggests that animal proteins, particularly fish, contain bioactive amino acids and omega-3 fatty acids that may support vascular function (Andhikawati *et al.,* 2021).

In the present study, the mean blood pressure among participants was within the normal range. To investigate potential dietary influences, Spearman's Rank correlation analysis was performed to assess the association between protein intake and blood pressure. The results indicated a significant negative correlation between protein intake and systolic blood pressure ($r = –0.217$; $p = 0.042$) as well as diastolic blood pressure ($r = –0.234$; $p = 0.028$). The negative

direction of the correlation indicates that higher protein intake is associated with lower systolic and diastolic blood pressure. However, the relatively small correlation coefficients suggest that the strength of this relationship is weak. The excessive protein intake observed among some hypertensive participants likely reflects the consumption of sodium-rich processed foods. Physiologically, the weak protective association of protein may occur because when foods containing protein are consumed, their protein components are gradually hydrolyzed by digestive enzymes in the stomach and small intestine into various bioactive peptides. These peptides are able to inhibit the activity of the angiotensin-converting enzyme (ACE). Inhibition of ACE reduces the conversion of angiotensin I into angiotensin II, a potent vasoconstrictor. The subsequent decrease in angiotensin II production reduces vascular tone, which lowers peripheral vascular resistance and contributes to reduced blood pressure. Additionally, protein is broken down into amino acids, such as arginine, the main precursor in the synthesis of NO. This process occurs through the action of nitric oxide synthase (NOS) in vascular endothelial cells. Once formed, NO stimulates signaling pathways that increase the production of cyclic guanosine monophosphate (cGMP) within vascular smooth muscle cells. Elevated cGMP acts as a signal for smooth muscle relaxation, resulting in vasodilation. This vasodilation plays a crucial role in reducing blood pressure by decreasing resistance to blood flow.

Although other literature has proposed extended mechanisms linking specific amino acids—such as phenylalanine, tyrosine, tryptophan, and glycine—to hemodynamic regulation (Heikal *et al.,* 2018; Houston, 2016; Poggiogalle *et al.,* 2019; Vajdi *et al.,* 2023), these biochemical pathways remain speculative in the present context, as our analysis evaluated total protein rather than amino acid profiles. Additionally, protein, specifically albumin, plays a vital physiological role in maintaining colloid osmotic pressure (oncotic) pressure, which regulates fluid balance between the intravascular and interstitial compartments. Hypoalbuminemia can lead to fluid shifts, a reduction in effective circulating volume, and compensatory RAAS activation, which in the long term may contribute to the development of hypertension (Liu *et al.,* 2024).

These findings are consistent with those of Nabil and Lestari (2024), who demonstrated a significant negative correlation between protein intake and blood pressure (r = -0.248; p = 0.005) among adolescents at SMAS Al-Manar in Medan Johor. Similarly, Kusumastuty *et al.* (2016), in a study of outpatient hypertensive patients, reported a significant relationship between protein intake and both systolic (r = -0.407; p = 0.001) and diastolic blood pressure (r = 0.519; p = 0.000), with a negative correlation direction. Furthermore, according to Ye *et al.* (2024), higher protein intake was significantly associated with a 69% reduction in hypertension risk, indicating a protective effect against high blood pressure (OR = 0.31; 95% CI, 0.11 – 0.89).

In conclusion, protein intake exhibited a weak inverse association with systolic and diastolic blood pressure among the participants; however, causality cannot be inferred from this cross-sectional design. While adequate protein intake is essential for growth and overall health, its direct cardiovascular benefits cannot be fully isolated from other lifestyle factors. Therefore, to achieve optimal blood pressure control, adolescents must adopt a comprehensive healthy lifestyle, including regular physical activity, a balanced diet, appropriate energy intake, and abstinence from smoking and alcohol consumption. Future longitudinal studies with multivariable adjustments are required to establish any causal association.

Limitations of the study

Despite its contributions, this study is subject to several limitations, which future research should address:

- *Study Design:* As this study employed a cross-sectional design, the findings represent observational associations rather than confirmed causal relationships.
- *Selection Bias:* The generalizability of these findings may be limited, as the sample was exclusively drawn from students in SMK Negeri 6 Kupang.
- *Subgroup sample Size:* The small overall cohort and extremely small hypertensive subgroups (Stage 1, n = 4; Stage 2, n = 6) limit generalizability and increase susceptibility to statistical noise.
- *Unadjusted Analysis:* The absence of data on critical confounders (body mass index and pubertal status), combined with sparse data constraints, prevented multivariable adjustments. Consequently, the independent effect of protein cannot be fully isolated.
- *Measurement Bias:* The results may be affected by measurement variability from the use of different blood pressure devices and the inherent recall bias of the self-reported SQ-FFQ.

5 Conclusions

This study identified a weak, unadjusted inverse association between dietary protein and blood pressure. Owing to the cross-sectional design and the absence of multivariable adjustment, causality cannot be established, and these results should be interpreted with caution. While protein is a crucial element of adolescent nutrition, its independent impact on cardiovascular health remains to be verified. Therefore, maintaining healthy blood pressure requires a comprehensive strategy that includes a well-balanced diet, an active lifestyle, and the avoidance of

smoking and alcohol. Further research utilizing weighed food record or adopt a randomized controlled trial (RCT) design is recommended to validate these findings.

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