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Abstract

Background: Adolescence is a key time to support better nutrition, reproductive health, and psychosocial well-being before adulthood. This study aimed to design and conduct an initial review of a stunting prevention model centered on young people.

Methods: The research took place in Tembilahan City, Indonesia, and followed several steps. The team started by gathering model components from earlier qualitative work, then asked 12 experts from different backgrounds to review and agree on these elements through two rounds of discussion. Once they reached consensus, these ideas became the foundation for TUNAS, a 12-week program focused on preventing stunting among adolescents, supported by families, schools, the community, health services, and policymakers. The program included six educational sessions for adolescents on stunting, nutrition, anemia, reproductive health, healthy habits, and physical and mental well-being, along with action planning. After the program, 50 adolescents provided feedback on how acceptable, appropriate,

and practical they found TUNAS, using a 30-item survey analyzed for reliability. To see if the program made a difference, the researchers also measured changes in knowledge, attitudes, and quality of life in 101 adolescents before and after the intervention.

Results: Twelve experts reached consensus on all 28 assessment items derived from 28 categories organized under eight core elements of the model. All six TUNAS sessions for adolescents were implemented as planned, with 100% attendance, and parent attendance was 24.8%. Assessments of 50 adolescents indicated that the TUNAS evaluation instrument had adequate to good internal consistency (Cronbach's α=0.76–0.86) and generally met Rasch measurement criteria, although three items and the institutional feasibility aspect still needed improvement. Among 101 adolescents, the median knowledge score increased from 11 to 13 and the attitude score from 56 to 62 (both $p<0.001$; $r=0.87$). All four quality-of-life domains also improved significantly (all $p<0.001$; $r=0.77–0.88$).

Conclusions: TUNAS was developed with the local context in mind and puts adolescents at the center of stunting prevention. After the program, knowledge, attitudes, and quality of life improved. Still, since the study did not include a control group, it is hard to say for sure that the program alone caused these changes. It seems important to test TUNAS in more locations and over a longer period to really understand how effective and sustainable it can be.

Keywords: Adolescents; Stunting prevention; Complex intervention; Modified Delphi; Quality of life; Health promotion

INTRODUCTION

Stunting remains a persistent public health challenge in low- and middle-income countries, driven by a combination of nutritional, health, and socioeconomic disadvantages that begin early in life.[1] While interventions targeting maternal and child malnutrition are well documented, the literature remains concentrated on mothers, infants, and young children.[2] This focus raises the question of how preventive strategies might be broadened to include the pre-pregnancy period, adopting a more comprehensive life-course perspective.[1,2]

Adolescence stands out within the life-course framework as a period marked by rapid physical growth and significant biological, cognitive, and psychosocial changes. The nutritional and health status established during these years can shape not only immediate well-being but also adult health

trajectories and outcomes for the next generation.[3] The idea of a triple dividend, where investments in adolescent health benefit adolescents now, their future adult selves, and their eventual offspring underscores the practical importance of focusing stunting prevention efforts before the onset of reproductive life.[4]

Multiple factors shape adolescent health and nutrition, including dietary habits, physical activity, and the broader social context in which these behaviors develop.[3] Interventions for adolescents must move beyond simply delivering information. Strengthening cognitive factors and attitudes that support healthy choices appears essential. Theory-based nutrition education has been used to address these determinants,[5] and evidence shows that greater knowledge correlates with more positive attitudes toward healthy eating among adolescents.[6] When considering intervention outcomes, it is also worth reflecting on quality of life as a broader indicator of benefit. Behaviors such as physical activity, diet, sleep, and screen time all relate to adolescents' quality of life,[7] suggesting that this outcome may help capture the perceived value of interventions in the present.

The complexity of adolescent health challenges becomes apparent when considering the range of influences, from individual and family factors to peers, schools, health services, and broader environmental and policy contexts.[4] This complexity points to the value of an integrated, adolescent-centered model for stunting prevention, one that links individual change with support from families, communities, institutions, and environments. It also seems important that such models look beyond knowledge gains to include shifts in attitudes and improvements in quality of life for adolescents.

Previous qualitative research in Tembilahan City found that eight interrelated components influence stunting prevention in adolescents: adolescent factors, family factors, social support, access to health services, institutional commitment, governance, service quality, and the environment. These findings indicate the need for a model that integrates individual and environmental determinants in adolescent-based stunting prevention.[8] However, experts have not evaluated the relevance of these components through consensus, user assessment, and intervention implementation. Based on these findings, we used a modified Delphi method to obtain expert consensus on the model components. After achieving expert consensus, we operationalized the model as TUNAS (Tumbuh Unggul melalui Nutrisi dan Aksi Sehat, or Growing Superiority through Nutrition and Healthy Action), a multicomponent, adolescent-centered intervention that integrates support from family, school, community, health services, and policymakers. We then assessed user perspectives on TUNAS using the constructs of

acceptability, appropriateness, and feasibility, and analyzed the measurement characteristics of the user evaluation instrument using the Rasch measurement model.

The Delphi method provides a structured, iterative consensus process to identify and prioritize critical components in developing complex health interventions.[9] In addition to expert consensus, user perspectives are needed to assess the model's acceptability, appropriateness, and feasibility. User assessments of these three constructs can then be analyzed using the Rasch measurement model to evaluate item suitability, measurement reliability, and person–item targeting.[10] However, important gaps remain in adolescent-based stunting prevention. Evidence on malnutrition interventions largely focuses on maternal, infant, and child nutrition, with relatively limited attention to the pre-pregnancy period and adolescence.[2] Yet adolescence is a critical period for growth, nutritional development, and intergenerational health trajectories[3], and adolescent health requires an integrated, multisectoral approach that addresses individual, social, structural, and environmental determinants.[4]

The current literature reveals that integrated stunting prevention models rarely focus on adolescents as the main population, nor do they often combine systematic development, expert input, user perspectives, and real-world implementation. Quality of life is also seldom treated as a central outcome in these adolescent-focused approaches, even though research shows clear links between adolescent health and behavior and later quality of life and health outcomes. [3,7]

This study addresses these gaps by developing and empirically evaluating an integrated stunting prevention model that places adolescents at the center. The model brings together individual, family, social, health service, institutional, governance, and environmental factors, with adolescent quality of life as its main outcome. The model was developed through expert consensus, operationalised as TUNAS, and subsequently evaluated by adolescent users after they had completed all six intervention sessions.

In response to these gaps, the present study designed and evaluated an integrated stunting prevention model that places adolescents and their quality of life at the center. The development process used a modified Delphi method to build expert agreement on the model’s core elements. We examined user perspectives on acceptability, appropriateness, and feasibility using a Rasch measurement approach. Finally, the model was implemented and assessed through a pre–post intervention design, focusing on shifts in knowledge, attitudes toward stunting prevention, and adolescent quality of life.

METHODS

Study Design and Setting

In designing this study, we drew on the MRC framework for complex interventions, which encourages a stepwise approach to both development and evaluation. The process unfolded in three phases. First, we developed the model, adapting a modified Delphi method and drawing on insights from earlier qualitative research. Next, we implemented the model as a 12-week TUNAS intervention. Finally, we evaluated the intervention through user assessments with 50 adolescents after six sessions, as well as pre- and post-intervention evaluations with a larger group of 101 adolescents.

Model development and evaluation followed the Medical Research Council (MRC) framework for developing and evaluating complex interventions. This framework emphasizes context, program theory, stakeholder engagement, identifying uncertainties, refining interventions, and evaluating the relationship between interventions, mechanisms, and outcomes.[11] We selected Tembilahan City, in Indragiri Hilir Regency, Riau Province, Indonesia, as the setting for this work. This context offered an opportunity to develop a stunting prevention model that centers adolescents. The approach aimed to bring together individual determinants with broader influences, including family, social support, health services, institutions, governance, and environmental factors.

1. Phase 1. Development of the Adolescent-Centred Integrated Stunting Prevention Model

Source of the Initial Model Components

The initial model components were derived from a preceding exploratory qualitative descriptive study involving 27 purposively selected informants. Inductive thematic analysis generated 73 codes, which were organized into 28 categories and subsequently developed into eight overarching themes: adolescent factors, family factors, social support, access to health services, institutional commitment, governance, quality of health services, and the environment. These eight themes represented the core elements of the initial model, while the 28 categories were used as assessment items in the subsequent modified Delphi process.[8]

The preceding qualitative study was not considered a formal Delphi round. The modified Delphi instrument therefore comprised 28 assessment items organized under the eight core elements of the model. Twelve experts independently rated each item using a five-point importance scale. For each

item, the mean, standard deviation (SD), and interquartile range (IQR) were calculated to assess the distribution of expert ratings and the level of consensus. The 28-item modified Delphi questionnaire was developed specifically for this study from the 28 categories identified in the preceding qualitative study. The questionnaire has not been published previously. An English translation is provided in Supplementary File 1, Appendix A.

Modified Delphi Consensus Process

Expert Panel Selection

We selected the expert panel using purposive sampling based on competencies and experience relevant to adolescent health services and stunting prevention. Expert criteria included decision-makers, program implementers, and academics with at least five years of experience in related fields. We identified 15 potential experts, and 12 agreed to participate. The panel comprised representatives from various fields and professional positions, including policymakers, heads of community health centers (Puskesmas), health promotion and nutrition workers from the Health Office, tertiary care specialists, population control and family planning/women and child protection counselors, primary care midwives, and academics. This multidisciplinary composition enabled assessment of the model from policy, service, clinical, public health, and academic perspectives. All potential panelists received an explanation of the study objectives through face-to-face communication, telephone, or email and provided written informed consent before participating.

Rounds 1 and 2: Expert Consensus

In the first round, panelists rated the importance of each of the 28 assessment items on a five-point scale, where 1 indicated the highest importance and 5 the lowest. Alongside these ratings, they could offer comments or propose modifications to the components. The panel had 14 days to complete their assessments, with reminders sent after one week and again just before the deadline. Once responses were collected, we summarized the results as group statistics and shared these assessments back with the panel as controlled feedback.

In the second round, panelists revisited their assessments after reviewing the group summaries from the initial stage. This step allowed us to gauge both the level of consensus and the stability of their judgments, while also capturing any further substantive suggestions for the model. The iterative rounds, structured feedback, and statistical summaries reflect the core logic of the Delphi method.[12,13] We analyzed all responses using IBM SPSS Statistics version 26.

Definition and Analysis of Delphi Consensus

In each round, 12 experts assessed each of the 28 assessment items using a five-point scale, with 1 representing the highest importance and 5 the lowest. For each assessment item, the mean, standard deviation (SD), and interquartile range (IQR) were calculated. Lower mean scores indicated greater perceived importance. For descriptive interpretation, a mean below 1.80 was considered to indicate very high importance, whereas a mean above 4.20 indicated low importance.

To assess consensus, we examined how much expert assessments varied. Components were considered to have reached consensus if both the standard deviation was below 1.5 and the interquartile range was below 2.5. These thresholds suggest that experts' ratings clustered closely together, both overall and within the central range. When a component met both criteria, we kept it in the model. If not, we reviewed the score patterns and panel comments before deciding whether to reconsider the component in the following round.

After the first round, we shared a summary of the group's assessments and their comments as structured feedback. In the second round, experts revisited the same components, allowing us to assess whether consensus and stability had been achieved. We continued to use the SD and IQR criteria to judge consensus. In contrast, we assessed descriptive stability by looking for consistent assessment patterns and the absence of major changes to the model. Since all components met the consensus thresholds and there were no substantial suggestions for revision, we concluded the Delphi process after the second round. We conducted analyses using IBM SPSS Statistics version 26.

Stopping Rule

The study protocol specified the consensus criteria a priori as SD <1.5 and IQR <2.5. Given the absence of a universally accepted definition of consensus in Delphi studies and the usefulness of the IQR for assessing the dispersion of ordinal responses, a sensitivity analysis using a stricter threshold of IQR ≤1 was additionally conducted to assess the robustness of the findings without altering the prespecified protocol criteria.[14,15,16]

2. Phase 2: Intervention Development and Implementation

Intervention Development

After experts reached consensus on the components of the Adolescent-Centred Integrated Stunting Prevention Model, the study operationalized them as TUNAS (Tumbuh Unggul melalui Nutrisi dan Aksi Sehat, or Growing Superiority through Nutrition and Healthy Action), the name of the

multicomponent intervention developed in this study. TUNAS is a 12-week intervention that prioritizes adolescents and integrates support from parents, teachers, community cadres, health workers, and policymakers. Development follows the principles of complex intervention, while intervention reporting refers to the Template for Intervention Description and Replication (TIDieR), including rationale, materials and procedures, providers and methods of administration, location, number and duration of sessions, tailoring, modifications, and fidelity.[17]

Intervention rationale and programme theory.

TUNAS was developed based on a life-course approach that positions adolescence as a strategic period for current health, adulthood, and the next generation.[3,18] The intervention was designed to increase knowledge about stunting and strengthen attitudes towards its prevention by considering family, social, health service, institutional, governance, and environmental support. Conceptually, increasing knowledge and attitudes, together with a supportive environment, are expected to contribute to adolescents' quality of life. This mechanism is a program theory and was not tested as a mediating relationship.

Intervention procedures.

The TUNAS program was a 12-week intervention centered on adolescents and involving parents, teachers, community cadres, and policymakers to create a supportive environment. Adolescents took part in six structured sessions, each lasting an hour, covering topics ranging from stunting and balanced nutrition to reproductive health, healthy behaviors, and developing an action plan. The first two sessions were delivered face-to-face, whereas Sessions 3–6 were delivered online via Zoom and an attempt to maintain engagement across different formats. Each participant received a book on early stunting prevention, and schools received two educational posters to reinforce key messages.

Parents were engaged through educational sessions that addressed stunting, its risk factors, prevention strategies, and the importance of family support. Teachers and community cadres attended a one-day in-person training intended to prepare them for their roles in supporting the intervention. Presenting a policy brief to stakeholders outlined the model and offered recommendations for adopting youth-centered approaches to stunting prevention. This multi-layered strategy aims to align practical implementation with broader policy and community support.

Each participant group met separately for in-person activities in a meeting hall in Tembilahan City. The adolescent sessions drew on a multidisciplinary team, including a pediatrician, a nutrition lecturer, the head of the Community Health Center, and an instructor from the local office responsible for population control and child protection. This approach brought together different perspectives on adolescent health. Notably, the intervention was standardized across all participants, with no individual adaptation.

Intervention fidelity.

We monitored intervention implementation for 12 weeks using a structured logbook that documented activities, target groups, materials and methods, duration, participant attendance, implementation of core components, and protocol deviations. We evaluated intervention fidelity descriptively based on adherence, dose delivered, and participant attendance. We calculated adherence as the proportion of core components implemented according to protocol, dose delivered as the proportion of sessions implemented compared to planned sessions, and participant attendance as the proportion of scheduled sessions attended by participants. We recorded any changes to the schedule, duration, materials, methods, or procedures as modifications during implementation.[17,19]

3. Phase 3: User Evaluation and Pre–Post Evaluation

User Evaluation

The user evaluation took place at the end of the twelfth week, once adolescents had completed all six sessions of the TUNAS intervention. Of the 101 participants who finished the program, fifty chose to take part in the evaluation and completed the instrument. Their responses formed the basis for the Rasch analysis. The evaluation asked adolescents to reflect on several aspects of their experience, including how acceptable and appropriate they found the program, both for themselves or their families and within their broader institutional context. The 30-item TUNAS user evaluation instrument was developed specifically for this study based on the model's core elements and the implementation outcome constructs of acceptability, appropriateness, and feasibility. The instrument comprised four separately analysed constructs: Acceptability (7 items), Appropriateness (10 items), Individual Feasibility (4 items), and Institutional Feasibility (9 items). The instrument has not been published previously. An English translation is provided in Supplementary File 1, Appendix B. Items were rated on a four-point Likert-type scale ranging from 1 (strongly disagree) to 4 (strongly agree), with higher scores

indicating a more positive user evaluation. We used the Rasch measurement model for analysis, relying on MiniStep version 5.12.0.0.

To evaluate the instrument's measurement properties, we considered several indicators. INFIT and OUTFIT mean-square statistics, along with point-measure correlations, showed how well each item fit the model. Reliability and separation indices for both respondents and items helped clarify the instrument's ability to distinguish respondents on the underlying construct. We also used principal component analysis of residuals to examine unidimensionality, assess response-category functioning, and evaluate alignment between respondents and items. Comparing the distributions of respondent and item means on the logit scale and reviewing the Wright map offered a more nuanced view of person-item targeting. Finally, we assessed internal consistency using Cronbach's alpha, which remains a standard approach for this purpose.

For item suitability, we assessed for INFIT and OUTFIT mean-square values between 0.50 and 1.50, along with positive point-measure correlations. These criteria help ensure that each item contributes meaningfully to the measurement. To check unidimensionality, we considered both the proportion of raw variance explained by the Rasch measure and the eigenvalue of the first residual contrast. The Andrich threshold helped assess whether the response categories functioned as intended. Finally, reliability and separation indices for respondents and items showed the instrument's capacity to distinguish among different levels of the construct and maintain a stable hierarchy of item difficulty.

Pre-Post Evaluation

Study Design

After implementing the model, we evaluated outcome changes using a one-group pretest–posttest design. The same respondents underwent measurements before (pre-intervention) and after (post-intervention) receiving the intervention.

Participants and recruitment

The study focused on adolescents aged 12 to 18 who attended junior high, senior high, or vocational high schools in Tembilahan City, Indragiri Hilir Regency. To participate, students needed to be enrolled in one of the selected schools, live in Tembilahan City, and be able to communicate, read, and write. Both parental consent and the adolescent's own assent were required in writing. We excluded those who were unwell during the study period or unable to complete the full intervention. Recruitment relied on school-provided lists, and eligible, willing students were selected according to each school's

allocation. This approach reflects both practical constraints and an effort to ensure that participants could engage meaningfully with the intervention.

In total, 101 adolescents took part in the evaluation phase. Baseline data were collected before the intervention, with follow-up measurements gathered immediately after the 12-week program concluded. Each participant received a unique identification code, allowing individual-level matching of pre- and post-intervention data. Because the study did not include a control group, the analysis focused on changes over time within the same group rather than establishing causal effects as in a randomized controlled trial. This limitation matters because it shapes both the interpretation and the practical application of the findings.

Sample size

The sample size calculation in the planning stage refers to Elba and Wijaya (2020), who reported a standard deviation of 15.38 knowledge scores before the intervention and 16.10 after the intervention on a 0–100 scale.[20] Based on the estimated combined standard deviation of 15.71, a one-sided significance level of 5%, a test power of 90%, and an expected minimum difference of 5 points on a 0–100 scale, we calculated a minimum requirement of 84 adolescents. After adding 20% to anticipate participant attrition, we set the recruitment target at 101 adolescents. A sensitivity analysis using the pairwise standard deviation of 13.42 reported in the source study and a two-sided test indicated a requirement of 95 participants after adjusting for 20% attrition; thus, the 101 participants still met the sample requirement.

Study Outcomes

The research outcomes included three main groups: knowledge about stunting, attitudes towards stunting prevention, and quality of life of adolescents.

Knowledge of Stunting

The research team developed a 15-item questionnaire specifically for this study to assess adolescents' knowledge of stunting. The instrument has not been published previously. An English translation is provided in Supplementary File 1, Appendix C. We scored each item using an answer key and summed the scores to obtain a total knowledge score. We scored items using the Guttman scale, with correct answers equaling 1 and incorrect answers equaling 0. Higher scores indicate higher knowledge about stunting. We evaluated item performance and internal consistency before the main study. For the 15 knowledge items with dichotomous scoring, corrected item-total correlations ranged

from 0.467 to 0.783, with all items exceeding the predetermined criterion of 0.30. Internal consistency was excellent (KR-20 = 0.930), and removing individual items did not improve overall reliability. Therefore, we retained all 15 knowledge items.

Attitudes Toward Stunting Prevention

The research team developed a 15-item Likert scale specifically for this study to assess adolescents' attitudes toward stunting prevention. The instrument has not been published previously. An English translation is provided in Supplementary File 1, Appendix D. Attitude measurement using Likert-scale items: strongly agree = 5, agree = 4, neither agree nor disagree = 3, disagree = 2, and strongly disagree = 1. Negatively worded items 1, 3, 6, 8, 12, and 13 were reverse-scored before calculating the total attitude score. Total scores ranged from 15 to 75, with higher scores indicating more supportive attitudes toward stunting prevention. For the 15-item attitude scale, corrected item-total correlations ranged from 0.371 to 0.776, indicating adequate item-total consistency across all items. The scale demonstrated good internal consistency (Cronbach's α = 0.886). Cronbach's alpha values for item deletion ranged from 0.871 to 0.886, indicating that deleting individual items did not significantly improve reliability. Therefore, the 15 attitude items were retained for the main study.

Quality of Life

Adolescents' quality of life was assessed using the Indonesian version of the WHOQOL-BREF, a previously published standardized instrument comprising 26 items across four domains: physical health, psychological well-being, social relationships, and environment. The instrument was scored according to the WHOQOL user manual, and raw domain scores were transformed to a 4–20 scale, with higher scores indicating better quality of life. The Indonesian WHOQOL-BREF has previously demonstrated moderate-to-good test–retest reliability across its four domains.[21,22]

Statistical Analysis

To describe participant characteristics, we used descriptive statistics, selecting either the mean and standard deviation or the median and interquartile range depending on the data distribution. We summarized categorical variables as frequencies and percentages. Before comparing pre- and post-intervention scores for knowledge, attitudes, and quality of life, we checked the normality of the difference scores using the Shapiro–Wilk test and Q–Q plots. We analyzed whether the data met the assumption of normality; we used parametric t-tests when they did, and the Wilcoxon test otherwise. We reported continuous outcomes with descriptive statistics that matched the data distribution, along

with test statistics, p-values, and effect sizes. All analyses were two-sided, with significance set at $p < 0.05$, and were conducted using IBM SPSS Statistics version 26.

Ethical Considerations

The Research Ethics Committee of the Faculty of Medicine, Padjadjaran University approved all phases of the study (No. 1271/UN6.KEP/EC/2024), and the study was conducted in accordance with the Declaration of Helsinki. Before participation, prospective participants and their parents or guardians received an explanation of the study's purpose, procedures, potential benefits and risks, data confidentiality, the voluntary nature of participation, and the participant's right to refuse or withdraw without consequence. We obtained written consent from a parent or legal guardian and written assent from the adolescent before participation. The researchers respected an adolescent's refusal or decision to withdraw, even if a parent or guardian had already provided consent. We replaced participant identities with unique codes and analyzed and reported data in aggregate to maintain confidentiality.

RESULTS

1. Phase 1. Model Development

Initial model components

The initial model was derived from the preceding qualitative study, which identified 73 codes organized into 28 categories and eight overarching themes. The eight themes represented the core elements of the model, while the 28 categories were operationalized as assessment items for the modified Delphi process.[8]

Expert Panel Characteristics

Of the 15 experts invited, 12 participated in the first round. All of these experts also continued to the second round. The table 1 below summarizes their backgrounds :

The experts involved in this study were predominantly female, with expertise in Policy Maker, Head of Community Health Center, Health Promotion Department of the Health Office, Nutrition Department of the Health Office, Specialist physician in tertiary care, Population Control and Family Planning, Women's Empowerment and Child Protection Office, Health Educator, Midwife in primary care, and Lecturer (Table 1).

Modified Delphi Consensus

Twelve experts completed both rounds of the modified Delphi. In the first round, the panel rated all 28 assessment items and provided comments on the proposed model. Summary statistics and panel comments were returned to the panel as controlled feedback. In the second round, the experts re-rated the same 28 items to assess consensus and descriptive stability. No substantive suggestions were made to add, remove, or modify the model components. Table 2 summarizes the expert ratings across both modified Delphi rounds:

All 12 experts participated in both rounds, allowing a consistent comparison of ratings over time. According to the prespecified protocol criteria (SD <1.5 and IQR <2.5), the panel reached consensus on all 28 assessment items by the second round.The absence of proposals to alter the model suggests that the panel found the existing components sufficiently comprehensive. The similarity in rating patterns across rounds suggests stability in expert judgments, which may reflect shared underlying perspectives or convergence through the Delphi process (Table 2).

When applying a more stringent threshold (IQR ≤1) in a sensitivity analysis, stronger consensus was observed for 21 of the 28 assessment items. Seven items, including family motivation, economic factors, and several aspects related to access to and quality of iron–folic acid supplementation, had higher IQR values. Although these components still met the original protocol criteria and remained conceptually important, the lower level of agreement among experts suggests that interpretations of these factors may vary more. It seems prudent to approach these particular assessment items with some caution when considering their role in the model.

The second-round ratings indicated that several assessment items received comparatively higher importance ratings within their respective core elements. Adolescent knowledge had the lowest mean score among adolescent factors, while family knowledge and parenting practices were equally highly rated within family factors. Peer support received the highest importance rating within social support, whereas access to health information was the highest-rated item within access to health services. Availability of funding and designated personnel were equally highly rated within institutional commitment, while standard operating procedures received the highest importance rating within governance. Quality of health services and environmental sanitation were the highest-rated items within their respective core elements.

2. Phase 2. Intervention Development and Implementation.

Based on the components of the Adolescent-Centred Integrated Stunting Prevention Model that achieved expert consensus, the model was operationalized as the TUNAS intervention. This 12-week multicomponent intervention prioritizes adolescents, with parents, teachers, community cadres, health workers, and policymakers providing a supportive environment. Table 3 presents the final components and implementation of the intervention:

All six planned youth education sessions were successfully delivered (dose delivered = 100%), with 100% participant attendance. Parent education was also delivered as planned (dose delivered = 100%), with 25 of 101 parents (24.8%) in attendance, while teacher/cadre training was successfully implemented with 9 of 12 participants (75%) in attendance (Table 3). The team distributed all planned educational materials and presented a policy brief to relevant stakeholders. The team implemented all core components of the intervention according to protocol, with no major modifications during implementation.

3. Phase 3. Pre–Post Evaluation

Participant flow

The study involved 101 adolescents drawn from six schools, each completing assessments before the intervention began. Every participant completed the full 12-week TUNAS program and returned for post-intervention assessments, providing paired data for all individuals in the analysis. The intervention itself included six educational sessions. Notably, we delivered every session as planned, and all adolescents attended each one. Table 4 presents the characteristics of the adolescent participants:

The intervention evaluation included 101 adolescents, most of whom identified as female. Participants represented a range of educational backgrounds: some attended junior high, others senior high, and nearly half were enrolled in vocational high school. Most were in Grade X. Mean height and weight gave a general sense of the group's physical characteristics, but these measures described the sample at baseline rather than tracking changes over time (Table 4).

User Evaluation and Rasch Results

After all six TUNAS intervention sessions, the user evaluation involved 50 adolescents. Assessing the evaluation instrument's measurement properties with Rasch analysis provides a clearer sense of how well the tool captures participants' experiences. These results appear in Table 5:

Internal consistency for the four constructs ranged from adequate to good, with Cronbach's α values between 0.76 and 0.86. Most fit indices, including mean INFIT and OUTFIT MNSQ, were close to 1.00, which suggests the items generally performed as intended. Items within the acceptability and individual feasibility constructs met the established fit criteria. However, a few items—specifically Q5 and Q29 in the appropriateness construct and Q23 in institutional feasibility—showed OUTFIT MNSQ values above the recommended threshold (Table 5). Despite this, their positive PtMEA values suggest they still contribute meaningfully to the constructs. These items were retained because of their conceptual relevance and positive PtMEA values, although further editorial and substantive review is warranted.

The response categories followed an ordered Andrich threshold, which is reassuring for scale functioning. Still, the first residual contrasts 2.51 for the appropriateness construct and 2.08 for institutional feasibility, suggest there may be underlying patterns in the data that deserve closer attention. Notably, item reliability for institutional feasibility was lowest at 0.41. The mean respondent score exceeding the mean item location points to a person-item targeting gap, especially for individual feasibility. This gap raises questions about whether the items are sufficiently challenging or nuanced to capture the full range of respondent perspectives.

Changes in Knowledge Following the Intervention

Before examining changes in adolescents' knowledge following the intervention, the normality of the knowledge change scores (post-intervention minus pre-intervention) was assessed using the Shapiro–Wilk test. The results of the normality assessment are presented in Table 6:

The Shapiro–Wilk test for knowledge change scores (post-intervention minus pre-intervention) produced a W statistic of 0.869 (p<0.001). This result suggests that the distribution of change scores did not meet the assumption of normality. Accordingly, we used the Wilcoxon signed-rank test to examine differences in adolescents' knowledge scores before and after the intervention. This approach seemed more appropriate given the data's characteristics (Table 6).

Table 7 presents the differences in adolescents' knowledge scores before and after the intervention:

As shown in Table 7, the median knowledge score increased from 11 (range, 5–15) before the intervention to 13 (range, 10–15) after the intervention. Sixty-nine participants had higher post-intervention scores (positive ranks), 32 showed no change (ties), and none had lower scores (negative ranks). The Wilcoxon signed-rank test showed a statistically significant difference in knowledge scores between pre- and post-intervention assessments ($Z = -7.220$, $p < 0.001$), with a large effect size ($r = 0.87$). Thus, implementing the TUNAS intervention was associated with increased adolescents' knowledge of stunting (Table 7).

Changes in Attitudes Following the Intervention

Before examining changes in adolescents' attitudes following the intervention, the normality of the attitude change scores (post-intervention minus pre-intervention) was assessed using the Shapiro–Wilk test. The results of the normality assessment are presented in Table 8:

The Shapiro–Wilk test for attitude change scores (post-intervention minus pre-intervention) produced a W statistic of 0.915 ($p < 0.001$), suggesting that the distribution of change scores was not normal. Given this result, we used the Wilcoxon signed-rank test to compare adolescents' attitude scores before and after the intervention. This approach seemed appropriate for handling the observed non-normality and allowed for a more reliable interpretation of the intervention's effect (Table 8).

Table 9 presents the differences in adolescents' attitude scores before and after the intervention:

As shown in Table 9, the median attitude score increased from 56 (range, 35–74) before the intervention to 62 (range, 51–74) after the intervention. Ninety-five participants had higher post-intervention scores (positive ranks), six showed no change (ties), and none had lower scores (negative ranks). The Wilcoxon signed-rank test showed a statistically significant difference in attitude scores between pre- and post-intervention assessments ($Z = -8.463$, $p < 0.001$), with a large effect size ($r =$

0.87). Thus, implementation of the TUNAS intervention was associated with more favorable attitudes toward stunting prevention among adolescents (Table 9).

Changes in Adolescents' Quality of Life Following the Intervention

Before examining changes in adolescents' quality of life following the intervention, the normality of the change scores (post-intervention minus pre-intervention) for each quality-of-life domain was assessed using the Shapiro–Wilk test. The results of the normality assessment are presented in Table 10:

As shown in Table 10, the Shapiro–Wilk test indicated that the change scores (post-intervention minus pre-intervention) for all four quality-of-life domains—physical health, psychological, social relationships, and environment—deviated significantly from normality (all $p < 0.001$). Therefore, we analyzed differences in quality-of-life domain scores between the pre- and post-intervention assessments using the Wilcoxon signed-rank test (Table 10).

The Wilcoxon signed-rank test showed significant differences in all four adolescent quality-of-life domains between the pre- and post-intervention assessments (all $p<0.001$). Median scores increased in the physical domain from 15.43 to 16.00, the psychological domain from 14.00 to 14.67, the social relationships domain from 13.33 to 14.67, and the relationships with the environment domain from 14.50 to 15.00. The largest median difference before and after the intervention was in the social relationships domain (1.34 points), while the smallest was in the environmental domain (0.50 points). These findings indicate a positive change in adolescent quality of life after the intervention. In the physical domain 27 participants had higher post-intervention scores and 74 reported no change, with no respondents reporting a decrease. In the psychological domain, 57 respondents reported an increase, 4 reported a decrease, and 40 reported no change. In the social relations domain, 21 respondents reported improvement, and 80 reported no change, with no respondents reporting a decline. In the environmental domain, 55 respondents reported improvement, and 46 reported no change, with no respondents reporting a decline (Table 11).

Discussion

Principal Findings

The development of the Adolescent-Centred Integrated Stunting Prevention Model, derived from eight core elements and 28 categories identified in the preceding qualitative study and subsequently evaluated through expert consensus, reflects a systematic model-development process. Translating this model into the 12-week TUNAS intervention enabled practical implementation, though support group participation, especially among parents, did not reach intended levels. User feedback suggested that the intervention was generally acceptable, appropriate, and feasible. Rasch analysis provided preliminary evidence of the instrument's measurement properties, though questions remain about item fit, reliability, and alignment between items and participants. Among the 101 adolescents involved, knowledge, attitudes, and all measured quality-of-life domains improved following TUNAS. Still, the absence of a control group makes it difficult to draw firm conclusions about the intervention's direct effects.

1. Phase 1. Modified Delphi and Model Development

The preceding qualitative study identified 28 categories organized into eight overarching themes, which represented the core elements of the initial Adolescent-Centred Integrated Stunting Prevention Model. These categories were subsequently evaluated as 28 assessment items through a modified Delphi process, with consensus achieved across both rounds and no substantive changes to the model. This convergence suggests a shared perspective among experts regarding the model's structure. At the same time, consensus reflects agreement on the relevance of the model components rather than evidence of intervention effectiveness.

Within the social support domain, peer support emerged as the most highly rated component in the second round of the Delphi process. This pattern suggests that, for the expert panel, peers were seen as particularly central compared to other forms of social support. This emphasis aligns with what is known about adolescent development, where peer relationships and the broader social context shape norms, decisions, and health-related behaviors. It follows that strategies for adolescent health may benefit from attending to these social environments, rather than focusing solely on individual-level interventions.[4]

Schools are an important platform for integrating peer support into adolescent health and nutrition interventions. A school-based approach can link educational activities with the involvement of students, teachers, families, health services, and the broader social environment.[18]

The study suggests several ways to operationalize peer engagement, including PIK-R adolescents, peer educators, group discussions, and youth action activities. These formats emerged from the model development process, but their individual effectiveness remains unclear. The modified Delphi method helped clarify which strategies experts consider most relevant, but it does not isolate the unique impact of peer support on intervention outcomes. To understand the specific role of peer components, future research will need to use controlled designs or component analysis.

The panel's consensus on factors such as adolescent characteristics, family and social support, access to health services, institutional commitment, governance, service quality, and the environment reflects an understanding of stunting prevention as a multicomponent and multilevel challenge. This perspective encourages interventions that extend beyond adolescent education to include support from families, schools, health services, communities, and policymakers. This approach aligns with the complex intervention framework, highlighting the importance of context, stakeholder involvement, program theory, and the interplay among components during intervention development.[11]

In this context, the modified Delphi method did not aim to rediscover factors already surfaced in the qualitative phase. Instead, its main value lay in confirming which components experts considered most relevant, establishing priorities, and assessing the model's stability. These insights informed how we operationalized the TUNAS intervention. The model was examined through intervention implementation and user feedback, while changes in outcomes were evaluated using a pre–post design.

2. Phase 2. Development and Implementation of the TUNAS Intervention

Phase 2 results showed that the Adolescent-Centred Integrated Stunting Prevention Model was successfully operationalized as TUNAS. This 12-week multicomponent intervention prioritizes adolescents and is supported by parents, teachers, community cadres, health workers, and policymakers. This approach is relevant because adolescent health and nutrition are influenced by multiple interacting determinants, requiring intervention strategies to go beyond individual approaches or single nutrition interventions.[18] Placing adolescents as the primary target also aligns with the life-course perspective, as adolescence is a critical period of growth and development and offers an opportunity to improve nutritional and health trajectories before entering adulthood and reproductive life.[3]

Operationalizing the conceptual model into TUNAS showed that the eight components identified and validated in Phase 1 can be translated into intervention components at the individual and supporting environment levels. The MRC framework for complex interventions emphasizes that intervention development needs to consider context, program theory, stakeholder engagement, uncertainty, implementation, and the relationship between the intervention and the desired outcome.[11] Thus, TUNAS not only operationalizes adolescent factors into educational activities but also translates components of family, social support, health services, institutions, and policies into the involvement of different supporting actors.

The main components of TUNAS are six structured educational sessions covering stunting, balanced nutrition, anemia and reproductive health, healthy behaviors, physical, mental, and social health, and developing a TUNAS action plan. This broad coverage aligns with evidence that adolescent health and nutrition interventions need to move beyond a single supplementation approach and consider multiple drivers of adolescent diet, growth, health, and development.[18] Structured health education in TUNAS also has an empirical basis in adolescent interventions. A cluster-randomized controlled trial in adolescent girls in Ethiopia showed that a school-based nutrition education intervention involving classroom education, school clubs, peer-group mentoring, counseling, and parent-teacher meetings was feasible and could improve several adolescent dietary outcomes.[23] These findings support educational packages that are not stand-alone but are combined with social and environmental support, as implemented in TUNAS.

The TUNAS program used a mixed approach, starting with two in-person sessions and continuing with four online sessions via Zoom. This decision reflects a broader understanding that delivery methods in complex interventions should align with both the local context and the intended function of each component, rather than being viewed as isolated features of the system.[11] In practice, all six sessions reached adolescent participants as planned, which suggests that this hybrid model was operationally feasible in the study setting. Still, because the study did not directly compare delivery modes, it remains unclear whether in-person, online, or blended formats would be more effective at achieving the intended outcomes.

Books and posters served as supplementary materials, making educational content available to participants beyond the scheduled sessions. All planned materials reached their intended recipients, suggesting careful implementation. The rationale for including these resources is grounded in the idea

that accessible information can support adolescents in developing health literacy and applying health knowledge in their daily lives.[24] However, because the study did not assess the individual impact of books and posters, it is not possible to determine how each medium contributed to the observed outcomes.

Parental involvement in TUNAS represents an effort to translate family factors identified in Phase 1 into implementation components. Including parents in TUNAS was intended to address the family-related factors identified earlier in the research process. Parents were offered sessions on stunting, its risk factors, prevention strategies, and the importance of family support. Despite these efforts, only a quarter of the targeted parents participated. This outcome highlights both the potential and the challenge of integrating families into school-based health interventions. As noted in previous work, involving families can be a valuable part of a broader strategy to encourage positive health behaviors among young people.[25] This highlights the gap between successful component delivery and the target group's level of exposure. In TUNAS, parent education achieved 100% dose delivery, but participant attendance was only 24.8%. Therefore, future implementations need to strengthen family involvement; however, because this study did not evaluate reasons for non-attendance, these data cannot determine the underlying factors for low parent participation.

Involving teachers, community cadres, and health workers shifts TUNAS beyond individual education toward broader social and institutional support. This cross-sectoral collaboration seems especially important because adolescent health and nutrition often depend on connections among education, health, family, and social systems.[18] During implementation, teacher and cadre training reached 75% attendance, and adolescent sessions drew on a multidisciplinary team that included pediatricians, nutrition academics, community health leaders, and counselors from several related fields.

Delivering policy briefs to stakeholders suggests that TUNAS is designed to operate at multiple levels, not just the individual. Communicating model components and recommendations to stakeholders aligns with the idea that stakeholders must understand complex interventions within their broader context. The effects of such interventions often depend on how components, actors, organizations, and environments interact.[11] Still, since the study only recorded the delivery of the policy brief, it would be premature to interpret this as evidence of policy change or institutional commitment.

Phase 2 focused on implementing the intervention as planned. All six youth sessions took place, materials were distributed, and both parent education and teacher/cadre training were carried out. The policy brief also reached relevant stakeholders, and the core components remained largely unchanged during this period. Yet while component delivery was consistent, exposure varied considerably: youth attendance was complete, teachers and cadres participated at 75%, but only about a quarter of parents were reached. Evaluating fidelity in complex interventions requires attention to these distinctions between delivery, exposure, and enactment.[26] In this context, Phase 2 reflects strong implementation of core elements, though exposure among support groups—especially parents—remained limited.

Phase 2 findings help frame the user evaluations that followed in Phase 3. Implementation in practice and user-perceived feasibility are related but distinct, and both perspectives are needed to understand how TUNAS functioned in this setting. The results suggest that the model developed earlier could be translated into a structured, multicomponent intervention in Tembilahan City. Strengths were most apparent in the consistent delivery of core components and full engagement with adolescents. At the same time, limited parental involvement points to areas where implementation could be strengthened. These observations matter for interpreting Phase 3, since knowledge, attitudes, and quality of life improved after adolescents received the full intervention, but support group involvement remained uneven.

3. Phase 3 User Evaluation

User evaluations provided information on TUNAS acceptability, appropriateness, and feasibility after adolescents received full exposure to the intervention. Cronbach's α values of 0.76–0.86 and mean INFIT and OUTFIT MNSQ scores approaching 1.00 indicated internal consistency and overall appropriateness of response patterns. However, Q5 and Q29 on the appropriateness construct, as well as Q23 on institutional feasibility, had OUTFIT statistics outside the established range. We retained these three items because they showed positive PtMEA and remained conceptually relevant, but they required editorial and substantive review. Decisions to retain or revise an item require consideration of the item's fit statistics, the direction of the item correlation, the content, and the item's conceptual contribution to the construct.[10]

The average respondent measure was above the average item location across all constructs, with +2.88 logits for acceptability, +1.97 logits for appropriateness, +3.79 logits for individual feasibility, and +2.39 logits for institutional feasibility. These findings show strong endorsement of TUNAS but also

indicate that the items are relatively easy to agree with. The largest discrepancy in individual feasibility suggests that item coverage is not optimal for differentiating respondents at a high construct level.

Although Cronbach's α values are adequate, respondent and item reliability, as well as separation indices, show more mixed results. The institutional feasibility item reliability of 0.41 and item separation of 0.84 indicate that the item difficulty hierarchy within that construct is not yet stable. Separation values of less than 2.00 across all constructs also indicate the instrument's limitations in differentiating between some strata of respondents and items. Furthermore, the first residual contrast of 2.51 for appropriateness and 2.08 for institutional feasibility suggests possible secondary residual patterns that warrant examination in a larger sample.

Thus, the Rasch analysis provides initial support for the measurement characteristics of the user evaluation instrument and indicates a trend toward positive evaluations of TUNAS. These findings do not prove the intervention's effectiveness or constitute definitive psychometric validation. Future research should use larger, more diverse samples, review items that show misfit, and add more difficult items to improve person–item targeting and item-hierarchy stability.

4. Phase 3 Pre-Post Outcomes

Changes in Adolescent Knowledge about Stunting After the Intervention

The study found that adolescents' knowledge about stunting increased after participating in TUNAS. The median knowledge score rose from 11 to 13, and the statistical analysis indicated a significant improvement with a large effect size. This quantitative improvement is consistent with the qualitative findings. Before the intervention, many adolescents seemed to view stunting mainly as being short, without recognizing its broader implications for reproductive health or the well-being of future generations. This gap in understanding is important, given that adolescence is a formative period for establishing nutritional habits and shaping long-term health.[3] Interventions at this stage should not only provide information but also help adolescents see the connections between nutrition, health behaviors, and outcomes across the lifespan.[18]

The observed increase in knowledge likely reflects the intervention's broader approach. Rather than focusing only on stunting as a childhood growth issue, the program connected it to diet, anemia, reproductive health, physical activity, and lifestyle. This seems consistent with the life-course perspective, which views adolescence as a key window for shaping future health.[3] These findings

717 suggest that adolescent health interventions may benefit from addressing multiple determinants
718 simultaneously rather than focusing on a single nutritional concern.[18]

719 This study's results are consistent with Oddo et al, who evaluated an intervention consisting of
720 school-based nutrition education, breakfast promotion, iron-folic acid supplementation, and social and
721 behavior change communication. The intervention increased knowledge scores by 3.3 points (95% CI:
722 2.6–3.9) and was accompanied by changes in several health behaviors. Oddo et al suggest that
723 increased knowledge can occur alongside changes in several health behaviors when nutrition education
724 is part of a multicomponent intervention package.[27]

725 Schools are an important platform for implementing adolescent health and nutrition
726 interventions.[18] School-based interventions can also integrate classroom learning with teachers, peers,
727 counselors, and parents.[23] However, providing information alone does not necessarily lead to
728 sustainable behavior change, so health education needs an environment that supports adolescents in
729 applying what they learn.[18]

730 This evidence comes from a cluster-randomized controlled trial in adolescent girls in Ethiopia
731 that integrated nutrition education, school club activities, peer-group mentoring, counseling, and parent-
732 teacher meetings. The intervention improved knowledge and practices related to dietary diversity and
733 meal frequency.[23] However, changes in some unhealthy food consumption remained limited, suggesting
734 that increased knowledge does not necessarily translate into changes in overall health behaviors.[23]

735 Improved health knowledge and literacy can be an initial mechanism that helps adolescents
736 understand, assess, and use health information in decision-making. School-based health literacy
737 interventions can improve health literacy, self-efficacy, and intentions to engage in health promotion
738 activities.[24] However, improving adolescent health and nutrition still requires support for the individual,
739 social, and environmental determinants that influence applying knowledge in daily behavior.[18]

740 This supports the structured, iterative, and multicomponent nature of this study's intervention,
741 integrating balanced nutrition, anemia and iron supplementation, reproductive health, physical activity,
742 and healthy lifestyle behaviors. A comprehensive approach is needed because adolescent health and
743 nutrition issues have complex determinants and cannot be addressed through supplementation or
744 nutrition education alone.[18]

745 Increased knowledge should also not be positioned as the ultimate endpoint of intervention. In
746 Indonesian adolescents, increased knowledge can be accompanied by changes in some health

behaviors, but these changes are not uniform across indicators.[27] Similarly, a multicomponent intervention in adolescent girls in Ethiopia improved knowledge and some eating practices, but did not change overall consumption behavior.[23] These findings suggest that increased knowledge is not always accompanied by consistent changes in all health behavior indicators, so that behavior change may require broader individual and environmental support.[23,27]

These implications support this research model, which integrates adolescents with their families, peers, teachers, health workers, communities, and policymakers. A multilevel and cross-sectoral approach is needed to create an environment that enables adolescents to make better health choices.[18] Thus, increased knowledge can be understood as a proximal outcome that supports the pathway to change towards better health attitudes and practices.

Overall, implementation of the intervention model in Tembilahan City was followed by a significant increase in adolescents' knowledge about stunting. This finding aligns with evidence from Indonesia that school-based nutrition interventions and behavior change can improve adolescent knowledge[27] and experimental evidence that school, peer, and family engagement can improve nutrition knowledge and practices.[23] These results also support the life-course perspective, which positions adolescence as a strategic period for building health capacity before entering adulthood and reproductive life.[3,18]

Changes in Adolescent Attitudes About Stunting Prevention After the Intervention

The data suggest that TUNAS contributed to a measurable shift in adolescent attitudes regarding stunting prevention. Median attitude scores rose from 56 to 62, and the range narrowed, suggesting a more consistent understanding among participants after the intervention—the Wilcoxon signed-rank test indicates a statistically significant change with a large effect size. Most respondents showed improvement, while a small number remained unchanged. No one reported a decline. These results raise interesting questions about how interventions like TUNAS can influence not only knowledge but also the underlying attitudes that shape health behaviors.

The quantitative results seem to echo the qualitative insights, where many adolescents initially viewed stunting mainly as an issue of height, without recognizing its broader implications for reproductive health or the well-being of future generations. This pattern is not surprising, given that adolescence is often overlooked as a window for preventive health. Yet, as Norris et al. (2022) and Hargreaves et al. (2022) have argued, the habits and health behaviors formed during these years can

shape outcomes well into adulthood and even affect the next generation.[3,18] It is worth considering how interventions might better bridge these conceptual gaps for adolescents.

These findings align with a cluster-randomized controlled trial in 417 adolescent girls in Nigeria that showed health education led to significant improvements in knowledge and attitudes toward malnutrition compared with a control group, at both three and six months after the intervention.[28] In the Indonesian context, an intervention package combining school-based nutrition education, breakfast promotion, weekly iron-folic acid supplementation, and social and behavior change communication increased knowledge and changed several adolescent health behaviors.[27] Knowledge scores increased by 3.3 points (95% CI: 2.6–3.9), while the odds of engaging in 60 minutes of physical activity per day increased (OR=2.3; 95% CI: 1.7–3.2). These findings support integrating health education with social and behavioral change strategies in adolescents.[27]

The rationale for integrating balanced nutrition, anemia and iron supplementation, reproductive health, physical activity, and healthy lifestyle behaviors in this intervention rests on the recognition that a complex interplay of factors shapes adolescent health. It is increasingly clear that providing nutrition information or isolated interventions is rarely sufficient to shift health choices or behaviors in a meaningful way.[18] Addressing these challenges calls for collaboration across sectors such as education, health, food systems, social protection, and the broader environment that influences adolescents' daily decisions.[18]

While shifts in attitudes are often viewed as a promising early sign of intervention impact, they do not always translate directly into sustained behavior change. Studies among Indonesian adolescents suggest that multicomponent interventions can enhance knowledge and influence certain health behaviors, though these effects are not consistent across all outcomes.[27] Adopting healthier behaviors appears to depend not only on individual attitudes but also on a wider set of determinants and the surrounding environment, pointing to the need for strategies that are both multifaceted and multisectoral.[18]

Findings from the qualitative phase of this study reinforce the idea that a network of influences shapes adolescent health behaviors, including family, peers, teachers, community, health services, institutions, governance, service quality, and the broader environment. In this light, efforts to improve attitudes should be situated within a model that extends beyond the individual, building support through families, schools, communities, health services, and policymakers. Without attention to these multiple

levels, interventions that focus solely on individuals may have limited reach, especially if the wider social and structural context does not reinforce the desired health behaviors.[18]

The observed improvements in attitude scores suggest a greater openness among adolescents to stunting prevention efforts. This pattern echoes experimental findings that health education can positively influence attitudes toward malnutrition,[28] as well as Indonesian evidence that school-based nutrition interventions, when paired with social and behavioral change strategies, can enhance both knowledge and certain health behaviors.[27] These results lend further support to the life-course perspective, which views adolescence as a critical window for shaping health trajectories before adulthood and the reproductive years.[3,18]

Changes in Adolescent Quality of Life Following the TUNAS Intervention

The data suggest that TUNAS was associated with improvements in adolescent quality of life across each WHOQOL-BREF domain. Median scores increased in the physical, psychological, social, and environmental domains, with large effect sizes across all changes. While these results point to broad gains following the intervention, it is worth considering how these domains interact and whether certain aspects of quality of life may be more sensitive to intervention than others.

Health-related quality of life is a relevant outcome for evaluating adolescent well-being following school-based promotive interventions.[29] Adolescence is also a crucial period because growth and development during this phase can influence health later in life and the health of future generations.[3] Conceptually, improvements in the physical and psychological domains align with this research intervention, which integrates balanced nutrition, anemia prevention, physical activity, reproductive health, healthy lifestyle behaviors, and psychosocial health. Adolescent health and nutrition strategies must consider individual and environmental determinants simultaneously and use a multifaceted, multisectoral approach.[18]

Experimental evidence suggests that school-based interventions can improve adolescent quality of life. In 3,519 students aged 12–15 from 56 schools in Finland, a nine-week mindfulness intervention improved HRQoL compared with an active control group (β=1.587; 95% CI: 0.672–2.502; $p<0.001$), and the benefits remained evident at 26 weeks of follow-up. These findings suggest that adolescents' HRQoL may be responsive to school-based promotive interventions, even if they are not directly stunting prevention interventions.[29]

The most pronounced improvement appeared in the social relationships domain. This reflects the model's emphasis on engaging not just adolescents but also their broader support networks, including families, peers, and community members. Still, without mediation analysis, it remains unclear which elements of social support contributed most to these gains. The observed changes in the environmental domain also resonate with qualitative findings about barriers such as access to health information, geographic challenges, and sanitation. Disentangling the specific impact of each intervention component is difficult, but these results suggest that a complex interplay of individual, social, and environmental factors shapes adolescent quality of life.

Improvements in quality of life do not always straightforwardly follow health interventions. For example, a cluster-randomized controlled trial among school-aged adolescents in Brazil found that a combination of physical activity, nutrition, school environment changes, and educational media did not consistently improve all aspects of HRQoL.[30] This points to the complexity of quality of life as an outcome, which does not necessarily shift in response to targeted health behaviors alone.[30] Comparing these findings with those of the present study makes it clear that intervention effects on quality of life are not uniform. This variation likely reflects differences in intervention design, population characteristics, duration, and outcome measurement. Without further analysis, it is difficult to draw causal conclusions about these factors. In this context, it seems more accurate to interpret the observed improvements in quality of life as the result of a multicomponent approach, rather than attributing them to any single element.

In Tembilahan City, the intervention model was associated with improvements in several domains of adolescent quality of life, including physical, psychological, social, and environmental aspects. While these results align with research suggesting that school-based promotive interventions can support adolescent HRQoL,[29] it is important to keep in mind that not all school-based lifestyle interventions yield consistent benefits.[30] From a life-course perspective, focusing on quality of life during adolescence remains important, since this period shapes health, nutrition, and behavioral patterns that extend into adulthood and influence the next generation.[3,18]

Strengths and limitations

1. This study's approach stands out for its careful, stepwise model development, drawing on contextual evidence, multidisciplinary panel input through a modified Delphi method, and user

evaluation using the Rasch measurement model before implementing the intervention with adolescents. Still, the Delphi panel was limited to 12 experts selected from Tembilahan City. The consensus that emerged reflects their perspectives and the local context, so the model's effectiveness and relevance beyond this setting remain open questions.

2. Only 50 out of 101 eligible participants completed the user evaluation. Relying on willingness to participate to form subgroups raises the possibility of self-selection bias. Those who chose to provide ratings may differ in important ways from those who did not, perhaps in their experiences or engagement with the intervention. For this reason, it is important to confirm the Rasch findings in a larger, more representative sample.
3. The Rasch analysis, limited to 50 adolescents, revealed some mismatch between items and respondents, suggesting that the psychometric evidence is still preliminary. It would be useful to refine the items further, especially to distinguish among those with higher levels of endorsement.
4. The intervention was evaluated using a one-group pretest–posttest design, which makes it difficult to attribute observed changes specifically to TUNAS. Since measurements were taken only before and right after the intervention, we also cannot speak to the durability of these effects. Relying on self-reports introduces the possibility of response and social desirability biases, and the external validity of the knowledge and attitudes instruments remains to be established.
5. Because TUNAS is a multicomponent intervention, it is not possible to isolate the effects of each component. Parental participation was also low, which suggests that the family-related aspects of the intervention may not have reached their full potential. The study did not include longitudinal measures of anthropometry, linear growth, nutritional status, or stunting incidence. As a result, while there are indications of changes in knowledge, attitudes, and quality of life, we cannot conclude that the intervention reduces stunting. Addressing these questions will likely require a multi-site controlled design, a larger sample, repeated anthropometric assessments, and longer-term follow-up.

Conclusion

This study produced an eight-component Adolescent-Centred Integrated Stunting Prevention Model that garnered expert consensus and initial support for its acceptability, appropriateness, and feasibility. The model was operationalized as a 12-week multicomponent intervention, TUNAS, and was

implemented without major modifications, although parental involvement remained limited. TUNAS implementation was associated with significant improvements in adolescents' knowledge, attitudes, and all quality-of-life domains.

These findings provide preliminary support for TUNAS as a school-based intervention framework that integrates adolescents, families, schools, health services, and policymakers. However, multi-site controlled trials with longitudinal anthropometric measurements, stronger family involvement, and longer follow-up are needed to confirm its effectiveness and sustainability.

Abbreviations

MRC: Medical Research Council; TUNAS: *Tumbuh Unggul melalui Nutrisi dan Aksi Sehat*; SD: standard deviation; IQR: interquartile range; WHOQOL-BREF: World Health Organization Quality of Life-BREF; INFIT: information-weighted fit; OUTFIT: outlier-sensitive fit; MNSQ: mean square.

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Author contributions:

ESH: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Project administration, and Writing – original draft. DH: Conceptualization, Methodology, Supervision, Validation, and Writing – review & editing. PS: Methodology, Supervision, Validation, and Writing – review & editing. YZ: Methodology, Supervision, Validation, and Writing – review & editing. All authors contributed to the interpretation of the findings, critically reviewed and revised the manuscript, read and approved the final manuscript, and agreed to be accountable for all aspects of the work.

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Availability of data and materials

The de-identified datasets generated and/or analysed during the current study are not publicly available because the consent obtained from the adolescent participants and their parents or legal guardians did not include unrestricted public data sharing. The datasets are available from the corresponding author on reasonable request, subject to applicable ethical and institutional requirements.

Ethics approval and consent to participate

Ethical approval for all phases of this study was obtained from the Research Ethics Committee of the Faculty of Medicine, Universitas Padjadjaran (No. 1271/UN6.KEP/EC/2024). All procedures were conducted in accordance with the Declaration of Helsinki and applicable ethical guidelines. All adult participants, including the modified Delphi panelists, provided written informed consent before participation. For adolescent participants, written informed consent was obtained from their parents or legal guardians, and written informed assent was obtained from the adolescents before their participation in the intervention, user evaluation, or pre–post assessments. Participation was voluntary, and participants could decline or withdraw without penalty.

Trial registration

The intervention component was not prospectively registered in a clinical trial registry. It was conducted as a non-randomised, one-group pre–post programme evaluation within a multistage intervention-development study. No clinical trial registration number is available. This status is disclosed transparently for editorial consideration.

Consent for publication

Not applicable.

Competing interests

The authors declare no conflicts of interest in this paper.

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Table 1. Characteristics of the Expert Panel in the Modified Delphi Process

No.	Characteristic	Round 1 (n)	Round 2 (n)
1	Sex		
	1. Male	3	3
	2. Female	9	9
2	Professional background		
	1. Policymaker	1	1
	2. Head of Community Health Center	1	1
	3. Health Promotion Officer, District Health Office	1	1
	4. Nutrition Officer, District Health Office	1	1
	5. Specialist Physician in Tertiary Care	2	2
	6. Officer, Population Control, Family Planning, Women's Empowerment and Child Protection Agency	2	2
	7. Midwife in Primary Care	2	2
	8. University Lecturer	2	2

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1067 Table 2. Expert Panel Ratings Across the First and Second Modified Delphi Rounds

Theme	Category	Round 1 Mean	SD	IQR	Consensus	Round 2 Mean	SD	IQR	Consensus
Adolescent factors	Adolescent knowledge	1.17	0.389	0	✓	1.58	1.165	1	✓
	Adolescent lifestyle behaviours	1.33	0.492	1	✓	1.67	1.155	1	✓
	Motivation	1.67	0.651	2	✓	1.75	1.215	1	✓
	Interest	1.92	0.515	2	✓	2.00	0.739	0	✓
	Attitude	1.33	0.492	1	✓	1.83	1.115	1	✓
Parent/family factors	Family knowledge	1.25	0.452	1	✓	1.50	1.168	1	✓
	Family lifestyle behaviours	1.17	0.389	0	✓	1.75	1.138	1	✓
	Family motivation	1.33	0.492	1	✓	1.92	1.240	2	✓
	Economic factors	1.67	0.492	1	✓	2.17	1.267	2	✓
	Parenting practices	1.17	0.389	0	✓	1.50	1.243	0	✓
Social support	Peer support	1.42	0.515	1	✓	1.58	1.165	1	✓
	School and teacher support	1.25	0.452	1	✓	2.00	1.044	1	✓
	Community support	1.50	0.674	1	✓	2.42	0.996	1	✓
Access to health services	Access to iron–folic acid supplementation	1.50	0.522	1	✓	2.08	1.311	2	✓
	Access to health information	1.17	0.389	0	✓	1.67	1.303	2	✓
	Access to integrated health posts and community health centres	1.67	0.985	2	✓	2.17	1.337	2	✓
Institutional commitment	Availability of funding	1.50	1.000	1	✓	1.42	0.669	1	✓
	Availability of infrastructure	2.00	0.953	2	✓	1.58	0.669	1	✓
	Availability of designated personnel	1.92	0.996	2	✓	1.42	0.629	1	✓

Theme	Category	Round 1 Mean	SD	IQR	Consensus	Round 2 Mean	SD	IQR	Consensus
	Student health-service space	2.00	1.044	2	✓	1.92	0.669	1	✓
Governance	Monitoring	1.25	0.622	0	✓	1.92	0.793	2	✓
	Coordination	1.58	0.793	1	✓	1.83	0.577	1	✓
	Assignment of responsibilities	1.92	0.793	2	✓	1.75	0.754	1	✓
	Standard operating procedures (SOPs)	1.42	0.793	1	✓	1.33	0.778	0	✓
Service quality	Quality of health services	1.25	0.622	0	✓	1.50	1.168	1	✓
	Quality of iron–folic acid supplements	1.58	1.165	1	✓	2.00	1.279	2	✓
Environment	Sanitation	1.42	1.165	0	✓	1.08	0.289	0	✓
	Culture	1.67	1.231	1	✓	1.67	0.651	1	✓

Note: The modified Delphi instrument comprised 28 assessment items derived from the 28 categories identified in the preceding qualitative study and organized under eight core elements. Twelve experts rated all items in both rounds. Consensus was defined a priori as SD <1.5 and IQR <2.5.

Table 3. Final Components and Implementation Fidelity of the TUNAS Intervention

Level/target	Final intervention component	Planned delivery	Actual delivery	Dose delivered	Participant attendance	Modification/ deviation
Adolescents	Six structured educational sessions: stunting; balanced nutrition; anaemia and reproductive health; healthy behaviours; physical, mental, and social health; TUNAS action plan	6 × 60 min; Sessions 1–2 face-to-face, Sessions 3–6 online via Zoom	6/6 sessions delivered	100%	100%	None
Educational media	Remaja Sehat Awal Pencegahan Stunting book	One book per adolescent	101/101 books distributed	100%	NA	None
Educational media	Educational posters	Two posters per school	12/12 posters distributed	100%	NA	None

Level/target	Final intervention component	Planned delivery	Actual delivery	Dose delivered	Participant attendance	Modification/ deviation
Parents	Stunting prevention, risk factors, and family-support education	1 educational session	1/1 session delivered	100%	25/101 (24.8%)	None
Teachers/community cadres	Capacity-building to support intervention implementation	One-day face-to-face training	Training completed	100%	9/12 (75%)	None
Policy stakeholders	Dissemination of model components and implementation recommendations	Policy brief	Policy brief delivered to relevant policy stakeholders	Delivered as planned	NA	None

Notes:
1. For non-session-based components, delivery represents the proportion of planned educational materials that were distributed.
2. NA, not applicable.

3. Table 4. Baseline characteristics of adolescent participants (n=101)

Characteristic	Category/Statistic	n (%) or Mean ± SD
Sex	Male	36 (35.6)
	Female	65 (64.4)
School level	Junior high school	25 (24.8)
	Senior high school	29 (28.7)
	Vocational high school	47 (46.5)
Grade	Grade VIII	25 (24.8)
	Grade X	54 (53.5)
	Grade XI	21 (20.8)
	Grade XII	1 (1.0)
Height, cm	Mean ± SD	156.5 ± 7.4
Weight, kg	Mean ± SD	46.6 ± 9.7

Table 5. Measurement Properties of the TUNAS User Evaluation Instrument Based on Rasch Analysis

Parameter	**Acceptability**	**Appropriateness**	**Individual Feasibility**	**Institutional Feasibility**
Number of items	7	10	4	9
Cronbach's α	0.80	0.83	0.76	0.86
Person reliability	0.61	0.72	0.64	0.77
Person separation	1.25	1.59	1.33	1.84
Item reliability	0.65	0.56	0.74	0.41
Item separation	1.37	1.12	1.67	0.84
Mean INFIT MNSQ	0.99	0.99	0.98	0.99
Mean OUTFIT MNSQ	1.03	1.00	0.96	0.96
Mean person measure, logits	+2.88	+1.97	+3.79	+2.39
Raw variance explained	42.3%	39.4%	54.4%	42.2%
First residual contrast	1.94	2.51	1.83	2.08
Response category thresholds	Ordered	Ordered	Ordered	Ordered
Items requiring review	None	Q5 and Q29	None	Q23

Table 6. Shapiro–Wilk Normality Test for Knowledge Change Scores

Variable	Shapiro–Wilk Statistic	df	p-value	Interpretation
Knowledge (post-intervention − pre-intervention)	0.869	101	<0.001	Non-normally distributed

Table 7. Differences in Adolescents' Knowledge Scores Before and After the Intervention

Variable	Pre-intervention, median (min–max)	Post-intervention, median (min–max)	Positive ranks	Negative ranks	Ties	*Z*	*p*-value	Effect size, *r*
Knowledge	11 (5–15)	13 (10–15)	69	0	32	−7.220	<0.001	0.87

Table 8. Shapiro–Wilk Normality Test for Attitude Change Scores

Variable	Shapiro–Wilk Statistic	df	*p*-value	Interpretation
Attitude (post-intervention − pre-intervention)	0.915	101	<0.001	Non-normally distributed

Table 9. Differences in Adolescents' Attitude Scores Before and After the Intervention

Variable	Pre-intervention, median (min–max)	Post-intervention, median (min–max)	Positive ranks	Negative ranks	Ties	Z	*p*-value	Effect size *r*
Attitude	56 (35–74)	62 (51–74)	95	0	6	−8.463	<0.001	**0.87**

Table 10. Shapiro–Wilk Normality Test for Changes in Adolescents' Quality-of-Life Domain Scores

Domain	***Shapiro–Wilk p-value for change score***	***Interpretation***
Physical health	<0.001	Non-normally distributed
Psychological	<0.001	Non-normally distributed
Social relationships	<0.001	Non-normally distributed
Environment	<0.001	Non-normally distributed

Table 11. Differences in Adolescents' Quality-of-Life Domain Scores Before and After the Intervention

Domain	Pre-intervention, median (min–max)	Post-intervention, median (min–max)	Negative ranks	Positive ranks	Ties	*Z*	*p*-value	Effect size, *r*
Physical health	15.43 (12.00–20.00)	16.00 (13.14–20.00)	0	27	74	−4.541	<0.001	0.87
Psychological	14.00 (9.33–18.67)	14.67 (12.00–18.67)	4	57	40	−6.051	<0.001	0.77
Social relationships	13.33 (9.33–20.00)	14.67 (9.33–20.00)	0	21	80	−4.015	<0.001	0.88
Environment	14.50 (10.00–18.00)	15.00 (12.50–19.00)	0	55	46	−6.451	<0.001	0.87

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFile1EnglishQuestionnaires1.docx